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Each year around 1.2 million people lose their lives and a further 39 million people are injured around the world from road traffic accidents, according to the World Health Organisation. They describe road traffic accidents as the 10th leading cause of death and the 9th leading cause of burden of disease to humans, costing OECD nations an estimated US$450 billion annually, or approximately 2% of GDP. Whilst there have been substantial savings in lives and injuries per head of population over the last 20-30 years, road trauma still represents a massive health problem for most western countries. Clearly, there is no room for complacency in the battle for safe motorisation.

Road crashes are rarely the result of a single mistake. It is well recognised by researchers internationally that there is commonly a chain of events leading up to a crash and that success can often be achieved by a range of intervention measures. The well-publicised crash and subsequent death of Princes Diana, Dodi al Fayed and their chauffeur in Paris, France on 31st August, 1997 is one example of a crash where there were a number of associated factors that contributed to the crash and severe outcome. Had her driver been more fit to drive, had they not been travelling at such high speeds, had they been properly restrained, and importantly here, had the tunnel where they crashed been better engineered with a continuous central barrier, the crash may well have been prevented or at least alleviated in its severity sufficiently enough for them to have survived the impact.

Crashes are clearly multi-dimensional and may require a concerted multidisciplinary approach to bring about success. Engineering, Enforcement, and Education (the three Es) are common
Human factors for highway engineers

approaches when setting out to reduce the road toll, involving a range of professionals such as engineers, enforcement officers, behaviourists, human factor psychologists, social workers, education specialists, safety administrators, to name just a few. Central to this safety effort is the work of the highway engineer whose fundamental role is to achieve safe mobility on our roads in spite of the numerous forces and influences at work. Fundamental also is the roll of scientific research on which to base effective road safety programs and countermeasures. Through such research, professionals can be guided in terms of safety priorities and mechanisms to bring about harm reductions on our roads. We must also maintain an open and constructive mind in the way we address safety problems if future savings are to be achieved.

Sweden and the Netherlands have adopted rather ambitious but admirable road safety targets for the future that have considerable humanitarian merit. Vision Zero, for instance, states that death and serious injury cannot be tolerated in a civilised society and that conventional wisdom, where safety is essentially traded-off against high levels of mobility, is untenable. It argues that road safety is a health problem and that mobility must to some degree be sacrificed in the interest of achieving a zero death and serious injury road toll. Ultimately, we can but accept such a zero road toll if we want to continue to consider ourselves to be a civilised society. Highway engineers clearly have a major role to play in bringing about substantial future road safety improvements. However, as Vision Zero maintains, it must be a systems-wide approach where the crashworthiness of the total driving environment is thoroughly assessed. This requires a multi-disciplinary approach where highway design must take account of a range of human, social, environmental and engineering factors. The various professions must work together, to ensure that all these critical aspects of the driving task are incorporated in the design and maintenance of future roads and highways.

We must stop constantly blaming the driver for his or her mistakes and accept that humans are not infallible, that they make mistakes for a variety of reasons, and therefore we must design our highways to be more forgiving, to accommodate these mistakes. Moreover, mistakes are not always the fault of the driver. Engineering principles sometimes conflict with human perceptions and behaviour and we must be aware of these influences and attempt to offset or accommodate these in designing safer roads. We must stop blaming the driver constantly for causing crashes and look beyond the obvious behavioural factors to examine in detail the role of the whole road system. Highways cannot continue to accommodate excessively high speeds and highway designers and other professionals must find new ways of reducing travel speed if we are to see real and continuing road safety improvements in the coming years.

The world is facing a major crisis in the years ahead as the population ages. Estimates show that in most western societies, older drivers will be around 3-4 times more involved in road crashes over the next 30 years, based on their increased numbers and level of mobility. Highway and vehicle design, currently based on the performance level of a young, fit adult, is not sufficient for these older road users who suffer from a range of visual, cognitive and physical age-related disabilities. Again, highways engineers need to take greater account of the ageing motorist when addressing such issues as adequate reaction time, levels of conspicuity and delineation, road signage, intersection complexity, pedestrian crossing points, and so on. The next older generation have grown up with the car and are more mobile and insistent on car
access. They are also less likely to want to give up their cars and will be more outspoken and politically motivated. They cannot and will not be overlooked or dismissed easily.

This important book is urgently needed as we attempt to reduce death and serious injury on our roads in the coming years. It is aimed at bringing together human factors and highway engineers to work towards a greater understanding of current road safety issues and incorporating a range of different road safety and transportation perspectives in the interest of greater road safety. It provides a lively, readable and stimulating text involving many experienced professionals' views on a range of relevant science, engineering, information processing, behavioural, social and educational topics. It explains why psychology is relevant and useful to the work of the highway engineer, it describes a number of relevant basic principles of psychology for highway design and outlines applications of psychology of use to highway engineering.

I commend this book to the highway design practitioner as well as students of road safety. It is well written and contains a number of valuable lessons from the writings of these eminent authors, lessons that cannot be overlooked if we are to continue to improve road safety. We pride ourselves on being civilised cultures and as such, cannot continue to allow the level of trauma, pain and suffering that currently exists each day on our roads as we go about our daily lives.

_Brian Fildes_
RACV Professor of Road Safety
_Monash University, Accident Research Centre_
_Melbourne, Australia_
_May, 2001_
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Preface

Building bridges is the domain of the civil engineer, not the psychologist, but this book attempts for the first time to bridge the divide between the two professions, hopefully enabling the engineer to have a better understanding of the behaviour, needs and performance characteristics of the road user.

Although written principally with the highway engineer mind, it will also be of use to our psychologist colleagues who wish to become acquainted with the diversity of modern traffic psychology or to access state-of-the-art reviews of particular aspects of road user behaviour. We hope you get a lot that is worthwhile out of this book.

Any comments that would help enhance a future edition in furthering communication between psychologist and engineer will be most welcome to rfuller@tcd.ie or jas@iep.uminho.pt.
ACKNOWLEDGEMENTS

Building bridges is the domain of the civil engineer, not the psychologist, but this book attempts for the first time to bridge the divide between the two professions, hopefully enabling the engineer to have a better understanding of the behaviour, needs and performance characteristics of the road user. Although written principally with the highway engineer mind, it will also be of use to our psychologist colleagues who wish to become acquainted with the diversity of modern traffic psychology or to access state-of-the-art reviews of particular aspects of road user behaviour. We hope you get a lot that is worthwhile out of this book. Any comments that would help enhance a future edition in furthering communication between psychologist and engineer will be most welcome to rfuller@tcd.ie or jas@icp.uminho.pt.

As may be seen from the list of contributing authors, this is the work of many. To each our sincere thanks, not just for the quality of their contributions but for their patience and tolerance. Just like a convoy, our rate of progress has been constrained by the slowest ship. We would also like to thank Ana Bastor Silva for the use of her figure, incorporated in the book cover, which shows the number of points of potential road-user conflict at a four-way junction. This number is dramatically reduced by a single-lane roundabout - an engineering design change which can significantly reduce the information processing load on the road user. Thanks are also due to the Transport Research Laboratory (UK) for permission to use the illustration in Figure 6 on page 50, to the several publishers acknowledged in the text for use of their materials and to Eddie Bolger (Trinity College, Dublin) for many of the illustrations used in Chapters 4 and 6.

Finally our thanks to our partners, Crid and Paula for tolerating our long absences while wedded to our word processors.

Ray Fuller and Jorge Santos, Dublin and Braga, July 2001
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Imagine someone enthusiastically bursting into your office with the news that they had invented a new system of transportation on land, a system that was cheap for users but which also offered a range of extra benefits depending on how much you were prepared to pay, a system that could be used by young and old alike to enhance their mobility and enable them to cover large distances in a reasonable time, a system that was usable at all times and in all but the most severe weather conditions. And it would be so popular that the average person in the developed world would use the system to cover thousands of kilometres annually.

Then they told you the down side. The system if applied worldwide would consistently kill about half a million people a year, around one hundred thousand in the US and EU, and that in addition up to seventy times as many people as this would be injured, with perhaps one in ten maimed for life. And oh yes, there would be untold material damage as well.

You might be inclined to send them back to the drawing board. But these statistics describe the road accident scene we have today and have had since well before the end of the last century. The fact of the matter is that using our road system to get around carries with it an enormous cost in casualties, in resources and in grief. One person out of every 200 can expect to die using the roadway. One person out of every three can expect to be injured. And each driver can expect to crash about once every 5 years. Since the early days of motorised traffic over a century ago, we have developed and proliferated a road and traffic system that confers excellent mobility but with devastating consequences for many.

We could of course reduce the frequency of these consequences by encouraging the traveller to transfer to potentially safer modes of transport such as rail. At another level, internet and
mobile communications (technologies that are now starting to converge around common protocols of data transfer) are beginning to offer an easy and cheap way of performing remote, real-time, interactions and information sharing, thus reducing the need for 'physical' mobility. However, understanding how the population at large might be attracted to alternative, safe, cheap and more manageable transport and communication systems is an essential, but little explored, field of psychological applied research.

In any event we have to deal with the here and now, with the system we have inherited, a system which is inherently unstable. This characteristic is hardly surprising when you consider a number of its key features. First the infrastructure itself is typically highly mixed, ranging from the narrow, winding streets shaped by the features of mediaeval town development or the regular grid layout so familiar in the USA to high speed national and international motorways. Second, road users are essentially independent, autonomous elements in the system, having radically different properties, from being on foot as a pedestrian to the driver of a 30 ton juggernaut. Third, the system has many different modes of communication to its users, from signs and signals and markings on the roadway to in-vehicle auditory and visual displays.

Thus even in these terms we have a complex, dynamic and fundamentally unstable system, the use of which, as mentioned earlier, has devastating consequences for many. This book is about the road user element of that system and in particular about the psychological characteristics which make road users vulnerable in roadway use. Such knowledge should enable highway engineers to design the system so that it is responsive to those psychological characteristics and thereby enable mobility with enhanced safety. But why psychological characteristics?

Psychology is the scientific study of human behaviour and mental processes. It is concerned with all of behaviour and all of mental life. As such it needs to be distinguished from psychiatry, which is mainly concerned with the diagnosis and treatment of mental disorder, particularly of organic origin. It should also be distinguished from psychoanalysis, which is both a theoretical framework and a method of treatment, stemming from the pioneering work of Sigmund Freud around the time of the invention of the Model T Ford.

So what goes on in people's heads and what they do is what psychology is all about. And that is why it should be of relevance to the highway engineer. Of relevance, because engineers need to know the characteristics of their ultimate clients, the people for whom they are designing and managing the road and transport system, the road users. They need to understand their needs and motives and goals; what limitations they have in vision and information processing and in speed of responding; how they perceive the road and traffic environment and how these characteristics vary with age and experience and fatigue and stress and emotion. They need to know why collisions happen and how they can control behaviour to prevent them happening. For so long, engineers have had to act like protopsychologists, making sometimes intuitive guesses about how road users might respond to various proposed design features, often using themselves as reference road users and iteratively carving out modified design solutions in the light of experience. In the process they have rediscovered a range of basic psychological facts and principles. But the science of psychology has more to offer. Hence this book, which is designed to provide a state-of-the-art review of psychological knowledge of direct relevance to the professional work of the highway engineer.
ROAD ACCIDENTS: LIVING AND DYING WITH WHAT WE'VE GOT

Designing an entire land transport system from scratch is regrettably out of the question for most communities. So to a certain extent we have to deal reactively with the accident problem generated by what has been constructed in the past. Needless to say, the three critical elements of that problem are the road user, the vehicle and the highway. In this three-way split, however, it is the actions or failed actions of the road user which contribute to 90-95 per cent of accidents.

The design of interventions to reduce accidents has traditionally used three major approaches, the three E's of Education, Enforcement and Engineering, the first two concerned with the road user and Engineering concerned with the vehicle and highway. Education aims to fit the road user to the task, whether as pedestrian, cyclist or driver, through the acquisition of relevant knowledge, skills and attitudes. Enforcement aims to induce greater compliance with rules of safe conduct by imposing penalties on violators. Vehicle engineering aims to enhance the control of vehicles, making loss of control and collision involvement less likely, and to reduce the severity of the impact of collisions when they do occur. Anti-lock Braking Systems are an example of the former and energy absorbing crushable fore and aft vehicle compartments are an example of the latter type of measure. Highway engineering attempts to modify identified accident locations in various ways to enable safer progress through them. Finally we might add a fourth E to our list and that is Encouragement. This concept refers to techniques of behaviour management designed to elicit safer road user behaviour through modifying its consequences. An example would be providing lower insurance costs for drivers who have not made any claims, sometimes referred to as the 'no-claims bonus'.

So highway engineering provides one of a range of interventions which may be employed to enhance safety in accident locations. To do this effectively, engineers need to be able to identify which elements of design are contributing to unsafe behaviour, loss of control and collisions. And to do this they need to know about the psychology of the road user. Such knowledge is also of course highly relevant to the task of safety auditing of new or modified roadways, enabling the analysis of design features from a broadly informed road user perspective.

THE PSYCHOLOGY OF THE ROAD USER

Road users come in all sorts of shapes and sizes and may be on the roadway for a variety of purposes from play to parading. But most individuals are in the process of travel in one mode or another, as pedestrian, cyclist, driver or passenger. We are concerned here with the active users of the system, those whose actions can directly influence safety outcome. This therefore includes all users except passengers. And amongst those active users, we shall be principally, though not exclusively, concerned with vehicle drivers, because it is their actions which are by far and away the most significant contributory factor in road accidents.
A considerable amount of accumulated research, published in journals such as *Accident Analysis and Prevention, Ergonomics, Safety Science, Human Factors, and Transportation Research*, describes general human limitations in driver perception, decision making and response execution and demonstrates that there are many individual and temporary factors which can also influence how effectively and safely drivers carry out their task. These range from education and experience to alcohol and aggression and sleepiness and stress. Such factors contribute to instability in driver performance and may be compounded further by the driver's momentary motivation for mobility, the seductive appeal of speed, speed for sensation, and speed for saving time.

For speed is a major determinant of the difficulty of the driver's task. Other things being equal, the higher the speed, the less time there is available to take information in, process it, make decisions, execute those decisions and correct any errors.

Let us try to get a clearer picture of the driver on the roadway at any moment in time, a kind of freeze-frame or snapshot of the various interacting elements such as those mentioned above, by putting them into some sort of coherent framework. We will start with the task of driving as it presents itself to the driver.

### The driving task

Driving a vehicle may be described as a dynamic control task in which the driver has to select relevant information from a vast array of (mainly) visual inputs to make decisions and execute appropriate control responses in order to achieve mobility with safety. Although there are occasions when the driver has to react to some unexpected event (e.g. a child dashing out from behind a parked vehicle), in the main, drivers execute planned actions which are shaped by their expectations of the unfolding road, pedestrian and traffic scenario in front of them and the reality that they actually observe.

![Diagram of contributing factors to demands on the driver](image)

*Figure 1. Contributing factors to demands on the driver*

In this description we can see that key factors are the *environment*, constituted by the roadway and physical conditions such as surface adhesion and visibility, *other road users* with whom the driver might potentially interact, and the information display, control and operational characteristics of the *vehicle* the driver is controlling. In addition, and crucially in this freeze-
frame view, the driver himself or herself provides two important task elements: road position and speed. Putting these elements together as presented in Figure 1, we have a description of the contributing factors to the demands on the driver at any moment in time.

The driver

What does the driver bring to this task in order to attempt to carry it out effectively and safely? Well first of all s/he brings certain constitutional characteristics, biological capabilities which prescribe individual performance elements such as stimulus thresholds (the minimum amount of energy in a stimulus needed to detect its presence), speed of information processing, reaction time and visual acuity.

Many of these limits vary systematically as a function of age. Building on these constitutional characteristics, the driver brings the knowledge and skills arising out of education and training, developed and honed with accumulated experience. Together these features define the upper limits of capability of the driver, his or her competence.

However, we know of course that the driver is not always able to operate at this level of competence. As mentioned earlier, what he or she is able to deliver at any moment in time can be affected by a range of variables collectively known as human factors. These include such things as fatigue and drowsiness, emotion, stress, distraction, the effects of drugs such as alcohol and motives such as for aggression. Such human factors interact with the driver's competence to produce his or her momentary capability. Figure 2 describes these driver characteristics.

The task-capability interface

So now we have a freeze-frame picture of the driver's task and a corresponding picture of what the driver is bringing to it. If we put these two together, then we have a simple model of the interface between task demand and driver capability, the task-capability interface.
From this model of the task-capability interface we can make an immediate and simple deduction: if capability exceeds task demand, then the driver is able to progress safely. However if capability falls short of task demand, then collision or loss of control is implied. The exception to this is when another road user makes some sort of defensive or escape manoeuvre, such as an unseen pedestrian leaping out of the way of the oncoming vehicle. Such manoeuvres effectively change task demand at a critical moment (see Figure 3). Figure 4 puts all of this together as the task-capability interface model. Note the important link between the driver's capability and his or her road position and speed. For a more detailed development of this model and its implications see Fuller (2000).

Figure 3. Possible outcomes from the interface between task demands and driver capability
Task difficulty homeostasis

However the model is not yet complete, because all we have so far described is a freeze-frame picture of key contributing elements. What energizes the model, what makes it run? There has been a long debate about this kind of question over the past quarter century or so. One is really asking what drives the driver and some of the conflicting viewpoints are described elsewhere in this book (see, for example, Chapter 4). For the purposes of this chapter, however, (and as advocated by its first author), let us take as a working hypothesis the idea that for most of the time drivers drive so as to achieve their mobility, their travel goals, while ensuring the difficulty of the task remains within acceptable limits. Thus if things are getting too hectic on the road, too demanding, the driver slows down. If the task is boringly easy, the driver speeds up, making it more challenging. We might call this process one of task-difficulty homeostasis and it is represented by the diagram in Figure 5.

In this process, the driver's capability, as s/he perceives it, and the driver's motivation for engaging with a particular level of task difficulty together determine the range of task difficulty that is targeted. The dynamic interaction of the driver with the unfolding road and traffic scenario determines objective task difficulty and the perception of this is compared with the driver's target. If perceived difficulty exceeds or is anticipated to exceed the target, then the driver takes actions to reduce the level of difficulty (such as by slowing down). On the other
hand if perceived difficulty is less than the target, then the driver takes actions to raise the level (such as by speeding up). Readers familiar with Wilde's Risk Homeostasis Theory (see for example Wilde, 1994) will notice some similarity here with that model, but there is a very, very crucial difference: Wilde considers drivers aim for a target level of experienced risk, not task difficulty, and whereas there may be conditions in which the two are correlated, they are clearly not the same thing.

Three implications of this conceptualisation which should be of immediate relevance to the highway engineer are that

- safety may be challenged if there is a discrepancy between the driver's perceived task difficulty and objective task difficulty, such that the driver underestimates real task difficulty;
- where shortening journey time has a value, if a driver can increase speed without increasing perceived task difficulty, s/he will do so;
- where conditions are such that the demands of the task exceed his or her capability, and the driver can do nothing to reduce those demands or enhance his or her capability, the driver will opt to avoid those conditions.

The first of these highlights the importance for safety of providing clear and reliable information to the driver, information about appropriate speed, alignment, adhesion and about any likely hazard immediately ahead. The second explains why safety interventions which make the task easier (such as straightening out a curve) may be 'consumed' by increases in speed. It also explains why 'traffic calming' measures which make the task more difficult (e.g., chicanes, throats, gateways, lane narrowing) induce lower speeds. A potential design strategy, then, might be to make the task appear more difficult than it objectively is. Finally the third of these implications explains why some drivers (for example those who are elderly) may avoid particular routes or times-of-day or even opt out of driving altogether and shift to a different mode of travel (see Chapter 17).
Risk homeostasis

So here we have, then, a representation of the ongoing dynamic interaction between the person behind the wheel and the road and traffic environment. To complete the picture, we need one further element, and this brings us back to the kind of situation described in Wilde's Risk Homeostasis Theory (RHT). Under certain conditions, we can imagine drivers deliberately driving in such a way that they accept a probability of crashing greater than zero. Their elected speed, for example, may be one at which they sense some probability (albeit very low) of loss of directional control on a bend, or if they should be required to brake or swerve abruptly; a certain inevitability of crashing into a pedestrian if one should suddenly run in front of them or into a vehicle that unexpectedly pulls into their path. Drivers might occasionally behave in this way because the certain rewards of high speed might outweigh the uncertain punishment of these rare consequences: they gamble on the loss-of-control or crash event not occurring, a kind of Russian roulette of the road.

This is precisely the situation captured by Wilde's RHT, in which target risk becomes the criterion by which drivers determine and adjust their behaviour, driving faster, for example, when perceived risk is less than the target and slower when risk is perceived to be greater (see Figure 6).

![Diagram](image)

**Figure 6. Simplified representation of risk homeostasis**

With these two conceptualisations, the task capability interface model and RHT, we can characterise both normal driver behaviour and active risk-taking from a psychological perspective. These conceptualisations are not the final word, of course, but nevertheless may serve to help understand driver behaviour and why so many road users fail to complete their journey without mishap. They should also provide a framework to help organise the material of this book, in terms of the methodologies, findings and recommendations which are presented.
Should we be concerned about highway safety?

It could be argued that given the complexity of the interface between the road system and the road user, it is perhaps surprising that we don't see more crashes than we actually do. For the fact of the matter is that millions of people on roads around the planet are continuously making adjustments to avoid crashing and deal safely with the errors of other road users. Something goes wrong in this process only once every 80,000 km for the average driver in a developed country, which at one level is a remarkable feat of human performance. It is only when we aggregate these failures that the problem emerges as a matter of serious concern for a community. So can the road and traffic system be designed to make it substantially safer? In 1997, the Swedish National Road Administration answered this question in the most positive manner possible, by embracing a long-term vision of a road transport system in which nobody is killed or sustains an injury resulting in permanent disability, a concept known as Vision Zero.

Whether such an objective is attainable is a moot point. At some stage in the process of approaching this goal, resources will inevitably have to be transferred from other life-enhancing activities (such as health care programmes) and eventually some sort of balance will emerge in which further investment in system safety will simply be offset by increased loss of life and limb in some other domain (see Elvik, 1999, for a stimulating discussion of aspects of this issue).

However, such considerations apart, it is of course possible to put an economic cost on accidents and evaluate the potential savings from changes in system design or engendered by other kinds of intervention. Such economic cost-benefit analyses can provide a powerful argument for decisions to invest in safety improvements. But beyond this there is the incalculable price paid in human lives, human pain and human grief. If for no other reason than to reduce this suffering, it behoves us to design the transport system in such a way as to optimally take account of human characteristics. That in a nutshell is what this book is all about.

**RECOMMENDED READING**


MULTIPLE PERSPECTIVES

Oliver Carsten, University of Leeds, UK

IS THE ROAD USER THE DOMINATING CAUSE OF ACCIDENTS?

Beginning in the 1970s, a series of in-depth studies of road accidents pointed to human error as overwhelmingly the most common contributory factor in road accident causation (e.g. Treat, 1980). The statement that 95 percent of all road accidents have human error as a component is by now almost a cliché and is reflected in other transport modes. For example, a U.S. Federal Aviation Administration report states that between two-thirds and three-quarters of accidents in commercial aviation have crew error cited as a major factor (Federal Aviation Administration, 1996). Some of the researchers involved in producing the findings on the role of human factors in road accidents qualified their conclusions. In his book Psychology on the Road, David Shinar, a member of the team that carried out the Indiana in-depth study in which a multi-disciplinary team investigated police-reported accidents to identify contributory factors and injury mechanisms, wrote of various investigations: “All of these studies point to the fact that - at least as far as expert opinion is concerned - approximately 90 percent of the highway traffic accidents are preceded by some information-processing failure or behaviour that an alert and relatively skilful driver would not have made. This does not mean, however, that it is ‘normal’ to remain consistently alert while driving, but only to say that at that particular moment, which preceded the accident, an alert driver would not have made that particular error” (Shinar, 1978, p. 112).

But such qualifications are often forgotten. Kåre Rumar has written of the Indiana and first TRRL (UK) in-depth studies: “These two completely separate rather large studies of several thousand accidents are almost unanimous in their pointing at the road user - the human factor -
as the dominating cause of road accidents" (Rumar, 1985). Similarly, Barbara Sabey, who was involved in the UK in-depth studies of the 1970s and 1980s has recently written: "Human factors play a major role in road accidents. Drivers’ performance and avoidance of collisions depend on their skills, judgement, anticipation, state of mind and physical well-being... Consistently over the years, the most prevalent factors [in accidents] have been human failures associated with speed, perceptual difficulties and drink driving" (Sabey, 1999, p. 11).

In one way, it can be argued that such statements are incontrovertible. Certainly, one would not want the majority of drivers to be thrill-seekers after speed, to be vision impaired and to be drunk. But in general they are not. The majority of crashes occur to individuals who may not have performed perfectly, but who were certainly not acting in any deliberately risky manner - they were simply driving, riding or walking in a rather average way. And yet, we have created a traffic system in which such average and expected performance can result in a crash and subsequent injury or even death.

**NEGATIVE CONSEQUENCES OF THE FOCUS ON HUMAN FACTORS AS THE CAUSE OF ACCIDENTS**

The focus of the in-depth studies on the predominant role of human factors has had some important negative consequences. First of all, it has led many traffic psychologists to devote a large amount of energy to creating complex and not very useful models of road user behaviour. Most of these models are only descriptive and are thus neither predictive nor verifiable. They tend to take the form of complex flow diagrams, which often state little more than that human behaviour is not straightforward and that a lot of factors influence it. It is not clear that these models have produced much in the way of findings that have affected the way that we treat the problem of road accidents.

Another and perhaps more serious negative consequence of the focus on road users’ contribution to accident causation has been the unwarranted attention paid to driver training and to publicity as means to obtaining safer behaviour. In a statement of the priorities in formulating a road safety strategy, Barbara Sabey writes: “Emphasis needs to be placed in introducing more relevant, practical training for young drivers, in particular to give practical experience of hazard perception, close following, gap acceptance and overtaking, which are major factors contributing to the occurrence of accidents” (Sabey, 1999, p. 21). She continues: “How to change attitudes to, and the perception of, road use need to be explored and better understood.” Leonard Evans makes a similar statement in his book *Traffic Safety and the Driver*: "the largest potential gains in traffic safety can be achieved by encouraging and stimulating changes in the social norms related to driving" (Evans, 1991, p. 355).

Of course drivers require training to equip them for the tasks of driving a motor vehicle in a variety of traffic environments. And of course we need to encourage responsible attitudes and improve public understanding of safety problems. But the evidence on the effectiveness of alternative training regimes is not encouraging and the evidence of the success of publicity campaigns is discouraging. As regards training, a review of young driver training regimes across Europe came to the conclusion that no regime could be identified as more successful
than any other; each country had a roughly equivalent young driver problem in terms of the excess of risk for young drivers as compared to that for all drivers (Finch and Twisk, 1995).

In terms of publicity, large amounts of money are expended by national and local governments on publicity campaigns aimed at improving road user behaviour. These campaigns are generally not evaluated. There is no evidence that non-deliberate errors can be reduced by publicity, and plenty of evidence that, even in the case of deliberate violations, particularly speeding, publicity is only effective when backed up by rigorous enforcement. It is often claimed that information campaigns have been successful in reducing drink-driving and in increasing seatbelt wearing. But the truth is that such campaigns have only been effective when they have been linked, in the public’s perception, with enforcement or with changes in the law.

**TWO EXAMPLE ACCIDENTS**

**A Rail Crash**

An accident that has generated a huge amount of publicity can serve as an illustration of accident causation. It comes not from the road mode, since few road accidents are investigated very thoroughly and where such investigations do take place they are generally confidential. On 5 October 1999, two trains, a Great Western Trains express and a Thames Trains local, collided head-on outside Paddington Station, London, resulting in at least 30 fatalities. It quickly emerged that the driver of one of the trains, the westbound local train heading out of London, had run through a red signal, even though his train was equipped with an automatic warning system. This system sounds a bell in the driver’s cab if a signal is passed at yellow (caution) or red (danger). Failure by the driver to acknowledge the bell by pressing a button results in automatic application of the brakes. The problem with the system is that pushing the button becomes an automatic response (Health and Safety Executive, 1999a).

There were several initial attempts to place the responsibility for the accident on the driver of the Thames train. The joint statement by the two train companies and Railtrack (the infrastructure owner) a day after the crash said that investigations would concentrate on the behaviour of the Thames train, i.e. the driver. The statement said that the signals were “in full working order” (The Guardian, 7 October 1999). The Chief Executive of Railtrack was reported as saying: “If that light has been green - that is, Railtrack had been at fault - I would have gone. But it was red. There is an important principle at stake here” (The Guardian, 16 October 1999).

Most of the debate, however, focussed on a series of flaws in the system. The following issues and problems emerged:

- The signal concerned had been passed at red eight times in six years (The Guardian, 7 October 1999).
- The signal set-up along the track was confusing and several of the signals were obscured to drivers on approach. Since there were up to seven parallel tracks, the signals were mostly mounted on overhead gantries. But the tracks were curved, thus making it difficult for
drivers to interpret which signal applied to them. Many of the signal heads were dangerously obscured by overhead power lines and even bridges (The Guardian, 20 October 1999).

- The Thames train was not fitted with Automatic Train Protection (ATP) or the Train Protection Warning System (TPWS) which would have automatically prevented the train from passing the red signal and thereby prevented the accident (Health and Safety Executive, 1999b).

- Many of the individual tracks were bi-directional - they catered to trains operating both into and out of London. This was unusual for fast train operation and naturally increased the risk of a head-on collision.

- Speed limits along the length of line were unusually high. The speed limit for the inbound train was 100 mph; that for the outbound train was 70 mph. The inbound train was actually travelling at 70 mph, the outbound one at 50 mph. Typical speed limits around other London main line stations are 30 mph (The Guardian, 7 October 1999). The high speeds clearly affected the severity of the crash (both trains caught on fire on impact) and perhaps reduced the possibility of avoiding the crash in the first place. That speed was a factor has been implicitly accepted by the Health and Safety Executive, which decided that when the lines were reopened speeds would be limited to 50 mph (The Guardian, 20 October 1999).

- Concerns were raised about the crashworthiness of the rolling stock and about the fact that the diesel fuel spilled from the Thames train ignited in the impact (statement in the House of Commons by Deputy Prime Minister John Prescott, 19 October 1999). Diesel fuel should have a high flashpoint and therefore should not ignite in such a crash.

Other concerns were raised at a more general, organisational level:

- There were assertions that the privatisation of the railways had led to fragmentation of the industry and a lack of coordination in the safety arena (Prescott, 1999).

- It was claimed that Railtrack had a conflict of interest in the safety area. As a private company it had a wish to keep costs down. But it was nevertheless largely responsible for safety through its Safety and Standards Directorate, which issued standards, prepared the safety strategy for the railways, and audited the safety plans and safety compliance of the train operating companies and of Railtrack itself (Health and Safety Executive, 1999c).

The overwhelming focus in this discussion has not been on the individual driver's error in passing the signal at red, but on the operational and environmental factors that led to the error. In addition, considerable attention has been focussed on organisational issues - on the structure of the rail network and the arrangements for safety management. The focus on underlying system factors and on organisational issues is in stark contrast with the attribution of road accidents mainly to road user error.

**A Road Crash**

Think of an accident in broad daylight at an urban T-junction in which the driver emerging from the minor road fails to perceive on approach that there is a junction ahead. He or she drives out at considerable speed and collides with a vehicle on the major road. As a result a serious injury occurs. A police officer attends the scene of the accident and notes that both the
Give Way sign on the minor road approach and white line markings at the junction are in good order. The police officer concludes that the driver is at fault and, as a consequence, the driver is prosecuted and found guilty of careless driving.

This case appears to be an open-and-shut one - the evidence of driver error and the predominant role of human factors seem to be incontrovertible. But perhaps the case is not quite so simple. A careful visit to the site and a drive through the accident location from the point of view of the 'offending' driver would reveal that the Give Way sign was somewhat obscured by a tree branch. Furthermore, the junction is not a true T. Instead it is shaped thus:

The minor road may well at one time have been the major road. The street lights and building line of the minor road carry across on to the major road in two straight lines, thus reinforcing the illusion that there is no junction ahead, but rather a continuing straight road.

Whose was the error in this case? Was the crash the fault of the driver on the minor road who was unfamiliar with the location? The driver was neither particularly fatigued nor alcohol-impaired. Or was it the fault of the highway authority who should have been aware of the potential problems at this location and who should have improved the junction with one of several possible alternative treatments? The highway authority should also have had a maintenance programme to deal with the obscuring of signs by vegetation.

IS THE HUMAN BRAIN FULL OF ERROR?

If we identify human error as the major component in traffic accidents and then implicitly blame the driver, we are in danger of blaming the victim of a poor traffic system. We know that the individual accident is an unpredictable event, but we also know that accidents as an aggregate are systematically over-represented at certain locations and in certain circumstances. In Britain, 62 percent of all injury accidents occur at junctions and 51 percent of all injury accidents at urban junctions (Department of the Environment, Transport and the Regions, 1999). Twenty-eight percent of injury accidents take place at night, even though only 10 percent of travel is probably made at night. Forty-six percent of accidents involving a pedestrian and a vehicle occur on urban arterial roads. Ninety-three percent of pedestrian injuries or fatalities are at locations with no pedestrian facility, not even a refuge.

Rather than blaming the road user, we should blame the designers and operators of the traffic system as a whole for creating a situation in which human fallibility inevitably leads to injury and death, so that some 45,000 citizens of the European Union were killed and 1.5 million injured during 1995 as a consequence of traffic accidents (ETSC, 1997). The problem is not the unsafe driver or the unsafe road user, but the unsafe system. In the case of other modes, as has been shown in the discussion of the Paddington rail crash, we are perfectly prepared to accept that the blame lies not with the individual but with the underlying system. But in the case of road traffic, we still too often think that it is the driver that should be improved rather than the system.
In the study of work-related errors, it is standard practice to view the major source of human error as being the design of the system. Thus Jens Rasmussen has written: "For improvement of safety, a more fruitful point of view [than allocation of causes to people or technical parts in the system] is to describe human errors as instances of man-machine or man-task misfits. In case of systematic or frequent misfits, the cause can then typically be considered a design error" (Rasmussen, 1987). He goes on to say: "When analysing incident reports, one rapidly gets the impression that human acts are only classified as human errors because they are performed in an 'unkind' work environment. An unkind work environment is then defined by the fact that it is not possible for a man to correct the effects of inappropriate variations in performance before they lead to unacceptable consequences."

This point of view - that errors arrive from inevitable human frailty and thus from a failure to build error-tolerance into the traffic system - is reinforced by an examination of the types of error that road users actually make. In our own in-depth study of urban accidents, carried out at Leeds (UK) in 1988-89, we investigated and analysed the explanatory factors that led to the immediate cause of the accident, such as a failure to give way (Carsten et al., 1989). The distribution of such errors is shown in Table 1.

<table>
<thead>
<tr>
<th>Error Type</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>Perceptual error, such as &quot;failed to look&quot; or &quot;looked but failed to see&quot;</td>
<td>16%</td>
</tr>
<tr>
<td>Unable to see, because of obstruction</td>
<td>12%</td>
</tr>
<tr>
<td>Cognitive (judgement) error, such as &quot;lack of judgement speed&quot; (of the other road user)</td>
<td>12%</td>
</tr>
<tr>
<td>Lack of skills</td>
<td>3%</td>
</tr>
<tr>
<td>Attitude problem</td>
<td>2%</td>
</tr>
</tbody>
</table>

Overwhelmingly, these errors are of the type that James Reason would classify as errors (i.e. unintentional mistakes, slips and lapses) rather than as violations (Reason, 1990). They are non-deliberate and they stem from an 'unkind' traffic environment, one which is not very forgiving of error.

**CAN ENGINEERING BE SUCCESSFUL WITHOUT TRAFFIC PSYCHOLOGY?**

Road safety engineers have, over the years, developed an intuitive understanding of human factors problems in road traffic, and as a result have an armoury of successful solutions for dealing with problem sites, routes and areas. In England, the central government provided in
the financial year 1996/97 £55 million to local highway authorities for 'local safety schemes', to which was added some £80 million of local funds. It is estimated that this expenditure would save a total of 6400 casualties, including 90 fatalities in a single year (ETSC, 1996). The cost of each scheme varied between £1000 and £250,000 and each scheme saved on average just over one injury accident per year.

We are all familiar with the techniques used by these schemes to facilitate the road user task: staggered junctions to replace crossroads, extending pavements into the roadway to make pedestrian crossing easier and make pedestrians more visible to drivers, bringing give-way lines forward to improve driver sightlines along major roads, and so on. The aim is to reduce workload and improve perception, so that it could be argued that the engineers are applying the principles of traffic psychology.

One of the best examples of a measure that simplifies the driver's task and therefore improves safety is the mini-roundabout. Where a complex junction has been replaced with a mini-roundabout, drivers emerging onto the roundabout have only one stream of traffic to survey and can carry out their task in the knowledge that even traffic with priority has been slowed down. The mini-roundabout can be seen as an archetype of the road safety engineering measure, and it is therefore worth investigating how it was developed.

The mini-roundabout was originated at the Road Research Laboratory by Frank Blackmore and his colleagues in the early 1970s (Todd, 1989). Blackmore himself was a retired Wing Commander from the RAF who joined the Road Research Laboratory in 1960 and became a member of the Traffic Planning Section, headed by J.G. Wardrop (Charlesworth, 1987; Road Research Laboratory, 1967). Blackmore was a civil engineer by training (his degree was from the University of Lausanne), and his colleagues included physicists and mathematicians, but no psychologists. At that time, roundabouts in Britain generally operated like those in other countries, i.e. with priority to traffic entering the roundabout over the traffic already on the roundabout. However a few local authorities had decided to install signs instructing entering drivers to give way to traffic on the roundabout. The Ministry of Transport asked the Road Research Laboratory to investigate this alternative practice and Blackmore led the study (Todd, 1989).

He found that giving priority to traffic on the roundabout drastically reduced the tendency of roundabouts to seize up. The effect was a 10 percent increase in capacity and a reduction of 40 percent in delay. He also observed a statistically significant accident saving of about 40 percent. Finally, he surmised that, because there was less need to accommodate weaving traffic on the roundabout, it was possible to introduce “roundabouts which are small by present-day standards” (Blackmore, 1963). Once again, the aim was capacity improvement rather than safety. The first trials of the new small roundabouts took place on the TRRL test track and were followed by an experiment on public roads in 1968. A set of traffic signals at a junction was replaced with a roundabout whose central island was three metres in diameter. Saturation capacity rose by 27 percent. When the new roundabouts were brought into more general use, a reduction in injury accidents in the range 30 to 40 percent was observed where the roundabouts replaced signal-controlled or give-way junctions, with even larger reductions
in serious and fatal accidents (Todd, 1989). The term 'mini-roundabout' was in use by 1971 (Blackmore, 1971).

So the story here is not one in which engineers set out to improve safety at junctions and devised an ingenious solution to the problems of driver task load. Instead, they stumbled on the notion of the small roundabout, and did so with the intention of improving junction capacity. The fact that there was a safety benefit was a piece of serendipity, a stroke of good fortune - though of course one which was quickly put to good use, so that the mini-roundabout has come to be used as much if not more for its safety benefit than for its capacity benefit.

AN INTEGRATED APPROACH

The mostly intuitive techniques that have been applied in road safety engineering have achieved a great deal. In spite of rising levels of traffic, the number of accidents has been falling steadily in most western countries. But that does not mean that we cannot do much better. A more systematic and more rigorous approach could achieve much more. Such an approach should draw on an understanding of human performance, of the variation in human performance (both within individuals and between individuals), of behaviour in varying situations, and of how, why and when errors occur. This is where traffic psychology can make a huge contribution.

What is required is true integration between engineering and traffic psychology to create 'human engineering'. The engineers will have to learn more about human limitations; the psychologists will have to be willing to dirty their hands by participating in experiments and trials which, to the core discipline, may appear to look too much like applied, as opposed to basic research.

The development of better solutions will be an iterative procedure, in which new solutions are compared with older ones. As new methods and new knowledge become available, we should apply them, remembering that a partial solution is better than none at all. An eclectic, empirical approach will produce greater dividends than an arbitrary selection of a single 'right' approach. Human behaviour is not so predictable that we can identify a priori how road users will behave in response to a particular implementation. Behavioural adaptation - how road users adjust their behaviour when faced by a change in the traffic environment or vehicle engineering - can be hypothesised, but its form and extent can only be confirmed through actual experience (OECD, 1990, and see Chapter 13).

THINKING CREATIVELY AND INDIRECTLY: THE ROUNDABOUT WAY MAY BE MORE EFFECTIVE

There is not necessarily an obvious straightforward path in traffic safety from identified problem to best solution. For any problem there are likely to be multiple solutions, and a single solution may address multiple problems. The mistake of thinking only about solutions in a direct way is a common one in traffic safety literature.
Examples may be useful here. In most countries, a major source of accidents in urban areas is the safety problem at unsignalised junctions, mostly give-way T-junctions or crossroads. In the in-depth study of urban injury accidents conducted by the University of Leeds, 62% of all the accidents in the sample were at various types of give-way junction (Carsten, Tight and Southwell, 1989). The problem in these accidents is generally not that the driver on the minor road has not realised that there is a junction, but that the driver, having slowed down or stopped at the junction, emerges and collides with a vehicle that he/she has either not seen or whose approach speed or path has been misjudged.

There are a large number of alternative solutions available for this problem, some in common practice and some more futuristic. Some of these solutions are:

- to replace a crossroads with two T-junctions (a 'staggered' junction) so that drivers going straight ahead across the major road have two separate manoeuvring decisions to make instead of one simultaneous assessment of both directions of the major-road traffic;
- to implement a mini-roundabout, once again reducing the decision to the assessment of a single traffic stream, reducing conflicting movements and reducing the closing speeds of the conflicting traffic;
- to implement a three-way or four-way stop sign in which traffic on all approaches is stopped (this can be seen as the North American equivalent to the mini-roundabout, but it is arguably more pedestrian-friendly);
- to improve sight lines by removing visual obstructions;
- to slow down the major road traffic by some form of road narrowing, horizontal deflection (chicane) or vertical deflection (hump or speed cushion);
- to introduce and enforce lower speed limits on the major road;
- to implement an in-vehicle warning system to alert the drivers on the minor road about the approach of vehicles on the major road and perhaps to indicate which gaps are unsafe;
- to implement an Intelligent Speed Adaptation (ISA) system in which vehicle maximum speed is controlled electronically and to include in that ISA a feature that slows down major road traffic on the approach to junctions.

It can be seen that most of these solutions are indirect - they reduce the task demands on the minor-road driver, and/or they increase decision time, and/or they reduce conflicting speeds and hence accident severity. The indirect solutions may also affect a greater number of accidents. For example, such solutions may mitigate accidents in which a minor-road driver deliberately pulls out into an insufficient gap in the hope that a major-road driver will brake in response.

We can also look at a proposed solution and estimate how effective it will be in terms of accident reduction. Again, care needs to be taken to avoid too narrow a focus. ISA can serve as an example here. One way to predict the accident savings from ISA would be to identify a group of accidents as 'speed-related' and to estimate how many of those accidents an ISA system might address. The problem is that the sources of information on how many accidents are speed-related, i.e. caused by one of the drivers going too fast, are police-reported data or in-depth studies. In either case, the investigator required virtually incontrovertible evidence that a driver was going too fast. For Britain, estimates of the number of accidents in which one or
more drivers was identified as going too fast for the situation are in the range of 3.5% to 20% (Sabey, 1999). Thus, following the logic that an ISA system will address only identified speed-related accidents produces a maximum estimate of system effectiveness of 20%. But this approach results in a very large under-estimate of how many accidents are speed-related. Indeed, it can be argued that all accidents are speed-related: they would not have happened if one or other of the involved parties had been travelling more slowly. Slower speeds give road users more time to anticipate, more time to avoid, a greater chance of success in avoiding and a lower collision severity if they do collide. As regards severity, Andersson and Nilsson (1997) concluded that, for a given type of road, the injury accident rate changes with the square of the ratio of a change in mean speed, the severe injury (including fatal) accident rate changes with the cube of speed change and the fatal accident rate changes with speed change to the 4th power.

The relationship between traffic speed and accident risk has been quite extensively studied. A detailed review of international research on the relationship between speed, speed limits and accidents came to the conclusion that a 1 km/h change in the mean speed of traffic produces a 3% change in injury accidents (Finch et al., 1994). Drawing on such findings, two separate predictions of the effectiveness of ISA have come to remarkably similar conclusions. For Great Britain, the best estimate of the reduction in injury accidents that would be achieved by the most versatile compulsory speed limiting system is 36% (Carsten and Tate, 2000). This compares with the prediction of a 30–40% reduction in injury accidents for the implementation of a similar system in Sweden (Várhelyi, 1996). These much higher estimates of system effectiveness stem from the presumption that ISA will have a general calming effect on traffic. Indeed ISA might be called 'electronic traffic calming' and traffic calming, in its traditional form, has been shown to be enormously effective in terms of accident reduction. In Britain, 30 km/h zones in urban areas enforced by infrastructure methods have been able to achieve injury accident savings of the order of 60% (Webster and Mackie, 1996).

This does not mean that even these more sophisticated predictions of accident savings are correct. Such predictions can be called 'engineering predictions' in that they are based on the assumption that behaviour will be modified by system introduction only in direct ways. They do not take into account the complex effects of behavioural adaptation, even though such effects have been confirmed for ISA in laboratory experiments. Currently we lack a methodology for modifying engineering predictions of safety benefit or disbenefit by taking into account experimental results on the human response to a system.

THE PROMISE OF T ELEMATICS

This discussion of ISA heralds, perhaps, the dawn of a new era in traffic engineering. Increasingly, sophisticated communications and computing systems will be applied to provide responsive engineering in the form of systems that adapt to current driver, traffic and environmental conditions, in contrast to the old style engineering of asphalt and concrete. IT systems in road transport are not entirely new - the first wave, including the introduction of ABS on vehicles and of responsive and adaptive traffic signal control, took place in the 1970s. But the possibilities of intelligent engineering are almost boundless. Increasingly, the major
obstacles will come not from the potential of the technology, but from the limited imaginations of the system designers and, of course, from the fact that the new systems must meet human needs rather than demand a different kind of human.

CONCLUSIONS

'Human-centred design', as it has been called, should be a requirement for all elements in the traffic system, including the roadway, the vehicle and the new technologies that are increasingly being deployed by the road and fitted in vehicles. Such an approach to design necessitates the cooperation of engineers and traffic psychologists. Psychologists can deliver their understanding of human performance and behaviour and of the variation both between and within individuals. Engineers can deliver their knowledge of the traffic system and their intuitive understanding of what has worked in the past. Together they can develop a vision of what might help in the future.

RECOMMENDED READING


ERGONOMICS OF THE DRIVER'S INTERFACE WITH THE ROAD ENVIRONMENT: THE CONTRIBUTION OF PSYCHOLOGICAL RESEARCH

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This chapter deals with the ergonomics of the interface between the driver and the road environment. We will start by defining the limits of the ground it covers and the issues it addresses. We will go on to outline a theoretical and methodological framework for analysing drivers' interactions with the road environment. In this presentation, we will give precedence to the approach developed in the fields of Cognitive Work Psychology and Cognitive Ergonomics, which appear to be particularly relevant when it comes to improving the technical and organisational conditions of driving. We will discuss in particular the contribution of psychological research in two main fields of application: the design of road infrastructure and the development of new driving support systems.

INTRODUCTION

From the perspective of the driver, Ergonomics is concerned with identifying and designing technical and organisational means for facilitating the driver's interaction with the road environment. In the broadest sense, the road environment comprises the vehicle, the road infrastructure and other road users. It also includes the rules of the highway code governing the use of the road infrastructure and interactions with other users, which are sometimes expressed in road markings and road signs. In this chapter, we will not deal directly with the interactions
involved in controlling the vehicle, nor with the mechanisms of perception, which are covered in other chapters of this book (see Chapters 7, 8 and 9). Rather, we will concentrate on analysing the cognitive mechanisms that come into play as and when the driver adapts to the characteristics of the road infrastructure and manages his interactions with other users.

From the standpoint of driving ergonomics, looking for ways of supporting the driver's interaction with the road environment raises two main issues:

- the first is related to the design of the road infrastructure, which means improving the characteristics of the road network and developing design and planning norms that improve 'road readability';
- the second one concerns the design of new driver support systems, including the provision of in-vehicle sources of information and new devices to help drivers perform the driving task.

Psychological research can contribute to the search for solutions by providing a theoretical and methodological framework as well as empirical results likely to support the design and assessment of these measures (see, for example, Chapters 5, 9 and 18).

**Road infrastructure as an interface between designers and road users**

The road infrastructure conveys a wealth of information that guides drivers' activity and their interactions with others in situ (explicitly through devices such as road signs and road markings, and implicitly by means of the environmental context and road layout, for example). The design of the infrastructure and the formulation of the rules determining its use result from choices made by the designers of the road system in the broadest sense (including in particular road and traffic engineers and the legislators of the highway code), so one can regard the road infrastructure as an interface between road designers and drivers. In adopting this viewpoint, we are effectively putting the emphasis on the use made of the infrastructure: the task to be performed then becomes central for deciding what information needs to be provided. The design problems raised relate to the compatibility between the choices made by designers and the information drivers need to achieve their objectives and perform their driving task efficiently and safely. This concept is also described by Hale and Stoop (1988), who position road design problems in terms of communication between road designers and road users and of compatibility between the formal rules of use underlying the design of the road and the effective rules applied by drivers when using the road.

Formal rules are essentially laid down in the highway code and are taken into account by designers in designing the road infrastructure, together with other technical design principles (Fleury, 1998). Designers' choices are particularly delicate in a system like the road system, in view of the multiplicity and diversity of the actors sharing and using the same space, each actor being autonomous, having his/her own objectives, knowledge and strategies. Furthermore, as Fleury (op. cit.) points out, these choices are not always optimised because of the diversity of the actors involved in a more or less direct way in structuring the road space. The malfunctions observed in terms of the operation and safety of the traffic system (errors, offences, conflicts, accidents) have led researchers to focus on identifying the factors and mechanisms at the root of these problems.
Concepts that have emerged in the 1980s, such as 'positive guidance' (Allen and Lunenfeld, 1986), 'road readability' (Mazet, Dubois and Fleury, 1987) and 'self-explaining roads' (Theeuwes and Godthelp, 1995b), all raise the question of how the road infrastructure could support drivers' activity. What these different approaches have in common is to stress the need to structure the road network by adopting homogeneous and consistent design principles that take account of the different tasks to be performed by the various road users and the constraints on their execution. They seek to identify the relevant infrastructure features likely to provide a clear picture of the functionality of the road space: for example how to cross a complex intersection; who has the priority at a specific location; what kind of information can be expected; what kind of road events could happen, and so on.

Such an approach involves helping drivers to detect, identify and interpret current situations and, given the dynamic nature of driving and the associated temporal constraints, facilitating their anticipation of on-coming situations and the events that could occur. Given the collective nature of driving, it also involves facilitating interactions between drivers by enabling each driver to be prepared for their occurrence and ensuring that the rules to be applied for solving potential conflicts are clear and easily understandable. Lastly, and in the longer term, reducing the variability of road infrastructure design should make it easier for drivers to learn its functionality and its use.

The questions raised from this perspective have led researchers to:

- propose diagnostic methods for spotting critical situations from a safety viewpoint (e.g., the Expectation Violation Analysis approach advanced by Allen and Lunenfeld (op. cit.) or the itinerary approaches and global safety approaches. These diagnostic approaches, which are based on acquired knowledge about driving activity combined with technical knowledge about road design, suggest that action should be taken at the level of the information to be conveyed to drivers, and indeed are an invitation to make profound changes in the road infrastructure;
- stress the need for improving the design process by bridging the communication gap between road system designers and traffic psychologists, suggesting that the former should spell out the rules of use induced by the design of the road and that the latter should formulate the results of their research in terms of the driver's effective rules of use (Hale and Stoop, op. cit.);
- lastly, in terms of psychological research, to focus work on the knowledge and strategies that drivers apply in controlling different driving situations and the tasks to be performed.

**New driving support systems: a new interface between the driver and the road environment?**

With the same aim of supporting drivers' activity and improving the operation and safety of the traffic system, there has been a rapid increase in research activity devoted to the design of new in-vehicle driving support systems over the past 10 years. The development of such systems poses crucial questions regarding technological choices, the consequences on drivers' future behaviour and the consequences for overall safety.
These new systems will mediate drivers' interactions with the road environment by creating new sources of information and/or offering new modes of action regulation. In the same analytical framework as above, they can be seen as an interface between designers and road users and, perhaps more importantly, may raise the same question of compatibility between the choices made by designers and effective driver needs.

These new systems will modify the conditions in which driving is performed and, as a result, changes in driver behaviour can be expected (both in the context of being 'assisted' drivers and in their interactions with other road users). The changes associated with the use of these new systems and their acceptance by drivers will depend on the particular characteristics of the system developed (types of task they are designed to support) and on the type of mediation they will provide during driving ('descriptive' as regards the state of the environment, 'prescriptive' as regards the regulating action to take and 'back-up' in the event of driver failure or his/her deliberate delegation).

It has to be pointed out that most systems under development at present are dedicated to specific driving tasks. Their range of competence is by definition limited to the area of that task (or to a sub-group of conditions in which that task is performed). The mediation offered is thus only partial, the driver will always need to have direct control over interaction with the road environment and he will remain responsible for the overall management of his driving. The integration of these systems into the overall driving activity thus becomes a critical issue that needs to be carefully studied. Earlier evaluation work of driving aid prototypes in real situations (Malaterre and Saad, 1986) highlighted the difficulties of integration linked to an overly normative conception of drivers' needs for assistance and to the substantial discrepancies between the functions assigned to these aids by the designers and drivers' objectives and strategies, which vary according to the situational context (infrastructure and traffic related) and the tasks to be performed.

Studying the integration of a new aid in driving activity entails taking account of the essential dimensions of the road situations in which that activity takes place and of the diversity and variability of the road situations that drivers may encounter during a journey. It also involves choosing functional units of analysis making it possible to examine not only the effect of the aid on the performance of the specific task to which it is dedicated (compliance with safety margins or speed limits, for instance), but also its compatibility with the performance of other related driving tasks (such as overtaking manoeuvres, interactions with other users, fitting in with traffic constraints, and so on). Finally, it calls for the selection of relevant indicators likely to signal the changes that could take place in drivers' activity.

These issues make direct demands on knowledge of the driving task and of the psychological mechanisms that govern drivers' activity in the complexity of real driving situations.
Traffic Psychology research aims to describe and categorise driver behaviour in situ (as safe or unsafe, legal or deviant...), to identify the internal factors (relating to the driver himself, such as his experience) and the external factors (the technical and social environment of driving) that account for this behaviour, and to reveal the psychological processes (perceptual, cognitive, motivational, ...) that govern drivers’ activity. The purpose of this research is two-fold: to contribute to increasing knowledge about driver activity and to help develop measures for improving road system operation and safety. Within the scope of driving ergonomics, psychological research is concerned with analysing driver activity in order to identify measures for facilitating drivers’ interaction with the road environment (infrastructure, other road users...) through road infrastructure design and/or the development of new driver support systems.

The questions prompted by the identification of these measures stem from complex situations, whose dimensions must be examined and taken into account when designing research studies, validating the results and formulating recommendations. Applying a systemic approach (see, for example, Hale and Glendon, 1987) entails focusing on interaction phenomena between the driver(s) and the technical and organisational components of the system (vehicle, road infrastructure, legislation, traffic management...) and hence going beyond a simplified view of causality in analysing system malfunctions. Adopting such an approach implies a joint analysis of the characteristics of the road environment and the characteristics of drivers.

From this standpoint, studying road situations, the tasks to be performed and driver behaviour is a significant part of the search for solutions. In-depth analysis of road situations is designed to identify their significant dimensions. It entails specifying the nature of the interactions (with the road infrastructure, with other users, and so on) and the demands (regulatory, structural, dynamic, etc.) drivers have to deal with when driving. Studying driver behaviour calls for an examination of how drivers perceive and weigh these different demands, and how they organise, perform and control the different tasks required in situ. It thus contributes to identifying the mechanisms that govern their driving and the difficulties they encounter when managing their journeys. Analysing driving errors is particularly useful for highlighting those mechanisms and difficulties. Errors may be considered as both a subject and a means of analysis (Leplat, 1986): a subject of analysis inasmuch as the mechanisms that induce them must be explained (and several theoretical frameworks have been developed that are useful for such an investigation, see, for example, Reason, 1990); and a means of analysis in that they reveal the critical interactions within the system and direct research towards the situations that deserve specific investigation.

This approach, classic in Ergonomics and Work Psychology, thus calls for analysis of the prescribed task (what a driver has to do in a given situation) and the actual task (what a driver effectively does) with the aim of identifying the possible discrepancies between these tasks and their origins (see, for example, Leplat 1990). The prescribed (or formal) task is the task to be carried out as conceived by the designer of the system and/or the safety manager. It sets out (more or less explicitly) a number of prescriptions, which are supposed to influence and to some extent guide driver activity. In other words, the prescribed task defines the behaviour expected of the driver, what he should do (in terms of performance and/or procedures to
follow). Analysing the prescribed task in a given situation thus involves identifying the demands and constraints imposed upon drivers’ activity (formal rules for using the road and for managing interactions with other users, as defined by the highway code; design and layout of the infrastructure; traffic conditions; and so on).

The actual task consists of what the driver actually does, the demands and constraints that s/he effectively takes into account. Identifying the actual task calls for a detailed analysis of driver behaviour with the aim of determining exactly how drivers organise and perform the driving task: what their goals and intentions are, what information they select from the environment, what motives and criteria underlie their decision-making, and what regulating actions they take. Psychological research in the field of driving ergonomics is concerned with analysing drivers’ behaviour, taking into account their own characteristics as well as the characteristics of the task to be performed. In the following sections, we will outline a conceptual framework for analysing drivers’ interactions with the road environment and discuss the methods that can be applied.

A conceptual framework for the analysis of driver behaviour

Research has led to the identification of the main characteristics of the driving task, which may serve as a general framework for analysing driver behaviour. It has provided several general models that describe the various tasks to be performed (navigational, situational, operational - see for example Allen et al., 1971) and which characterise the psychological activities involved in driving. In this section, we will emphasise the main features that characterise the driving task and the nature of certain malfunctions identified through observation studies and in-depth accident analysis. This will provide a basis for outlining an avenue of research focusing on the cognitive dimensions of driving activity, and especially on the symbolic knowledge and the regulating strategies involved in the control of road events.

General characteristics of the driving task. Like many activities performed in dynamic environments (Amalberti, 1996; Hoc, 1996), driving is characterised as:

- a complex task, subject to temporal constraints and calling for a continuous adjustment to evolving road situations;
- a task that implies the organisation and performance of multiple inter-related sub-tasks associated with the control of the vehicle, on the one hand, and the control of road events, on the other (Allen et al., op. cit.);
- a task in which the driver is facing uncertainty and has to take decisions that involve risks, given the number of interactions to be negotiated (with his vehicle, with the road infrastructure, with other road users, and so on).

Driving may also be defined as a relatively unstructured task (Saad, 1975) in that:

- the formal task, such as prescribed by the 'highway code', only partially defines the conditions to be taken into account and the procedures to be followed in a given situation. This is due to the very complexity of the driving task and the difficulty of defining a system of rules of a fully operational nature (Leplat, 1998);
- most of the information required for driving is informal;
because of the content and duration of present-day driver training programmes, driving experience is mostly acquired 'by doing', i.e. through practice and experience of road situations. Thus drivers essentially acquire knowledge and develop strategies in a rather 'unsupervised' manner.

Drivers' capacity to learn from experience is a measure of their ability to find heuristic solutions to the dynamic problems they are faced with in managing their journeys. This ability to adapt may be regarded as the result of a 'structuring of the task' (Saad, op. cit.) based on:

- the acquisition and organisation of knowledge about the structure of the road space, the (formal and informal) rules governing its use and interactions with other road users, and the dynamics of different road situations;
- the development of strategies for information gathering and processing and of rules of action.

Critical aspects of the driving task: managing variations in road situations. Errors, incidents and accidents demonstrate the limits of drivers' adaptation to their task, and the factors responsible for that need to be analysed. It is thus important to understand the reasons for such deviations, identify the conditions in which they are most likely to appear, and analyse the mechanisms that could explain their occurrence.

Deviations are particularly common when drivers have to manage variations in road situations and pose serious problems that are known to have a significant impact on the reliability and safety of man-machine systems (Hale and Glendon, op. cit.; Leplat, op. cit.). For instance, some research shows that when crossing intersections, drivers may take undue time to become aware of conflicts with other drivers, or display a certain inertia in the regulating actions they take (Saad et al., 1990). Factors connected with the features of the road environment (disparity between the functional characteristics of an intersection and the regulations governing it, or the visual aspect of the intersection), as well as factors related to driver characteristics (general experience or specific experience of the site), have been identified as the causes of these problems. In-depth accident studies have highlighted the problems associated with the temporal constraints underlying the occurrence of accidents and have confirmed the importance of predictive activity when driving (Malaterre, 1990; Van Eslande et al., 1998). The disparities between drivers' expectations and predictions and the events that actually occur during their journeys seem to be a result of processing errors and the belated detection of critical situations, reducing the available margin for resolving them.

Focusing on the cognitive aspects. Briefly summarised, the elements characterising the task and the nature of certain malfunctions point to an avenue of research that puts the emphasis on the cognitive aspects of driving and whose purpose is to analyse drivers' knowledge and mental representations of different road situations and the relevant control strategies they adopt (Mazet et al., 1987, Saad et al., 1990).

As in any complex human activity requiring adaptive behaviour, one may assume that the driver's mental representations of the situation in which s/he is involved are going to play an important role in its management. In the field of cognitive psychology, the notion of representation refers to the idea of an internal model developed by the individual for dealing
with complex situations. The symbolic structures that enable the individual to deal with such situations result from a construction based on an analysis of the situational data and the retrieval of stored knowledge, as well as on inferential mechanisms (Falzon, 1989). These representations, variously labelled by different authors as 'circumstantial representation' (Falzon, op. cit.), 'current representation' (Hoc and Amalberti, 1994) or 'situation awareness' (Endsley, 1995), are local models for managing a particular situation and generating appropriate responses to variations in the environment. They consist of a body of knowledge built up for each particular task and serve as a guide for the control of the activity, enabling the situation to be understood and categorised and procedures to be developed. They thus play an important 'functional' role (Leplat, 1985), in particular by enabling the individual to make predictions about the evolution of the driving situation and to anticipate the effects of his or her own actions upon the course of events. The effectiveness of these representations depends on whether they adequately reflect 'reality'. In a dynamic environment, where understanding the current situation starts from a prior representation of the situation and the expectations it engenders, the challenge for the individual is to constantly adapt his or her representation to the evolving circumstances (Amalberti, op. cit.; Hoc, op. cit.) by taking account of the relevant new elements of the situation, which could change the task s/he is about to carry out.

From a safety standpoint, one of the main problems is then to identify the information drivers will need if they are to realise that their expectations, and more generally the situational model on which they are basing their behaviour, are no longer appropriate and must be modified (Hale and Glendon, op. cit.).

An analysis of the content and organization of the knowledge and know-how acquired by drivers in their interaction with the road environment and the tasks they perform, of the conditions and mechanisms of their activation in a driving situation, and of the environmental variables likely to influence them is crucial to understanding their behaviour in traffic and to identifying the difficulties they may encounter when managing their journeys.

**Research objectives.** Within this conceptual framework, the driver's behaviour in a particular situation is regarded as a function of the information available at a given moment (both information actually present in the road environment and information stored in the driver's memory, acquired with experience), of its processing and of the decision-making criteria underlying the regulating actions he takes. In view of the dynamic dimension of driving and the evolving nature of the road events to be controlled by the driver, the main questions to be answered are the following:

- what in the driver's view constitutes a variation in the road situation necessitating an immediate or anticipatory regulating action?
- to what extent does the road environment facilitate the detection and anticipation of variations in the road situation?

In terms of research objectives, the considerations outlined above may be re-expressed as follows:

- how, in the dynamics of driving, does the driver deal with variations in road situations? On the basis of the actions taken, can one identify the rules (formal and/or informal) s/he uses for coping with such variations?
• what are the features of the road situation (infrastructure design and traffic conditions) that enable the driver to categorise the current situation and bring into play the knowledge needed to decide what regulating action to take?
• what knowledge can s/he draw on to make predictions about the evolution of the current situation and plan an appropriate response?

Changes in road situation may be linked to, among other things:
• changes in the road infrastructure: for example, a main road that passes through an urban area, a bend after a straight section of road, or an intersection;
• changes induced by the behaviour of other users: a user arriving at or crossing an intersection, for instance, or a driver slowing down in front of the driver or cutting in on her or his lane.

For the driver, these variations may be more or less predictable and more or less expected, depending on whether or not s/he has the knowledge and the information needed to detect and identify them as s/he drives along. Critical variations may occur due to a change in the road infrastructure that the driver could not anticipate in view of the road characteristics upstream of the change: for example, when the driver cannot anticipate the presence of a sharp bend and momentarily loses control of the vehicle, or when the driver does not expect to come across traffic lights and has to make a sudden stop. These critical variations are often related to 'coherency' problems in the sequencing of different types of road environment (Fleury, op.cit). Critical variations may also be related to the behaviour of other road users, when the action they take unexpectedly interferes with the tasks the driver is performing or planning to perform. Different elements could be at the root of these problems, such as the application of contradictory systems of rules by the different participants in a situation, the lack of communication between users, or a failure to understand another driver's behaviour or intentions.

This suggests that there are two main types of driving problem and points to the approaches to be adopted for designing the road infrastructure and driving aids:
• one set of problems has to do with identifying infrastructure characteristics likely to facilitate the reading of road situations and the detection of changes in the situation, which can be grouped under the general heading of 'readability of the road';
• a second set of problems relates to the management of interactions between users and calls for the cues and modes of communication likely to facilitate the dynamic management of interactions to be identified.

Several avenues of research have focused on these issues, referring to different theoretical frameworks, methods and levels of analysis. This is the case in particular in work on the mental categorisation of the road environment, which seeks to identify the content and organisation of knowledge in the memory (especially that relating to different categories of the road infrastructure). This work contributes to identifying infrastructure features likely to facilitate drivers’ classification of road situations and hence their anticipation of road events that could have implications for their driving (Mazet, Dubois and Fleury, op. cit. and see Chapters 5 & 9). The methods used are mainly experimental, entailing the classification of photographs of road scenes, and the dynamic components of driving activity are not taken into account directly.
Other research puts greater emphasis on an analysis of 'circumstantial' representations built up while driving and the effective regulation strategies adopted by drivers in the dynamics of driving situations. This work deals as much with interactions between drivers and the road infrastructure as with interactions between drivers. Since the methods and results of research into mental categorisations are outlined in Chapter 5, we will focus in this chapter on research aimed at identifying drivers' strategies in real driving situations and at determining the variables (both internal and external) likely to influence them. Before outlining this second approach and giving some examples of research done, it would be useful to discuss the methods that can be applied for analysing driver interaction with the road environment.

Questions of method

Analysis of driver activity is based on various models and uses very diverse methods and investigative techniques: interviews or questionnaire surveys of drivers (in or out of traffic situations), behavioural observation in real traffic (at the site or on board vehicles), and experiments in controlled settings (in the laboratory, on test tracks, or on driving simulators). It is not within the scope of this chapter to discuss the advantages and limitations of each method and technique, the choice of which closely depends on the model chosen, objectives of the study and existing knowledge about the task and activity to be investigated. The various methods and techniques should be viewed as complementary and should be used in combination when studying complex phenomena such as those involved in traffic safety. We will, however, emphasise in this chapter the merits of undertaking in-depth analysis of drivers' activity in real driving situations and its contribution to the field of driving ergonomics.

Contribution of the analysis of drivers' activity in real driving situations. The need for developing more functional models of driver behaviour has often been stressed. This implies adopting less atomistic views of the driving task and developing the analysis of driver activity in more realistic environments that preserve the essential dimensions of driving situations (dynamics, interactions with the infrastructure, interactivity of other road users' behaviour, and so on) and drivers' activity (inter-related activities and the management of concurrent tasks). This view is in accordance with Ranney's (1994) seminal review of research paradigms in road safety. He concluded that "moving the focus of research away from the driver in isolation and focusing more on the interaction of the driver and driving situations would improve the ecological validity of roadway safety research. It would better define the limits of generalizeability by revealing the deficiencies of controlled research in artificial settings, where there are no demonstrable connections to real-world driving. It would also move theory beyond artificial obstacles created by the idea that human errors contribute to an exceedingly high percentage of accidents and allow work to focus on identifying factors that create incompatibilities among the drivers, the vehicles and roadway systems" (p. 747).

We take the view that analysing drivers' activity in real driving situations should make a significant contribution to this development and, at a more general level, that it should be an essential stage in any research in the field of road and traffic ergonomics, enabling the significant dimensions characterising the road situations to be identified and drivers' actual behaviour to be described and analysed. It provides a way of analysing drivers' adjustments to
the diversity and variability of the road situations they encounter and of revealing the situational conditions that they actually take into account when managing their journey. Combined with verbal reporting and interview techniques, it serves to reveal the knowledge drivers bring into play in controlling road events, the motives and criteria underlying their decision-making and the regulating actions they take. In other words, this approach should help to identify a set of relevant variables for explaining behaviour observed in traffic, variables whose respective weights have to be assessed according to each main category of driving situation.

**Studying activity in real driving situations.** The analysis of actual driving situations (or on-site as opposed to laboratory situations) raises a number of theoretical and methodological problems that require consideration. In actual driving situations, the activities performed by the driver are numerous and many factors may explain the observed behaviour. These situations, which were not, of course, designed by the analyst who is to study them, must embody several levels of description and analysis if a valid explanation is to be found.

The type and level of analysis used to investigate actual situations largely depend upon research objectives and the theoretical models that govern the choice of observables and the methods used. In practice, they also depend on the resources (human and technical) and time available.

Some observations of behaviour in real situations are made from an essentially descriptive standpoint (Fleury, op. cit.): they seek to establish some kind of picture of drivers’ behaviour on the road (for example, recording the speeds practised on different road networks, the numbers of drivers breaking the speed limit, and so on) or to establish a quantified relationship between some characteristics of road design and drivers’ behaviour (such as the percentage of non-observance of traffic lights and the length of time they remain on amber).

Observations on the ground can be viewed as exploratory research which seeks to identify the different features of the infrastructure and the traffic conditions linked to the tasks performed and/or to the variables characterising the drivers themselves (e.g., age and experience) and which are likely to explain drivers’ behaviour in specific road situations. For example, what are the infrastructure variables likely to induce drivers to slow down when passing through a built-up area on a main road, or what are the variables that determine the adjustments in speed implemented by drivers when crossing an intersection?

Other observations are more directly guided by hypotheses about certain psychological processes that could explain the way drivers interact with the road environment. Observation sites are then carefully analysed and selected, as are the variables (internal or external) used to test these hypotheses. Observations may be made on-site or on board vehicles, and may or may not be associated with interview techniques and questionnaire surveys of drivers (in or out of driving situations). They may be confined to the analysis of a limited number of road locations and/or tasks to be performed during a road journey, or on the contrary take account of broader functional analysis units and seek to explain the way the driver manages the different tasks to be performed during an entire journey.
Detailed investigation of drivers' activity on board instrumented vehicles. Over the past few years, on-board observation methods have become more sophisticated thanks to numerous technical improvements such as video techniques and on-board devices offering the possibility of gathering a large amount of behavioural data that can be more easily related to controlled variations in the driving situation. As a result, there has been an appreciable increase in the amount of research carried out in real driving situations (especially for evaluating the integration of new driving support systems in drivers' activity).

It has to be pointed out, however, that many observation studies in the field still focus solely on driver behaviour and neglect the situational context in which this behaviour takes place. When the contexts are taken into consideration, they are done so only at a very global level (average traffic density, for example) and the variations likely to occur within these general conditions are rarely controlled. Reference to the context is particularly important in order to get a better understanding of driver behaviour in situ, however. Moreover, analysing the processes at work in driving activity requires the latter to be studied as it unfolds. It is thus necessary to develop data analysis procedures that allow for a more detailed examination of road events and preserve their sequencing. It will then be possible to examine in greater detail variations in road situations and the manner in which drivers monitor and control these variations. In particular, it will enable the key parameters of driving activity to be analysed, namely its temporal and sequential aspects.

Unfortunately, the progress of this type of research is considerably limited at the moment because of the problem of analysing situational data. In effect, there is no automated means for describing the road situations in which driving takes place. Currently, description of the context is carried out 'manually' on the basis of a systematic analysis of video recordings made during a journey. However, there is a need to develop a system enabling the description of the context to be automated and for it thus to become an aid for the ex-post analysis of road situations and behaviour. Multidisciplinary research projects dealing with this issue are underway (see for example, Rombaud and Saad, 2000).

**Some Examples of In-Depth Analysis of Drivers' Activity in Real Driving Situations**

The research presented here is designed to illustrate the influence of situational variables (both infrastructure- and traffic-related) and variables linked to the drivers' experience on the mechanisms at work in the control of complex real driving situations. It seeks to explain the way in which drivers manage these situations during their journeys and to shed light on the difficulties they encounter in doing so. Research on two types of situation will be described, drivers' strategies when approaching and crossing an intersection and car-following on motorways.
In-depth analysis of drivers' strategies when crossing an intersection

An intersection can be regarded as a zone of transition along the road where the driver may have to adjust her or his speed so as to comply with the regulatory and/or functional requirements resulting in a change from the previous driving situation. More precisely, we will define it as a zone of potential interaction with one or several other road users. A number of research studies have shown that, when crossing intersections, drivers display a certain inertia in the regulating actions they take or take time to become aware of conflicts with other drivers, and these are factors that can lead to accidents. Taking this research further, a detailed analysis of this type of road situation was carried out (Saad, Delhomme and Van Elslande, 1990). Its objectives were:

- to analyse drivers' strategies when passing through intersections and examine to what extent those strategies are linked to mental representations of that type of road situation;
- to examine the role played by the characteristics of the road infrastructure and the traffic situation in the choice of strategy adopted; and
- to assess the role of driving experience in determining the mechanisms that underlie driver behaviour.

The methodology used entailed making observations from within an instrumented vehicle (equipped for measuring several indicators, such as drivers' speed or braking actions, and for making a video recording of the journey) during an actual drive on the public highway. In addition, in-depth interviews were conducted with each driver after the journey using two types of aid (presentation of the video recording of their journey and slides of different scenarios of interaction with other drivers at the junctions studied).

During the journey, the drivers were required to pass through five intersections, four of which were on a main road with central islands at each junction and the other on a secondary road with no islands. At all the intersections concerned, there were road signs giving the drivers priority over other users. Two groups of drivers participated in the experiment - one of 12 experienced motorists and one of 10 novices.

Analysis of drivers' speed regulation. For the purposes of this analysis, we selected only those situations where the driver's progress was not hampered by the presence of longitudinal traffic on the same lane as him. We then singled out, on the one hand, situations in which there was no traffic visible on the lateral branches of the intersection and, on the other hand, situations in which another vehicle was visible and likely to interfere with the driver's trajectory. The results revealed variations in speed regulation at the different junctions.

When crossing the intersections located on the main road, drivers' speed adjustment appeared to be a function of the characteristics of the intersection and of traffic conditions. No significant difference in behaviour was found between experienced drivers and novices.

In the absence of traffic at the intersection (see Figure 1), the drivers modified their speed significantly in the approach to only two of the four intersections studied. The speed reduction was linked to infrastructure characteristics that represented a discontinuity in relation to the previous driving situation (extent of the road installations and visibility over the whole
intersection, or a change in the conditions of progress, such as a reduction in the number of lanes approaching the intersection). In the other cases, the cues present at the intersection were not sufficient to prompt a reduction in speed, failing to signal treatment of the intersection as a zone of transition in the journey. This confirms the idea advanced by Monseur and Marchadier (1971) that it is important for road design either to highlight the intersection visually or to incorporate structural constraints that clearly identify it as a transitional zone.

![Speed (Km/h)](image)

**Figure 1. Curves of average speeds in the absence of traffic at four intersections on a main road**

When there was a vehicle visible on another approach to the intersection, there was a significant reduction in speed at all four intersections. The presence of another user at the crossroads thus contributed to the representation of a change in the driving situation calling for some regulating action. This indicates, moreover, that although they had priority, drivers took account of the interaction situation created by the approach of another road user. Drivers' speed adjustment may be seen as a means of giving themselves more time to assess the risk of interference and to be prepared for dealing with it.

The results obtained at the fifth intersection located on a secondary road essentially reveal the effect of driving experience (see Figure 2). The experienced drivers modified their speed significantly at the intersection, while the novices did not. These differences seem to be linked to the difficulties of detecting the intersection in the approach to it (an effect of perceptual continuity) and to the representation of the relative status of the two roads (associated with the level of traffic flow).

**Analysis of drivers' verbal reports and interviews.** The drivers were interviewed in order to complement the analysis of observed behaviour by seeking in particular to identify the variables that drivers took into account and the rules they applied to manage their interaction.
with other users at the intersection. Their analysis highlighted the diversity of cues they use to
gauge the likelihood of interference with others (such as their position at the intersection, their

![Curves of average speeds at the intersection located on a secondary road as a function of the driver's experience](image)

Figure 2. Curves of average speeds at the intersection located on a secondary road as a function of the driver's experience

relative proximity and their approaching speed), as well as the 'interactive' dimension of the
regulating action they took (in the sense that it depends on the behaviour of the other and is
aimed at influencing that behaviour if need be). Depending on the outcome of their assessment
and on how the interaction situation evolves, drivers resort to different types of regulating
action (to keep an eye on the other driver's behaviour, giving him a signal if there remains any
doubt about his intentions, or making a significant adjustment in speed). It has to be pointed
out, however, that drivers control the interaction in a way that is essentially aimed at ensuring
that the other user will stop when they approach. This strong sense of priority and the
difficulties sometimes encountered by drivers in processing the variables characterising the
interaction situation and in interpreting others' behaviour and intentions are at the origin of
some accidents at intersections (Malaterre, op.cit; Van Elslande et al., op.cit.).

**Conclusion.** In conclusion, it is important to stress the differences observed in the performance
of the same formal task, namely, crossing an intersection when one has priority. In effect, our
findings highlight the plurality of the mechanisms that may explain the observed behaviour and
hence the means that could be used to influence it. The characteristics of the intersection itself,
as well as the characteristics of its approach, play a significant role in drivers' speed
adjustment. The onset of an interaction situation, when another road user is seen to approach
the intersection, also induces a change in behaviour. Finally, driving experience seems
particularly critical when some features of the road infrastructure make it difficult for the driver
to detect the presence of the intersection and/or when the status of the road on which he is travelling engenders an expectation about the risk of interference with another driver.

**Managing car-following situations on motorways**

A car-following situation is generally considered to begin once a driver can no longer drive at the speed he would like to because of the presence of other users in his lane. Depending on the number of vehicles on the road and the traffic lanes available, this constraint may be more or less great and more or less long-lasting. Different degrees of density may characterise the state of the traffic, which ranges from occasional constraints to heavy congestion. Within these different conditions, there may be sharp and rapid local fluctuations in traffic flows.

Car-following situations call for the driver to adapt to the constraints and variations of the traffic, and in particular to detect 'critical' variations, i.e. those which require a regulating action to restore adequate safety margins or prevent a collision. In this kind of traffic, where drivers' actions are closely interdependent, the degree to which a driver adapts his behaviour depends on the safety margins he adopts and the way he controls his interaction with other users.

Formal safety recommendations advise drivers to maintain a 2 second time headway, and values lower or equal to 1 second are generally considered to indicate risk-taking behaviour. Previous research revealed the disparities that exist between these formal rules and drivers' actual practices in situ (Fuller, 1981). It is thus important to understand the reasons for such deviations, identify the conditions in which they are more likely to occur and analyse the mechanisms that could explain their occurrence.

While much experimental work (on tracks or in driving simulators) has been conducted to analyse the perceptual mechanisms involved in car-following situations, the cognitive control and the decisional aspects of this activity have been little investigated. The study presented here (Saad, 1997) was aimed at determining more precisely the situational demands (infrastructure- and traffic-related) to which drivers have to adapt when driving in car-following situations and at analysing how drivers take these situational demands into account and how they organise, perform and control the different tasks required. A specific objective was to identify the information and knowledge on which drivers based their categorisation of the situations they encountered and the strategies they applied in managing those situations (motives, criteria and decision thresholds for the type of regulating action taken).

**Analysis of driver behaviour.** An analysis of driver behaviour indicated that there were frequent variations in the safety margins maintained, which very often fell to low values (= 1.5 s). A number of 'critical car-following episodes' were identified, 33 of which involved experienced drivers and 40 involved novices. It should be noted that for each driver the critical episode represented approximately half the duration of the car-following situations in which they were involved. An examination of the critical episodes enabled us to characterise both drivers' behaviour and the environmental conditions likely to influence their activity (level of traffic constraints and infrastructure characteristics, immediate interactions with other drivers).
Most of the critical episodes observed were 'unstable' ones, i.e. they were associated with a lane change manoeuvre performed either by the driver himself (mostly overtaking manoeuvres) and/or by another road user. When traffic density was high, the critical episodes were long and sometimes associated with drivers' braking actions (this was mainly the case for novice drivers). These unstable episodes were observed particularly frequently along some stretches of motorway characterised by transition zones that impose temporal and structural constraints on the tasks to be performed (lane-changing manoeuvres in order to follow an itinerary or to join another section of motorway). It was also in these zones, or in their immediate vicinity, that critical variations caused by other drivers pulling into the driver's lane were particularly frequent. Finally, it should be noted that several incidents or conflicts between the driver and other road users occurred in these zones. These observations confirm that areas of co-activity, where drivers have to co-ordinate the execution of their own tasks with those of others, may represent 'reliability blackspots'.

Our analysis also emphasised the interactive dimension of driving in such traffic conditions. Although the critical margins observed during the journeys very often resulted from the driver's own decisions (closing up on another driver before overtaking, for example), they were also partly imposed by the actions of other users. This is particularly evident when another user cuts in on the driver's lane. Such manoeuvres often result in rapid and significant reductions in the driver's margins. The integration of the resulting variation happens more or less quickly depending on traffic conditions. In heavy traffic, slower adjustment strategies were particularly necessary, because if the driver wished to modify the margin with the preceding vehicle, he had to ensure that this correction was compatible with the distance of the vehicle following him. If pressure from the rear was too great, such variations could only be integrated progressively, which requires a certain amount of time.

One-third of the critical sequences observed were directly associated with such cutting-in manoeuvres, and novice drivers were more frequently exposed to them than experienced drivers. Several elements may explain the frequency of such events for novice drivers, such as the lanes they use (they mostly drove in the middle and right-hand lanes), their driving speed (generally slower than the overall traffic flow) and their uncertainty regarding future events or the choices to be made in zones of transition (directional or merging zones), with the result that they left longer margins and thus provided other drivers with an opportunity to move into their lane. This finding suggests that novice drivers' involvement in critical episodes seems to be due more to their difficulties in managing the complex interactions involved in car-following situations than to deliberate risk-taking. Experienced drivers seem more able to manage (and to avoid) such critical interactions, mainly because they are familiar with the conditions in which they are likely to occur. Some 'anticipated' lane changes are indicative of this, for example, when a driver anticipates another vehicle joining his lane before the other driver has made his intention known by indicating, or when he changes lane on nearing a traffic entry zone before any other road user is actually visible.

Analysis of drivers' verbal reports. An analysis of drivers' verbal reports and interviews complemented the analysis of observed behaviour. It enabled us to identify the range of variables that drivers take into account in managing their interactions with other users and, in particular, their safety margins in car-following situations. They include the characteristics of
the infrastructure; the overall speed, density and stability of the traffic flow; the vicinity, extent and duration of safety margin variations; and the nature of the immediate interactions with (and between) other drivers.

The regulating actions taken (or not taken) by the drivers depended not only on the size of the margin with the preceding vehicle, but on the overall traffic situation and its dynamics, as well as their intentions and priorities in the particular situation. They also depended on other drivers' behaviour or intentions (as observed or expected) and were sometimes aimed at influencing that behaviour.

Finally, the results suggest that, when managing their interactions with other road users, drivers (and especially experienced drivers) draw on a number of 'reference situations' and base their decisions on a representation of the 'typical behaviour' of other road users in those situations. If they detect any deviation from that norm, they intensify their monitoring of the situation and/or take some form of anticipatory regulating action (changing lane, reducing speed). One of the main problems from a safety standpoint, as is highlighted by an analysis of the conflicts observed during the journey, is to realise that the situational model on which drivers base their behaviour may no longer be appropriate and needs to be updated.

**Conclusion.** This research enabled us to define more precisely the situational demands (infrastructure- and traffic-related) of car-following situations on motorways and to reveal some determining factors of drivers' strategies. This was particularly useful for drawing up an investigation procedure in order to assess the impact of an Adaptive Cruise Control prototype on drivers' strategies (Saad and Villame, 1996).

More generally, it demonstrated that driving in such traffic conditions is a complex activity, insofar as it not only involves adjusting safety margins in relation to a preceding vehicle but also calls for broader-based traffic monitoring and interaction management with other road users. These results highlight the importance of the cognitive mechanisms involved in the control of car-following situations and signal a need for further analysis, in particular of the mechanisms involved in the control of interactions with others. Recent research work has been devoted to deepening the analysis of the way a driver recognises the intentions of other users (Dusire and Mundutéguy, 2000) or understands the meaning of other road users' signals (Renge 2000). Such research should provide a basis for identifying the means of communication that could facilitate drivers' interactions.

**CONCLUSION**

The aim of this chapter was to give an overview of some of the questions raised in the field of driving ergonomics and to explain how psychological research can contribute to the search for solutions. We have given precedence to an avenue of research that puts the emphasis on the cognitive aspects of driving and whose purpose is to analyse drivers' knowledge and representations of different road situations and the relevant control strategies they adopt. We have also taken the view that analysing drivers' activity in real driving situations should make a significant contribution in the field of driving ergonomics, enabling the important dimensions
characterising road situations to be identified and drivers' actual behaviour to be described and analysed. A detailed analysis of the role played by the characteristics of the road infrastructure in the control actions made by the driver should contribute to identifying solutions as regards road design. The knowledge of drivers' actual practices in organising, performing and controlling different tasks in various situational contexts should also enable us to deal with the question of the integration of new driving aids in the overall driving task.

**RECOMMENDED READING**


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LEARNING AND THE ROAD USER

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INTRODUCTION

Effective, efficient and safe use of the roadway has to be learned. This is the case whether we engage with it as pedestrian, cyclist or driver of a motor vehicle. Each of these different uses requires different knowledge and skills, but there is also a lot of common ground. All road users need to know the basic 'rules of engagement', the basic code of behaviour for roadway use; and at an even more fundamental level, all users need to understand elements of the nature of movement, inertia, acceleration and trajectory.

Learning involves a change in behaviour as a result of experience (rather than as a result of factors such as fatigue and motivation). That experience may be direct, such as when we learn something by trial-and-error, or it may be at a more representational level, such as when we learn by observing and then imitating the behaviour of someone else or when we are given instructions about how to behave. Examples of the latter would be a teacher explaining to a child the rules for safe crossing of a road or a driving instructor telling a trainee driver to overtake only when there is sufficient clear roadway ahead.

In describing the learning process, psychologists frequently make a distinction between these direct and representational modes of learning, and indeed they are frequently approached from different perspectives within psychology, direct learning being of major interest to behavioural psychologists and representational learning of major interest to cognitive psychologists. This is not to say that there are not representational elements to direct learning processes or that the principles which apply to those direct learning processes do not also apply to representational learning. There are and they do. But the separation of these viewpoints probably owes more to
historical process than to logical analysis and to an extent is also bound up with rather different philosophies of the nature of psychology as a science. Behavioural psychologists of the more radical tradition argue that the subject matter of psychology should be observable behaviour and the search for the systematic conditions under which it occurs. This level of description has traditionally eschewed reference to unobservable mental events as explanatory constructs. Cognitive psychologists on the other hand are principally concerned with such mental events. We can see these different approaches in the kinds of questions asked by each. To take the task of overtaking another vehicle as an example, the cognitive psychologist might ask "what kinds of mental representation are involved in initiating and accomplishing this task?". The behavioural psychologist on the other hand would be more interested in "what are the conditions under which overtaking behaviour occurs and what are the consequences of that behaviour to the driver?". The behavioural approach is fundamentally concerned with the 'why' of behaviour rather than the 'how'. This chapter is about this behavioural approach to the road user because not only can it tell us a lot about why people learn to behave in particular ways on the roadway but also about motivation to behave in particular ways. It also provides a relatively simple model for understanding the psychology of the effectiveness of a vast range of highway design features. For a more cognitive approach to the road user, however, the reader is directed to chapters 3, 9 and 12.

**BEHAVIOUR ANALYSIS**

Imagine walking along inspecting elements of one of your construction projects and your mobile phone bleeps. You take it out, press the appropriate button and speak. Let us now describe this simple everyday behaviour from the perspective of the behavioural approach. The behaviour of interest in this instance is that of answering your phone. This is made up, of course, of a whole series of behavioural steps (reaching, pressing, positioning, speaking) but we can think of it as one behaviour or response for the sake of this discussion - the same analysis would apply if we adopted a more microscopic approach.

The main question to ask from the behavioural viewpoint is why you behaved in a particular way, why you responded by answering your phone, at the particular moment you did. After all, in your repertoire of possible behaviours, you could have simply carried on with what you were doing, you could have lit a cigarette, you could have turned a somersault or enacted a myriad of possible alternative behaviours. To get at this question, let's ask a further question. What might have happened if, in all of your previous experiences with this particular phone, attempting to answer it had resulted in failure - there was always no-one there at the other end of the call? Would you then have responded to the telephone? The simple answer is no you probably wouldn't. Just as we do not try to answer someone else's phone when it rings (it's obviously not for us), we will generally not respond to a stimulus that has no consequences for us. The reason we usually *will* answer our phone when it rings is precisely because it does have some consequence, such as some professional or social communication. Consequences of behaviour that are desireable, pleasant, rewarding have the effect of making the behaviour more probable in the future. And because this involves making the particular behaviour more likely in the total repertoire of behaviours, the behaviour is said to be strengthened or *reinforced* by its consequences. The corollary to this is the situation where the consequence of
the behaviour is undesirable, aversive or punishing. Say every time you answered the phone you received a painful electric shock from the instrument. You would soon stop using it. A punishing consequence to behaviour has the effect of lowering its probability, of suppressing it and sometimes eliminating it altogether. So rewarding consequences strengthen behaviour, punishing consequences weaken it. Consequences therefore provide a powerful mechanism in the process of learning what to do or not to do. Translating this into the language of human motivation and intention (which will perhaps be more satisfying for the more cognitively inclined reader), it may be said that we behave in such-and-such a way in order to obtain pleasant or rewarding consequences or to avoid or escape from unpleasant or punishing consequences. Thus we drive faster (response) in order to get somewhere more quickly (rewarding consequence). Correspondingly we steer around a bend (response) in order to avoid running off the roadway (punishing consequence).

It is worth noting at this point that in order to have an effect on behaviour, particular consequences (such as a rewarding or punishing event) do not have to occur every time the response is made. Indeed consequences can sometimes maintain a response more effectively when they occur only intermittently. Thus even if it is known that a speed trap occurs only occasionally along a particular stretch of road, drivers may nevertheless regularly drive more cautiously.

But this is not quite the whole story. The question above asked why you behaved in a particular way, why you responded by answering your phone, at the particular moment you did. Simply looking at consequences alone does not help answer this part of the question. So let's pose a further question. Do you answer your phone when it has not rung or bleeped? Of course not - there would be no-one at the other end, there would be no rewarding consequence. The phone ringing is actually a precondition, a necessary antecedent event, which makes answering the phone rewarding. In other words the phone ringing acts as a signal to say "hey, answering the phone now (and only now) will be worthwhile"; it acts as a stimulus to enable you to discriminate between those conditions when the behaviour (of answering) will be followed by a rewarding consequence and those conditions when it will not. For this reason, such important antecedent events are known as discriminative stimuli.

One further point. As there develops a stable and well-learned relationship between an antecedent event, a response and its consequence, the response can progressively become 'triggered' by the occurrence of the antecedent event. It's as if there is a shift in the control of the behaviour from its consequences to its discriminative stimulus. This shift is referred to as the stimulus control of behaviour. Answering a telephone is a good example of this. The relationship between the phone ringing and a rewarding consequence to answering it is so reliable that the response of answering becomes almost automatically triggered by the phone ringing.

Thus we have three related terms in this basic behavioural model: antecedent events, which act as discriminative stimuli, signalling the relationship between a response and its consequences, the behaviour or response itself, and the consequences to that behaviour. This is sometimes referred to as a three-term contingency of Antecedents, Behaviour, Consequences, or if you like, the A-B-C of behaviour (see Figure 1). Simple as this model is, it is nevertheless very
Human factors for highway engineers


![Three-term contingency of behaviour analysis](image)

**Figure 1.** The three-term contingency of behaviour analysis. Antecedent events signal the relationship between a particular behaviour and its consequences

**LEARNING TO BE SAFE AND LEARNING TO BE UNSAFE**

According to behaviour analysis, any novice driver is confronted with the enormous task of learning the conditions under which particular behaviour-consequence contingencies occur: the A-B-C contingency of each situation encountered on the roadway. This task is not helped by the fact that many of the three-term contingencies will be discovered to work only on a probabilistic basis. Thus they will be particularly difficult to learn and this difficulty perhaps accounts in part for the over-representation of inexperienced drivers in traffic accidents (see chapter 16 for further discussion).

Perhaps less obvious a problem is that because punishing consequences to potentially hazardous acts are relatively rare, risky behaviour may become shaped and maintained, most especially where the risky behaviour is rewarding in itself. Thus dangerously high speeds have been observed on quiet country roads where drivers have learned that the probability of a hazardous obstruction is very low (Svenson 1978); drivers approach intersections at higher speeds where they think it relatively unlikely that another vehicle will enter their roadway (Lovegrove 1979) and, as a result of experience, drivers are prone to a progressive encroachment onto each other's road space (Naatanen and Summala 1976). These phenomena provide examples of what might be called *learned riskiness* (Fuller 1992). They arise because the contingency between a rewarding behaviour and a punishing consequence is improbable. Potentially unsafe behaviour may continue without a punishing consequence for a time, perhaps a long time. But eventually the low probability and therefore unexpected obstruction will occur, eventually another vehicle will enter the roadway where it is not expected and eventually passing vehicles will clip each other's wing mirrors, or worse. Evans (1991) puts the problem as follows: "To avoid crashes over long periods of time requires adopting safety margins that incorporate the possibility of events of much greater rarity than are encountered in everyday driving" (p.329).
margins that incorporate the possibility of events of much greater rarity than are encountered in everyday driving" (p.329).

The behaviour analysis model can be particularly useful if one is concerned with controlling or trying to change someone’s behaviour and this is a major reason why it is relevant to the work of the highway engineer. Highway design is about enabling mobility in the first instance, but it is also about ensuring that the highway is used safely. In other words it is in part about controlling and sometimes modifying the behaviour of the road user. So in terms of the behaviour analysis model, how does the highway engineer achieve this control?

**ROAD USER CONTROL BY CONSEQUENCES**

Perhaps the most direct application of behaviour analysis to enhance safe road user behaviour is through the use of rewarding and punishing consequences, the former to establish and maintain safe behaviour and the latter to discourage unsafe behaviour. The fundamental problem here is that a potentially unsafe behaviour for the driver, such as high speed, can have rewarding consequences (e.g. avoiding being late for an appointment) as well as punishing ones (crashing into an unexpected obstruction). The rewarding consequence is typically fairly certain, the punishment is typically uncertain, if not improbable. The issue then is how to change the balance between these competing consequences in favour of supporting safer behaviour.

A prevalent example of the use of punishment to control unsafe high speeds reliably is the road hump (Sarin et al. 1991), an example of which is shown in Figure 2. If this is taken at speed it is extremely uncomfortable and at higher speeds will damage the vehicle. The road hump is cheap, effective and it is always there to respond to the undesirable behaviour of the driver. Another way in which the engineer can punish high speed is to make the driving task too difficult at such a speed. Designs which involve narrowing of the carriageway and acute lateral shifts in lane alignment have this property. Decreases in carriageway width are exemplified in 'throats' and lateral shifts may be seen in chicanes and the use of roundabouts (see Figure 3).

![Figure 2. Typical example of use of a road hump in a residential area](image)
But the more general problem of either punishing unsafe behaviour or rewarding safe behaviour is that for most of the time on the road it is impossible for the behaviour to be monitored and followed by appropriate consequences. To have police monitoring behaviour and delivering punishments, even on a very intermittent basis, would most likely not be cost-effective. And the use of other road-users to provide such feedback has only been explored with a narrow range of safe behaviours such as fastening seat-belts (Geller 1988). Video surveillance techniques at particular locations, such as speed and red-light cameras, may provide a partial solution. Furthermore there may be some future in the application of remote and in-vehicle monitoring and recording technology as being developed in the area of telematics. However the political acceptability of such developments is an open question.

Outside of the domain of highway engineering a more molar attempt at the manipulation of consequences to driver behaviour has been through the application of rewards for accident-free records over a designated period. Such interventions have been found to reduce accidents and be cost-effective where both direct and indirect costs of accidents are taken into account (e.g. vehicle repair and replacement costs, insurance cover costs, loss of work days) (see Wilde and Murdoch 1982). However this procedure has the particular weakness of not specifying for the road user the behaviours that are required for safety and it has been shown that these behaviours have to be in the driver's repertoire if the strategy is to be successful.

The complementary procedure to rewards for safe driving records is the punishment of unsafe ones. This happens to a limited extent in most countries in the form of penalising adjustments in insurance premiums as a consequence of culpable accident involvement. However there is typically much room for the development of a more sensitive use of such penalties (see discussion by Fuller 1991). In many countries the insurance process has made the civil liability system more one of compensation than deterrence.

**ROAD USER CONTROL BY ANTECEDENTS**

Antecedent events define the conditions under which particular behaviours are followed by particular consequences. Most punishing consequences are actually avoided by road users because they are signaled as an outcome of unsafe behaviour. You see the speed camera ahead and check your speed. In the same way the road sign for a road hump or its presence on the
roadway ahead act as discriminative stimuli. They tell the driver that a high speed will be punished.

The road sign is almost the archetype of the discriminative stimulus. It gives advance notice of what behaviour-consequence relationships apply to the road environment immediately ahead. For this reason when drivers see a hazard warning sign they don't usually step on the gas. They are more likely to increase level of vigilance and slow down or prepare to do so. Traffic engineers have a veritable arsenal of discriminative stimuli at their disposal to signal appropriate speed choice (for a safe outcome). The most direct are signs indicating a speed limit (fixed or variable, advisory or compulsory) and written instructions on the roadway (e.g. see Figure 4).

![Figure 4](image1.jpg)

**Figure 4.** Written instructions on the roadway can be a powerful discriminative stimulus

Less direct but nonetheless signaling the fact that too high a speed will result in undesirable consequences are devices such as rumble strips. They can work particularly well as hazard warning signs because they stimulate the driver through three sensory systems: vision, vibration and sound; although the latter may be particularly annoying to residents in the vicinity (see Figure 5).

![Figure 5](image2.jpg)

**Figure 5.** Example of the use of rumble strips as a discriminative stimulus signalling an upcoming hazard
Because real discriminative stimuli can come to control behaviour we can use illusory stimuli in the same way. Thus rather than signalling the relationship between high speed and the possibility of a punishing consequence with an actual police presence, we can more cheaply and more simply use a discriminative stimulus for their presence, for example in the form of a two-dimensional full-size simulated police vehicle (see Figure 6).

Figure 6. A simulated police vehicle can act as a discriminative stimulus for a real police presence

Another device that can be used in this way involves manipulation of the visual stimuli we use as a cue to the speed at which we are travelling. Perception of speed is related directly to the rate of flow of visual stimuli in the field of vision as we travel forwards. This flow increases in speed in the retina from the point of expansion (a central point at the apparent ‘end’ of our motion path) to the peripheral visual field. We tend to interpret a high rate of flow as indicating
a high speed and vice-versa. Since this rate of flow (for any given speed) is faster the closer roadside elements are to the edge of the roadway (i.e. the nearer they are in the driver's peripheral vision), we can create an illusion of increased speed by bringing road-side elements closer to the edge of the roadway, or decreasing roadway width or by using a sequence of lateral lines across the carriageway with progressively decreasing intervals between them (see Figure 7). All of these devices can create a subjective impression of higher speed and therefore have the potential of slowing drivers down. What is being manipulated is the discriminative stimulus for speed choice.

**CONTROL BY RULES**

Thus far we have been talking in terms of external controls on behaviour, controls out there in the environment. An alternative is provided by the internal control of 'rule-following'. Rules may be described as statements of contingencies. For example the rule "do not overtake on a blind corner" may be translated as a statement of the contingency "if there is a blind corner (discriminative stimulus) and you overtake (response) you may crash into an oncoming vehicle (punishing consequence)". Rules of the road and rules of good driving practice in a road-user's head may be thought of as internalised statements of contingencies. When made explicit, they not only provide a useful method for transmitting knowledge about contingencies, but they do so without the learner having to experience them directly. They are also of particular use in those situations in which the naturally occurring contingency, i.e. what actually happens, is not very effective at maintaining the desired behaviour. An example would be in the control of slow speeds through a built-up area. Seeing a clear run ahead, drivers may drive over the speed limit without experiencing any punishing consequence such as a collision. But just so long as the road user follows the correct rule for the conditions, even if on many occasions following the rule is experienced to be unnecessary, a safe outcome is more likely to occur. As amply demonstrated in the commercial aviation sector, in which rules are expressed as Standard Operating Procedures for most routine actions performed by air, ground and maintenance personnel, control by rules is a strategy with a remarkably safe record.

Unfortunately there is evidence that where rule-following is not supported by the natural contingencies, the control of behaviour may transfer from the rule to those contingencies. If a driver sees that s/he can break the speed limit without punishing consequences, and is motivated to go faster, then the control of behaviour by the rule may be suspended. Because of this problem, Skinner (1988) emphasised the role of enforcement in the maintenance of rule-following behaviour, that is the addition of consequences other than naturally occurring ones to the behaviour in question. Although rewards for rule-following have been tried out successfully in only a few contexts, punishment for failure to follow a rule has been the more prevalent procedure. This is exemplified by police speed-traps and more generally the detection and penalisation of traffic law violations (see review by Evans 1991). Creating a perception amongst road users of an enhanced enforcement of traffic regulations can produce remarkable changes in behaviour leading to significant decreases in accident statistics (see Epperlein 1987).
IMPLICATIONS FOR THE HIGHWAY ENGINEER

This psychological analysis has several important implications for the traffic engineer, in particular to do with the design of discriminative stimuli. Drivers have to learn the relationship between these and the consequences of particular behaviours, especially their choice of speed. In order for discriminative stimuli to be effective they need to:

- provide clear and unambiguous information. This includes providing good information about road alignment, the features of road junctions and directions (see Figure 8). Furthermore, clear signing of potentially punishing stimuli, such as the location of speed cameras or road humps, should also improve their effectiveness by acting through the stimulus control of behaviour rather than through its consequences. It is preferable to deter as opposed to punish.

- be used in a systematic and consistent way. If a bend sign is used to signal a bend of particular severity, other similar bends should be signed in the same way. If a sign is used inconsistently, drivers may learn to ignore it.

- be reliable. A once notoriously unreliable sign was that indicating roadworks ahead, often left standing days or even weeks after completion of the road maintenance or improvement work. It is thus not surprising that drivers tended not to respond to them, slowing down only if they could see roadwork in progress. A more prevalent problem with reliability is with school and children-crossing signs. They are only relevant when children are actually in transit to and from school. However they are permanently there as discriminative stimuli to passing motorists and so they learn to ignore them. Research shows unambiguously that drivers do not slow down on seeing the sign. Their reliability can be improved, however, by the addition of flashing signals which are only activated at the critical times of day. The flashing signals constitute a more reliable discriminative stimulus (see Figure 9).
Lastly it can help both safety and mobility if the road user is directly told what to do, specifying the desired behaviour, thereby saving the individual the task of having to learn what the contingencies actually are at any given potentially hazardous location. Obvious examples are the use of signals to control movement through junctions and pedestrian crossings. Channelisation can tell the driver where to go, or the pedestrian where to look. And varying maximum speeds can guide drivers through roadway sections without them having to lose control in order to learn that they were going too fast (see Figure 10).

Figure 10. Elements such as channelisation and varying maximum speeds through hazards are ways of directly telling drivers what to do

**Behaviour Adaptation**

Time has value. We use it to be productive ("time's money"), to enjoy leisure pursuits (finding time to read, listen to music, go for a walk, etc), to coordinate activities with others (from timetables to assignations) and simply to be able to do more things (saving time). When travelling, getting to our destination more quickly earns time for the traveller. Thus vehicle drivers are generally motivated to travel as fast as regulations, road conditions, task demands and the capabilities of their vehicle allow.
This fundamental observation has important implications for the highway engineer. For one thing it implies that the driver must not be given cues (discriminative stimuli) which suggest that the speed tolerance of the roadway is faster than its design specification. This is why, for example, it is so important to signal potential hazards such as a sharp bend at the end of long, straight stretches of roadway. The straight part of the roadway suggests tolerance of high speed, but then the conditions change and the driver needs to recognise this in time to adjust speed (and perhaps also level of vigilance) appropriately.

No less obvious is the fact that if a roadway section is redesigned in such a way that drivers can negotiate it at a higher speed, if nothing else changes, they almost certainly will. This has important implications for safety management. Let us take the example of the roadway section described above. Because of accidents involving drivers losing control of their vehicles when attempting to travel through the bend at too high a speed, let us say it is decided to realign the roadway and increase the radius of the bend, a change motivated exclusively as a safety intervention. What will happen now? Well, of course, drivers will now travel through that section of the roadway at a higher speed than before (and perhaps also with less vigilance than before). This response to changing conditions is generally referred to as behaviour adaptation. The important question is, however, does the change in behaviour, the increase in speed, have the effect of maintaining accident rate at its previous level, prior to the realignment of the roadway? Some researchers have argued forcibly that this is indeed what happens. They conclude that such safety interventions are "consumed" as increases in mobility: We have more or less the same accident rate per km as before, it's just that crashes now occur in what has become a shorter journey.

The clearest articulation of this idea, and in perhaps its most extreme form, is represented by the work of Wilde (1994) in a concept known as Risk Homeostasis. He argues that road users, and in particular vehicle drivers, weigh up the rewards and punishments (or in economic terms, benefits and costs) of driving both cautiously and with risk. Out of this process there emerges a level of risk of crashing which the driver is prepared to accept. But according to Wilde this level of risk is more than just something one is prepared to accept - it becomes a target level of risk which the driver actually aims to experience. Thus if the level of risk at any moment of time on a journey is experienced as more than the driver's target level, s/he will take action (such as slowing down) to lower the level to the target value. On the other hand, if the level of risk experienced is less than the driver's target level, s/he will take action to raise the level experienced to the target level. Thus the target level of risk is rather like the setting on a thermostat in a central heating system and driver actions are like the boiler switching in and out to maintain temperature at a constant, predetermined level. Temperature for the driver, however, is of course a level of experienced risk (see Figure 11). It should be clear now why this concept is called risk homeostasis. Wilde argues further that the aggregated target risk level in a jurisdiction is greater than zero and is directly translatable into the frequency and severity of crashes experienced by that jurisdiction. In other words, countries get the traffic accident toll they are prepared to accept, indeed that they collectively target.

Wilde's viewpoint has a very serious implication for traffic safety interventions, including engineering interventions. Put most simply, if a driver has a target level of risk, and a section of roadway is redesigned to make it safer, the driver will experience less risk. The driver will
then respond by driving less cautiously in order to bring experienced risk back up to the target level and will thereby completely absorb or compensate for the safety benefits of the redesign. This compensatory behaviour typically involves driving more quickly, and so safety benefits are consumed in terms of greater mobility. Safety interventions across an entire road system have the effect of making it a faster system: but they have no lasting effect on safety. To make a system safer, argues Wilde, the only solution is to lower target risk levels.

Figure 11. Simplified diagram of key elements of the Risk Homeostasis concept

There has been considerable debate about this theory and the evidence used to support it. From the theoretical perspective serious questions have been raised about the validity of the concept of drivers being able to make subtle risk assessments; about why drivers experiencing risk as less than their target should voluntarily raise it when risk is described (by Wilde) as intrinsically aversive; about the fact that in many collision situations it is abundantly clear that drivers have underestimated the riskiness of their own driving behaviour. Empirically the theory predicts that the accident level (rate x severity) in a jurisdiction should remain more or less constant over time, and yet there are very stable and marked seasonal variations in this level (see for example Evans, 1991). A review of the then available evidence was published in 1990 under the auspices of the OECD. That review reported that there was no conclusive evidence for a homeostatic mechanism keeping traffic accident levels more or less constant. Nevertheless there was reliable evidence of compensatory responses to a wide range of engineering interventions. However these responses typically did not absorb completely the potential safety benefits of the interventions. Thus for example:

- increases in lane width cause increases in average speed (5-10 km/h per each additional metre in lane width) - but there is also a reduction in accident frequency;
the addition of a paved shoulder to two-lane rural roads increases speeds by up to 10% - but there are decreases in accident rates by up to 40%;
- the addition of edge-lines to two-lane rural roads increases average speeds - but decreases are found in accident frequency and severity.

The evidence, therefore, supports a notion of *behaviour adaptation*, but not one of risk homeostasis.

The phenomenon of behaviour adaptation has several implications for highway engineers concerned with improving road safety. The first is to be aware of the process and, when possible changes in behaviour are undesirable, to take action to prevent their occurrence. Thus for example one might argue for the introduction of an enforced speed limit over a redesigned section of roadway which might otherwise encourage unwanted higher speeds. A second implication is to consider the use of feedback to the driver that the roadway might be more risky than it objectively is. Narrowing the carriageway with a hatched central area provides an example of this (see Figure 12). A third possibility is the use of hidden safety features such as break-away light standards and crushable bollards. Because the risk-reducing characteristics of such features are invisible to most drivers, there should be little behaviour adaptation to them.

Figure 12. This central hatching discourages overtaking and makes the roadway appear more hazardous

**CONCLUSION**

Human behaviour is subject to control by antecedent events and by its consequences. This is no less true of behaviour on the roadway than of any other learned behaviour. Highway engineers have in their turn a great degree of control over the nature of those antecedent events on the roadway and also to an extent over the nature of the consequences of behaving in particular ways. Within psychology, the application of this behaviour analytic approach to the modification of behaviour is sometimes referred to as behavioural engineering. And this is precisely what the highway engineer has been doing when introducing 'traffic calming measures', signs warning of hazards ahead, speed limits and so on. Highway engineers have
been acting as behavioural engineers. And they have been doing this for some time now, but in the absence of any explicit theoretical model. It is hoped that this introduction to behaviour analysis will provide a useful conceptualisation to assist in the process of designing novel methods of controlling road user behaviour, of evaluating the design-related causes of collisions and for assessing potential problems in road safety audits. And finally it is hoped that these ideas will enable a greater awareness of the possible behavioural consequences of new roadway designs and of modifications to existing infrastructure that have been introduced to enhance both mobility and safety.

**RECOMMENDED READING**


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The concepts of ‘Inherent Safety’ and ‘Self-Explaining Roads’ have been proposed as being of particular importance in obtaining a structurally safe traffic system. ‘Inherent Safety’ refers to the principle that potentially dangerous encounters should be reduced as much as possible. The ‘Self-Explaining Road’ (SER) concept refers to designing roads such that correct expectations from road users are more or less automatically evoked. That is, road users are provided with direct information about the type of road, and of the behaviour required of the road user. With this concept, it is imperative that the design of infrastructure is tuned to the way road users categorise the road environment. Using homogeneous sets of characteristics within road categories, and different characteristics between categories, are possible ways of achieving this. For an explanation of underlying psychological concepts, see Chapter 9.

Although several studies have been performed on the optimization of the subjective categorization process itself, no studies appear to have explicitly addressed the relationship between cognitive road classification on the one hand and actual driving behaviour on the other. In this chapter we will present a study which investigated this relationship, specifically exploring how driving behaviour (in a simulator) was related to the driver’s categorisation of the road scene. Apart from presenting some preliminary data on this critical issue, it will provide perhaps a flavour of the nature of empirical psychological research in this area.

The experiment was divided into a picture sorting task and a driving simulator task. The picture sorting task was used to investigate the effect of certain road characteristics on optimal
cognitive road classification. The simulator task was used to investigate the effect of road characteristics on driving behaviour.

The characteristics of the four existing (‘official’) categories of roads outside built-up areas in the Netherlands that currently exist, and that form the base-line for the present study, are summarized in Table 1. Note that in the present study the word ‘Motorway’ is used in the sense of the British ‘Motorway’ (American ‘Freeway’), the highest standard of road available, whereas ‘Motorroad’ (‘Autoweg’ in Dutch) refers to a slightly lower-order road with intersections and a 100 km/h speed limit. These are single or dual carriageway national main roads.

Table 1. The four current categories of road outside built-up areas in the Netherlands. For each category the speed limit and the possible presence of other traffic is given

<table>
<thead>
<tr>
<th>Category</th>
<th>Speed limit</th>
<th>Cyclists</th>
<th>Slow motor vehicles</th>
<th>Oncoming traffic</th>
<th>Crossing traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Motorway</td>
<td>120</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B Motorroad</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>+/-</td>
<td>+</td>
</tr>
<tr>
<td>C 80 km/h road for motorized traffic</td>
<td>80</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>D 80 km/h road for motorized + slow traffic</td>
<td>80</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Both the picture sorting task and the driving simulator task were performed with three road design conditions, each by a different group of participants. In Condition 1, a group of participants was assigned to a database that contained a number of road scenes (‘Current Roads’) per road category (A, B, C, D; see Table 1). Typical properties of these roads were that they had relatively few characteristics that were common within a category and relatively many that overlapped across categories. This reflects the road network as it is presently. In Condition 2, a group of participants was assigned to a database which contained eight Self-Explaining Roads per road category. Typical properties of these roads were that they had relatively many characteristics that were shared within a category and only a few across categories. In Condition 3, a group of participants was assigned to a ‘mixed’ database which contained six Current Roads and two Self-Explaining Roads per road category. For both experimental tasks the participant groups from these three conditions were homogeneous with respect to sex, age and driving experience. Different participants were used for the picture sorting task and the simulator task, to avoid the possibility that performance on one task would affect performance on the other. Table 2 shows road characteristics for the ‘Current Roads’ (CR) design, based on the existing guidelines, and for Self-Explaining roads, based on the SER concept.
Table 2. Road characteristics for the CR design and the SER design, according to the standard guidelines and the SER-concept, respectively

<table>
<thead>
<tr>
<th></th>
<th>Current Roads</th>
<th>Self-Explaining Roads</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Width of carriageway</td>
<td>8.35/7.95</td>
<td>6.75</td>
</tr>
<tr>
<td>Width of lanes</td>
<td>3.50</td>
<td>3.10</td>
</tr>
<tr>
<td>Edge lines</td>
<td>0.15/0.20</td>
<td>0.10</td>
</tr>
<tr>
<td>Recovery lane</td>
<td>1.10/0.60</td>
<td>0.35</td>
</tr>
<tr>
<td>Width of emergency lane</td>
<td>3.50/4.00</td>
<td>-</td>
</tr>
<tr>
<td>Guard rail</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Number of carriageways</td>
<td>2x2</td>
<td>2x2/1x2</td>
</tr>
<tr>
<td>Centerline markings;</td>
<td>0.10/0.15</td>
<td>0.10</td>
</tr>
<tr>
<td>Space in between</td>
<td>3-9</td>
<td>3-9</td>
</tr>
<tr>
<td>centerline markings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width of bicycle lanes</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

To investigate the effects of road design on driving behaviour, the possible effects of interfering variables had to be excluded. Therefore all road environments fulfilled the following requirements: there was no other traffic visible, there were no traffic signs that could provide information about the category the road belonged to, and there were no sharp bends in the road that could influence driving speed.

The CR design reflected the real variety of road scenes within each existing road category. The road characteristics of the current roads represented in Table 2 were taken from the design guidelines for motorways and the guidelines for non-motorways in the Netherlands. In order to evaluate the contribution of road elements that are supposed to improve categorization, the SER design was obtained by selectively and systematically adding or removing road characteristics to or from the database for the current road design. The choice of road characteristics for the SER design system was based on previous studies of road design and subjective categorization.

For the SER design all characteristics were standardized, so that only one value was used for each dimension within each road category. For example, width of carriageway was varied systematically so that all roads within one road category had the same width. Width was chosen to be systematically smaller for lower order road categories because a smaller carriageway corresponds to a lower driving speed, which better suits a lower order road. Consequently, road width was informative on road category. Similarly, emergency lanes and guard rails (in the Netherlands mainly used on motorways) are typical characteristics of motorways and have a confusing effect when placed on another road category (Theeuwes, 1994a).
The number of carriageways has also been shown to be important for the distinction between road categories (Kaptein & Theeuwes, 1997). However, the guidelines for the number of carriageways on motorroads are ambiguous: both single carriageways (1x2 lanes) and dual carriageways (2x2) exist. To avoid false anticipations from the driver as a consequence of this ambiguity, in the SER design a choice had to be made between single and dual carriageways. A dual carriageway motorroad would help to distinguish between motorroads and 80 km/h roads for motorized traffic and a single carriageway motorroad would help to distinguish between motorroads and motorways. It is known from the literature that motorroads and roads for motorized traffic are difficult to distinguish and that motorways are easily interpreted as an homogeneous category (Theeuwes & Diks, 1995a). Therefore, a dual carriageway was chosen.

Spacing between centerline markings was varied between roads for motorized traffic and other roads to further improve the distinction between motorroads and 80 km/h roads for motorized traffic. The choice between a 3-9 and a 9-3 mark-gap ratio had to be made. Normally the 9-3 mark-gap ratio (nine metres of white stripe and three metres of space in between) urges caution, which implies a slower driving speed, and would make it easier to categorize a road as a lower order road. Therefore a 9-3 mark-gap ratio was chosen for the lower order road category, the 80 km/h road for motorized traffic.

The absence of centerline markings makes roads for motorized + slow traffic more homogeneous and easier to distinguish from roads for motorized traffic only (Theeuwes & Diks, 1995b). Red-coloured bicycle lanes on roads for motorized + slow traffic further stresses this distinction, since the possibility of encountering slow traffic is communicated through road design (Kaptein & Theeuwes, 1996).

THE PICTURE SORTING TASK

Forty-eight participants, men and women, ranging from 23 to 45 years of age participated. All had had their driving license for at least 5 years and drove more than 10,000 kilometres a year. Pictures were computer-generated images (printed from the driving simulator database) as seen from the driver’s point of view. For each of the four existing road categories, different pictures of road environments, typical for these categories were selected. Examples are presented in Figures 11 and 12 at the end of the chapter.

For each road design principle, a separate group of 16 participants was used. Each participant had to sort 32 pictures. They were asked to imagine themselves driving on the road and how they would behave and what behaviour they would expect from other drivers on the same road. The pictures were sorted in such a way that the behaviour on the roads in a pile was the same, and different from the other piles.

For all three conditions a similarity matrix was generated, in which the similarity between pictures x and y was defined as the number of participants who placed x and y in the same pile. To derive a representation of the underlying structure (i.e., the subjective categories), a hierarchical cluster analysis was performed on the similarity matrices. The results of this analysis reflect how the different road scenes are subjectively represented relative to each other.
and for the Current Roads condition are presented in Figure 1 in the form of a so-called dendrogram.

This shows a group (I) consisting of all the eight motorways (A), two motorroads (B) and one 80 km/h road for motorized traffic (C); a group (II) of six motorroads (B) and seven 80 km/h roads for motorized traffic (C); and two groups (III and IV) of four 80 km/h roads for mixed traffic each (D).

Figure 2 shows the categorization of road scenes in the SER condition. The dendrogram shows a group (I) consisting of all eight motorway scenes (A), a group (II) of six motorroads (B), a group (III) of eight 80 km/h roads for motorized traffic (C) and two motorroads (B), and a group (IV) of all eight 80 km/h roads for mixed traffic (D).

Figure 3 shows how road environments of the Mixed roads condition (Current roads plus Self-explaining roads) were categorized. The dendrogram in Figure 3 shows a group (I) consisting of all eight motorways scenes (A), three motorroads (B), and one 80 km/h road for motorized traffic (C), a group (II) of five motorroads (B) and seven 80 km/h roads for motorized traffic (C), and two groups (III) and (IV) of four 80 km/h roads for mixed traffic (D).
Current road design versus Self-Explaining road design

As hypothesized, the systematic application of Self-Explaining Roads principles led to a subjective classification that was more in accordance with the underlying intentions of the
existing road category system. There was only little divergence of road environments within each self-explaining road category, because road characteristics were homogeneous within road category and were systematically varied across road categories. However, for the existing system, motorways (A) were frequently categorized in the same group as motorroads (B) and 80 km/h roads for motorized traffic (C).

Another problem discovered with the existing system was that motorroads (B) and 80 km/h roads for motorized traffic (C) were mostly seen as roads of the same category. The most important difference between these two road categories appeared to be the number of carriageways. Eighty km/h roads for motorized traffic that had a dual carriageway were all categorized as motorroads. In contrast, in the SER design all 80 km/h roads for motorized traffic had a single carriageway, and all motorroads had a dual carriageway: This removed the apparent confusion in the current system.

Finally, the subjective groups III and IV within the current system contained 80 km/h roads for all traffic with centerline markings and 80 km/h roads for all traffic without centerline markings, respectively. This indicated that 80 km/h roads for all traffic (D) were divided on the basis of the presence or absence of centerline markings. In the SER system, however, 80 km/h roads for all traffic were indeed seen as a single road category.

**Self-Explaining road design versus Mixed road design**

In the ‘mixed’ condition, just as in the CR design there was a large variety of road environments within each road category. The subjective categories were almost the same as with the CR design. The only difference was that the two categories with 80 km/h roads for all traffic (D) in group III and IV were closer together in the graph, and that motorroad B4 was put into the category of motorways.

Self-Explaining Road scenes within the SER design were categorized differently from their identical counterparts within the Mixed design. This indicates that the entire set of road environments to which a road belongs, the context, is important for how roads are categorized.

**DRIVING SIMULATOR TASK**

Forty-eight men and women (different from the participants in the Picture Sorting Task), ranging from 23 to 45 years of age, participated in the driving simulator task. All had their driving license for at least 5 years and drove more than 10,000 km a year.

The experiment was carried out in the driving simulator of TNO Human Factors (see Figure 4). This consisted of:

- A mock-up, which is the front half of a Volvo 240. During the simulator task, participants were seated in this fixed base mock-up and had normal controls at their disposal (steering wheel, accelerator, brake, clutch etc.). In this experiment an automated gearbox was used.
- A vehicle model computer (Intel 486; 66 MHZ) that continuously computed driving speed and heading angle, based on the participant’s inputs. Also the control loading signals for the steering wheel and gas pedal were calculated. The speed and heading angle were used to calculate the new world coordinates in X, Y.
- A supervisor (Intel Pentium Pro 200 MHZ) that controlled the experiment, storing the data. The data were stored on RAM-disks and copied to the hard disk after each run.
- A computer generated image system (Evans & Sutherland ESIG 2000) that generated a visual scene. The image was projected on a screen in front of the mock-up by means of three high-resolution BARCOGRAPHICS 801 projectors.
- A sound generator. The sound of the vehicle (noise of engine and tyres) was generated, based on sampled sounds by an AKAI S3200XL sampler.

![Diagram of TNO driving simulator](image)

The stimuli were computer-generated road scene images projected on the screen in front of the driving simulator. This task environment was provided by the ESIG 2000 image generation system. Pictures from it were also used in the sorting experiment. In the simulation there was no other traffic on the road, there were no traffic signs concerning the speed limit or the official category of the road, and there were no sharp curves. The road environment was modelled on the currently existing design characteristics (see Table 1).

Before driving began, each participant was instructed to imagine taking a drive on a quiet weekend day at noon and to behave as s/he thought was most appropriate in the given road
environment. After each run the participant was asked to fill out a questionnaire. The questions addressed the selection of an appropriate speed for each environment, the influence of the road environment on driving speed, the ease with which road categories could be distinguished, the extent that road category determined driving speed, and the experienced realism of the simulation. Finally, participants were asked to describe all specific reasons they had had to choose their driving speed.

Current system versus Self-explaining design

Figure 5 shows average driving speed per road category for Current Roads and Self-Explaining Roads. On each next-higher order road category participants drove faster. There was no interaction for road category and repetition. Average driving speed from road categories B and D of Current Roads differed significantly from road categories B and D of Self-Explaining Roads. For both categories participants drove significantly faster with the SER design.

![Average driving speed by official road category for both Current Roads and Self-Explaining Roads](image)

Figure 6 shows the standard deviations of driving speed per road category for Current Roads and Self-Explaining Roads. For both design conditions, road category A had a significantly lower standard deviation than the other road categories. In addition, road category B from the CR design had a significantly higher standard deviation than the other road categories from this design. Standard deviations in road category B of Current Roads differed significantly from that for Self-Explaining Roads. Standard deviations for road category B were significantly lower for Self-Explaining Roads than for Current Roads.
Mixed design versus Self-explaining design

A separate analysis was performed on the effects on average driving speed for the road scenes that were identical under the Mixed and the SER design. These subsets are labelled as a, b, c and d, respectively, in order to distinguish them from their parent categories (A, B, C, D). Figure 7 shows the results.

In three of the four SER environments, participants drove faster in the higher-order road category.

Figure 8 shows the standard deviations of speed for identical (Self-Explaining) scenes per road category for both the mixed and SER design. SER scenes from road category B had significantly higher standard deviations than those from the other road categories. Standard deviations from road environments of road category A in the SER design were significantly lower than those in the Mixed design.
Figure 7. Average driving speed in two SER environments by official road category for both Mixed and SER design sets.

Figure 8. Standard deviations of speed in identical SER road scenes per road category for Mixed and SER design sets.
Questionnaire

There were no salient differences in the questionnaire responses to Current Roads and Self-Explaining Roads. The effort in finding an appropriate driving speed for each environment, the ease with which road categories could be distinguished, and the extent to which road category determined driving speed, were all approximately the same across the two design conditions. The most salient differences were that slightly fewer participants claimed that the environment influenced their driving speed on Self-Explaining Roads compared with Current Roads (10 and 14 participants, respectively) and that on Self-Explaining Roads fewer participants claimed it was realistic to drive in the driving simulator (7 and 12, respectively).

Participants were also asked to describe specific determinants of driving speed. Tables 3 and 4 provide the details.

Table 3. Number of ‘naturally’ occurring road characteristics that were claimed to determine participants’ driving speed in the simulator

<table>
<thead>
<tr>
<th></th>
<th>Lights</th>
<th>Bicycle paths</th>
<th>Houses</th>
<th>Trees</th>
<th>Lateral clearance</th>
<th>Curves</th>
<th>No other traffic</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR design</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>29</td>
</tr>
<tr>
<td>SER design</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>4</td>
<td>7</td>
<td>11</td>
<td>9</td>
<td>5</td>
<td>4</td>
<td>49</td>
</tr>
</tbody>
</table>

Table 4. Number of road characteristics that were explicitly manipulated in the designs and that were claimed by participants to determine driving speed

<table>
<thead>
<tr>
<th></th>
<th>Number of carriageways</th>
<th>Width of carriageway</th>
<th>Emergency lanes</th>
<th>Bicycle lanes</th>
<th>Guardrail</th>
<th>Road markings</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR design</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>SER design</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>37</td>
</tr>
</tbody>
</table>

Arguments that participants gave as determining their driving speed were that the number of carriageways gave information about the type of road, in that a dual carriageway labelled a road as a motorroad and a single carriageway labelled it as an 80 km/h road. Moreover, the presence of certain objects was mentioned as giving an indication of the road category and of the speed to maintain.

Current road design versus Self-explaining road design

The effect of Self-Explaining Road design on average driving speed by road category showed that driving speed on motorroads (B) and 80 km/h roads for all traffic (D) was significantly
higher than in the Current Road design. This provided evidence for a larger difference in driving speed between motorroads and 80 km/h roads for motorized traffic (C). Thus, a wider road, a dual carriageway and larger space between centerline markings for all motorroads from the SER design led to a larger difference in driving speed between these roads and 80 km/h roads for motorized traffic. It also showed that differences in driving speed between 80 km/h roads for all traffic (D) and 80 km/h roads for motorized traffic (C) in the SER design were small compared to the CR design condition. A uniform width of carriageway, the absence of road markings and presence of bicycle lanes in all 80 km/h roads for all traffic leads to an increase of driving speed on these roads compared to those from the CR design.

Road category A of both road designs (motorways) had a significantly lower standard deviation than other road categories. A more uniform driving behaviour was maintained within this road category. The effect of road design on standard deviations by road category showed that the speed variability for motorroads (B) was significantly less for the Self-Explaining condition. Thus, a significantly more uniform driving behaviour was maintained in road category B from the SER design.

Participants were exposed a total of three times to the same set of road environments to provide them with a clear impression of the available set of road environments, so that they could determine their driving speed on the basis of the entire set of road environments. An overall increase of driving speed by repetition and an increasingly consistent driving speed within each road category was found. Although absolute driving speed increased in all road categories, relative differences in driving speed between road categories remained the same. As expected there was a decrease in speed standard deviation with each repetition on Self-Explaining Roads, but this decrease was not significantly larger than with current roads.

**Self-Explaining stimulus set versus Mixed set**

In the comparison of the Self-Explaining stimulus set with the Mixed set participants drove faster on SER environments in road categories designed for higher driving speeds. Road environments with different road characteristics elicited different driving speeds (CR versus SER), whereas identical road environments in different road designs elicited the same driving speed (SER in SER environments versus SER in Mixed environments). This indicates that the whole set of road environments, the context, did not affect speed significantly for these roads. The absence of any difference in driving speed between the SER roads from both designs indicated that in this experiment road characteristics in themselves might have had strong effects on their own.

In both design conditions, standard deviations for road environments of road category A were significantly lower than for those of the other categories. The standard deviation of this road category from the SER design was significantly lower than that from the Mixed design. The whole set of road environments thus affected speed variability within road category A.

Results from the Questionnaire component of the study revealed that participants from the CR design used more unmanipulated ('natural') and fewer manipulated road characteristics to
determine their speed and participants from the self-explaining road design used more manipulated and fewer unmanipulated road characteristics to determine their driving speed. Participants from the SER design were more influenced by manipulated road characteristics such as number of carriageways, width of carriageway, bicycle lanes and guard rails in determining their driving speed. Participants from the CR design mostly relied on bicycle paths, houses, trees and lateral clearance.

Participants also mentioned in what sense these road characteristics influenced their driving speed. Objects such as houses were correlated with secondary roads and possible crossing traffic or pedestrians, which caused a decrease in driving speed. Lateral clearance was correlated with safety, because it would help the driver to adjust to dangers, which enabled a higher driving speed. Thickly wooded road environments were correlated with bad anticipation of dangerous situations and therefore caused a decrease in driving speed. Straight roads elicited a higher driving speed and red bicycle lanes indicated a built-up area, which caused a decrease in driving speed. Finally, dual carriageways were labelled as a typical characteristic of motorroads and caused an increase in driving speed, while single carriageways were labelled as a typical characteristic of 80 km/h roads, and caused a decrease in driving speed.

To investigate further the effect of cognitive road classification on driving speed, driving behaviour in the driving simulator task was re-analysed in terms of the subjective road categories (I, II, III, IV) as derived in the picture sorting task.

Figure 9. Average driving speed by subjective road category for both CR design and SER design
Figure 9 shows the average speeds for each subjective road category. Road environments from both the CR design and the SER design elicited different average driving speeds. In the SER design participants drove at higher speeds on each higher order subjective road category. In the CR design, participants drove at higher speeds on the lower order road category IV than on road category III. More remarkably, driving speed was higher under the SER design than under the CR design for the subjective categories II and III (for all three task repetitions).

The standard deviations of speed are shown in Figure 10. Standard deviations from road category I and road category II of the CR design differed significantly from those of the SER design. Standard deviations of driving speed in road categories I and II were significantly lower in the SER design. Road categories III and IV from the SER design had significantly higher standard deviations.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure10.png}
\caption{Standard deviations of speed by subjective road category for both CR design and SER design}
\end{figure}

**CONCLUSIONS**

In this study, design changes for roads following SER principles were found to lead to more appropriate subjective road categorization. Road scenes contained in the subjective categories within the SER design were more similar within categories and more different between road categories than in the existing design. In addition, the more selective and systematic application of road characteristics led to a subjective road classification that was more in accordance with the ‘official’ road category system.
The associated driving behaviour, on the other hand, showed that in the SER condition average driving speeds increased considerably for the two subjective categories roughly corresponding to ‘motorroads’ and ‘80km/h roads for motorized traffic’ (II and III). Speed variability showed a more complex pattern: it decreased for the two highest-order subjective categories (I and II), and it increased for the remaining two categories (III and IV).

Accident risk is generally considered to be both a function of average driving speed and of speed variability. When average speed goes up, the increased risk may be compensated for by less speed variability (i.e., a more homogeneous flow of traffic). This is what happened for the subjective category type-II roads under the SER design, although it is not possible to say whether the compensation of one effect by the other would be complete.

For subjective category III – 80 km/h roads for motorized traffic - the situation with regard to risk was that both average speed and speed variability increased under the SER design, which are obviously effects that add to each other. For this category, applying SER principles may have led to overreliance from the road user’s view because of the apparent transparency of the design.

As a general conclusion it should be observed, however, that the application of SER principles did elicit overall driving behaviour that was more in accordance with intended design speeds. In cases where this goes together with less speed variability throughput would be expected to improve considerably.

The implications of this type of finding to actual highway design are manifold. First, the research methodology and the results originating from it provide a catalogue of effects that permit the a priori evaluation of design strategies under consideration. Second, the findings show how extremely sensitive road users are to environmental features that may not strike the practitioner as important. Third, it is exactly because of this fact that the behaviour of road users can be affected by the application of relatively simple means.

**RECOMMENDED READING**


Figure 11. Stimuli in the picture sorting task: CR Design
Figure 12. Stimuli in the picture sorting task: SER Design
Competence at a task such as driving a motor vehicle refers to what the driver is optimally capable of doing. It arises out of a combination of basic ability, training and experience. However what the driver actually does at any moment of time, his or her actual driving performance, sometimes falls short of this. Drivers, just like their vehicles, sometimes operate below their optimal level. Some of the characteristics of degraded performance are:

- a diminished ability to concentrate;
- an increase in judgement errors;
- an increase in failed detection of critical events;
- needless risk-taking;
- reduced regard for others' safety.

Those factors which can intervene to undermine performance are collectively called human factors. Most road accidents are linked to what somebody did or failed to do. Thus the study of human factors clearly has enormous importance for road safety. This chapter is about these human factors, what they are and how they affect driver performance. It is also about what the highway engineer can do through highway design to prevent, capture or tolerate decrements in driver performance. However, before we look more closely at the nature of human factors, we need to recognise that there are different levels at which a task can be performed.

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1 Note that in this context I am here using the term human factors in a restricted sense. The concept of human factors more generally includes all aspects of the relationship between the human (operator) and a given system (e.g., machine) in a given environment.
LEVELS OF TASK PERFORMANCE

There are three rather different levels at which a task such as driving can be performed, a skill-based level, a rule-based level and a knowledge-based level.

Skill-based performance is so well learned you can do it automatically, without thinking - acts such as writing, reading, changing gear when driving, are all good examples. However the first steps to this level of performance may begin rather slowly with each step being executed in a conscious, uncoordinated way, and requiring a large part of attention (working memory capacity). After much practice this clumsy performance is replaced by largely unconscious, integrated and smooth actions, using little working memory capacity. This development represents an important component of traditional training. It produces routine performance.

At the next 'level' is rule-based performance. In this, performance is guided by a set of rules which may be written as conditional statements of the form "If...then", for example "if there is a STOP sign ahead, then slow down and prepare to stop". These rules may be learned directly, such as through formal driver training, driving handbooks and learning the rules of the road. These sources of information tell the driver what to do under various conditions, such as when engaging in particular manoeuvres (e.g., turning) or at various road features (e.g., light-controlled junctions). But many rules governing performance will be represented not in the driver's head but out there in the world in the form of roadside instructions or even as in-vehicle warnings. It may be argued that, excepting the execution of overlearned and automatic control responses (e.g., steering and changing gear), the task of driving a motor vehicle is largely rule-based in the senses described above.

Where events are such that there is no rule to guide behaviour, such as where there is a novel problem with which the driver has to deal, reference must be made to his or her broader representation of knowledge of the vehicle, the highway or traffic system, the behaviour of other road users or even of basic principles, to enable formulation of an appropriate solution as to what to do. This is known as the knowledge-based level of performance. This knowledge-base grows with experience so that experienced drivers have recourse to a relatively extensive knowledge-base compared to novice drivers. Thus, the latter are likely to produce a higher proportion of wrong 'solutions' when faced with a novel situation.

No matter at what level a task is being performed, human factors can undermine that performance. However some human factors can undermine some levels more than others. For example driving in very noisy conditions is more likely to interfere with knowledge-based performance (e.g., solving a problem) than with skill-based performance (e.g., changing gear).

PERFORMANCE VARIABILITY

Human performance is not like the performance of a typical machine component. It is not constant but is intrinsically and fundamentally subject to variation over time. One reason for this is that performance is often linked to level of arousal or activation. Although we often use the word 'arousal' to refer selectively to sexual arousal, in this context it means the activation
or energizing of our nervous systems. It refers to the level of physiological activation of the individual (especially the central nervous system) and correlates roughly with feelings of alertness. It is low when you feel drowsy at night before going to sleep for example and high during the day when you are working at full tilt or are in a state of emotional excitement. For most people there is a regular variation over each 24 hour period: arousal is subject to a circadian rhythm. It is typically at its lowest around 04.00 hrs and may reach its peak around 12-16 hours later. At very low or very high levels of arousal, performance is typically not as good as at more moderate levels. We don’t perform as well when we are very drowsy or at the other arousal extreme, when we are extremely agitated or enraged over something. There may be marked individual differences in the time of day at which arousal level may peak. More introverted individuals typically reach a peak earlier in the day than more extraverted individuals. This implies that some people will perform some tasks better in the morning, others later in the day.

Although we have an endogenous circadian rhythm of physiological arousal, it is nevertheless subject to influence by external factors. Thus for example, continuous monotonous experience can induce a lowering of arousal, while on the other hand being bombarded with stimulation can induce a high level. Humans have become fairly adept at manipulating their arousal levels through various means such as taking stimulant drugs (caffeine in coffee, tea and cola drinks, nicotine in the mainstream smoke of cigarettes), listening to loud music and, on the road, providing heightened stimulation through driving faster. One implication of this is that engineers might consider extremes of roadway stimulation confronting drivers (either very high or very low) as factors that might degrade performance, mediated through their effects on arousal level.

**PERFORMANCE LIMITATIONS**

In mechanical engineering it is understood that system components can function only within a limited range of conditions. The bearings on a crankshaft will eventually fail if not adequately lubricated. In the same way human performance will fail if conditions exceed its tolerance limits. For example, people have only so much capacity to perform mental work. There is a limit to the rate at which we can take information in and process it. That limit may be reached and exceeded if we have to drive under extreme time pressure, not giving ourselves enough time to take all relevant information in, or if we have to interpret very complex information about the roadway and the behaviour of other road users. Exceeding human capabilities in these ways is not usually expressed as a catastrophic failure (as a machine component might shatter). Human failure occurs in more subtle ways such as in wrong expectations, poor judgement and increased errors.

**Limits in sensation and perception**

Our senses of course are bounded by performance limitations. Chapters 7 and 8 discuss some of these, particularly in relation to the human visual system. If we can’t detect something with one or more of our senses, we are not going to be aware of its presence. Furthermore in
processing sensory information we may get both false sensations and false perceptions. False sensations sometimes occur when a receptor is in a fatigued state. For example if you fixate a particular colour for 30 sec or so, looking then at a white surface will yield not a sensation of white but the complementary colour (and brightness) of the original colour stimulus. If the original colour was dark red, the white surface will appear light green, if blue, yellow. False perceptions can arise from the properties of the stimulus or of the person doing the perceiving. In the famous Müller-Lyer illusion, lines of equal width appear dissimilar on account of the orientation of the 'wings' drawn at the ends of the lines (see Figure 1).

![Figure 1. The Müller-Lyer illusion](image)

Another discrepancy between objective reality and our perception is the so-called 'speed adaptation' effect, which arises from the immediate past experience of the person. Travelling for prolonged periods at a high speed makes a slow speed seem considerably slower than it objectively is. In one study (Schmidt and Tiffin, 1969), in which drivers drove at 70 mph for 40 miles, drivers' subsequent attempts to drive at 40 mph (with the speedometer occluded) were wildly underestimated. The average speed selected was in fact 53.4 mph. This last example has implications for the management of drivers' speed on exit from high speed roads such as motorways. The likelihood is that drivers will approach the first off-motorway bends and junctions at a higher speed than they imagine.

Taking information in and interpreting it requires the use of memory. Memory is crucially involved in the process by which we make sense of what we see, hear, feel and so on. Without memory we cannot make sense of what our eyes are seeing or our ears are hearing. Without memory we could not recognise a face as a face, a tree as a tree, a car as a car and so on. If the information from, for example, our eyes is degraded - if they don't get a clear picture - this may make it very difficult for memory to help us recognise what we are seeing. Take a look at Figure 2 below and think about what you see. For most first-time viewers the picture appears as an amorphous compilation of splotches of shades of grey.
The picture is, in fact, of a cow. Even with this prompt you may not be able to see the animal immediately. Its head, which is facing you, fills the left part of the picture. Now once you have recognised the cow, note how the picture is perceived very differently from before. The important point is that nothing has changed in the picture; what has changed is in your head. What has changed are the dispositional traces of memory which act in your brain to enable recognition of objects out there in the real world.

Typical conditions in which information from our eyes may be degraded, and therefore our recognition memory system potentially challenged, are:

- poor contrast in the target stimulus or between the stimulus and its background;
- poor levels of illumination;
- transition from dark to light;
- transition from light to dark;
- taking only a quick look.

Mindful of the need to design road signage to eliminate or minimise these kinds of problem and ensure detection and legibility, Forbes and colleagues pioneered experimental research of the problem in the United States (see for example Forbes and Holmes, 1939). In their early work they were able to determine letter size requirements to give sufficient sign reading time, taking into account vehicle speed, viewing time needed for glance reading and the time required to make necessary manoeuvres (e.g., changing lane, stopping). A linear relationship between visibility distance and letter height was found of about 50 feet for each inch of letter height in daylight for black-on-white letters. Studies since have shown that legibility depends not only on letter height but letter width, the height to width ratio, spacing between letters and between lines of information, and on contrast and illumination. It has also been found that three-to-four familiar words can be read at a glance.
Apart from 'absolute' legibility and 'glance' legibility, signs vary in their ability to attract the driver's attention. This is largely a function of the level of brightness contrast within the sign and level of brightness contrast between the sign and its background. Colour contrast might add to this effect but colours are essentially effective in proportion to their brightness contrasts. Location in the road environment - sign lateral positioning and height - and drivers' reading habits are also important. Dynamic signs are particularly good at attracting attention - our receptors are most responsive to changes in stimulus energy. Hence the effectiveness of flashing lights and variable pitch/amplitude auditory warning signals on emergency vehicles.

Of course even the best designs supporting detection and reading under normal conditions are vulnerable to the influences of weather such as heavy precipitation and fog or mist. Fog creates a number of problems for the driver. In extreme conditions, consecutive features in the roadway scene (such as dashed centre-line markings) may need to be integrated over time to enable the driver to determine the direction of the road. This integrative function needs a minimum road speed to work - but that speed may be too fast to enable avoiding an obstruction, should one occur. Another solution drivers sometimes use to solve this problem, (i.e. which way does the road go?) is to track the rear lights of another vehicle. Again this may lead to adopting a speed which is too high should the leading vehicle suddenly slow down.

A further problem in fog is that the eye, confronted with an homogeneous visual field, may adopt a short focus of about 1 metre on average. This is actually known as the 'dark focus' of the lens because it also happens in darkness. Visible objects close to the eye, such as the windscreen, may bring the eye's focus even closer. The result of this is that it may take the driver longer to detect and recognise faint distant objects looming out of the mist.

But perhaps the most important fog effect of all is its influence on distance judgement and speed. A single human eye has no instantaneous ability to respond to three dimensional space: it (or more precisely the retinal surface of light sensitive cells at the back of the eye-ball) works a bit like a video camera in producing a continuous series of two-dimensional images. The perception of depth and distance in vision comes from the brain's interpretation of a potentially large number of cues appearing in the two-dimensional images from each eye. These include apparent size (based on knowledge of size-distance relationships and yielding the perception of linear perspective), brightness contrast, shading, visible details, relative position and overlap. Considerably more information about depth and distance is provided by movement: of the head in relation to the visual scene, of elements of the scene, or of the viewer in the scene. Some depth information is also provided by the image disparities arising from the use of the two eyes in binocular vision (although this is only functionally useful over a few metres). In dense fog, many of these cues are either distorted or not available at all. This has the effect of making objects appear further away than they actually are. In one study of this phenomenon, participants overestimated the distance to objects in front by 100%. Such findings are obviously relevant to an understanding of the rather disastrous multiple crashes in fog that are all too frequent on fog-bound motorways (see also discussion of fog effects on apparent speed in Chapter 7).

With degraded information, such as when a driver takes only a quick look, memory may make a biased interpretation. This bias may be in terms of:
• the most likely interpretation (based on what is usually the case);
• the most recent interpretation (based on what has recently been the case);
• what the driver has been led to expect (based for example on what someone has said).

It is thought that a proportion of motorcycle accidents involving side-crashes into cars are caused by car drivers taking only a quick look on entering a roadway and perceiving what is usually the case (i.e. no motorcycle approaching). Remember that memory is always involved in recognition. When memory does not get a clear ‘picture’, or gets the wrong cues (i.e. bits of information to work on) it can interpret things as being rather different from what they actually are - it can produce illusions.

We can make use of this process constructively to generate an illusion to enhance, rather than detract from, safety. An important cue to speed used by the brain is the rate of flow of information from the point of expansion to the peripheral visual field, with the peripheral rate of flow contributing the most intense sensation of motion (see Chapter 8); perceived speed and rate of flow being strongly correlated. We can artificially increase this rate of flow by marking the roadway with transverse lines with a progressive decrease in inter-line interval (see Chapter 4). As the driver passes over these, an illusion of increased speed is created, motivating the driver to slow down. This kind of intervention has reliably reduced approach speeds to hazards such as roundabouts and consequently reduced the frequency of accidents.

Limits in information processing

The capacity for information processing is limited. This limitation applies to the rate at which we can take information in and the amount we can keep in mind and use at any moment of time. If the amount of relevant incoming information exceeds the driver’s capacity, some of it will be lost. If the lost information is crucial (e.g., sign indicating lane closure ahead), that loss could increase vulnerability of the driver to collision. Rate limitations are partly determined by how redundant the information to be processed is. In general we can process more redundant information and we can process it more quickly. Information that we are expecting has high redundancy. Therefore, other things being equal, the more predictable the roadway and its characteristics, the easier the driving task and the easier it is to use safely. The implication for the highway engineer is that the design of road features should take account of road-user expectations. Correct expectations should be established through road design and the use of road markings and signs. In its fully-fledged form, this principle is expressed in the concept of the self-explaining road (see Chapter 5).

Information processing: vulnerability to degrading factors from within

Information processing by our senses and by memory can be degraded by factors such as fatigue, alcohol, stress and poor motivation. Information processing is also especially vulnerable to too high or too low arousal, as mentioned earlier. Under very high arousal a driver may get tunnel vision - a very narrow focus of attention as if looking through a tunnel. The driver may also find that he or she replaces the right action with a wrong one which is
simpler and more practised. But perhaps the more prevalent condition is where a driver's arousal level has fallen too low, predisposing him or her to a loss of vigilance and perhaps even to falling asleep at the wheel. It is estimated that at least 10% of all recorded crashes and up to 20% of motorway crashes are linked to low arousal and falling asleep at the wheel (Horne and Reyner, 1995). Factors which can induce low arousal include:

- time-of-day
- sleep deprivation
- alcohol
- large meals
- high ambient temperature
- physical or mental exhaustion
- repetitive tasks
- monotonous stimulation.

Some of these factors will be discussed in more detail below in the section on vulnerability of human performance.

Information processing is also vulnerable to insufficient attention. Attention to a task may be diverted in a number of ways, leading to performance error. One kind of diversion is called attentional capture. Attention is captured by some non task-related stimulus such as your name being called, an unexpected noise or something interesting going on around you. Another kind of diversion of attention involves some sort of preoccupation with non task-related stimuli. During normal work about 10% of time, sometimes more, is typically spent in irrelevant thoughts, in daydreaming and in fantasy. Attention can be distracted in this way by things going on in your head such as personal worries, reminiscences, thinking about events to come, fantasies, feeling uncomfortable and feeling tired.

The highway engineer can help manage problems of arousal and attentional capture in driving by using the following strategies:

- avoiding low-arousal inducing road alignments (typically straight, with non-varying landscaping);
- avoiding attentional conflict when critical information is being presented (e.g., other light sources near traffic signals, advertising hoardings near directional or hazard warning signs).

Limits on memory

Although there is continuing controversy about the how brain memory processes work, we can think of there being two kinds of memory, distinguished by how long each stores information. Short-term memory holds information temporarily, for a few seconds, while you use it. For this reason it is often referred to as working memory. For example you might read from a telephone directory a number you wish to call and then keep it in mind temporarily while you dialled it. Short-term memory has a limited capacity of roughly 7 +/- 2 chunks of information. If you try to put more into short-term memory, you will lose some of what is already there. It is rather
like a shelf on which you can put only so many objects. Once it is full, putting on more will only mean some items falling off. Forgetting the sequence of interim route destinations on a journey is a symptom of a short-term memory overload when driving. The capacity of short-term memory can, however, often be increased by reorganising information into larger and larger chunks. Thus the sequence of numbers 353160824279 would be very difficult for most people to hold in short-term memory, to keep in mind so to speak, however the same sequence 'chunked' is much more manageable: 353 160 824 279.

From the engineer's perspective, the important general implication from what we know about short-term memory is clearly to avoid overloading it. This is most easily done by repeating critical information 'out there in the world', rather than relying on the road user to keep it in his or her head (see for example the widespread use in France of the 'Rappel' sign).

Long-term memory holds information more-or-less indefinitely and seems to have an almost limitless capacity. It is what we normally think of when we use the term memory (as in 'he has a brilliant memory for his soccer team's performances'). Problems with the use of long-term memory can arise when:

- the information has been only weakly represented or encoded. This means that the information has few, if any, links with information already successfully stored in long-term memory;
- the information has been stored in long-term memory but the attempt to retrieve it fails. This often occurs when the associated ideas we start with in attempting to recall the target information are not connected strongly enough with that information. We can experience this problem when searching for a word once we have been given its definition (e.g., what is the word that means 'bestowing advantages, privileges etc on someone by dint of family relationship rather than merit? Can you easily make the connection to the word? The answer, if you cannot quite make the connection, is nepotism);
- the information has not been correctly represented in memory in the first place. This can produce the equivalent of a familiar computer-use problem GIGO: garbage in, garbage out.

Conditions of driving which are associated with memory-related errors are typically as follows:

- the larger the number of steps in a sequence, the greater the likelihood that one or more of them will be omitted (this is particularly noticeable in novice drivers);
- the greater the memory loading of a particular procedural step (i.e. the amount of necessary knowledge-in-the-head), the more likely it is that items within that step will be omitted (such as a verbal sequence of route directions);
- procedural steps that are not obviously cued by preceding actions or that do not follow in a direct linear sequence from them are most likely to be omitted (e.g., turning off lights before leaving the vehicle).

Just as for short-term memory, a basic strategy to avoid long-term memory-related errors is to place the necessary knowledge (such as the sequence of steps in a road diversion) 'in-the-world' rather than to rely on it being stored in the driver's head. This information should be located close to the vulnerable phases of the task.
One way in which learning something can be aided is through the use of mnemonic (memory) devices such as acronyms or simple rhyming lines or indeed virtually any meaningful way of organising or structuring the information-to-be-remembered.

**Limits on decision making**

When making decisions, humans are prone to a number of biases which can distort the outcome, as we have already noted in the context of having to interpret degraded information. These biases include biases of frequency, recency and confirmation. For example in driving, high frequency events on the roadway are more likely to be detected than low frequency.

We can illustrate the nature of decision-making biases by taking the example of troubleshooting when something is not functioning properly with the driver's vehicle. The essence of troubleshooting is identifying the failure(s) causing a particular set of symptoms. In the course of troubleshooting, the driver needs to adopt one or more hypotheses or predictions as to what is causing the symptoms. Each hypothesis needs to be objectively tested in order to determine its validity.

The first bias to which we are prone in this process is to opt for hypotheses with a high probability of being correct, i.e. on the basis of frequency of being correct in the past. This is clearly a useful strategy, reinforced by past experience, but it tends to blind us to improbable, but nevertheless possible hypotheses. A second bias is that we tend to give more weight to information found early in the diagnostic process. This leads us to make up our minds pretty quickly as to what is causing the problem. A third bias is that once we have begun to have confidence in one hypothesis, we tend to look for evidence supporting it, while discounting evidence that refutes it. These limitations can lead to errors and mistakes.

Biases may be even more evident in the dynamic situation of real-time driving. Under conditions of uncertainty we can imagine the driver rapidly generating and testing hypotheses or expectations (such as the road direction beyond a 'blind' corner or hill top), revising expectations as progressively more information becomes available. Sometimes critical decisions (such as speed or trajectory) are based on incorrect hypotheses or expectations and there is no opportunity to recover the situation once the error has been recognised. Taking a bend at too high a speed and overtaking another vehicle which, during the manoeuvre, turns into our pathway are examples of this kind of expectation error. There is not a lot the highway engineer can do about the last problem. But as highlighted in Chapter 4, speed guidance at critical road segments can be provided to help avoid incorrect expectations.

**The vulnerability of human performance**

Human performance is vulnerable to a number of factors which can degrade it. These include fatigue, drowsiness, alcohol and other drugs, emotion and stress. Motivation can also undermine performance, especially motivation for risk and motivation for speed.
Fatigue

The effects of fatigue may go no further than a psychological condition within the individual. However they may extend to affect performance. Symptoms of fatigue include restricted field of attention, slowed or impaired perception, decreased motivation, subjective feelings of fatigue and task aversion, and decreased performance in the form of irregularities in timing, speed, and accuracy.

Major causes of fatigue include inadequate rest or recovery from prolonged work and not enough sleep. Individuals differ in how much sleep they need and the amount needed typically declines with age. However sleep loss over a number of nights can seriously affect performance. It is also stressful, partly due to the effort of trying to keep awake. Sleep loss can cause a person to fall briefly into sleep for seconds or shorter. These "microsleeps" may not even be noticed. Hence they can be dangerous when they occur during tasks which require continuous attention such as driving. Sleep loss can also cause a driver to fall completely asleep while at the wheel. Although the driver will feel very drowsy before this happens (see below), the onset of sleep happens just like a switch being thrown. Crashes off the roadway or into other vehicles, without any evidence of attempting to brake, are evidence of having fallen asleep. Major causes of drowsiness are:

- not enough sleep
- sleep of poor quality
- radical shift change (e.g., from day to night work)
- after drinking alcohol
- after lunch or dinner
- sedative drugs.

There is evidence to suggest that sleepiness at the wheel can be overcome for a period of at least 2 hours by the driver stopping, quickly drinking two cups of coffee and then napping for about 10 minutes. Such evidence clearly reinforces the provision of refreshment areas at intervals on long motorway stretches, for example. And should the driver actually fall asleep, thermoplastic raised-rib markings (rumble lines) can provide a warning that s/he is passing over the lane boundary.

Alcohol

Alcohol taken long before driving can still affect the driver, even several hours later. This is because the body can only metabolise alcohol at a fixed rate, no matter how much has been consumed. This rate is equivalent to about 1 bottle of beer an hour, although there are individual differences. If a typical driver drinks at a faster rate, alcohol will build up in the bloodstream and this will continue to affect performance until it has had time to be metabolised. Drinking 2 bottles of beer in 1 hour on an empty stomach will lead to loss of inhibition, some loss of co-ordination and safety of driving will be affected for 1 hour. Drinking 4 bottles of beer will cause faulty decision-making and further loss of co-ordination
and drowsiness. Safety of driving will be affected for 3 hours. Six bottles of beer will significantly slow reactions and safety of driving will be affected for 5 hours.

Apart from loss of inhibition and co-ordination, poor decision-making and drowsiness, alcohol can affect driving performance by bringing the point of fixation of the driver progressively closer to the front of the vehicle, as a result preventing effective detection of upcoming hazards, anticipatory reactions and planning. It is hardly surprising then that driving while intoxicated frequently involves loss of control of the vehicle and is the largest single contributor to road accidents.

Other drugs

Evidence is accumulating of increased psychoactive drug use in car drivers. For example in a random sample of 1,237 drivers in Italy, Zancaner et al. (1995) found 2.2 per cent to be under the influence of drugs of abuse or psychoactive drugs. However, the role of most drugs in contributing to crash frequency is still unknown.

Legal drugs may be taken for legitimate medical purposes or may be abused; illegal (that is, illicit) psychoactive drugs may be taken for recreational and other purposes (for example, to avoid or escape a deprivation state). Under all of these conditions, some drugs may impair road-user performance and safety. Although the recreational use of drugs is not immediately associated with car usage, there may be a particular problem with travel from such venues as discos where drugs have been taken.

It is noteworthy that, with the exceptions of alcohol and popular minor tranquilizers, it is generally unknown which drugs under what conditions may impair road-user performance and safety. Epidemiological evidence clearly demonstrates that benzodiazepine users are over-represented in injured and fatally injured drivers. Furthermore controlled laboratory and driving task studies support the notion that cannabis (tetrahydrocannabinol) induces impairment, and a growing incidence of cannabis in the blood of fatally injured drivers is found in some countries, but the evidence for its relationship with crash causation is ambiguous.

Determining the relationship between drug dose-level and increased crash risk is a complex issue for epidemiological and experimental research (see ETSC, 1999a). Other problems which confound interpretation of the relationship between drug levels (however measured) and driving safety include:

- most drugs are unlike alcohol in that they do not exhibit a simple relationship between drug blood level and impairment level;
- drugs within a particular category, e.g., antidepressants, can vary widely in their influence on driver behaviours such as braking distance;
- medically impaired drivers may be safer driving with their drugs than without (for example, antipsychotic drugs with schizophrenic patients). It should be noted in this respect that laboratory studies tend to use young, healthy subjects in evaluating drug-induced effects;
- there are large individual differences in response to particular drugs;
• short-term effects may differ from long-term effects. The crash risk of elderly patients using long half-life benzodiazepines (defined as those that take more than a day for half the dose to be eliminated from the body) is increased by 45 per cent. This drops to 25 per cent after one year of use;
• there are many drugs in current use and several are often taken at the same time. Combinations of drugs may have synergistic effects (for example, codeine and antipsychotic drugs with alcohol) or antagonistic effects. The number of possible interactions is astronomical;
• blood levels of some psychoactive drugs (for example, cannabis) drop very sharply after uptake and yet the behavioural effects often occur only when blood levels of the psychoactive constituent have returned to a very low level.

At the moment, the relevance of drug usage for crash involvement is still largely unclear. Enforcement strategies that can have an impact on drug usage in traffic still have to be developed. Because of the problems indicated above, behavioural testing may have to become the critical means of documenting intoxication, rather than assessing drug levels directly. However the development of sensitive and reliable behavioural test batteries, operable in field conditions and sensitive to both drug and alcohol impairment, has not yet been accomplished. Furthermore, as the use of illicit drugs becomes ingrained in general life styles, incidental enforcement is unlikely to have a preventative effect through increased subjective probability of detection. For prescription drugs, preventative effects are more likely to be achieved through detailed information to the users.

Emotion

Emotion affects performance largely by affecting the functioning of the nervous system and by distracting the driver from the task in hand. Some intense emotions such as anger, frustration, anxiety and fear can produce a state of high arousal. Other emotional states, such as depression and feelings of grief, can be associated with low levels of arousal. As mentioned earlier, performance tends to fall off at both ends of the arousal continuum. Both over- and under-arousing conditions can also undermine motivation.

Stress

Stress when driving can be felt as a perceived difficulty in meeting driving task demands. Typical causes of stress in driving are:

• work overload (inadequate recovery, demands which exceed physical or mental capability);
• time pressure (lateness, push to make up lost time);
• social pressures (trying to 'prove' yourself to others, feeling loss of self-esteem through criticism by peers or others, conflict with others);
• noise. Noise above 86 dB(A) can cause annoyance (especially where you have no control over it), distraction, increased fatigue, increased mistakes, especially in demanding tasks, and increased accident liability;
• temperature. When a person feels uncomfortably hot or uncomfortably cold, performance can deteriorate and mistakes increase;
• get-home-itis. This refers to the taking of short-cuts to complete a journey quickly and cease driving. This factor strongly overlaps with the topic of motivation, discussed below.

Apart from stresses during driving, there can be stresses outside of it. These may also affect driving performance. Examples of such stresses are relationship problems, financial and other worries (e.g., ill relative).

Motivation for risk

One of the human factors which makes for variability in performance is motivation. When considering driving performance, motivation may be expressed as the level of effort you are prepared to make to do the task effectively, efficiently and safely. Poor motivation is likely to lead to a sloppy style of driving and a lack of concern for safety. A further problem is that conditions may arise which actually motivate unsafe behaviour.

In order to understand this process, we need to grasp a few basic principles of behaviour analysis, as described in Chapter 4. The approach of behaviour analysis is founded on the assumption that instrumental behaviour, that is essentially any act (other than a reflex response to a stimulus such as blinking your eyes when a bright light comes on) is controlled by its consequences. The consequences of behaviour provide the motivation for it. We behave in particular ways to obtain pleasant consequences or to avoid unpleasant ones (e.g., we work to obtain an income; we drive around an obstruction to avoid collision with it). In this sense behaviour is 'controlled' by its consequences. Thus we might take a short-cut on a journey in order to save time (rewarding consequence) and slow down to the speed limit to avoid censure from a policeman (punishing consequence). However, for consequences to control behaviour, other conditions usually have to be met. Particular conditions can become triggers for particular behaviours. In this sense behaviour is activated by these conditions, a process known as stimulus control. Thus we can say that behaviour is under the control of two events - both activating conditions and consequences. A road sign which informs drivers of a closed lane ahead is a direct way of bringing the lane's (unavailable) use under stimulus control. The sign is telling the driver that if s/he tries to continue in the lane, the consequences will not be rewarding.

The consequences of behaviour also provide a mechanism for learning. The 'rewarding' of a particular behaviour (with a pleasant consequence) makes it more likely to occur again under similar circumstances. The 'punishing' of a particular behaviour (with an unpleasant consequence) makes it less likely. In a novel situation, when we don't know quite what to do, we sometimes discover the answer by trying out various possibilities. Actions which work successfully are retained. Those which fail are discarded. This process is called trial-and-error learning. As its name implies, trial-and-error learning involves error, the making of mistakes.

This analysis provides a framework for incorporating the processes of motivation and learning in understanding the causes of risk-taking. A person may engage in a risky behaviour because
it has rewarding consequences. So we may ask: what consequences can motivate risky behaviour?

**Consequences which can motivate risky behaviour.** Since a primary goal of driving a motor vehicle is often that of reaching a destination by a certain time, saving of time becomes a priority when journey delays have arisen. This is reinforced by social pressure (punishing consequences for being late) which drivers are motivated to avoid. Thus driving in ways which may save time become potentially rewarding options, motivating potentially risky behaviour. Examples of such tactics are driving faster, accepting shorter gaps in stream entry or stream crossing, overtaking recklessly and running red lights. Another kind of consequence that can motivate risky behaviour is the approval of significant others. If passengers in the vehicle condone inappropriate behaviour as a group norm, and the driver values being accepted by the group, s/he is likely to comply with that norm (see later discussion under *Social Factors*).

What are the possible consequences of these actions for safety? Although accidents are usually triggered by one final act or failure to act, they nevertheless have multiple causes. When all of those causes occur together in the right pattern - an accident is inevitable. The fact that a pattern of events is typically necessary for an accident to happen means that the driver can sometimes get away with mistakes. Such a *forgiving* system can enable the driver to get away with unsafe practices for a long time (i.e. without aversive consequences). In this way, the driver can unwittingly learn unsafe behaviour.

Antecedent events can come to trigger risky behaviour in the following way. A response used to save time over a particular section of roadway, such as breaking the speed limit, will be rewarded and reinforced if it works and does not lead to punishing consequences. Repetition of this process will mean that the same response of speeding may then occur in the future, triggered by entry on the same section of roadway, even when there is no need to save time. The unsafe practice will have become routine and automatic.

**INDIVIDUAL DIFFERENCES**

Individuals do of course differ in their physical characteristics. Vehicle design typically tries to accommodate to the 95th percentile in key characteristics (seated height, arm and leg reach, foot strength etc) of the population of car drivers. However by definition, some designs will be unsuitable for some people. Consequences may be discomfort, distraction, numbness, fatigue and restricted information (including less than 360 degree visual access around the vehicle).

Highway design similarly needs to recognise that road users are not a collective of clones. Individuals differ not only in terms of their physical characteristics but also on a number of relatively stable psychological characteristics such as intelligence and personality. Over time, each individual may also become different as he/she goes through the ageing process and becomes more experienced. Some of these differences have implications for road user safety.
Personality

**Denial.** One way in which we can deal psychologically with painful, unpleasant experiences is to ignore their existence through a process called denial. This can be effective in the short-term in enabling us to continue everyday activities without interference from disturbing emotional reactions triggered by the painful experience. However by postponing dealing with those experiences we become prone to their influence through mental distraction, feelings of stress and labile emotions. Some individuals are more prone to use denial as a coping method than others. Some individuals may also use denial inappropriately when driving, by pretending to themselves that mistakes have not been made, that regulations (e.g., regarding speed) have not been violated, that they have not abused other persons through their behaviour and so on. Such denial processes must work against the individual using past experience constructively in developing their driving knowledge and skills.

**Extraversion.** An important personality dimension which has a physiological basis is extraversion-introversion. Every individual can be located somewhere on this dimension. Extreme extraverts are stimulus seekers and an important source of stimulation for them is the company of other people. Extraverts also typically reach a peak of arousal much later in the day than introverts, and so tend to be ‘evening’ rather than ‘morning’ people in terms of optimal performance. Extraversion can be associated with increased risk-taking and included under this is a disposition to behave impulsively.

**Stress.** Individuals vary widely in their responses to stressors. Only certain stressors affect any particular person. For example, time pressure might cause one person to feel a complete lack of control over their driving options; another individual might be motivated to increase their level of performance. The point is, the emotional, psychological, and physical effects of stressors tend to be specific and to affect only certain individuals.

**Experience.** Inexperienced drivers are typically more prone to error and to having accidents. Given a particular road and traffic scenario they may:

- not know the correct manoeuvre so they try a different manoeuvre which turns out to be unsafe;
- not know how to carry out a particular manoeuvre correctly;
- not have had enough practice in carrying out the manoeuvre correctly;
- not have enough experience of dealing safely with the effects of human factors on their performance.

Chapter 16 deals in detail with young drivers and Chapter 15 with young road users.

**Age.** As we age, a number of physiological changes progressively occur which have implications for how we perform as road users. For example our visual system becomes impaired in various ways. As a result, lighting requirements for a given task may double. Whereas 50 footcandles (538 Lux) may be sufficient for a 25 year old, a 55 year old may need 100 footcandles (1076 Lux) to perform the same task. With age, the speed with which the eye adapts to light or dark also decreases. Hearing sensitivity decreases, especially at the upper end...
of the frequency range. In general there is a loss of strength, flexibility and tolerance of fatiguing conditions, especially driving at night. Chapter 17 deals in detail with characteristics of road users who are elderly.

**ERRORS AND MISTAKES**

The human factors described in this chapter can undermine performance and increase the frequency with which errors are made. Human action often has three elements: a plan (goal state and means to achieve it), a sequence of actions initiated by the plan and an outcome (success/failure). Failure can arise from the occurrence of an error in either or both of the first two elements.

**Types of error**

There are several different types of error (Reason, 1997):

- **Slips** - you carry out part of a sequence of actions incorrectly, perhaps due to a shift of attention away from the task. An example would be crunching the gears;
- **Lapses** - you omit part of a sequence of actions, perhaps through a short-term memory limitation. An example is forgetting to check your wing mirror before changing lane or overtaking;
- **Trips** - you fail to detect, say, an obstruction (e.g., when reversing) or pick up information incorrectly. An example would be a directional road sign reading error;
- **Fumbles** - you temporarily lose motor control. An example would be your foot slipping off a control pedal.

All of these types of error occur where the plan is adequate but actions fail to go as planned.

**Mistakes**

Mistakes occur where the plan itself is inadequate, that is where you select the wrong sequence of actions (actions may be executed perfectly). There are two types:

- **rule-based mistakes** involve application of the wrong rule in a given situation. An example would be carrying out the wrong procedure having switched car type (negative transfer);

Switching on the screenwipers instead of the indicator is a common example. Unfortunately a number of factors can make the transfer task more difficult. You may be strongly affected by the vehicle you usually drive or have recently driven. Another problem is operating under *time* and other *pressures*. Under pressure, we tend to fall back on over-learned procedures - ways of doing things that are most habitual. Sometimes these are inappropriate for the particular task we are carrying out;
knowledge-based mistakes, in which in dealing with an unusual problem situation, you work out a solution which is wrong. This can happen in driving where you draw the wrong conclusions about someone's intentions before you have enough information (see earlier discussion of the limits on decision making). An example would be assuming someone who is signalling a turn will actually do so.

**Error management**

At the heart of safe driving is the selection of a speed appropriate to the prevailing road and traffic conditions. However as soon as a driver allows other factors (factors such as time-saving and speed for its own sake) to determine a higher speed, then s/he increases task difficulty. An increase in task difficulty carries with it the implication that there is less room for dealing with the unanticipated hazardous behaviour of other road users or for recovery from error.

And making errors is the condition of the human road user. Although highly adaptive, we are nevertheless unreliable (i.e. variable) in our performance. This unreliability arises out of inherent limitations in what we can do and, as discussed above, variability in performance due to factors such as fatigue, shifting arousal levels and motivation. Because we have to expect error from the human road user, we need to design a road system that has the characteristics of error prevention, error tolerance and error recovery. Some general suggestions of design elements in which these error management goals might be achieved are listed immediately below:

**Error prevention**
- good information
  - perceptual elements of roadway alignment
  - lighting (reduced luminance during night driving primarily affects foveal vision rather than the peripheral vision we use in part to sense speed and guide the vehicle)
  - signing of hazards
  - marking of hazards
  - signing of routes
  - road marking
  - control by lights
  - thermoplastic rumble surfaces
- speed controls
  - traffic calming elements
  - enforced restrictions

**Error tolerance**
- roadway width
- hard shoulders
- crash barriers
- breakaway light standards
- minimal roadside furniture
Error recovery
- vehicle design (e.g., ABS and power steering)
- road surface adhesion.

SOCIAL FACTORS

In considering the individual and the factors operating on him or her, we must note that groups tend to establish norms of behaviour amongst group members and to differentiate themselves from other groups. Most of us like to feel accepted by significant others and to be part of a group. The threat of withdrawal of their approval or of rejection from the group can produce enormous pressure on us to conform to group norms. These social forces can work to enhance or undermine safety, depending on what those group norms are. If it is the norm in your group to ignore speed restrictions, it is difficult not to conform. It is important for many people to conform: to avoid discrepancies between their behaviour and norms of behaviour as they perceive them to be. Thus:

- in a stream of traffic there are social pressures to maintain the speed of the flow (pressure may be applied for example by other drivers who follow you very closely);
- passengers may exert pressure on their driver to drive at a high speed;
- the driver may fear the social consequences of arriving late for an appointment;
- drivers typically want to drive like others. However they overestimate other drivers' speed, believe that other drivers think they are driving too slowly and drive faster themselves as a consequence (Åberg et al., 1997).

These expressions of social influence can work against safe engagement with the road and traffic system. But the same forces can also be used constructively. Roadside posting of the number of vehicles maintaining speed within designated limits has been shown to reduce high speeds, for example (see Van Houten and Nau, 1983). Increased feedback to drivers regarding the quality of their performance would seem to be a potentially productive avenue for further development. A detailed analysis of social factors in driving is presented in Chapter 14.

CONCLUSIONS

Many human factors which have the potential to influence human performance are beyond the reach of the design interventions controlled by the highway engineer. Indeed it may be somewhat sobering, if not unnerving, for the engineer to appreciate the extent to which human performance is vulnerable. Nevertheless millions engage with the highway system daily and complete their journeys safely, despite human factor influences. The effects of many of these on performance do not go unnoticed for most people, who can then make choices which take account of felt or anticipated impairment. For example, a tired driver might opt to rest before driving off, select a less congested route, or drive more slowly. Problems only really arise when impairment has not been recognised (e.g., after drinking alcohol) or where the driver is not able to make adaptive choices easily. This last situation arises for example when the driver
is under pressure to reach a destination within a limited time period or when constrained by the high speed of flow of a motorway traffic stream. Under such conditions the demands of the driving task may well exceed the driver’s momentary capability and loss of control will ensue.

At appropriate points throughout this chapter, implications of human factors for highway engineers have been suggested. These are now brought together as a summary of principles engineers might consider in responding to human factor problems:

Arousal
- avoid low-arousal inducing road alignments (typically straight, with non-varying landscaping. Medium complexity helps maintain activation);
- consider the needs of fatigued and drowsy drivers (provide refreshment areas at intervals on long motorway stretches. Provide thermoplastic raised-rib markings (rumble lines) to warn drivers passing over the lane boundary);
- avoid stimulus-driven high arousal states (e.g., too much critical information on a fast road section).

Information processing
- avoid attentional conflict when critical information is being presented (e.g., other light sources near traffic signals, advertising hoardings near directional or hazard warning signs);
- avoid informational overload (e.g., excessive sign posting. To reduce load in negotiating 4-way intersections, consider replacement with two staggered T-intersections or a roundabout);
- avoid memory-related errors by placing the necessary knowledge ‘in-the-world’ rather than rely on it being stored in the driver’s head. This information should be located close to the vulnerable phases of the task;
- design road features to take account of road-user expectations;
- avoid incorrect speed expectations by using speed guidance at critical road segments;
- consider controlling for the effects of speed adaptation: drivers will approach the first off-motorway bends and junctions at a higher speed than they imagine.

Error management
- employ practices of error management: prevention, tolerance and capture (as described above under Error Management);
- increase feedback to drivers regarding the quality of their performance (e.g., roadside posting of the number of vehicles maintaining speed limit).

Finally, for a review of the behavioural effects of road design measures which have been shown to influence safety by changing driver behaviour, see Sagberg et al. (1999).

RECOMMENDED READING


VISUAL FACTORS IN DRIVING

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THE ROLE OF VISION IN DRIVING

Vision is one of the major senses with which we perceive the surrounding world. At the same time, it usually appears to make no sense to question the processes behind vision, since 'it works' without effort and the world looks just fine.

However, one only has to consider the drawing in Figure 1 to admit that there is more to vision than just meets the eye. The reader may easily agree that the two lines converging onto the upper horizontal line can be perceived as the edge lines on a road receding into the distant
horizon. Moreover, if you consider the two thick horizontal lines, the upper one looks wider than the lower one, although they are objectively the same size. From this simple observation, we can conclude:

- that our perception is not a copy of the retinal image,
- that we have a tendency to interpret the visual input in three dimensional terms (whether this is an innate or learned ability is beyond the scope of this chapter, and the interested reader is advised to refer to textbooks on perception);
- that our perception can be erroneous. In the present case, it seems that the tendency to perceive the upper line as longer might be linked to our 3D interpretation of the drawing. The line would appear to be farther away on the road. Thus, if its retinal image is the same size as the lower (closer) one, it must be larger (due to the inverse size/distance relationship).

Such preliminary remarks are meant to alert the reader to the fact that vision, which is obviously involved in driving, relies on external inputs, sensory encoding and mental processes. For that reason, visual information processing has to be taken into account in road engineering design. In that domain, the main (complex) question is how to obtain a safe correspondence between the driver's visual needs and/or abilities and the visual road environment.

Accepting that the information input to the typical driver is mainly visual (Hills, 1980), the problem remains to determine which visual cues are involved, depending on the actual sub-task of the overall driving process (e.g., highway cruising vs. intersection crossing), and on the internal state of the driver (i.e., his/her age, experience in driving, level of awareness, and other human factors). One way to tackle this problem has been to look for correlations between the driver's visual performance and accident rate, involving large-scale investigations. We will review some of this research, which is related to the scientific and social problems of refining and extending the visual standards for driving.

Background

In 1968, Burg reported the results of a large-scale study, involving visual measurements in Californian drivers. To provide driver-licensing administrators with previously unavailable information on which to establish effective vision-screening procedures for driver license applicants, a number of visual performance, personal, and driving habit characteristics of some 17,500 volunteer California driver license applicants was compared with their 3-year driving records (accidents and convictions). Of all the visual tests, dynamic visual acuity was most closely and consistently correlated with driving record, followed by static acuity, field of vision, and glare recovery. All relationships were in the 'expected' direction, that is poor vision was associated with poor driving records. As expected, among all variables studied, age, sex, and average annual mileage played the largest role in influencing driving record. Accident and conviction frequencies increased with increasing mileage, were lower for females than for males, and were highest for the young age groups.
In a subsequent report, data from the 1968 California driver vision study were reanalyzed. For the main analysis, the sample was divided into four age groupings: under 25, 25-39, 40-54 and over 54. The most consistent result throughout the study was the failure to find a direct relationship between poor visual performance and high accident rates for young and middle-aged drivers. For the over 54 age group, dynamic and static visual acuity showed the most consistent relationship with accident rates. Considering that visual capacities normally decrease with age, this suggested a causal relationship between visual performance and the risk of accident while driving.

To elucidate the possible traffic safety risks induced by visual field defects, various methods have been developed, using either driving simulators or real driving situations. For instance, in a simulator study, the capacity to detect stimuli of different sizes appearing in different positions of the screen in front of the driver was measured. Two groups of normal subjects and a number of subjects with different visual field defects were studied. In the groups of normal subjects, the median reaction times were homogeneous. There was a slight difference between central and peripheral stimuli, which was somewhat larger for the older subjects. Among the subjects with field defects, individual variations were very dominant. However, the most interesting finding was the quasi-inability of most subjects to compensate for visual field defects under the test conditions. The authors concluded that the use of test methods that come close to duplicating real world driving tasks may reveal functional capabilities differing from what would be assumed based on clinical (or laboratory) tests. Another study tried to determine the effect on driving of restricting vision. This was undertaken by comparing the driving performance of young, normal subjects under conditions of simulated visual impairment with a baseline condition. Visual impairment was simulated using goggles designed to replicate the effects of cataracts, binocular visual field restriction, and monocular vision. Driving performance was assessed on a closed-road circuit for a series of driving tasks including peripheral awareness, maneuvering, reversing, reaction time, speed estimation, road position, and time to complete the course. Simulated cataract resulted in the greatest decrement in driving performance, followed by binocular visual field restriction. Thus, it appears that visual deficits exhibit positive correlations with driving performance and potential exposure to road accidents. One parameter, which seems to be related to this aspect of the problem, is the driver's age.

Aging. Older adults rely on the automobile to maintain their mobility and independence, in spite of the fact that age-related behavioral and biomedical changes may make driving more difficult. Indeed, accident and fatality rates begin to rise after age 55. One research goal, therefore, is to identify functional measures that differentiate older adults who drive safely from those who do not (Ball and Owsley, 1991). In particular, one can examine the elderly drivers' perception of their driving abilities, compared to their clinically tested functional skills in the area of visual perception, and their actual in-car driving performance. The specific skills assessed include peripheral visual field, depth perception, color sensitivity, static visual acuity, dynamic visual acuity, and figure-ground discrimination. Results indicate that clinically tested visual perception skills (notably peripheral vision and color sensitivity) and actual in-car driving performance could be related. Many studies also indicate that people generally tend to over-estimate their driving abilities.
For example, subjects, ranging in age from 30 to 83, participated in a closed-course driving test and in laboratory tests of visual perception. Driving tests included responding to traffic signals, route selection, avoidance of moving hazards, and judgment at stationary gaps. Lab tests included measures of perceptual style, selective attention, reaction time, visual acuity, perceptual speed and risk-taking propensity. Analyses were conducted to determine how well lab measures predicted driving performance. Results revealed different patterns of correlations for different age groups. For younger drivers (30-41), lab measures generally showed no association with measures of driving performance. For older drivers (74-83), measures of information processing were associated with overall rated driving performance, while measures of reaction time showed strong correlations with objective driving measures. These results suggest that different mechanisms are utilized by drivers of different ages, and that the slowing of reaction time associated with aging has certain effects on driving skills related to vehicle control.

Efforts to assess visual deterioration with increasing age, coupled with new mechanisms proposed to limit the exposure of visually impaired drivers to driving risks, have emerged in response to the increase in older drivers. Visual functions discussed in this context include static acuity (photopic, mesopic, and in the presence of glare), dynamic visual acuity, visual field, contrast sensitivity, and motion perception (see definitions in next section). More recent surveys point out that, whereas static acuity and color deficiencies are only weakly correlated with crash involvement, peripheral vision appears to play a more critical role.

Drugs and alcohol consumption. The behaviors involved in driving a motor vehicle are also impaired by alcohol to varying degrees. Certain skills important for driving, in particular the brain's ability to observe, interpret, and process information from the eyes and other senses are impaired even at the lowest levels of alcohol concentration in the blood that can be measured reliably (Moskowitz and Burns, 1990). It seems reasonable to assume that a driver cannot operate a vehicle safely if information processing is slowed, visual perception is degraded and/or the ability to allocate attention to multiple sources of information limited.

It is important to understand that crashes are not limited to drivers with high levels of alcohol. Rather, there is a significant risk that extends to low and moderate levels. Drivers need to know that they are impaired and are at increased risk of crash when they have consumed even small amounts of alcohol. The safety-minded consumer will restrict alcohol use to times and places that do not include driving.

To identify the impairment effects of alcohol on driving performance and to determine whether providing enhanced visual information concerning roadway alignment would improve the performance of subjects when sober and/or alcohol-dosed, simulations of continuous roadway treatments (i.e., standard and wide edge lines) were evaluated experimentally (Ramney and Gawron, 1986). Twelve subjects drove a simulator at three levels of blood alcohol concentration. The effects of alcohol included increases in the number of times the speed limit was exceeded, the number of obstacles that were struck, and the magnitude of tracking errors that were made in the approach and negotiation of curves. Edge line presence was associated with faster curve entry speeds and reduced amount of road used in curve negotiation. Increased speed entering curves could be one aspect of driving behavior in nighttime and low-visibility
conditions, when ambient cues are not degraded, leading drivers to drive too fast for degraded focal visual abilities. One implication of this finding is that given clear edge lines in conditions of poor visibility and related degraded focal ability (as in fog), drivers may opt for too high a speed, especially under the influence of alcohol.

More generally, it has now become an important issue to understand whether psychotropic drugs, which are being increasingly used, can affect driving performance. It is in particular a matter of debate whether psychoactive drugs, such as benzodiazepine, will affect the overall nervous system, resulting in sleepiness for instance, or whether more specific effects on perceptual abilities can be evidenced. For instance, recent reports suggest that benzodiazepine use increases significantly the risk of motor vehicle accidents. It is proposed that, even if no direct relation between drug administration and driving performance can be evidenced, caution has to be exercised because of induced sleepiness. Recent studies suggest that visual dynamic sensitivity might be sensitive to GABAergic drugs. Recently, we found in our laboratory a significant effect of midazolam on visual segmentation processes (figure-ground discrimination), suggesting that these drugs, via visual deficits, might affect driving performance.

Selected visual determinants

Throughout this short review, we saw that, beyond classical evaluations of static visual acuity (the minimum visual angle that our optic system can resolve), a number of visual tests were proposed, that might predict driving performance more efficiently. We will now present some of the most promising ones in more detail.

Useful terms. We need first to define some terms, related to basic concepts in visual perception and its measurement.

- **Illumination** is the amount of light falling onto a surface. It refers to the lighting conditions in the environment and to how the objects are struck by photons, directly from light sources or indirectly from reflections by other objects.
- **Reflectance** refers to the fraction of incident light that is reflected by a surface.
- **Luminance** is a measure of the amount or intensity of visible light energy emitted or reflected from a given source or surface.
- **Contrast** between two adjacent regions is their relative luminance levels.
- **Lightness** is the perception of a surface's reflectance. **Lightness constancy** refers to the ability to perceive the constant reflectance properties of surfaces, despite changing conditions of illumination.
- **Fovea** is a small region in the center of the retina, about 2 degrees in diameter that contains exclusively cone-shaped photoreceptors (*cones*), and is responsible for highest spatial acuity. Rod-shaped photoreceptors (*rods*) are located everywhere in the retina, except in fovea. They are used for vision at low levels of illumination.
- **Photopic** conditions of vision are viewing conditions under high level of illumination (e.g. normal daylight), in which the cones in our retina are active and color is perceived.
Scotopic conditions of vision refer to vision under low levels of illumination when rod activity dominates vision, particularly at night (night vision).

Myopia (or nearsightedness) is a condition in which people can see well at short distances, but cannot focus properly on distant objects. Night myopia is a similar effect observed in conditions of night vision.

Accommodation is the process by which the image is focused on the retina. In degraded conditions of vision (night, fog), a special case of accommodation error arises from the fact that the eye tends to slip into a relaxed state of 'dark focus accommodation'.

Psychophysics is a branch of psychology. It includes behavioural studies of quantitative relations between people's perceptual experience and physical properties of a stimulus. Psychophysical methods were developed to find the sensory threshold for a given sensory dimension, which corresponds to the weakest stimulus value that can just barely be perceived.

Contrast sensitivity is a measure of the limits of visibility for low contrast patterns (how faded can an image become, before it is invisible). Everyone who has been driving in fog can intuitively see its potential relevance to road safety. The image in Figure 2 was proposed by Campbell and Robson (1969) to illustrate the form of the contrast sensitivity function. Their results suggested the existence within the nervous system of linearly operating independent mechanisms selectively sensitive to limited ranges of spatial frequencies.

![Figure 2. Test your own contrast sensitivity function.](image)

Figure 2. Test your own contrast sensitivity function. In this image, the luminance of pixels is modulated in the horizontal dimension, with the modulation (spatial) frequency increasing logarithmically from left to right. The contrast of the modulation increases from top to bottom. Note that the bars appear taller in the middle of the picture. The inverted U-shaped curve of visibility that you can draw on the figure is your contrast sensitivity function.

Present visual standards are generally based on the observer's ability to see small high contrast black and white letters or symbols. Current research shows that such vision tests are not adequate to evaluate an individual's target detection and recognition capability over ranges of target size and contrast used in real situations. New vision tests are being developed that use the observer's report of the visibility of sine-wave gratings (that look like fuzzy bars) to assess visual capability with much more sensitivity than that of standard tests.
In a simulator study, for instance, it was found that contrast sensitivity was better than visual acuity for predicting a pilot's ability to detect a small, semi-isolated, air-to-ground target. This type of result provides a piece of evidence for the predictive validity of contrast sensitivity.

Owsley, Sekuler and Siemsen (1983) measured the contrast sensitivity function on a large sample of adults, ranging in age from 19 to 87. The sensitivity for stationary gratings of low spatial frequency remained the same throughout adulthood. At higher spatial frequencies, sensitivity decreased with age, beginning around 40 to 50 years, and corresponding to the expected reduction in visual acuity with age. When a low spatial frequency grating was made to move, young adults' sensitivity improved by a factor of 4-5 over sensitivity to a static grating; this motion enhancement was markedly diminished in adults over 60 years, implying an impairment of temporal processing in the elderly. The reduced retinal illuminance characteristic of the aged eye (caused by the progressive yellowing of the lens) could account for a large part of older adults deficit in spatial vision, but appeared to play little role in their deficit in motion vision. It is argued that the reduction in motion sensitivity may affect routine activities, such as visually guided locomotion, which depends on low spatial frequencies.

Night vision. In a study by Fejer and Girgis (1992), a total of 380 randomly selected patients aged 16 to 80 years, who did not have eye disease, underwent testing for night myopia (changes in refraction of the eyes under low-illumination conditions). Overall, 17% of the subjects were found to have night myopia. The results indicate that driving in the dark could create visual difficulties for certain younger patients that a night myopic correction would eliminate. In another study, it was found that, at luminance levels equal to those recommended for road lightning at night, acuity was about two-third of its normal value in daylight. Night myopia was only present for very low luminance, well below normal night-driving conditions. It was concluded that neural mechanisms, rather than optical ones, are responsible for the acuity loss experienced by drivers at night.

In another study conducted by Owens and Leibowitz (1976), the relationship between night myopia under simulated night driving conditions and the dark focus of accommodation (see above) was examined. Over a range of luminance and contrast conditions typical of the night driving situation, college-aged subjects accommodated to about one-half the difference between a distant simulated road sign and their individual dark focus. Subsequent laboratory and field experiments demonstrated that: (1) a negative correction equal to one-half the value of the dark focus significantly improved night visual performance as compared with their normal or full dark-focus correction, and (2) greater improvements in performance were obtained for subjects who exhibited a relatively near dark focus.

Recent studies explored the possibility that drivers' ability to steer a vehicle under challenging conditions may decline with advancing age. Older drivers are frequently reluctant or unwilling to drive at night, apparently because they lack confidence in their visual capabilities. They used a simple night driving simulator, designed to evaluate the effects of reduced luminance on steering performance of younger and older subjects. The results showed that the resistance of steering performance to degradation in low light declines with age.
A last interesting aspect, related to night vision and driving, concerns glare from the headlights of oncoming vehicles. Disability glare affects elderly drivers, but we all know young people around us who refrain from driving at night, explaining that they have difficulties recovering from glare.

Concerning general adverse visual conditions, Owens and Sivak (1993) investigated the contribution of reduced visibility to fatal accidents. They evaluated accidents that occurred during morning and evening time-periods, called Twilight Zones, during which natural illumination varied systematically in conjunction with the annual solar cycle. Fatal accidents were found to be over-represented during darker portions of the Twilight Zones. The contribution of reduced visibility was also indicated by higher overrepresentation of fatal accidents in low illumination under adverse atmospheric conditions and with pedestrians and cyclists as opposed to all other accidents. Reduced visibility was more important than drivers' drinking as a contributor to fatal pedestrian and bicycle accidents, while the reverse pattern was found for all other fatal traffic accidents.

Still another example concerns driving in fog. Snowden, Stimpson and Ruddle (1998) report a simulation experiment, in which it was shown that observers tend to underestimate their own velocity in foggy weather. This result seems to be related to an apparent reduced perception of speed under conditions of reduced contrast. It is also the case that under such degraded conditions, when monocular cues to distance may be greatly reduced, drivers tend to overestimate the distance to objects. The interesting point here is that accidents in fog, due to exaggerated speed in foggy weather and distortions of distance perception, might be due to a deficit in visual perception (of which drivers are not conscious), rather than to their irresponsibility. This line of argument might also be applied to night driving, and to driving under the influence of drugs. Roadway engineers might want to consider these facts.

Useful field of view. The useful field of view is defined as the visual area in which information can be acquired within one eye fixation. A number of reports argue for a reduction in the size of the useful visual field as a function of age. This loss, however, can be recovered partially with practice. Standard acuity and perimetric tests of visual field, although efficiently diagnostic of disease, underestimate the degree of difficulty experienced by visually healthy older adults in everyday activities requiring the use of peripheral vision. To aid in predicting such performance, a model incorporating the effects of distractors and secondary task demands was developed (Ball et al., 1988). Subjects responded to dual tasks, one central, one peripheral (10 to 30 deg in eccentricity). The most interesting finding was a practice effect, where performance improved on peripheral tasks after practice, and improvement persisted six months post-training. If confirmed and extended to performance on clearly driving-related tasks, this could have implications for testing and licensing.

Experimental results suggest that the size of the useful field of vision may not be influenced by the speed of traveling. This finding contradicts the postulated tunnel vision at increased speed. However, the size of the useful field of vision seems to decrease when the driver deviates from the prescribed speed of traveling, driving either too fast or too slow. It is assumed that the resulting internal workload could exhaust the drivers' capacity and consequently cause perceptual narrowing, which is a peripheral manifestation of central overload. This idea is
confirmed in other studies, which suggest that the functional or useful field of view is very sensitive to foveal demands. As the foveal primary task becomes more difficult, peripheral information extraction is perturbed, and it is perturbed increasingly as the retinal eccentricity of the peripheral information increases. This is the case even when compensatory adjustments are made for acuity loss.

Finally, Wood and Troutbeck (1992) investigated the importance of the visual field on driving performance. This was undertaken by simulating binocular visual field defects for a group of young normal subjects and assessing the impact of these defects on performance on a driving course. Constriction of the binocular visual field to 40 deg or less, significantly increased the time taken to complete the course, reduced the ability to detect and correctly identify road signs, avoid obstacles and to maneuver through limited space. The accuracy of road positioning and reversing was also impaired.

Implications for design interventions

Concerning what we have just presented, the reader might react by saying that interacting factors like visual deficits (normal or pathological), aging and drug-addictive behaviour, are beyond the control of highway engineers. Legislative measures ought to be taken, in order to remove from the highway 'deviant' people. It is certainly true, as we mentioned, that researchers work hard to elaborate new visual standards for driving licensure. However, having too strict standards might result in 'false positive' measures, preventing people from driving who are not more susceptible to accident than others. Another limit is sociological, in the sense that normality is always a relative affair. For instance, the average population age is increasing in western countries, and elderly people want to stay on the road. In this sense, the highway engineer will have to deal with this social context. From our point of view, this will, for instance, result in a necessary taking-into-account of the glare sensitivity of elderly people, requiring adjustment of road lightning or glare prevention from oncoming vehicles. The 'useful field of view' concept might help in the positioning of road signs. Contrast sensitivity might be used to design visible road markings in adverse visibility conditions, and so on.

Finally, the reader will have noticed that motion sensitivity is often mentioned in what was just presented. From our point of view, this is no surprise, since the driver's visual environment is, in essence, dynamic. We will now discuss this point more extensively. We will in particular present experimental work, trying to show how basic research might help clarify the complex domain of the visual information used in driving.

We will concentrate mainly on the control of steering and more precisely on the perception of heading. In this chapter, we will ignore interactions between the perception of self-motion and the perception of object-motion, which will be dealt with in Chapter 8. Finally, we will try to suggest possible concrete outcomes for everyday highway design.
THE ROLE OF MOTION VISION IN DRIVING

Two modes of visual information processing

In an important paper, Leibowitz et al. (1980) tried to relate the general problem of vehicle guidance to developments in the field of psychophysical and neurophysiological mechanisms in vision. They revisited the concept of two visual systems, considering that vision of space and vision of object identity may be subserved by anatomically distinct brain mechanisms, involving two parallel processes; one ambient, determining space at large around the body, the other focal which examines detail in small areas of space. The two modes of processing concept can best be described in functional terms. It posits two independent and dissociable modes of processing: (1) a 'focal' mode that is in general concerned with the question of 'what' and subserves object recognition and identification; (2) an 'ambient' mode concerned with the question of 'where' which mediates spatial orientation, locomotion, and posture, and of interest to us here, vehicle guidance.

Focal vision is present in central vision, where visual acuity is maximal. Today, it remains the quasi-exclusive aspect of visual processing addressed by visual requirements for obtaining a driver's license. On the other hand ambient vision seems to be at work throughout the visual field and exhibits coarse spatial resolution and good temporal resolution. It is moreover less sensitive than focal vision to large variations in stimulus parameters, being for instance quite effective in low luminance conditions.

Relationships between ambient vision, motion perception and the control of self-motion were notably investigated by Brandt and his co-workers. They showed that stimulation of the peripheral visual field with moving patterns could induce, in a stationary observer, a powerful sensation of being him/herself in motion in an otherwise stable environment. The sensation of self-motion is a common visual illusion, which may be perceived while gazing at moving clouds, streaming water, or when a train moves on the adjacent track in a railway station. This compelling sensation of body movement can even affect postural balance. One might assume that these illusions are inferences based upon the conscious or unconscious assumption of a stable environment, so that when the environment does in fact move, the observer infers that he himself is moving. This interpretation would be consistent with the individual’s past experience as the entire visual surround seldom moves uniformly under natural conditions unless the body moves relative to the earth. Psychophysical evidence is presented indicating that motion-vision plays a predominant role not only in the perception of self-motion but much more generally, in dynamic spatial orientation.

The concept of optic flow

This approach to the problem of the visual basis for the control of locomotion was also formalized by Gibson (1979), who introduced the concept of optic flow, to describe the transformations of the light pattern (optic array) projected onto the entire retina during motion of the self. In an 'interactionist' approach, he suggested that our motion through the
environment produces a pattern of optic flow, which specifies the properties of our displacement. At this point, understanding the information in optic flow requires an analysis of its properties. In the original analyses, the laws of linear perspective were used to derive the changing optic array of a moving observer. Optic flow is described as a two-dimensional motion field. Figure 3 represents optic flow resulting from pure translational motion of an observer over a flat surface, which can be an equivalent of a road depicted by random dots dispersed on the surface.

In this figure, all optical motions radiate outward from a common 'focus of expansion', which corresponds precisely to the direction of locomotion. From this example, it is easily conceived that such an analysis led researchers to suspect that a new body of visual information was potentially available to a moving observer. One question was whether human observers were able to perceive such information with sufficient precision for effective control of locomotion (or vehicle steering).

Figure 3. Optical trajectories generated by linear forward motion relative to the ground. Element motions seem to emanate from a common point (the cross at the top of the figure), the focus of expansion of the optic flow, which corresponds to the observer's direction of travel (heading direction).

Useful information in optic flow

In the seventies, the first experimental studies concluded that heading judgments from optic flow were quite inaccurate. In conditions were subjects had to point in the direction of perceived focus of expansion during visual simulations of forward motion, heading errors were of the order of 5 to 10 degrees. Considering that safe control of steering requires an accuracy of about 1 degree, these results led researchers to doubt the usefulness of optic flow in the control of locomotion.

Important steps forward were later realized by William Warren at Brown University, revisiting the question (see Mestre, 1992, for a review). He suggested that these poor results might be due to methodological problems, including the observer's task. He designed a new protocol in which observers were presented with visual displays simulating motion relative to a ground surface populated with random dots (quite similar to Figure 3, above). After seeing the motion, observers had to decide (in a two-alternative forced choice procedure), whether it looked as if
they were heading towards the right or the left of a target line located on the ground. With this procedure, it was found that heading accuracy was of the order of 1 degree.

This result is of significant importance. It suggests that the information is in essence of a relativistic nature. In other words, drivers do not have to judge their direction of heading in an absolute sense, but relative to the road environment. They want to know whether their trajectory is aligned with the road, which is exactly what was found in these experiments. In the related problem of speed estimation from optic flow, we found similar results, showing that, whereas absolute speed is only given within a scale factor, variations in self-speed are perceived with a precision of 5-10%.

Two other points are worth noting. First, as can be expected if ambient vision is involved in optic flow perception, manipulations of dot density in the optic flow revealed that the perception seems not to depend on the location of a singularity, like the focus of expansion, but rather relies on the perception of the globality of the optic flow.

Secondly, in subsequent experiments on the perception of heading during curvilinear motion, where the focus of expansion is missing, the idea was confirmed that subjective judgments depend on the global optic flow structure.

It was also noted that judgments are then dependant on the visual trajectories over time in the flow. This suggested that the perception of heading requires longer time than the simple detection of a moving object, for instance. This relatively slow processing of motion information for the perception of the three-dimensional structure of the environment is a classical result in psychophysics.

Finally, for small radii of curvature, a deterioration of performance was systematically observed, with a tendency to underestimate the radius of curvature when motion relative to the ground was simulated. This last result might have implications for the design of road curvature. However, more data are required on this point, given that visual displays stimulated only the central part of the visual field, whereas peripheral vision might play a crucial role here.

**OTHER SOURCES OF INFORMATION FOR THE CONTROL OF STEERING**

Having demonstrated that the optic flow triggered by our own displacement is a useful source of information for the perception of heading, and thus logically involved in the control of steering, it would be far too limited to draw conclusions from experiments using a random dot environment. The road environment is more complex, and contains more sources of information.

**The role of edge lines**

Gordon (1966) already noted that "when the moving vehicle is aligned with the highway, each point on the road border and lane marker falls on the angular position previously occupied by
another point of the border, and the road assumes a steady state appearance" (see Figure 4).

![Figure 4](image)

Figure 4. Schematic representation of a steady-state appearance assumed by the optic flow due to the road edge lines, when the driver’s trajectory is perfectly aligned with the road. The same principle applies to perfect alignment with a curved roadway (see also Figure 5).

We are then confronted with what Gibson called a 'higher-order' (visual) parameter. Whereas we just noticed that drivers are keen to use optic flow to control their trajectory, we now find that they are able to use its stable appearance to steer their vehicle, using edge lines. We can then say that driving corresponds in this case to a tracking task, the problem being to maintain visual stability of edge lines. Riemersma (1981) demonstrated that, during simulated road driving, edge line motion was an effective visual cue for the control of heading and lateral control. One interesting consequence of this is that, under nighttime conditions, delineation systems appear to be a privileged visual cue for facilitating driving on straight and curved roads.

**The role of the visual road environment**

It has often been suggested that the road environment itself can modulate the perception of self-motion. For instance, we will have more of a sensation of increased speed while driving along a small road bounded by trees, than on an empty highway. Denton (1980) describes an experiment in which he systematically distorted the geometry of the road layout, in simulation conditions. He used a bituminous-like pattern, on which transversal white stripes were drawn. The spacing between bars was exponentially reduced. Results clearly show that subjects reduced their speed when confronted with these patterns that gave a visual sensation of increased velocity of self-motion. We will not go into technical details here; let’s assume that edge-rate - the rate at which the bars drifts in the visual field - is a good cue for speed perception. In a field-study in the UK, they indeed found a reduction in speed following this setup near dangerous roundabouts (see also Hills, 1980) and this design feature has now been implemented in several countries to control approach speed to particular hazards.

In the domain of heading perception, recent studies report distortions in perceived heading direction, due to asymmetries in optical velocities in the right and left peripheral visual field. For instance, subjects tend to perceive themselves as heading towards the side where the highest optical velocities were present. Although much care has to be taken before translating
this kind of result to a real driving situation, it suggests that the actual road environment might play a direct role in the way visual motion information is processed. This could have important implications for the design of a road environment. Much work is needed here, both fundamental and applied. But just imagine that, on a road with trees on just one side, this type of misperception of heading might actually occur. This could first explain certain weird accidents on small empty roads; it may secondly favour a new approach to the road architecture process.

To conclude this part, let us make two further remarks. First, it becomes obvious that the road environment structure plays a role in the perception of a car's trajectory. In this sense, we propose that the 'objects' along the road, including road signs, might also play a role. This approach suggests only that every road element has to be taken into account in a 'dynamic visual approach' to driving. In research, it corresponds to a new viewpoint on optic flow, suggesting that object-based information has to be taken into account. Secondly, the role of singular objects might be greater than we think. A singular object might capture attention, and induce an eye fixation on it. We do not want to get into the problem of eye movements here. However, Land and Lee (1994) showed that, in curve negotiation, the eyes tend to fixate the inside edge of the road near a point known as the 'tangent' or 'reversal' point of the road, which is a point where the inside of the curve changes direction (Figure 5). This suggests that subjects pick up useful information there, and that attracting their attention (and eyes) towards the outside of the curve (with road signs for instance) might not be the brightest idea in mankind for road safety (this comment is not intended to apply to the use of chevrons to give advance information about the presence and direction of a curve ahead).

Figure 5. While negotiating a curve, drivers tend to fixate a region (circled) where the inside edge of the road changes direction. This is also the point where the horizontal component of the optical motions of the road markers changes direction (from leftward to rightward in this case).
CONCLUDING REMARKS

"Take the driver's point of view!" might be the principle message from this short review about the implications of vision for safe driving. The highway engineer might however think that this is a casual attitude, leaving him/her with all the work, from basic studies to concrete solutions for highway design. Thus, we must try to be a little more specific.

The role of motion vision in driving has been emphasized here. Obviously, it seems important to depart not only from the bird's eye view of the highway, but also from a static point of view. The control of steering is in essence a dynamic control process and it involves of course dynamic visual information. This is not to say that basic visual functions are not involved. We tried to introduce a few, such as contrast sensitivity, night vision or peripheral vision. What is important to understand here is that the main problem is to fill the gap between basic clinical evaluations of vision and the globality of the driver's task. For instance, from what we introduced here, the engineer might want to reconsider the design of edge lines, making sure that they are visible in fog. However, this honorable approach does not guarantee that an accident will not occur on the precise part of the highway where a real test will be conducted, just because a driver fell asleep or makes use of the clearly visible edge lines to drive too fast. This is an extreme example, but it is true that attentional and cognitive factors, tiredness, experience of driving and perceptual style are a few amongst the many variables involved in car driving safety.

Another problem concerns the transfer from laboratory results to real conditions. One solution, as we already mentioned, is to design prototypes that can be tested in real conditions. It is surely true also that driving simulators have a role in this process, enabling researchers to test visual hypotheses in interactive situations as opposed to evaluating passive observers' judgments.

Finally, there is a major concern about a quantitative aspect of the problem. Different people have different visual capacities. We saw briefly the effect of aging and of drugs on visual functions and the risk of car accidents. There are significant efforts, especially in the US, to update visual standards for obtaining a driver's license. However, as we already said, finding correlations between visual functions and accidents is difficult, partly because of the multifactorial aspect of driving. In addition, social factors come into play inside an aging population that wants to keep a certain level of independence. This means that the highway engineer will have to work for the common population, which is of course a vague and loose concept. In the end, I would like to stress that it appears more and more that the highway has become a 24-hours life place, and that trying to improve its architecture in terms of safety requires the collaboration with highway engineers of many specialists in vision.

RECOMMENDED READING

There are many excellent books about visual perception. A most readable is:

Concerning the role of optic flow in the control of self-motion:


Finally, for a survey of visual factors in driving:

INTRODUCTION

Two main issues can be identified in the research on motion perception applied to road traffic: vehicle guidance and collision avoidance. To control a vehicle along a desired trajectory we need to perceive our path of self-motion. To avoid collisions with unexpected objects on the road or with other road users, we need to perceive their specific shapes and motion paths, along with our own motion. One can study object-motion perception in isolation in the laboratory, through the use of special artifacts, to eliminate or at least severely reduce self-motion perception. However, in the real world, we are always performing some kind of movement: locomotion in near space, head movements to change our field of view or at least some eye movements to track or to search for objects.

Putting things in simple words: in the driver's eyes there is no such thing as a stable picture of the road environment, even when s/he is waiting at a red light at an empty road intersection. Instead, in the retina, some kind of motion pattern is always present, resulting from self-motion of the eyes, the head or the whole body. Any collision avoidance manoeuvre, therefore, should be seen as a task of second level complexity, with the task of vehicle guidance at the first level.

Contemporary researchers on motion perception, both fundamental and applied, make extensive use of concepts like optical flow and optical array that were originally made popular by an American psychologist, James J. Gibson (1979). To ensure the comprehension of this
chapter by a reader who might not be a specialist in motion perception, we will first introduce
the concept of optical flow as well as the sub-concepts of global and local optical flow. The
quantification of optical flow will be also introduced.

Optical flow can be intuitively defined as the coherent motion pattern produced by any sort of
movement in the visual field. The layout of a given motion pattern is a function of both the
illuminated textures of objects in the near space and of the movements performed. If someone
is performing some movement in a space composed only of static objects, the visual output will
be a unique pattern of optical flow generated by self-motion, with all the visual field elements
moving in a coherent way. This kind of visual motion, produced by subjects when they displace
their eyes, is defined as global optical flow. If in the visual field of a moving observer, a
person, animal or object has its own movement, it produces a sort of local dynamic disturbance
in the visual field of the perceiver. Its visual combination with the visual output of the observer
self-motion is called local optical flow. Therefore, perceiving the motion of an object during
self-motion involves two logical steps: (1) we need to differentiate (segment) the object's visual
motion from the global optical flow, that is to detect the presence of a local optical flow and (2)
we need to dissociate in the local optical flow the 'part' that is due to the movement of the
object from the 'part' that is due to our own motion. Furthermore, to catch something (for
example a ball) or to avoid a collision (for example with a car) we must achieve a correct
perception of both our own motion path and the trajectory of the object.

To quantify the optical flow a vectorial analysis has proven to be a good tool (refer to Jansson
et al., 1994, for an extensive discussion on this issue). We can represent each point moving in
the three dimensional environment by a vector on the projection plane (e.g., the retina of the
perceiver). The direction, orientation and length of each vector will be a function of the moving
visual path and speed of each point in space. Thus the global optical flow can be represented by
an array of vectors distributed in the visual field. The local optical flow can be represented by a
set of vectors differentiated from the global ones by their length, direction, orientation and
distribution.

In this chapter we will focus on the driver's perception of other road users and objects. In the
previous chapter by Daniel Mestre the reader will find an approach to the visual cues for self-
motion perception and related applied issues.

To the professional interested in road design, signalization, traffic management and/or traffic
safety, a certain number of methodological and practical questions should be outlined
concerning the driver's perception of moving objects. A first technical issue is the measurement
of optical flow. Assuming that vectorial analysis is a good approach, how can we apply it to
road scenes and to the quantification of object-motion? A second question is related to the
availability of empirical data about drivers' performance in collision avoidance tasks. This is a
major problem because, for obvious ethical reasons, we cannot put persons in dangerous
situations in order to study their behaviour. From an applied view-point, three other major
questions arise: (1) are there stable and predictable mechanisms underlying object-motion
perception during self-motion, (2) what factors can impair the driver's perception and (3) is it
possible to use some sort of visual artifact to improve performance in potential collision
situations? This set of questions will be considered in the next two sections.
METHODOLOGICAL ISSUES

Measuring motion in the road environment

For a researcher working mainly on fundamental issues (e.g., basic mechanisms and psychophysics of motion perception) the measurement of motion for a given scene is not necessarily a matter of concern. Through the use of abstract images, generated by special computer programs or dedicated apparatus, the researcher is able to control the amount and type of motion to be seen by a subject. Therefore, computing motion parameters becomes a matter of deductive calculations. However, to the professional or the researcher concerned with practical questions, the measurement of motion becomes a central issue. This is, of course, true for both real traffic scenes as well as for video or computer images used in a driving simulator. A naive approach would consist in just counting the number of points in a picture of the scene and then computing some motion parameters. Unfortunately this would be not enough since a given pattern of motion (optical flow) is the result of the movement of a given person in the environment and of the displacements of objects from a defined point of view of the visual scene. Also requesting an expert to evaluate the optical flow in a road scene is not useful. Because perception deals with both lower and higher level functions, even a gifted researcher would be unable to produce any sort of computational output of his own perceptual activity. Today, the uniquely available approach consists in video recording of road scenes (or in making a direct digital copy of frames from simulated scenes), from the point of view of the driver. Image analysis techniques can then be used to get a graphical representation of the optical flow, as well as to extract quantitative motion parameters like the number of vectors, their lengths, directions and orientations plus the vectorial distribution in the visual field (Figure 1).

These techniques have been used to analyze road sequences as well as to calibrate scenes for simulated experiments (please refer to Correia et al. (1996) for details on technical specifications and examples). Empirical results have shown that the performance of an experimental subject can be predicted from the output of the image analysis. For example, reaction times to detect the movement of a vehicle in simulated situations are clearly related to the computed quantitative motion parameters (e.g., number of vectors and their distribution in the visual field).

However, several improvements of these image capturing and analyzing techniques are required before they become usable as ordinary tools by road traffic experts. The problems faced nowadays by researchers are in relation to the sampling of recorded images, the number and quality of software functions and the hardware requirements needed to compute huge amounts of visual data.

Even with sophisticated computer graphics systems, frame rate is about 25-30 Hz and spatial resolution of displayed images barely reaches 1280x1024 pixels. These values are still a poor sample with regard to human visual skills. For example, the majority of the population is able to discriminate details of about 1 minute of arc subtended at the eye; to accomplish this level, recording and imaging systems would need about 3000 pixels per line, even for a reduced field.
of view of 50 degrees. This sampling limitation of the visual input implies that, at least in some

Figure 1. Optical flow representation of a real road scene. Vectors toward the observer are related to the movement of the driver along the road. Vectors with the opposite orientation are generated from the motion of the overtaking vehicle.
road situations, a driver may be able to detect the movement of a small target (e.g., a child crossing the street) while the image analysis system will have no input at all to process. Other technical limitations are related to software functions and computational power. Image analysis is very demanding of CPU speed, memory and storage of data. The weakness here is mainly due to the hardware limitations of available and affordable systems.

Considering the rate of development of the image capturing and computer industries, it is reasonable to expect more powerful tools, at reasonable cost, in the near future. This means that in the next few years affordable and efficient tools for road scene analysis should become progressively available.

**Measuring the driver's visual performance**

Understanding human visual performance in dangerous situations is a major challenge to the traffic researcher. Because vision is mainly a matter of complex and automatic low-level routines, asking a driver what happened in a traffic accident he was involved in lacks any practical usefulness. Of course one could interview drivers and get some interesting subjective opinions. However to establish a relationship between the driver's story and his visual-motor performance might become a matter of (science-)fiction and speculation, not of applied research. That is why the experimental approach is the only acceptable strategy to study the driver's visual performance: we need to put drivers in carefully controlled traffic situations if we want to understand their perceptual skills. But then another problem arises, since for obvious ethical reasons, we cannot put persons in situations with high probabilities of mental stress or physical injury.

Two main research methods have emerged to solve, or at least to reduce, the problems described above. One is based on a mental imagery anticipation technique that has been extensively used in Time-to-Collision studies. The other is based on measurement of the visual activity (through reaction times or thresholds) that occurs before an evasive action. To allow the study of drivers' performance in dangerous situations and to have a better control of experimental variables, both methods have been used mainly within simulated driving situations, based on video recordings of real situations or computer generated sequences.

In the mental imagery approach, an initial sequence of an impending traffic conflict situation involving the subject is presented; then the visual sequence is occluded (by stopping the image projection or through the use of special devices such as stroboscopic glasses) and the subject is requested to press a button or to give a verbal indication of the moment when he would collide with an obstacle or another road user. This subjective evaluation can be compared with objective data computed from the complete sequence of images or from the known parameters of speed and distance (see for example, Schieff and Detwiler, 1979; Cavil and Laurent, 1988).

A salient problem with this approach arises from the use of occlusion. In several real situations, like those of road traffic, the primary source of information is the visual input that one gets
over time from the environment. By occluding a road scene and asking a driver to calculate the moment of a collision we are changing the nature of the task itself, from a perceptual to a mental imagery task. Of course, one could argue that, given the seminal works of authors like Kosslyn (1980) or Shepard and Metzler (1971), a large set of behavioural and neurophysiological data points to a clear functional and structural proximity (or even identity) between some perceptual and imagery dimensions. However, later experiments made by Kosslyn (1993) have also demonstrated that, even for a simple visual object, the amount of activity measured in the common brain area used to process both perceptual and imagery data is much higher for imagery processing. A simple and reasonable explanation of this finding might be that imaging an object is a hard task, involving 'building' it in our mind from some information stored in memory, while perceiving an object relies on an external input immediately available to our visual system.

This explanation might help us understand the results obtained by Horst (1991) in a field experiment in which the effects of occlusion on drivers' braking performance was studied. The author found impairment of the driver's braking performance while approaching an obstacle, and an increasing amount of variance both within and between drivers, as a function of the duration of the occlusion. Much of the error and variance of the collision estimations might well be due to the underlying mental imagery task; the underlying processing effort being much higher than that related to the perception of a contingent road scene. However, with the current state of knowledge, it is difficult to argue in favour of a clear relationship between the data from mental imagery experiments and the performance of a driver in real situations. Nevertheless, to the curious reader interested in psychological issues, we should point out that mental imagery experiments are among the most interesting in contemporary research in psychophysics and cognitive neuroscience.

For applied purposes, an alternative approach consists in studying the perceptual processes that occur before an evasive manoeuvre is initiated by a driver faced with a dangerous traffic conflict. The underlying rationale is based on a logical segmentation of evasive actions. We can define a first period, dedicated to the perception of our own motion, as well as of the motion pattern of other road users; a second period, dedicated to deciding what to do (e.g., change gear, brake), and a third period dealing with the execution of the chosen evasive manoeuvre. The appropriateness of the decision and the efficiency of the action might depend on some previously acquired driver expertise and on neuromotor readiness. To a given driver involved in a given road task, these skills could be assumed to be relatively stable. Therefore the variance of the final performance on a collision avoidance task could be attributed mainly to the perceptual demands involved. Using this rationale, a typical research situation consists in presenting a subject with road scenes and asking him to press a button as soon as he detects the motion of another road user. Psychometric functions can be calculated from the subject's reaction times, and/or proportions of correct identifications. Thus, relationships between motion parameters (e.g. driving speed, trajectories) and visual performance can be established.

Although this technique could be considered to be more robust and useful than the imagery approach, it also has its own practical problems. Let us consider the calculation of safety intervals between vehicles in a platoon. For the practitioner this should involve working with two general variables: driver reaction time (e.g. measured from the change in speed of the
leading car) and vehicle dynamics, measured from when the driver starts braking to when the desired new speed is achieved. Working with perceptual times would make the computation much more complicated. It would involve taking perceptual time and adding it to another calculation or estimation of both a decision time (e.g. start braking) and a final reaction time (e.g. the actual braking movement).

The study of motion perception with the technique described above is the approach of the authors of this chapter and, in the next section, some related experimental findings will be discussed. Of course, keeping in mind the methodological problems that we have just mentioned, the experimental data should be used only as a starting point to build general guidelines for road and traffic design. To allow precise predictions of road users' behaviour, further research must be carried out with driving simulators and instrumented vehicles. Driving simulators will allow the study of a full behavioural sequence. Again, just as for the image analysis technique, hardware improvements are necessary to enable simulated experiments with high levels of visual realism. Field studies with instrumented cars are the final test for road traffic research. However, because of the ethical limits already quoted, only situations with low conflict risks can be used. In practice, this will imply a massive gathering of field data (requiring large samples of drivers). Here, in the same way as for studies of accident statistics, data aggregation will be needed to find salient and consistent relationships between variables.

PRACTICAL IMPLICATIONS FROM SIMULATION STUDIES

In the previous section, we have summarized the methodological issues relevant to the road traffic professional. We will now present some experimental findings and their implications for road design and management. Due to the complexity of the subject, the empirical data available are scarce and, at the present time, we should consider it as useful for the development of some general guidelines, rather than for ready-to-use prescriptive and authoritative rules. Within the first subsection we will focus on general characteristics of the driver's motion detection of other road users. In the second subsection, the impairment of motion detection by the road layout, as well as the possibilities of enhancing drivers' perception, will be discussed.

General findings on object-motion perception

In the introduction to this chapter we argued that in the real world there is no such thing as object (e.g. car, pedestrian) perception independent of the driver's self-motion. Thus, to understand the skills of the driver in detecting any moving object, we always need to take into account his own displacement on the road, and its visual consequences.

Let us consider this from the driver's perspective. When we are driving along an empty straight road, the global optical flow has a simple and coherent shape. All vectors emanate from a central point in the visual field, called the focus of optical expansion, with increasing magnitudes from that point out to the borders of the visible space. Experiencing a curve in the roadway implies combining a translational component of the vehicle movement with a rotational one. The image projected to the retina will change and show a 'curved' optical flow.
Furthermore, the driver will make head and eye movements to focus on some road or vehicle details, and this kind of self-motion will also have an impact on the global flow path.

On the object perception side, we can also consider several possibilities, including (1) movements along our path, like those of leading vehicles or of vehicles travelling in the opposite direction, eventually performing an overtaking manoeuvre; (2) perpendicular displacements relative to our direction of motion, for example at an intersection; (3) a progressive movement from a perpendicular to a parallel path, for example when another vehicle is approaching us from a freeway access; (4) somewhat erratic movements of pedestrians trying to cross the road, and so on. If we now take into consideration that the visual path of a moving object depends, in the driver’s eyes, both on the kind of object displacement itself and on the global path produced by the self-motion of the driver, we will be confronted with a huge field of possibilities.

By adopting a pragmatic position, we can accept some simplification of the interplay between self-motion and object-motion. For example, in road traffic we can ignore the body, head and eye movements of the driver, on the grounds of their much lower magnitudes compared to those related to vehicle displacement. We may also accept that, at least for applied purposes, we do not need to study all the possible motion paths available in road traffic. Instead, we can just examine a few typical or extreme situations and then try to derive predictions for other cases. For example, we could consider empirical data on the perception of other vehicles at intersections and then combine it with studies about movements on the same path, like overtaking manoeuvres or braking of a leading car.

For applied purposes a major question arises: is there any rule or model allowing us to established a clear relationship between object-motion and self-motion?

The interference effects of the driver’s motion on his perception of other road users. In a very elegant and carefully balanced set of experiments, Probst and co-authors (1986) have clearly demonstrated that the main factor of interference in object perception is the global movement within the visual field (generated by self-motion). Other non-visual channels (vestibular and somatosensory) have a much smaller impact, almost residual, in object-motion perception. Because these were fundamental experiments with ‘abstract’ visual stimuli and unusual motion paths we cannot make a direct application of the interference values that were found to the road traffic domain. Nevertheless, the data were so consistent that some implications for road traffic should be considered. The visual input generated by the driver/vehicle movement would be the major factor of interference in the perception of other road users’ motion. Therefore, an interference phenomenon on object perception would occur, even when someone is driving a car at a stable speed, without experiencing variations in body pressure due to accelerations or decelerations.

Now, let us move forward to a deeper level of detail. What kind of interference has self-motion on object-motion perception? Probst and co-authors have conducted some field experiments and the data show a close agreement with the results of more fundamental studies (Probst et al., 1987). On a closed road, each driver was requested to follow a leading car with average speeds
varying from 50 to 70 km/h. Whenever he detected a change in speed (receding or approaching) of the other vehicle, he had to press a button. The field results were then matched with data from a related visual task carried out in the laboratory (where only small head/eye movements could occur). The authors found that reaction times were much higher in the dynamic field test than in the relatively static laboratory experiment. They also found that increasing driving speed and decreasing the relative speed of the target vehicle would cause higher reaction times. The difference in reaction time magnitudes between extreme situations was increased by about 1 second or even more. This is very significant, if we consider that in traffic conflict analysis, 1.5 to 2 seconds are commonly accepted as minimal safety margins between road users.

From the above experiments a general rule might be outlined: increasing the amount of motion in the driver's whole visual field will produce higher impairment rates in the detection of relative motion of other road users. This impairment or performance deterioration would affect the precision of detection (e.g., ratio between correct and erroneous detections), as well as the reaction time needed to perceive others' motion paths. However, the results of several simulated experiments carried out by one of this chapter's authors, clearly pointed to significant differences between the detection of an approaching versus receding object.

The shape of interference: impairment versus enhancement in the detection of a leading car. When a leading object was approaching the subject, reaction times were found to be much higher than in a receding situation, with a magnitude of difference reaching 0.5 seconds for some tasks (Santos et al., 2000). In this study, the amount of global optical flow (e.g., the density of motion or the number of vectors in the visual field) was also manipulated with image analysis techniques. It was found that, with increasing densities, performance impairment increased for approaching movements and performance enhancement increased for receding ones. In other words, opposite effects were discovered, with increased reaction times for an approaching object and lower reaction times for a receding one, all other conditions remaining constant. Therefore, instead of a general impairment phenomenon, we have to consider an impairment versus enhancement model. When we are moving forward and a vehicle to be detected is approaching, its motion path is almost the same of that of the whole visual field and a motion capture phenomenon can occur. In optical flow terms, the vectors generated by both the vehicle and by our own movement have almost the same direction and orientation. To perceive the approach situation we can only rely on the differences in motion magnitude (vector lengths) due to the differential velocity between our car and the other vehicle. However, when a vehicle is receding, its vectors have an orientation opposite to those of the global optic flow field and we can use not only magnitude but also orientation difference as cues to detect the vehicle's relative motion. Therefore, motion contrast is enhanced.

One could argue that the experimental results we have just discussed lack practical interest from a road safety perspective. Only the approaching movements between a driver and other road users could lead to potential traffic conflicts. Therefore, we can disregard the positive effects found for receding motion paths and establish a simple and general traffic rule: the perception of other road users' motion is always impaired by the visual consequences (the global optical flow) of the driver's self-motion. Considering the whole set of experiments we have reviewed, we could be even more specific stating that the impairment effect increases (1)
for higher driver speeds, (2) for lower relative speeds of the approaching vehicle, for example with slower braking, and (3) with larger amounts of motion density in the visual field, generated by detailed environments. However, this set of conclusions must be handled carefully by road experts. We should note that the supporting experiments were mainly concerned with car following tasks on straight roads and in the real world the potential number of motion paths is much more complex.

More complex paths: perceiving the motion of other vehicles at intersections. When the driver is approaching an intersection he must anticipate the local motion of other vehicles and take an appropriate manoeuvre to avoid a potential collision. We placed subjects in simulated road situations where they had to estimate (by pressing on a mouse button) whether the other vehicle would arrive before or after them at the intersection. The driver's trajectory was rectilinear in one case (Berthelon et al., 1991), and curvilinear (using different curve radii) in another (Berthelon and Mestre, 1993). In the case of the driver's rectilinear trajectory, we noted that participants saw the other vehicle arriving after them more often than it really did. In particular, when it arrived a very little time before the driver at the intersection, it was seen as arriving after him. Within an optic flow perspective, this result is relatively clear. When the other vehicle arrives after the driver, its local motion has the same direction but not the same amplitude as the set of vectors of the global optical flow. Conversely, when it arrives before the driver its local motion has a direction different from the direction of the surrounding global flow. But if the vehicle arrives just a little before the driver the visual motion amplitude is very small, so its direction is difficult to discriminate from the direction of the global flow which could explain why subjects saw it as arriving after them at the intersection.

In the case of a driver's curvilinear displacement, the results were quite similar, also showing an interference effect of the global optic flow on the perceived motion of the other vehicle. This effect was linked to the rotational component of the global flow that impairs the adequate perception of an approaching vehicle that would reach the intersection before the observer. The interference is noticeable for a driver's trajectory with a small curve radius. From these experiments, an implication for road traffic would be to avoid putting intersections after a curvilinear path, in order to avoid misperception of other vehicles' motion. However, a remaining question is whether abstract or realistic visual stimuli on a large screen (like those used in these experiments) produce visual outputs similar to those that occur in real driving situations.

The key effect of visual motion adjacent to the target vehicle. The studies we have been reviewing so far were made by several research teams with quite different road layouts, vehicle models and dynamic parameters. Therefore it is not yet possible to offer the traffic engineer a set of consistent or integrated guidelines and implications. Nevertheless, at least one new interference aspect of global motion on object perception might be considered of general interest in the road traffic domain.

Santos (1997) carried out a simulated experiment with two road layouts with opposite distributions of optical flow. This was achieved by manipulating the amount of detail of the textures and objects in the scene and by measuring the resulting visual motion with image analysis techniques. One layout (F1) had a high mean density of optical flow in the area of 16
degrees surrounding the leading vehicle, a small general mean density and also a small mean density in the other areas of 16-33 and 33-50 degrees. The percentage number of points with motion in the image compared with the points without motion were 68, 30, 35 and, 20 per cent, respectively. The other layout (F2) had a small mean density of optical flow in the area of 16 degrees surrounding the leading vehicle, a high general mean density and also a high mean density in the two peripheral areas, the values being 28, 63, 67 and, 68 per cent, respectively. Subjects were required to detect changes in relative position (approach or recede) as quickly as possible.

The results for the approaching condition pointed to an impairment of perception mainly due to the global optical flow surrounding the leading vehicle. The general optical flow as well as the peripheral one seems to have only a reduced impact on motion perception (Figure 2). Further data analysis for the receding movement demonstrated the same functional interference but with an expected inversion: the lowest reaction times were obtained with the highest values of optical flow surrounding the vehicle.

![Detection times (ms)](image)

Figure 2. Mean detection times in milliseconds of an approaching leading vehicle, with drivers' speeds of 0 and 50 km/h, for road layout F1 (large amount of optical flow surrounding the vehicle) and F2 (small amount of optical flow surrounding the vehicle)

The perceptual effect found in this experiment, as well as in other related experiments, was strong enough to allow a general prediction: the interference effect of self-motion perception on object perception is due to the global flow surrounding the target, regardless of the peripheral
motion or the relative motion paths of the target and perceiver. In other words, it is reasonable to assume a general mechanism of object-motion perception, based on a contrasting processing of the dynamic visual paths of the object itself and of the other objects in the near visual field.

For the road traffic professional, the above prediction is of obvious interest. If the research data had pointed to an interplay between the perception of object-motion and the perception of the whole visual field, the opportunity for practical measures would be dramatically reduced. In fact, it would be very unrealistic to argue for interventions in all the areas surrounding the road network just to favor a more precise perception of other road users. However, the main effect on object perception seems to be due to interference from the adjacent dynamic visual field. Therefore, through limited interventions in road design and signalization, it should be possible to promote a better perception of moving objects and thus to improve the driver's collision avoidance performance.

Object related attributes: vehicles and pedestrians. Until now we have only approached the driver's perception of other road users by relating it to the dynamic characteristics of the whole visual field. Could we find in the research reports some clues about the perceptual effects of the object itself? When an object is approaching us, its visual projection shows an expanding shape. Lee (1976) proposed that the expansion rate (named Tau) could be used by subjects to compute the time remaining until contact or collision.

The mathematical model proposed by Lee was tested in several studies both in sports (for example, catching a ball) and in the traffic domain. Unfortunately, most of these studies were unrealistic for traffic purposes, since the perceiver was constrained in a static position, just waiting for a moving object. In experiments with self-motion the results supported the idea that the expansion rate (Tau) as well as the optical flow variables were used by subjects (Cavallo et al., 1997).

Another related issue is the amount of motion (e.g., optical flow) that an object is able to generate. We could speculate that it would be easier for a driver to detect the motion of an object rich in detail than to detect another one with a single colored surface. A detailed object would be easier to detect since it generates greater amounts of motion, expressed in terms of number of local vectors. During the preparation and preliminary evaluation of some experiments it was accidentally discovered that a visually detailed leading vehicle, for example with clear borders between car components and different textures for each one, seems to be easier to detect than a simplified model (Santos, 1996).

We should note that, for applied purposes, the inherent characteristics of objects are less interesting than those related to road design and signalisation. In fact, it would be unrealistic to expect that both the users and the manufacturers would ever accept a standardized design of cars and clothing, even if we have discovered some related effects on motion detection. Nevertheless, one special case should get the interest of traffic researchers and practitioners: the perception of vehicles versus the perception of pedestrians. To perceive a vehicle we are facing a single motion pattern. Instead, when a person walks around, the resulting visual pattern is a combination of complex body, arm and leg movements. Fundamental researchers usually refer to this as non-rigid or biological motion as opposed to the rigid motion of objects such as
cars. As yet there is no available applied research, carefully planned and controlled, on pedestrian motion perception by drivers. This kind of research is quite difficult to design, because of safety concerns in real road situations and because of the complexity of the generation of realistic body movements with currently available road and traffic simulation tools. However, understanding the rules of pedestrian detection would be of great interest to all of those concerned with traffic management and safety in urban areas.

Two case studies on drivers' motion perception

In the previous sections, we have reviewed several studies useful to aiding an understanding of the general principles of driver motion perception. We will now review two simulation experiments in which the driver's performance was tested in very specific and realistic road layouts. The first study is an example of how road materials and signalisation can impair drivers' perception of a leading vehicle. The second illustrates how discrete signals and other reference objects can enhance the driver's detection of another vehicle at an intersection.

Factors of perception impairment: road pavements and chromatic bands. Chromatic bands are widely used as road safety devices. The underlying assumption seems to be that, when a driver is approaching a potentially dangerous area, the visual and sound 'noise' generated by chromatic bands should promote an attentional alert and a reduction in speed. Also, some alternative pavements have been used for both economic and safety reasons. For example, pavements made of concrete are considered to be more durable and safer (allowing better adhesion of vehicles) than traditional and less expensive bituminous ones. However, little is known about possible countereffects on safety of alternative pavements and chromatic bands. The concrete pavement is brighter than traditional ones, so we can ask if it would impair visibility and thus the driver's perceptual performance, due to changes in contrast with surroundings, road signalisation and other road users. The use of chromatic bands represents a severe change in the road surface layout and, keeping in mind the studies reviewed previously, we would predict that it would impair the driver's performance in detecting the motion of other road users.

To clarify the above questions, Noriega and co-authors (1998) carried out a simulated experiment with three kinds of pavement: concrete, bituminous and bituminous with chromatic bands. Measures of patterns and luminance ratios were performed in the field, so that the digital textures representing road surfaces could be designed to achieve a high degree of realism. One hundred and six drivers, with ages from 20 to 57 years old, participated in this study. Each driver was requested to press a button, as soon as s/he was able to detect the motion path (receding or approaching) of a leading white car.

The number of wrong detections in the sample was analyzed for the approaching condition, i.e. the number of times that drivers detected a receding movement when the leading vehicle was actually approaching. As we can see in Figure 3, the higher value of wrong detections was obtained for the pavement with chromatic bands. The concrete and the bituminous pavement had smaller values, with no significant difference between them. A closer inspection of the data reveals that there is no evident relationship between the luminance contrast of the vehicle against the pavement and the number of errors. However, a clear relation exists between the
increase in driver errors and the increasing amount of motion (optical flow) measured in the area of the pavement adjacent to the leading vehicle.

How can we interpret these findings? First, the contrast between objects seems to have no impact on the driver's performance. Even if this conclusion is against common sense, several fundamental and applied studies have consistently shown that, in dynamic situations, the textures and related brightness values of surfaces are not important *per se*. Therefore it seems that, at least for motion detection tasks and related driver manoeuvres, brighter pavements such as those made of concrete could be used without expecting negative effects on road safety. Second, the pavement with chromatic bands seems to have a very negative effect on the motion task studied. This effect could be explained by the larger amounts of motion 'noise' it generates, when compared with regular pavements. Within an applied perspective we can now ask whether the assumed safety benefits of chromatic bands are being reduced or even eliminated by an unexpected negative effect on motion detection performance.

![Figure 3](image)

**Figure 3.** Average wrong detections (errors) of an approaching leading vehicle, with three kinds of road pavement. Values are given of optical flow and luminance contrast for each pavement

A subtle remark concerning this experiment might be that the worst results for the pavement with chromatic bands could be explained by the lack of contrast when the white vehicle was moving over the lighter bands. However, the same pattern of results was obtained in a later study, where a gray vehicle was used to ensure equivalent contrast with each road area taken separately.
The empirical data we have been discussing surely need to be replicated in other studies, even more applied-oriented, for example in full interactive simulators and real road conditions, before definitive recommendations can be outlined. Nevertheless, some general comments can be developed right now. In the last decades, traffic signalisation devices have shown an enormous increase both in number and complexity. Much of this technical growth is based on trial-and-error tests in the field, as a pragmatic effort from traffic professionals to answer the increasing demands for road mobility in our society. However we might speculate that, at least in certain cases, we are over signalizing roads and thus pushing the driver to his or her limits of information processing. More precise techniques for the evaluation of signalisation and road design would certainly be welcomed by the traffic professional. Such techniques should permit better analysis of the benefits and risks of road devices considering the limits of the driver's mental resources and skills.

Factors of perception enhancement: road signals at intersections. As shown earlier, global optical flow due to self-motion of the driver can impair the perception of other vehicle motion when arriving at an intersection. In addition, we know that environmental complexity, profusion of advertising notices and of road signalisation might also have a negative interference effect on the driver's object-motion perception. Thus, we now need information about how to enhance the perception of another vehicle's path when arriving at an intersection and about the kind of environmental layout which can promote it. In this vein, our experimental studies, with very realistic simulated road scenes, showed that the presence of a road sign near an intersection acts as a sort of spatial reference and gives rise to better discrimination of the other vehicle's motion (Berthelon et al., 1995). It was as if the interference of global flow was reduced by the presence of this reference. On the other hand the road sign could induce a local perceptual interference, due to the fact that participants analysed the relative motion between the road sign and the other vehicle. It should be mentioned that similar results were found both for the driver's rectilinear and curvilinear displacement.

In another experiment, we also found a spatial reference effect when trees were placed in the background of the visual scenes (Berthelon et al., 1997). Other authors have obtained similar results. Uchida et al. (1999) established that, at intersections, fences along the roadside of a vehicle on a collision course promote its earlier detection (by approaching drivers) than conditions without fences.

However, these results need to be replicated in order to be useful for road traffic engineering and the effects of different aspects of the structure of the visual environment require further detailed research.

CONCLUSIONS

In this chapter we have reviewed theoretical concepts, methodological issues and results of experiments on drivers' perception of other road user's movements. The ability to perceive rapidly and precisely these movements can be considered a key component of successful collision avoidance manoeuvres.
From the experimental data we could extract two major implications for road safety. First, the visual consequences of driver displacement (global optical flow) are the main interference factor in his or her ability to perceive the movements of others. Second, this interference phenomenon is due to the visual motion adjacent to the target object, produced by the driver's displacement in a given environment. The visual motion of objects (like buildings or trees) placed far away from the driving path, seems to have only a limited impact, if any, on performance.

Some examples were provided of impairment and enhancement factors of motion perception due to chromatic bands and road signs, respectively. However, to develop more specific implications or even to achieve some practical rules and predictions, we still need to perform further experiments in real road conditions or in powerful driving simulators.

To analyze or to simulate the overall visual information available in road networks, huge amounts of computer power are required. That is why research in this field has been relatively scarce and conducted mainly at a few specialized research laboratories. Nevertheless, it is reasonable to expect that in the next few years powerful tools will become available at reasonable cost, thus allowing access by the traffic professional to more specific information on drivers' visual performance and its relation to road design and signalisation.

**RECOMMENDED READING**

For general references on visual perception and motion perception please refer to the recommended readings in Chapter 7 by Daniel R. Mestre.

On visual perception and driving a good source of information can be found in the series of Vision in Vehicles books edited by A. G. Gale *et al.* and published by Elsevier.
INTRODUCTION

The design of many roads and their typical appearance reflects the way roads have developed through history. In this development road design has not been considered as a system property optimally adapted to human capabilities. Thus we have inherited what is by no means a structurally safe traffic system. The crucial question is how potential errors occurring in traffic can be reduced by designing a road environment that is optimally adapted to the goals and needs of road users. It is commonly estimated that over 90% of the traffic accidents are related to human error. Because better education, information and enforcement may have only limited effects on accident reduction, it is absolutely crucial that the road environment is designed in such a way that human errors are reduced to a minimum (see e.g., Theeuwes and Godthelp, 1995a). The crucial question is what design principles can reduce the probability and consequences of an error during driving?

In order for road design measures to have the desired effect on the behaviour of the driver, the road environment should be perceived by the driver in the way it was purposely designed. Note however that perception is an active construction process: it is the result of an interaction between sensory input, expectations and other information processing characteristics of the driver. Therefore, it is quite feasible that drivers may perceive the road environment in a manner different from what the road designer initially had in mind. For example an urban 4-lane road may be designed for a driving speed of 50 km/h; yet, if drivers perceive the road as 'a type of highway' even though it is in a built-up area, it is likely that they will behave and treat the road as a highway.
In general it has been estimated that over 90% of the information that a driver has to process is visual (Hills, 1980). Since the visual system is limited and the driving environment is relatively complex, in many circumstances perception of the road environment will rely on top-down expectations. In other words, drivers will perceive those events that are in line with their expectations and will overlook events that are not in line with their expectations. Typically, accidents occur because drivers did not expect particular events to happen and did not anticipate adequately. Studies investigating errors occurring in actual traffic show that expectations do play a crucial role in the occurrence of accidents. Accident data show that a large portion of drivers involved in automobile crashes do not act too late but do not act at all to avoid the collision (Sussman, Bishop, Madnick & Walter, 1985). In addition, Malaterre (1986) indicates that 59% of all accidents are the result of inappropriate expectations or interpretations of the environment.

This chapter discusses some theoretical issues regarding road design. The first section discusses how the road environment will be perceived by the driver, depending on the level at which the driving task is performed. The second section discusses the role of saliency and conspicuity of road elements in designing a road environment. The third section addresses the role of expectations and how this affects our perception and interpretation of the road environment. The final section gives some practical advice and rules on how to design an optimal road environment.

**PERCEIVING THE ROAD ENVIRONMENT**

In general it is recognized that human behaviour is intrinsically goal directed. In order to understand how people perceive the road environment, it is important to consider both the current state and the state the person tries to accomplish (i.e., 'goal state'). In order to accomplish a particular main goal (e.g., travelling from location A to B), the main goal is divided into smaller subgoals. Each smaller goal can be accomplished by a particular set of actions. For example, to accomplish a main goal such as 'being at a particular time at a particular place', at lower levels, drivers may decide whether or not to pass a car, drive a particular speed or whether or not to stop for a traffic light.

To understand the effect of road design on drivers' behaviour we developed a theoretical framework based on various existing psychological models (e.g., Rasmussen, 1985) that allows appreciation of the possible effects particular road measures might have. As an example, at one level of the driving task, the control level (i.e., keeping the car on the road), actions are performed within a very brief time constraint and at a so-called skill-based level (c.f., Rasmussen, 1985). At this level, actions take place with little conscious control. This implies that road measures that aim to induce certain changes at this level of the driving task (for example, forcing drivers to change lanes, as in work zones) should do so by providing information at an appropriate level. Just putting up a sign which indicates to the driver to change lanes, without actually providing lane markings on the road to guide the delineation manoeuvre, would be an example of providing information at the wrong level. Signs to warn the driver that a delineation is coming up are important; yet, to let the driver negotiate the lane change manoeuvre at the appropriate level of the task hierarchy, it is crucial to provide also information at the control level (i.e., by providing lane markings).

To elaborate the theoretical framework, the driving task can be divided into three dimensions: *task*...
hierarchy, task performance, and information processing. Figure 1 gives the structure of the road user task in these three dimensions. The X- and Y-axes give the stages of information processing and the task hierarchy, respectively. The Z-axis gives the level of task performance which is related to experience with the driving task.

**Task-hierarchy**

With respect to the task hierarchy, the highest **strategic** level entails the general planning of a trip, including the determination of trip goals, route, and modal choice, plus an evaluation of the costs and risks involved. For example, someone may want to travel from location A to B (for reasons of work or leisure), following a particular route (for reasons of time or pleasure), with a particular time schedule (utility). The strategic level determines the boundaries within which the task at the **manoeuvring** level will be performed.

![Task Hierarchy Diagram]

**Figure 1. Structure of the driver's task in three dimensions**

Given the boundaries of the strategic level, performance at the manoeuvring level is largely constrained by the actual environmental input. This level includes manoeuvres such as overtaking, stopping, parking, crossing, giving way, etc. The **control** level is the lowest level in the task hierarchy and entails tasks dealing with vehicle handling such as the control of the vehicle on the road, steering, shifting gears and so on. Control actions are performed within a relatively short time constraint and automatically, that is, as soon as a particular routine is required, it is automatically executed.

**Task performance**

The efficiency with which a driver can perform the driving task depends upon the task level and upon the proficiency of the driver with a particular task. Rasmussen (1985) recognizes three levels of task performance: tasks performance can be knowledge-based, rule-based or skill-based. **Skill-based behaviour** is performed automatically and represents sensory-motor performance which takes place without conscious control and provides smooth and highly integrated patterns of
behaviour. Shifting gears and steering control are examples of this type of behaviour. Rule-based behaviour consists of a sequence of subroutines controlled by a stored rule or procedure which is developed over time through repeated practice with a particular situation. When a particular situation occurs, the rule or procedure is retrieved from memory and is executed in a manner similar to the execution of a cookbook recipe. The rule or procedure is retrieved from memory on the basis of previous successful experiences or learned procedures. Knowledge-based behaviour occurs in unfamiliar situations when there is no rule for control from previous encounters. The behaviour is performed at a higher conceptual level involving inductive or deductive reasoning and understanding of the situation. An example might be finding the appropriate road to a particular destination. Knowledge-based behaviour is required when faced with unusual situations and/or when the person does not have much experience with a situation.

Information processing

The different stages of the information processing sequence play a key role in the driving task. Information processing occurs at each level of the task hierarchy and its characteristics will be related to the level of task performance. With increasing experience with a particular task, the level of task performance will move from knowledge-based to rule-based, thereby changing the type of information processing occurring. Due to the hierarchical nature of the driving task, however, many elements will never become fully automatized at the skill level.

The effect of the road design on different driving task levels

Strategic level. The design of the road environment plays a minor role at the strategic level of the driving task. As noted, at the strategic level aspects such as the goal of a trip (e.g., work or leisure) and the route choice are important. For example, drivers may choose a certain route not because it is fast but because it offers a lot to see along its length. In this sense the design of the road environment affects the driving task at a strategic level. Note since the levels are hierarchically organized, choosing a road for certain reasons at the strategic level will contribute to determination of constraints at the manoeuvring level. For example, when choosing a road for reasons of leisure, people will drive less fast, will pass cars less frequently and will look more at the road surroundings.

Manoeuvering level. At the manoeuvering level the road environment has a large influence on driving behaviour. At this level, the execution of a driving task is controlled by previous experiences with road environments in which the manoeuvre was successful. Given the occurrence of a particular environmental condition, a manoeuvre will be performed at a rule-based level by executing a more or less fixed set of actions. This rule-based manoeuvring behaviour is based on memory representations which develop through experience with the driving task in particular road environment settings. For example, when overtaking a car on a freeway, several implicit assumptions stored in memory are activated, e.g., the assumption that there are no oncoming cars, that there is no slow traffic, that there are no driveway exits and no traffic lights. On the other hand, there are presumptions that other cars might be overtaking your car, or that other cars might drive much faster. When overtaking the car in front, all these assumptions may control the
execution of the manoeuvre (e.g., checking the outside mirror and increasing speed).

Control level. At the control level, road design also plays a crucial role. Since the total performance is smoothly integrated and rolls along without conscious attention or control, it is absolutely crucial that the road design fits well with what drivers need, in order to perform this fully automated task. For example, course control is based on a combination of correlates of lateral speed, lateral position and heading rate (Riemersma, 1988). This type of information is rather 'primitive' and enters the visual system at an early perceptual level. If for some reason information regarding any of these parameters is not adequate (for example, the line markings go off the road or are not clearly visible), it is possible that loss of control will occur. Since the action is executed in a more or less automatic fashion, the wrong input into the system will immediately result in the wrong output, particularly if there is no actively sought feedback. Again because the driving task is hierarchically organized, problems with performing the task at a lower level will also influence the performance at a higher level. For example, learner-drivers who have problems with course control, might decide not to overtake another car or might decide to look less frequently in the rear-view mirror. On the other hand, there is also an influence from top to bottom levels. For example, driving under high time constraints (a planning aspect) will result in frequent overtaking, and will require a stricter course control.

THE ROLE OF CONSPICUITY OF ROAD ELEMENTS

In a road environment there is an enormous influx of visual information and appropriate sampling and integration of information is critical for the driving task. In optimizing the information acquisition process, the extent to which driving-relevant objects and events are capable of attracting the attention of the driver is considered to be crucial. Failure to detect these objects and events may result in inappropriate actions and behaviour on the part of the driver. The efficiency with which an object is capable of attracting attention is commonly referred to as conspicuity or saliency (Hughes and Cole, 1984). In this view, what is noticed in the environment is solely determined by the physical properties of the object and its background.

Typically when designing a road, driving-relevant objects are made as conspicuous as possible. For example, relevant signs such as stop signs and yield signs are large and red while less relevant signs such as street names are small and perhaps blue or brown or green. The underlying notion is that drivers will immediately notice the conspicuous signs. When examining the definitions of conspicuity in the literature, two properties are mentioned in nearly all definitions. First, conspicuity is determined by the object-background characteristics; second, a conspicuous object exerts control over the visual system in such a way that attention automatically is attracted to the object. The first property is an environmental aspect whereas the latter is the behavioural consequence of the presence of such a salient object. It is important to note that conspicuity should always be considered in relation to the background. A red sign is conspicuous in a road environment in which there are not many red signs. Yet, a red sign among very many other (red) signs (as for example in a busy business district with many billboards and flashing lights) may
become inconspicuous. Also, simply adding more signs to warn a driver is not necessarily a good solution because the addition of more signs will basically render all signs somewhat less conspicuous.

**Definitions of conspicuity**

Formally conspicuity is defined operationally as that sensory attribute of a visible object in its surroundings by which it is able to control sensory selection via the visual system (Engel, 1977, p.3). Cole & Jenkins (1980) define a conspicuous object as one that would for a certain background be seen with certainty within a short observation time, regardless of the location of the object in relation to the line of fixation. The visual field in which the relevant object can be discovered in its background during a brief presentation of the stimulus pattern is known as the 'conspicuity lobe'(Engel, 1977). This concept is based on the assumption that, to be detected, an inconspicuous object should be close to the fixation point, whereas a conspicuous object will be noticed even when it is presented in the far periphery. Important in Engel's definition is the control the object exerts over the visual selection system. A conspicuous object takes control over the next eye-movement saccade: it demands to be looked at.

It has been argued that a sign should be made so conspicuous as to attract attention before the driver comes within reading distance of it. Conspicuity is considered to be concerned with attracting attention to hazards when not actively searching for them or as an 'attention getting' effectiveness. Also, in order to ensure that particular other road users are noticed, measures are taken to increase their conspicuity, for example flashing lights on slow moving vehicles, road crossings and on emergency vehicles.

In order to imagine what is meant by conspicuity and the conspicuity area, you can perform the following test: first, fixate an object; then move your eyes a little bit away from the object, and try to fixate a location near the object (e.g., move your eyes in small steps to the right of the object). After a few steps, the object has disappeared in its background, that is, you moved your eyes so far into the periphery that you cannot discriminate the object from its background. When you have to move very far into the periphery before the object disappears, then the object is very conspicuous. However, if after a few steps the object has disappeared then it is an inconspicuous object. The eccentricity (the visual angle) at which an object disappears gives a measure of the conspicuity of the object. The obtained eccentricity is the radius of the conspicuity area or lobe. When, in situations of free search, an eye fixation falls within the conspicuity area of an object, it is assumed that the object attracts attention followed by an eye shift towards the object. Objects which are very conspicuous (e.g., a red traffic sign against a green background) do have very large conspicuity areas. For example, when you are driving along a road and fixate around the vanishing point, you are still capable of detecting a red sign against a green background because your point of fixation falls within the conspicuity area of the sign. It is clear from this example that, other things being equal, the conspicuity of an object is directly related to the speed at which the object can be detected.
The effect of conspicuous road elements

From a road design perspective it is important to address the role of conspicuity of road elements. As indicated above, if a sign is conspicuous and you are searching for a sign then you will be able to find the sign very fast. Yet, in many definitions of conspicuity it is assumed that people will look at conspicuous objects and events even when they have no intention to look for them. When a particular road design is inadequate and several accidents have occurred at that site (i.e., black spot) road designers will often try to improve the situation by increasing the conspicuity of the relevant sign. For example, they might add flashing lights to the sign or install a larger sign to warn the driver. The reasoning is that drivers cannot miss these signs because they are so salient.

In a set of laboratory studies the question was addressed whether people always look at the most conspicuous object (Theeuwes, 1991). In these studies, subjects had to search for a particular target (a small line segment placed in the middle of a small circle). There were 16 circles on the computer display and the line segment subjects were looking for was placed randomly in one of the 16 circles. One of the circles was very conspicuous because it was red while the others were green. The question addressed was whether people would always start searching at the most conspicuous object (i.e., the red circle). The time it took to find the target was measured. The results showed that subjects started searching randomly at any of the 16 circles, basically ignoring the conspicuous red circle. Yet, when the line segment subjects were searching for was always positioned in the only red circle, subjects were very fast at detecting it. In other words, people do not automatically look at the most conspicuous object. When it is not relevant for the task they are able to ignore it. Yet, when it is conspicuous and relevant for the task, then conspicuity helps a lot because people can find the conspicuous object very fast.

Hughes & Cole (1984) introduced the distinction between attention and search conspicuity. In their field study the conspicuity of target disks erected along an experimental route was determined under two different instructions to the subjects. One group of subjects had to report verbally "all objects or things that attracted their attention". These subjects did not know about the presence of the experimental disks. The other group of subjects received the instruction to locate and report the target disks along with all other traffic signs. The frequency of reporting the target disks was a measure of their conspicuity. For instructions given to the first group this measure was called attention conspicuity since the target disks had to attract attention in order to be noticed. For instructions given to the second group the measure was called search conspicuity, since drivers were actively searching for the target disks. As expected the hit rate for attention conspicuity was very much lower than the hit rate for search conspicuity. In line with the earlier mentioned laboratory studies (Theeuwes, 1991, 1994b), this field study shows that people do not necessarily look at (or in Hughes & Cole's study 'report') conspicuous objects when they are considered irrelevant to the task in hand. Hughes & Cole further confirmed these findings showing that eye movement patterns of driver's watching a movie displaying a road scene depended very much on the instructions given to the drivers.

In conclusion, these findings indicate that drivers do not necessarily look at the most conspicuous road elements. For many years, it has been erroneously assumed that drivers will always notice road elements so long as they are conspicuous. The findings above suggest that our eyes do not necessarily go to these conspicuous road elements. In order for conspicuous objects to be noticed
it is important that the road environment is designed in such a way that these conspicuous elements are expected and considered to be relevant for the driving task.

ROAD DESIGN AND THE ROLE OF EXPECTATIONS

As noted above drivers do not necessarily look at objects in the road environment that are conspicuous. Those events and objects that are considered to be relevant to the driving task and which are in line with on-line expectations are more likely to be perceived and acted upon. Since perceiving the road environment is the result of this interaction between sensory information, task demands and expectations of the road user, it is crucial to design a road environment that takes into account expectations and task demands of the driver. Driving is often a visually demanding task, indicating that it is typically not possible to scan exhaustively the road environment for possible clues of what the appropriate behaviour is. Drivers will therefore rely on their experience with the driving task and perceiving the road environment will very much rely on top-down expectations.

People try to structure their world. From studies investigating representations in memory of objects, it is known that people classify objects as belonging to a particular category (Rosch, 1978). Through experience, internal representations develop, which contain the typical characteristics of a category. The category to which an object belongs tells something about the characteristics of the object as well as the behaviours associated with it. Based upon this general notion that people try to structure their world, it is suggested that road users will categorize the traffic environment. It is not the individual objects, nor the individual environments that will be stored in memory but an abstract representation of the world which contains a basic set of typical properties. These prototypical representations develop through experience.

Categorization is the grouping of our experiences into categories (groups, classes, rubrics). This is done by treating different units (stimuli, objects) the same: to call them the same, to put them in the same pile, or to react in the same way to them. To categorize a stimulus means to consider it not only equivalent to other stimuli in the same category but also different from stimuli outside that category. Our categorical knowledge is organized in a hierarchical structure, containing a basic level which is the first level learned by children, the most informative and the most widely used in our language. One object is a better exemplar than the other, a phenomenon called 'goodness of example' or 'graded structure'. One can think of a hierarchical structure containing the concepts animal-bird-robin, with robin at the basic level. If we know that something is a robin, we know also that it is a bird and that it is an animal. Also, we know that it can fly and has wings (information stored at level bird) and a red breast (stored at level robin). Furthermore, a robin is a good example of a bird, while a chicken is not such a good example.

There are different categorization models, each making different assumptions regarding the representation of categories in memory and about the way we produce categorizations. Besides models which are based on rules (classical models) and similarity (exemplar and prototype models), there are also mixed models in which categorization is based on rules as well as similarity. It seems that humans use a lot of ways to categorize: besides rules, exemplars and prototypes we can also categorize on the basis of goals and theories.
Sampling information from road environment

There are some differences between categories of environments and those of objects. Environments have fewer limitations in the way attributes are arranged. For example, the attributes of a school (tables, books, chairs) can be arranged in various ways while the legs of a table can only be placed in certain locations. Also, we are part of our environments, though not of objects. On the other hand, it has been claimed that environments are perceived and categorized in a manner analogous to objects (Ward, 1977).

In many respects categorization of environments shows the same phenomena as that of simple objects. The categorization of environments also shows an hierarchical structure with a basic-level. In addition, people not only distinguish environments on the basis of physical characteristics, but also on the basis of goals to go there or the behaviours that take place in them. Finally, there are indications that a 'graded structure' is present within environmental categories; that is one environment is a better example than another for a particular category.

Rosch (1978) described two general principles for the formation of categories, cognitive economy and perceived world structure. Cognitive economy refers to the function of category systems and asserts that the task of category systems is to provide maximum information with the least cognitive effort. Perceived world structure refers to the structure of the information and asserts that the perceived world comes as structured information rather than as arbitrary or unpredictable attributes. Thus maximum information with least cognitive effort is achieved if categories map the perceived world structure as closely as possible. Applying the first principle of cognitive economy to the road environment entails that road users try to reduce the large number of roads that exist in the 'real' world to a few behaviourally and cognitively relevant road categories. It is to the road user's advantage to differentiate among road categories only when the difference is relevant. To categorize a road as belonging to a certain category implies that it is similar to all other roads within that category and different from roads outside that category. For the road environment, the perceived world structure suggests that road users see the environment consisting of a set of attributes that are highly correlated. The world does not consist of a set of attributes that are randomly picked. Thus, through experience with the road environment, road users develop a perceived world that contains attributes that are likely to occur in combination (Mazet & Dubois, 1988). Thus, if one sees a four lane freeway, one expects some road markings, an emergency lane and fast traffic that moves in the same direction.

In order to ensure unity in the way people structure and act upon their world, it is required that there be a high degree of consistency in the physical appearance of an object or environment and a high degree of consistency with respect to the behaviour required in relation to that object or environment. When these conditions are fulfilled, it can be expected that the prototypical representation of certain road environments will be more or less the same for everyone (Theeuwes, 1996, 1998; Theeuwes & Diks, 1995b). For example, Theeuwes & Diks (1995b) showed that there is a large consistency among a representative group of Dutch drivers regarding the prototype of a freeway. All people more or less agree on what a motorway in the Netherlands looks like and how to behave on such a type of road. However, there was hardly any consistency among drivers with respect to other types of roads outside the built-up area.

The prototypical representation of the road environment which is the basis for the categorization process contains 'information' regarding the typical spatial relationships between the road elements.
and road users, so called schemata and 'information' regarding the typical sequences of events in time, so called scripts or frames. Classification of a road environment activates particular scripts and further schemata which, in their turn, induce where - in place and in time - particular kinds of road user and elements can be expected. If the environment induces inappropriate expectations, errors are likely to occur.

The nature of contextual effects on the processing of road environments is thought to be the result of an interaction between incoming perceptual information and the higher level memory representations (i.e., schemata and scripts). For example, it has been demonstrated that objects that are obligatory in the schema are encoded more or less automatically (with a minimum use of processing resources), whereas objects which do not fit in, require more resource-expensive encoding processing, involving active hypothesis testing. It is suggested that scenes are processed in two stages. Holistic information is extracted first, followed by search for specific features. The holistic information can be assessed within a single fixation of the scene (Potter, 1975). This information is thought to activate the scene schema which is held in a presumed pictorial memory system. A search is then initiated for specific objects which have now been transferred to working memory.

Riemersma (1988) investigated subjective road categorization as represented in the 'heads' of Dutch road users. For the built-up area, the results indicated that the official objective criteria for road categorization, as used in the design of road environments, are only marginally present in the subjective categorization. In addition, the study showed that the estimated safe speed depended only on the effort it would require to keep the car on the road. The probability of the occurrence of an encounter with another road user (e.g., pedestrian) did not have an effect on the estimated safe speed. Outside the built-up area, Riemersma (1988) demonstrated that the emergency lane, which in the Netherlands discriminates freeways from other types of fast speed road, is not used in the subjective categorization. In addition, roads which were not freeways but which allowed a high speed were often erroneously classified as freeways (15-20%).

Mazet & Dubois (1988) claim that the categorization of road environments occurs only on the basis of the behaviour displayed in these environments. This implies that different categories of roads that generally require the same type of behaviour will subjectively be represented by the same prototype. A residential area where everybody drives at 80 km/h (although the speed limit is 50 km/h) and a city highway where the same speed is utilized will be categorized in the same way, although they look quite different. Inappropriate categorization is dangerous because the inappropriate categorization will induce inappropriate expectations.

The role of expectations in detecting road elements

Theeuwes & Hagenzieker (1993) have demonstrated the effect of contextual information on visual search in road environments. More specifically, their study explored the effect of the object-context relation 'position'. This property refers to the fact that objects which are likely to appear in a given scene often occupy specific positions in that scene. This effect of 'position' information is particularly important because this relation might be violated in every-day traffic situations. Theeuwes showed that errors occurred when road users had wrong expectations regarding the
location of particular target objects. Figure 2 gives an example of the stimulus material used in this study.

With respect to this example, subjects were instructed to search for a traffic sign and respond "yes" when they found it and "no" when they thought that no traffic sign was present. In the upper picture, the traffic sign is positioned at an expected location which gave a search time of 1.1 sec and 6% errors. In the lower picture, the traffic sign is positioned at the left side of the road which is an unexpected location given the overall lay-out of the scene. In this condition, search time was 1.7 sec and in 33% of the cases subjects thought that no traffic sign was present. Since the conspicuity of the traffic sign is exactly the same for both pictures (they are left-right reversals of each other), the difference in performance can only be attributed to the top-down search strategy induced by the lay-out of the scene.

It should be realized that the effects of contextual driven search might be much stronger in real driving, especially in conditions in which there is a relatively high visual load such as when driving in busy traffic in urban environments, or under reduced sight conditions, when driving in the dark or in twilight. In these situations, rapid resource-inexpensive and conceptually-driven feature
detection is advantageous. The study shows that objects at unexpected locations are not seen too late but, in many cases, not seen at all.

Given these considerations, it is clear that extremely dangerous situations may occur when the design of the traffic environment induces incorrect expectations regarding the spatial arrangement of objects in that scene. The importance of inducing the correct expectation is supported by studies discussed earlier showing that visual selection does not so much depend upon the conspicuity of the target objects but more on the demands of the search task (Theeuwes, 1993). It is potentially dangerous when a traffic environment induces incorrect expectations, because conspicuous signs and/or other infra-structural measures can hardly correct these expectations when they have not been perceived.

Although there is no empirical evidence regarding the time frame of these expectations, it is likely that once expectations are activated they cannot be changed easily. When initially the lay-out of a road indicates that it is a freeway, the driver may keep on interpreting the road as a freeway. Gradual changes to another type of road will lead to confusion and incorrect expectations. Consequently, the same type of road should be maintained in a section which psychologically is interpreted as one unit: for example, a road connecting two cities, or a road from a shopping to a residential area. Because people interpret a connecting road as a single psychological 'unit', it should be designed as such, that is, one type of road.

**Subjective road categorization**

A category represents a set of objects or environments which are considered to be equivalent (Rosch, 1978). In order to determine what road users consider as a road category, it is necessary to determine the perceived similarity among different road environments. Similarity data are typically analyzed by multidimensional scaling (MDS), which is a set of procedures in which the judged or otherwise assessed similarities between members of a set of stimuli are used to produce a geometrical representation of the stimuli. Similar stimuli are represented as closer to each other in geometric space, while dissimilar stimuli are represented farther apart. Road environments which are considered to be close in geometric space can be considered as being part of the same road category while road environments which are far apart are thought to belong to different road categories.

Theeuwes & Diks (1995b) used this MDS technique to determine the similarity among road environments outside built-up areas. Participants sorted into piles pictures of the various existing road environments. Instructions were to put pictures of environments which they thought were similar in the same pile and pictures they thought were different in different piles. Participants sorted pictures of existing roads outside built-up areas with respect to the behaviour they would show and expect on these roads. These roads belonged to one of the four 'official' main road categories outside built-up areas in the Netherlands. If the official categorization is clear and self-evident, it was expected that participants would have been able to sort the pictures in coherence with the four official categories. If, however, there is not enough clarity and homogeneity in the official categories and not enough diversity between the official categories, one would expect that the subjective categories might be different from the official ones.
Figure 3 shows the results of this study. The four official categories are given at the bottom of the figure. The results are based on a two dimensional solution of the MDS analysis based on the similarity matrix of the roads. The boundaries around the data points are based on a subsequent cluster analysis. As is clear from this figure, the freeways ('A' roads indicated by open circles) all seem to cluster together quite well suggesting that people thought that these roads were quite alike. In fact, it suggests that there is a coherence between the official road categorization and the way people categorize them. However, as is clear from the figure, other official clusters of roads (B, C and D roads) do not cluster together. For example, road types B and C were classified in four different clusters. Road type D is clustered basically in two groups: roads D1 to D4, all clustering together, are small rural roads without a center lane marking, while roads D5 to D8 are roads with a center lane marking. Note that officially these roads belong to the same category.

![Figure 3. Two-dimensional solution of MDS analysis regarding subjective road categorization. The results of the cluster analysis are represented by group boundaries.](image)

This study demonstrates that the subjective categorization (the way people categorize the roads in their 'heads') does not match the official road categorization. It supports the idea that road behaviour is related to the appearance of the road and that road characteristics and traffic behaviour are cognitively integrated by drivers into subjective categories. In addition, the results indicate that the four 'official' categories used as stimuli are only partially reproduced in the subjective categorization. The fact that the 'official' categories which do not correspond well with the subjective categories are those road categories with the highest rate of accidents suggests the importance of correct interpretation of road design. If too many accidents occur on a road, putting
up a traffic sign with a lower speed limit will not have any effect as long as the road itself is not changed. If, on a particular road, everyone is driving too fast, this is probably caused by the road design, that is the road looks like a road where you can drive fast. If this speed is undesirable, because cyclists have to cross or because of the presence of slow traffic, putting up warning signs will probably not show the desired effect, because those signs will have a low credibility as long as the road appearance remains the same. Only by changing the road design so that the design corresponds to the subjective categorization are the correct expectations and behaviours likely to be elicited.

**DESIGN RULES FOR AN OPTIMAL ROAD DESIGN**

Studies investigating errors occurring in actual traffic show that expectations do play a crucial role in the occurrence of accidents. As noted earlier there is evidence that a large proportion of accidents are the result of inappropriate expectations or interpretations of the environment (e.g., Malaterre, 1986). Note that for any given driver, collisions are rare, indicating that errors during driving may not be fed back to the driver. On the other hand, correct expectancies, that is finding an object where you expected it, are consistently reinforced because the traffic environment is reasonably predictable.

Because expectations play such an important role it is crucial that the design of roads is adjusted to these expectations. Purely by their design, roads should elicit safe behaviour. By taking into account the constraints and the limitations of the driver (all drivers including the elderly), road design can reduce the number of errors occurring in traffic (Theeuwes & Godthelp, 1995a).

The type of roads which elicit safe behaviour by their design are recently classified as Self-Explaining Roads (SER) (Theeuwes & Godthelp, 1992). In the Netherlands, the design of freeways and *wooners* are to some extent self-explaining and inherently safe. On the other hand, a very large proportion of Dutch roads - for example the 80 km/h rural roads - are not designed according to the safety principles mentioned above. These type of roads are not easily classified because they do not have any prototypical recognizable properties, nor do they compel the traffic behaviour required on these roads. For example:

- the probability of the occurrence of slow traffic cannot be inferred from the road design;
- the probability of the occurrence of oncoming traffic is often unclear;
- the location and the presence of crossings and exits of driveways is not well marked;
- the estimation of the location and the required speed of curves is often difficult and inaccurate.

Figure 4 and 5 give some examples of the classification problems raised above (see also Chapter 5).

The use of consistent and easily understandable codes can to some extent reduce these problems. The design of roads should reflect the probability of encountering particular types of road user. Along the same lines is the concept of 'Positive-Guidance' as developed by Alexander & Lunefeld (1986). This suggests that the traffic situation should be in line with the expectations of the road users.

In addition to the development of a road which is self-explaining, is the development of a modern
traffic control system which can add some 'intelligence' to the road environment. For example, navigation systems in the car with variable directional signs along the road can guide traffic, can reduce uncertainty in finding the optimal route, and can remove instabilities (e.g., traffic jams) in the traffic flow. Variable speed advice dependent on the local circumstances (intensity, rain, fog) can optimize the traffic flow.

Figure 4. The probability of the occurrence of slow traffic cannot be inferred from the road design: Should you expect bicyclists on this road? (The answer is "yes")

Figure 5. The probability of the occurrence of oncoming traffic is often unclear: Should you expect oncoming traffic? (The answer is "yes")
On theoretical grounds we have identified some criteria which will increase the self-explaining character of roads. When developing the 'road of the future' one should start with a few easily recognizable and distinguishable road categories. Four categories can be distinguished: freeways, highways connecting larger regions, rural and urban roads, including those connecting residential and shopping areas, and *woonerfs*, that is residential roads going from door to door. For these four categories, self-explaining roads should fulfill the following tentative criteria:

- unique road elements (homogeneous within one category and different from all other categories);
- unique behaviour for a specific category (homogeneous within one category and different from all other categories);
- unique behaviour should be linked to unique road elements (e.g., *woonerfs*: obstacles - slow driving; freeway: unobstructed roadway - fast driving);
- the lay-out of crossings, road sections and curves should be linked uniquely with the particular road category (e.g., a crossing on a highway should physically and behaviourally be completely different from crossing on a rural road);
- one should choose road categories which are behaviourally relevant;
- the same road category should connect a section which psychologically is interpreted as a single unit (e.g., a road connecting two cities);
- there should be no fast transitions going from one road category to the next;
- when there is a transition in road category, the change should be marked clearly (e.g., rumble strips, gateways);
- when teaching the different road categories, one should not only teach the name but also the behaviour required for that type of road;
- category-defining properties should be visible at night;
- the road design should induce speed conformity and make explicit the direction of traffic movement;
- road elements, marking and signing should fulfil the standard visibility criteria;
- traffic control systems should be uniquely linked to specific categories (e.g., on freeways, systems that regulate traffic flow and on rural road, systems that restrict driving speed).

**RECOMMENDED READING**

Once upon a time, an astronomer, a physicist and a mathematician were on vacation together in Scotland. Looking through the window of the train, they saw a black sheep in the middle of a field. "How interesting - the astronomer observed, in Scotland the sheep are black!" And the physicist responded: "No, they're not! Only some Scottish sheep are black!" The mathematician looked beseechingly at the sky and then stated: "In Scotland, there is at least one field with at least one sheep with at least one black side" (Ian Stewart). But the story doesn't end here, because the psychologist who analysed the story commented to his colleague: "Excellent example of perceptual illusion and conceptual error! The sheep was probably white; but the expansion effect of the darkness of the colours of the field and the speed of image perception made these observers believe the sheep was black. In fact, it is very probable that all Scottish sheep are white."

The explanation of human behaviour is often multifactorial from the point of view of a psychologist. The habit of thinking in terms of multiple causation that explains, in the best of cases, 40-60% of the variance, convinces us of the necessity of looking for more and more complex explanations for simple phenomena: 'the perceptual illusion of the black sheep'. The explanation of human error in traffic and transport as a whole is multifactorial, because there are many factors that can explain the appearance of one error or another. But very frequently, the concrete human error or errors causing a certain accident have an immediate detectable cause, which could have been avoided. The difficulty is related to predicting and preventing the appearance of human error, for a specific operator, time and situation.

Another lesson derived from the adapted fable of the sheep is that some analysts tend to
convert the explanation of the complex exception into an explanation of the norm: 'all Scottish sheep, either white or black'. Possibly, this difficulty has its origin in reflections similar to this one: "The position of a scientist trying to understand traffic safety has more in common with that of an astronomer than with that of a... physical or biological scientist. The traffic safety scientist must try to devise ways to extract information from a system that is to a large extent given" (Evans, 1991,11). This attitude is not always very practical in solving real problems. In fact, it is as if a cancer researcher considered the study of the patients diagnosed with this illness as the only way to obtain information. In this sense, the exclusive study of the human error that causes an accident is indispensable, but it is also reductionist.

The first two reflections and/or suggestions in this chapter are oriented toward considering that knowledge about human error, in order to facilitate its prevention, requires the empirical study of each environment (such as simulation, Traffic Conflict Techniques (Hyden, 1987) or crash-events analysis). For example, a broad study carried out on a Spanish freeway included a detailed analysis of the behaviour of the drivers (Carbonell et al., 1995). We found that on two different stretches, with hardly any curves, similar types of rear-end crashes took place, both seemingly due to attentional errors. The sample of accidents was very small and this explanation was generally unsatisfactory. We decided to observe the global behaviour of the drivers and the conflict situations in those areas. We asked the drivers, among other things, about their reasons for, duration of and distance of displacements. We also analysed their driving activities, especially their visual scanning habits. The results were quite clear: in general terms, on one of the stretches (A), a very large number of the drivers had spent several hours driving on the freeway. Their driving norm was assimilated in many cases to that of 'automatic pilot', or they frequently carried out alternative tasks, dedicating little time to visual scanning. The other stretch (B) had a large proportion of 'brief users' of the freeway who abandoned it in one or two exits. These users maintained their vision very fixed on the right sector of the roadway (looking for and going toward the exit), and they were surprised when a vehicle suddenly appeared too close in front of them, (another brief user who didn't want to miss the exit).

Two conclusions serve as a preface: if we had studied only the accidents (exceptions) and not the complete situation (conflicts), including the attentional, motor and motivational behaviour of the drivers (situational expression of the error), appropriate preventive measures would have been difficult to devise. Unfortunately, this brief chapter will only be able to contribute heuristics toward facilitating that preventive work. But the ideas contributed can serve to complement the meticulous analyses that have been carried out in other chapters of this book on more specific aspects.

THE BASIC AGREEMENT ON WHAT ERROR IS AND IS NOT IN TRAFFIC BEHAVIOUR

The definition of the concept of human error has been the object of controversy, and in its application to traffic psychology has been used in diverse senses (McKenna, 1988). In a generic sense, the problem seems to reside in finding the more appropriate approach or
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approaches to defining the concept.

Individual approach vs external approach (self referred vs externally referred errors)

Some definitions have accentuated the 'individual criteria' of the human subject who commits the error. So, for example, the classic definition by Rasmussen et al. (1987), that error is an "act that is counterproductive with respect to the person's intentions or goals", approaches the most recent by Reason (1990): "planned actions that fail to achieve their desired consequences without the intervention of some chance or unforeseeable agency". Other authors have preferred to look for an external approach, more or less normative, more or less definitive; this is the generalist case of Mashour's (1974) "deviation of current performance from the desired performance or criterion", the strictest one by Barkan et al. (1998): "failure to detect an unsafe state", or the most systemic and interactive by Nicolet (1987): "behaviour, or its effects, which lead a system to exceed acceptable limits".

Seemingly, both individual and external orientations are contradictory and irreconcilable. It doesn't seem possible to gather, under the same concept, intentions and failed individual plans (self-referred errors) and the limits and requirements of the system (externally referred errors). However, in traffic situations both elements are present. Specialists in traffic know that the work in this field often involves considering a maximisation of benefits, very often defined for individual options (such as mobility, exchange of goods, etc.) and at the same time a minimisation of costs, very dependent on the so-called 'common good' (such as risk, ecological impact, etc.). Whereas, in the past, each specialist's historical background supported a special dedication to one of these two approaches, the current situation requires a more holistic approach to the problem of traffic. In fact, remarkable examples of solutions already exist (Carsten, 1998 and see Chapter 2) such as the mini-roundabout that reduces driving tasks, thus increasing safety (reduction in injury accidents of 30 to 40%), and at the same time increasing traffic capacity (saturation capacity increase of 27%). Furthermore, it seems just as valid to consider as human error navigational mistakes made by a driver when selecting an exit on the highway that takes him away from his destination (system design error leading to failure to perceive the sign), as that of the driver who reaches an area of highway construction without realising it, and is forced to reduce the speed of his vehicle abruptly (individual attentional error leading to failure to perceive the sign). The relevant difference between these two approaches, from the psychological point of view, is that people tend to accept the self-referred errors as their own more easily than the externally-referred errors.

The premeditation approach

Another criterial perspective is the one that has focused on the degree of intentionality or deliberateness of the act. Premeditation has been a definitive criterion of violation, compared to the error that is generally considered non-intentional. This distinction has been fruitful in the last decade and includes the consideration of a different delimitation of the psychological origin of both types of behaviours: the processing of information in the case of errors, and social and motivational factors in the case of violations.
This distinction has been useful in renewing attention to 'low level' performance (Van Winsum, 1996; Groeger and Clegg, 1997), particularly related to processes like attention or perception and, in general, to perceptual-motor skills and operational performance. The attentional and perceptual errors are some of those most studied and those making the most enlightening contributions.

Nevertheless, premeditation doesn't allow us to distinguish clearly between errors and violations. In fact, they are not such different concepts. At the same time, both unintended and intended deviations from normative, reference behaviour can be interrelated events. Two examples regarding speed can clarify this paradox. In the first case (norm transgression by mistake), the driver, after several hours of driving on a freeway (even if he respects the speed limits during this time), passes immediately to a local highway or an urban area. This driver has to make acute and intentional efforts to adjust his speed to the normative limits of the new situation. However, the inflexibility of behaviour can lead him to making the error of a non-intentional violation. The second case (interrelated events) is even more evident. The driver who deliberately transgresses the speed limits on a freeway directly increases the probability of committing errors (depending on his level of capability), and therefore of experiencing a situation of serious conflict or accident.

Premeditation means responsibility, in fact, and non-premeditation tends to be interpreted as absence of responsibility. It is typical to see the driver arguing with the traffic officer that he didn't mean to run a red light, as a reason for exoneration: "I didn't want to, but it happened". This is exactly the psychological conclusion people draw when they make an error.

Psychologists have taken the idea of confusing volition with motivation quite far, and they affirm that errors have their sole origin in information processing. As psychology has demonstrated systematically and clearly for decades, the consequences of behaviour are some of the most powerful motivational agents in its formation, consolidation and change. This is also valid for traffic, as much for adapted behaviours as for errors (see Chapter 4).

The relevance approach for the prevention of accidents

The Error vs Violation distinction has often been accompanied by an evaluation of their relative contributions to danger. This has generally been estimated based on the accident probability associated with each of the two types of aberrant behaviour. In general, violations and errors are obtained through self-reports and questionnaires (as orthogonal factors produced by factor analysis), and their degree of danger is estimated through regression analysis. These types of studies conclude by drastically stating that errors are not very relevant in the prediction of the accident or conflict situation.

Some reviews have questioned methodological aspects of this type of approach (Maycock, 1997). Independently of these doubts, laboratory investigations and on-road studies also question this conclusion, both concerning the operational level of performance (Groeger, 1989; Van Winsum, 1996), as well as the tactical level of risk estimation and decision making.
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(Kruysse, 1992; Barkan et al., 1998). Risk is not an intrinsic characteristic of error nor is it of violation. The novice driver, who, after taking too much time to interpret a warning sign, tries to brake and forgets to change foot pedals, causing the vehicle to accelerate, makes a high risk error if he is too near the vehicle in front of him and moving at such a speed that a conflict or an accident occurs. To drive without a seat belt when it is obligatory is a clear violation, but it is only a risk if an accident occurs or the driver should brake abruptly. To err in detecting risk in a dangerous situation is as serious and dangerous as exceeding the speed limits in a residential area.

Thus, errors regarding risk exist, and may give rise to conflict or accident. But the most frequent situation is that errors happen without immediate safety consequences, in the same way that it is very normal to commit violations without consequences. For this reason, it has been said that the road system is forgiving (Groeger, 1989; Fuller, 1992), and that accidents are relatively rare events controlled by chance as much as by systemic factors (Hyden, 1987; Kruysse, 1992). The study of error in the prevention of accidents however, seems as necessary as the study of other factors, both from the point of view of the behaviour of road users and the improvement of the operation of the system as a whole.

**Interaction in the Determination of Error**

The analysis of error from the perspective of the system as a whole presents a series of advantages compared to the study of the driver, or other elements, in isolation. The global perspective encompasses or contains the other. It implies the consideration of the road system as an integral whole in which the accident will happen as an outcome of locating oneself beyond the limit of the system's possibilities. The driver's errors can be a case where the driver takes the possibilities of the system to the limit or the system makes demands beyond his own limits. In both situations, we are faced with an error having dangerous consequences.

Let us continue with this point by introducing the expert reflection of a venerable engineer. Some time ago, he commented with colleagues of diverse specialities on their ways of conceptualising certain situations. He gave an example to the youngest members of the group in the following way: "We have a magnificent roundabout, of a lovely design, in which there have been three accidents of diverse degrees of graveness during the past weekend. The cause, the abuse of alcohol of some young drivers. How should I interpret this fact? Who should analyse and/or solve the problem?". The engineers, in particular, looked briefly at each other, but then went on to exchange insinuating glances with the psychologists, sociologists and even someone from traffic administration standing nearby. But nobody was prepared to respond. Severely, the venerable engineer looked at all of them and remonstrated thus: "Foolish engineers! You are only seeing a part of the problem. Indeed the young driver that is excessive in his alcohol consumption is a syndrome that our society should deal with, but these accidents are also a symptom: we have not built a roundabout for drunk drivers". We are sure that it's not necessary to build roundabouts for drunk drivers, but the venerable engineer's point of view is useful to us for introducing some insights concerning the detection of error.

There are studies which present the idea that errors and failures in a system cannot be
attributed (from a scientific point of view) to any one element because error is an intrinsic component of the system that will always exist. In this sense, Reason (1994) makes a statement proposing the existence, intrinsic to all systems including the road system, of what he calls resident pathogens, which create the conditions that give rise to failures. Wagenaar and Reason (1990) state that the events that are potential precursors of accidents (among them the erroneous behaviours of the drivers) are only haphazard tokens of the permanent weaknesses within a system. In other words, every context of traffic defined as a system (the venerable engineer's roundabout with the drivers operating their vehicles in it) has some maximum and minimum tolerance limits. Human error can take place: (a) within tolerance limits, a case that happens frequently, and here we will say that the traffic system is forgiving; (b) near the limits of the system, something less frequently, and where we will be faced with more or less serious conflicts; or (c) beyond the limits of the system, when an accident will occur.

If the interaction is clear up to this point, the question is whether we should worry about the human errors that result in accidents, or should we look for the symptoms or precursors of error. Indeed, is it even possible to detect reliably the precursors of human error?

Regarding the first question, Reason (1990) distinguishes between Active Failures and Latent Failures. He defines Active Failures as the errors the driver commits directly in his interaction with the system, of which he forms a part, and whose effects are felt almost immediately. Latent Failures are the negative products or results of strategic decisions made in the organisational and directive spheres of the system. They may remain inactive (latent) for a long time, revealing their presence when they are combined with active failures, creating a potentially conflicting or dangerous situation and increasing the risk of an accident. Latent failures create situations conducive to error, thus increasing the probability of their occurrence. In addition, they can also have the effect of exacerbating the consequences of the error, due to weaknesses or 'cracks' in the system itself. A typical situation involving Latent Failure on a freeway would be the repair or maintenance work zones or an accident, even when they are properly signalled. The presence of an obstacle on the freeway is contrary to the driver's expectation; it is an unexpected and unpredictable situation that requires detection, interpretation, decision-making and changes in execution.

We agree with Reason on the necessity of defining as latent the possibility of the appearance of errors, and with Kruysse (1992) when he states that the explanation for active failures can be found in latent failures (the former are a consequence of the latter), and that therefore the most effective strategies for preventing accidents are those which concentrate on the analysis of latent failures. However, we should add that the occurrence of human errors without immediate safety consequences can be the best symptom for the detection of latent failures, and consequently of active failure in the sense expressed by Reason.

The second question we raised is how to detect these symptoms. As a starting point, we know that errors and their occurrence, involving risk or without it, are more systematic than they may seem. Considering only some elements of the system, we can approach error detection from different perspectives (Fuller, 1990): design, operator and process.

The first two are partial approaches, but they can contribute relevant information.
makes it possible to define the tolerance limits that we can allow, and by default, the non-
acceptable uses of the system. The analysis of the operator allows us, as we will see in the next
section of this chapter, to identify error prototypes that can occur in a wide range of different
situations. These errors, committed by the operator, can have their origins in information
processing or in motivational factors, or be due to transitory states of the subject produced by
the consumption of alcohol, fatigue, sleep, stress, etc. (in this regard, see Chapter 6).

However, not all error and information types are present in each and every concrete context.
Instead, human error is the result of the interaction or transaction between the demands of the
system and what the operator does (Fuller, 1990), or in other terms, the result of the process. In
a practical sense, to detect process errors implies putting the emphasis on the study of the
person-situation interaction. The prototype of interactive studies at this time are the Traffic
Conflict Techniques (Hyden, 1987). Some examples can be presented of how these techniques
operate at two distinct levels of analysis: problems / errors that we can find in a specific
situation, and the definition of problems / errors more common to a generalised situation.

Specific studies are published with little frequency, but excellent examples exist (see Bastos
and Seco, 1997; Summala et al., 1996). The authors of the first study investigated roundabouts
(priority given to those already on them) with a configuration in the form of a cross, for
isolated light vehicles that choose the exit straight ahead from the entrance. They considered
the driver's behaviour in relation to speed, path choice and trajectory, dividing the movement
into three areas (approach and entrance, contour and exit). It was found that drivers tend to take
the easiest, straighter trajectory rather than follow the contoured path, and that the critical
decision point was near the transition between the first and second zones (Bastos and Seco,
1997). Thus errors are defined by this use of the system: errors in the selection of the trajectory
due to speed and resulting difficulties in the control of the vehicle; trajectory in conflict with
other vehicles and resulting abrupt manoeuvres and so forth.

The study by Summala et al. (1996) arose from an analysis of accidents and previous conflicts
at unmarked crossings in which the driver crosses a cycle path. At these intersections, the point
of greatest conflict occurs where the cyclist approaches from the right, and the driver turns
towards the right. The behavioural analysis detected that most of the time the driver's visual
scanning is concentrated on the search for the biggest and most frequent danger (focusing on
the vehicles that approach from the left), leading to reduced attention to the smallest and
habitually less frequent danger, such as a cyclist approaching from the right.

In summary, the attempts to detect process errors consist basically of confronting the way the
system is made and the way the operator uses it. The objective is to find the dysfunction in that
transaction.
ERROR TYPOLOGY OR GIVING NAMES TO THE ERRORS

In the first section of this chapter, we have considered the main characteristics of human error in traffic behaviour, the need for their study, detection and prevention; in the second, we have suggested ways to access their detection. This is a good moment to stop and give names to human errors. A more extensive review of the typologies of human error in driving can be found in Carbonell et al., 1997.

These error typologies try to refer the error to the cognitive-behavioural functioning of the person who commits the act, rather than the act itself or its consequences. These classifications have proliferated, and it may be of interest to recognise their basic elements.

In the first place, an information processing model was established to classify human errors into three large typologies, according to the general level of information processing at which these errors occurred: input errors, mediation errors and output errors, and eight basic groups were established: (1) error of perception, not perceiving a signal; (2) error in decoding, misunderstanding a signal; (3) error in mental representation, wrong ideas; (4) not respecting a procedure or rule, wrong attitude; (5) error in person to person communication; (6) delay in decision-making; (7) error in the selection of an action; (8) error in the scale of effort/intensity of the action. Error types (1) and (2) are input errors, (3), (4), (5) and (6) mediation errors, and (7) and (8) output errors. This is a convenient, although very elementary and not very representative, classification of traffic situations.

One of the most widely used classifications has been the outcome of the development of a theoretical conceptual framework, the Generic Error Modelling System (GEMS) (Reason, 1987), which was derived from the classification of levels of performance introduced by Rasmussen (Skills, Rules and Knowledge Model). This in turn was based on ideas about cognitive control in carrying out tasks. A distinction between controlled and automatic processing gave rise to the concept of the division of human activity structured hierarchically into three levels of cognitive processing: an automatic level (skills), a semi-automatic/semi-controlled level (rules) and a controlled level (knowledge). In accordance with this division, the classification of errors was presented in similar terms: skill-based errors (slips and lapses), rule-based errors (rule-based mistakes) and knowledge-based errors (knowledge-based mistakes).

Skill-based errors are caused by "actions not developing as planned": a satisfactory plan resulting in an undesired action. The plan of action is correct, but the action itself is not. Skill-based errors can occur, for example, because of the erroneous application of automatic routines, due for example to a lack of focused attention and generally relate to abilities at the perception-motor level. Therefore, they take place at a lower level than that of conscious information processing. There is hardly any conscious control of the action, and there may be slips (having to do with execution) and lapses (having to do with attention).

A characteristic of this type of error (perceptual-motor) is that it is based on automated action. However, some recent investigations question the idea that these errors necessarily arise as a direct outcome of an erroneous application of an automated routine. This type of error may be
Insights on how to work with human error

linked more to a reduction in the efficiency of task performance due to overload (see Chapter 11) or to an allocation of resources to other tasks. This phenomenon is very evident in attentional errors.

Rule-based errors (or errors arising from applying the wrong set of rules) occur as a result of applying stored rules at a semi-automatic/semi-conscious level erroneously or incorrectly in the execution or the solution of a problem in familiar situations. They give rise to concrete plans of action which are in themselves erroneous (for the specific situation in question) and which produce mistakes based on rules which are usually of an if-then structure. A characteristic example is the analysis that Jorgensen carries out (1988) relative to the crossroad regulated by traffic lights. This author describes very illustrative dilemma situations of rule based-errors. For example, consider the dilemma which arises at the moment of the traffic light changing from green to amber, when the driver is at such a distance and maintains such a speed that he can choose to continue or to stop. A driver might apply a rule of maximisation of safety and brake, but then be involved in a rear-end crash because the driver behind him didn't choose the same rule.

Research by Hale et al. (1988), underlines the importance of these two error levels, skill- and rule-based, and even more so, the continuous change from one level to another level that occurs in the driving process. They conclude that one of the critical points giving rise to conflicts or accidents are deficiencies in the transition from the Skill-based level to the Rules-based level.

Knowledge-based errors (errors based on wrong hypotheses without specific rules and based on knowledge about the system) take place at higher levels of information processing, and at a level of conscious performance. For example a driver seeks to abandon a freeway at a certain point, and as he believes he still has some kilometres to go, he begins the manoeuvres which will place him in a satisfactory position once he has exited the freeway. First, he overtakes two long-vehicles in front of him, anticipating that if they take the same exit he does, it will be more difficult to overtake them later. When he is finishing the process of overtaking the second vehicle, he discovers that the exit is very near. He must then choose between the possibility of making an error which affects his mobility (completing the manoeuvre correctly, but with a risk of missing the exit) or another which affects his safety (completing the process of overtaking abruptly and trying to leave the freeway without being involved in a collision with the second vehicle or negotiating the exit ramp at too high a speed).

These three basic types of error have their corresponding subtypes that can be consulted in diverse works (for more information see Reason, 1990).

How Human Errors Can be Prevented

Up to this point, we have concluded that human errors are part of the system and can be detected just as well when they take place actively (accidents, conflicts, forgiven errors...) as when they are in a latent state (analysis of conflicts, analysis of operator behaviour, unchaining psychological factors...). The problem we consider now is how to prevent them.
The first question we can ask ourselves is why a person (the operator) doesn't make more effort to prevent errors. The answer is not simple. In fact, empirical tests exist that demonstrate that drivers, at least many of them, make real, intense and intentional efforts to prevent errors. On the other hand, for the operator it is difficult to prevent something that he frequently doesn't detect.

People try to carry out self-monitoring and, therefore, preventive behaviours when they realize their tendency to make certain errors. This has been verified in studies of error in daily life, but it has also been observed in specific analyses of traffic behaviour. A good example was provided by Godthelp (1988) in his work centering on the limits of path error-neglecting in straight lane driving. This empirical study demonstrates that drivers tend to increase the distance to the near-side line limit of the road as a function of increase of speed. Godthelp interprets this behaviour as a transition from a system of 'ignoring errors' to a system of 'correction of errors'. In a generic sense, this can be an adaptive behaviour (of prevention) when we drive, for example, on a highway. However, when the driver is on a road with a lane in each direction, he tends to approach the near-side. In this case, it seems that the objective includes avoiding the consequences of the errors of other drivers.

In general, the adaptation models have provided excellent examples of preventive behaviour, and they point out self-monitoring as the main mechanism for the prevention of errors. For example, Van Winsum (1996), in an investigation of steering behaviour when driving on curves, highlighted that direction errors in this context are related to the turn angle required by the curve and the driver's ability to execute the manoeuvre; the turn angle is determined by the radius of the curve and the speed of the vehicle. When the driver approaches a curve, an 'anticipatory adjustment' takes place, so that the less expert driver tends to choose lower speeds and the more expert driver, higher ones.

In conclusion, we may observe that the 'top-down', tactical level (decisional) of control of one's behaviour in traffic defines limits which affect the operational level, as much in the example of straight line driving as in curve driving. This mechanism makes it possible to 'catch errors in the act' or to anticipate their appearance. Nevertheless, the difference between the plan of action and the action actually executed is not always so evident and therefore self-monitoring fails to detect and correct the errors. Also, force of habit can be so strong as to lead one to select incorrect plans of action for the specific context. Force of habit has an equal effect on intentional behaviours and not so intentional behaviours, such as the selection of relevant information, the evaluation of risk, and some low risk decisions on the highway (Carbonell, 1994).

Absence of familiarity with the task (e.g., driving on a highway) and incorrectly attributing the consequences of one's own actions can collaborate in the non-detection and therefore lack of correction or prevention of errors. Not long ago, a driver travelled 35km at night and in the wrong direction on a Spanish highway. When he was stopped by the police, the driver was astonished. It was the first time he had driven on that highway; in fact he hardly ever used highways. The whole time that he was driving he was very cautious (moderate speed, very near the line on the right...). He said he was bothered by some of the behaviours of other drivers.
who sounded their horns and flashed their lights. Our driver believed that it was some type of polemic among other drivers, who were probably imprudent and hurried. Luckily, the low density of traffic at that hour and the know-how of those who crossed paths with this 'appropriately misled' driver, avoided serious consequences of his behaviour.

How we can make it possible for the operator of the system to detect and prevent more errors than those he is prepared to detect and prevent is the second question in this section. The answer to this forces us to consider what is making the errors persevere and remain undetected by the driver. As Fuller has stressed (1990), it is possible to learn from one's own errors, but it is also possible to learn to make them. The control of antecedent stimuli and the consequences of behaviour are found at all levels of the system, according to Fuller (see Chapter 4). The reinforcing consequences of erroneous behaviours, such as driving at a high speed, which the road setting generally provides in a 'natural' way (for this reason we call it 'forgiving'), form and maintain erroneous behaviours, thus being called 'consequence traps' by this author. These traps occur as a result of learning contingencies (between antecedent - and consequent stimuli) which lead to the formation and maintenance of the erroneous and risky behaviours of drivers. If we want to prevent human errors we need to intervene in the antecedents and consequences of the erroneous behaviour (Fuller, 1990; 1992; 1994).

Highway engineers have worked on both antecedent stimuli and consequences in the form of real and apparent potential hazards, for example controlling drivers by using techniques of 'traffic calming' measures, such as introducing a road hump which punishes the driver if his speed exceeds a band of critical values. Punishment is in the form of discomfort to vehicle occupants or damage to the vehicle itself. Nevertheless, it becomes necessary to delve deeper in both of these directions in order to prevent human error.

The study of human error has shown that people detect 47% of their errors through the consequences or results of their actions. The implied psychological mechanism is the mismatch between expected outcomes and actual outcomes. In other words, the behaviours cause effects that violate the expectations on a perceptual level (the driver thinks: "this should not be here"), conceptual level ("this should not happen") or intentional level ("this is not what I wanted to do"). This principle can be applied to traffic behaviour, through immediate and specific information on one's own behaviour (Rothengatter, 1997), provided by in-car or on-road systems.

In an excellent study, Kuiken (1994) shows the benefits of intrinsic feedback, that is, that which is discharged in a natural and immediate way, as a criterial function of the execution of the task. In contrast, delayed feedback, and even the verbal warnings that anticipate the repetition of the situation in which the error was previously made, are not as effective. This analysis is valid for behaviours as diverse as the erroneous exceeding of the speed limit, the appropriate speed on a curve, and maintaining driving inside the limits of the highway. Other more recent works have also pointed out the effectiveness of direct tactile feedback (in which for example the pedal presses on the foot on the accelerator) on the errors regarding observance of the speed limit. Feedback should take place in an immediate way after the behaviour, so that the human operator can observe the link between both events; the effect will
become more efficient, as the inter-situational consistency between the behaviour and the feedback increases: a limited number of experiences is not enough to produce an adapted habit.

On the other side of this process, antecedent events, which reliably signal the relationship between a particular behaviour and its consequences, will provide the required stimulus conditions for the activation of the behaviour. Examples of antecedent or discriminative stimuli are numerous. This is a category that includes a wide range of elements like hazard warning signs, restricted sight distance (curves instead of long, straight stretches), lane narrowing (real or illusory), lateral lane shift, road edge and centre markings, hatched road markings, rumble strips and areas, dynamic signs, regulated and advisory maximum speed, light controlled intersections and pedestrian crossings, mandatory 'stop' and 'yield' signs, and so on (see Fuller, 1994). For a discriminative stimulus to be effective, it needs to be clear and unambiguous, consistent, reliable (Fuller, 1997), and of course, highly perceptible and explicit in its objective.

SOME FINAL COMMENTS

This chapter has attempted to sketch a conceptual framework which provides a functional explanation of the mechanisms through which errors occur and, therefore, of the mechanisms through which they can be recovered. These mechanisms form the basis of the means of intervention for safety. Errors occur at all levels of the system, and it would be desirable to modify contingencies in such a way that road-user behaviours were safe in relation to the demands the system imposes in each situation.

Nevertheless, as we have pointed out elsewhere, all our prevention efforts have to continuously face mutations in drivers' behaviours, due to two tenacious processes and with effects which are often undesirable for safety: the first one, much discussed in this chapter, the forgiving character of the system that consolidates all kinds of behaviours into drivers' goals, including their errors; and the second, the driver's natural adaptation process to new situations and technologies that imply at least an initial period of increase in errors and therefore risk.

Moral: we will continue to study more than one sheep, in more than one field to know enough about the Scottish sheep and to be able to predict their colour. Moreover, the psychologist in the story was probably right, because when we have studied and predicted enough about the colour of the sheep, it is possible that they will change colour and we will be faced with new types of ... error.
RECOMMENDED READING


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Mental Workload

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Introduction

When mental workload is mentioned, most people are likely to think of difficult tasks, or conditions in which many tasks have to be performed simultaneously, or conditions in which tasks have to be performed in a limited time. There is nothing wrong with these assumptions, in particular the word difficulty reflects mental workload very well. There are, however, other factors affecting mental workload than just increased task demands alone. The capabilities of the task-performer, the operator, also play a major role.

The difficult task situation is one of the extreme conditions in mental workload. When the task at hand is very demanding and undermining performance task demands are too high. However, before this stage is reached, people can actively try to cope with the increased demands and, so to say, 'protect' performance by investing more effort in it. In this condition people "try harder". Another extreme condition is when task demands are low, for example in monotonous tasks. In this condition the operator's state can easily become sub-optimal for the task, as it provides inadequate stimulation. Fortunately in this condition also, people can actively counteract their state for some time by investing effort. This type of effort compensation is called state-related effort or compensatory effort. Effort compensation in conditions of high task demand is called task-related effort or computational effort (Mulder, 1986). In both conditions of effort compensation, mental workload is high compared with normal, optimal task performance. It is worth remarking that from the level of task performance alone, these different conditions cannot be distinguished from each other.
How common these task situations are can be illustrated by looking at the driver of a car on a long journey. Suppose the driver, a woman, lives in a big city in Austria and is headed for a large city in Italy. At the start of the journey task demands will be high, as in the city there is a lot of traffic. However, being familiar with her home town, she knows where extra attention is required, facilitating the task. Soon she will reach the motorway, as most long distances are most easily covered by taking the motorway. Provided that traffic density is not extremely high, motorway driving is a relatively simple task in a monotonous environment. Nevertheless, attention is still required as car driving is not as yet automated and, in order not to drive off the road, corrective steering wheel movements have to be performed continuously. When she finally arrives at her destination, a journey through busy city traffic is again required. This time she is not familiar with the city and the roads may look unfamiliar. At the same time she may be required to look for directions and search for signs leading her to her destination. Both during the long journey, and at the start and end mental workload is high. The causes are different however. During city driving a lot of information has to be processed, while during the low-stimulus monitoring task the driver's state may easily become sub-optimal. However, in both conditions active effort investment can counteract detrimental effects and protect performance. Effort investment is one of the key concepts in mental workload research.

In all tasks and accordingly in car driving also, mental workload is determined by the interaction between the state or capability of the driver and the task itself. As in the above example, there are periods in driving where multiple tasks increase demand, for example when a task is added, such as having to use a route navigation device. Mental workload is in general increased as a result of such added tasks. There are also conditions in driving in which a decreased driver capacity has important implications for an increase in mental workload. Decreased capacity can result from a monotonous environment, lack of experience, or more temporary factors such as fatigue or illness. In such conditions, driving performance can in many cases still be protected from deterioration by effort investment. As pointed out earlier, effort investment is 'trying harder', is actively trying to counteract a sub-optimal state or to deal with high task demands (see also Brookhuis and De Waard, 2000, De Waard and Brookhuis, 1997).

Effort investment is a conscious and voluntary process, and it is usually a very effective way to keep performance at an acceptable level. There are, however, costs involved in effort investment. While a relatively short-lasting effort investment has limited costs and is a flexible way to deal with increased demands (or a reduced operator state), prolonged effort investment is better avoided. It has been suggested that prolonged effort investment involves repetitive activation of the cardiovascular defence response and this may lead to hypertension (Johnson and Anderson, 1990). There are also limits to the investment of effort. Performance (e.g., lane control in driving) will drop if effort investment is insufficient or ceases. This can happen both in conditions of very high task demand and in conditions where the driver’s state is affected.

It is clear that mental workload must be defined in terms of the operator on the one hand, and the task on the other. Actually, mental workload is often defined as the proportion of mental capacity that is required for task performance (O’Donnell and Eggemeier, 1986). Consequently, mental workload is not determined solely by the task demands. A task can be demanding for one, while another can easily perform the same task. Consider driving in city traffic for an
experienced driver compared with a novice driver. The novice driver has to work hard (keeping control over the car, processing all information) while the experienced driver also has to invest effort, but usually (s)he has enough spare capacity to have a conversation, for example. However, after a bad night's sleep there will be reduced capacity for both of them and the task will be more demanding. The main message here is that there are large individual differences in capability and state, and these affect mental workload. Accordingly, it is not possible to make simple statements with respect to the effects of a certain task on mental workload. Reality usually is more complex.

In this chapter measures of mental workload are discussed, as well as how to determine mental workload in traffic. Examples are given of the effects of road delineation on mental workload, and how an increase in mental workload can be used to modify drivers' speed choice.

**METHODS OF MEASURING MENTAL WORKLOAD AND THEIR RESULTS**

Techniques to measure mental workload are generally classified into three categories: performance (behaviour), self-report and physiological. Measures from all three categories have been used in traffic research. Apart from general measures there are also specific traffic-related measures, such as car-following performance. The different measures will be briefly discussed below.

**Performance measures**

Performance measures are always speed or accuracy measures. In car driving, the primary task is to keep the car on the road preferably within the driving lane and not to collide with other road users. Primary task performance measures are accordingly longitudinal and lateral vehicle control measures. Average speed and headway, as well as the standard deviation of these measures, reflect longitudinal control. Thus for example, sedative drugs can make it more difficult to maintain a constant speed, reflected in an increase in the standard deviation of speed or in a lower or higher average driving speed.

Lateral position on the road is an important indicator of driver impairment. Again, as a result of some drugs (including alcohol) weaving increases (Louwerens et al., 1987). As a matter of fact, the amount of weaving of a car is frequently used by police as a justification for stopping a car. Variability in lateral position usually increases in demanding conditions, although the opposite effect has been reported (De Waard and Brookhuis, 1997). Sometimes, in demanding conditions, task performance improves. This is mainly due to the fact that in certain situations such as driving on a motorway, there is little need to minimise weaving. Motorway lanes are typically wide and allow for fairly large steering errors. As a result, people sometimes allow relatively larger steering errors in such non-demanding conditions compared with demanding conditions. In contrast, it has been found that drivers responding to the negative effects of medicinal drugs (e.g., sedative anti-hayfever drugs (De Vries et al., 1989)) on their driving performance are more inclined to drive on the safer side of the driving lane of a motorway, that is more towards the right-hand line of the right lane in right-hand side driving countries.
While lateral position control is a good and sensitive measure of eye-hand co-ordination, higher level processes, such as the perception of speed changes of other traffic, are probably more important as safety-related performance measures (Brookhuis et al., 1994). Rear-end collisions are far more common than swerving out-of-lane accidents. For this reason, Brookhuis et al. (1994) equipped experimental cars with sensors and developed measures of car-following performance. In tests, participants had to follow a lead car at a constant distance, while the lead car changed speed according to a regular pattern. The speed data of the lead and following (experimental) car were used as input for coherence analyses. Coherence analyses provide three measures; coherence, phase shift and modulus. Coherence is a type of correlation between the two speed signals, which indicates how well the experimental car followed the speed changes of the lead car (i.e., how well the task was performed). Phase shift is a measure that indicates the delay between the two signals and accordingly indicates delay in reaction. Finally, modulus indicates amplification between the two signals and is a measure of the amount of overshoot in reacting. Coherence analyses have been used in assessing the effects of car phone use, of fatigue, of low amounts of alcohol and of medicinal (anti-hayfever) drugs on performance. Results of these studies show that alcohol, a sedative drug, and handling a car phone, all had an effect on increasing reaction time when following a lead car, while with respect to lateral position control a deterioration in performance was found only after the use of alcohol (for details see Brookhuis et al., 1994, and De Waard, 1996). Apart from this more advanced speed-coherence technique, a device measuring distance to a car in front can also give information on headway control. Time-to-reach an object in front (e.g., a car) is frequently used as an important safety measure (Summala, 1988).

The performance measures mentioned above are all related to the primary task of vehicle control. In order to perform this task, resources need to be allocated. The idea is that total processing capacity for task performance is limited (e.g., Wickens, 1992). For most tasks, capacity is sufficient and as performance is not affected it is accordingly difficult to determine differences between tasks and mental workload. A way to determine how much of the capacity is needed for performance is to add a secondary task. Such a task should use the spare capacity (Brown and Poulton, 1961) and if full capacity is exceeded, either primary or secondary task performance deteriorates. Reaction time tasks, mental arithmetic, or memory search tasks are most frequently used as secondary tasks. Secondary tasks are also used in traffic research as a loading device (e.g., Verwey and Veltman, 1996). Brookhuis et al. (1991) examined the effects of car phones on driving performance. In order to load drivers with a demanding task, a combined memory calculation task had to be performed. Digits were presented through the car phone, and the driver's task was to add the presented digit to the previously presented digit. The result had to be spoken out loud, while at the same time the most recent digit had to be memorised to be able to add it to the next presented digit. This paced serial addition task, the PASAT, imposes a heavy load on participants comparable to a difficult telephone conversation. Another example, also involving handling of a telephone, can be found in De Waard et al. (1997). In that study participants had to drive a simulator car while being distracted by a demanding telephone number lookup task. This task was so demanding that weaving seriously increased. However, as soon as participants had to perform the demanding task, they decreased their driving speed. By compensating in speed, they were better able to combine both tasks.
This latter example illustrates an important disadvantage of the secondary task technique. In order to meet the demands of both primary and secondary tasks use of the same resources is required. However, if these are limited, the driver may give more priority to one of the tasks and one cannot always be sure which task receives priority. Also, most added secondary tasks (such as the calculation tasks) have a poor relationship with real-life car driving. It is more ecologically valid to use a subtask that is already part of the driving task, but that is not necessarily required for maintaining vehicle control. An example of such a secondary task is the frequency of glances in the rear view mirror (Brookhuis et al., 1991, De Waard, 1996, Fairclough et al., 1993). It was found that participants less frequently checked the rear view mirror in conditions of high workload, that is while driving on a busy road, and if they had to handle a car phone (Brookhuis et al., 1991). Fairclough et al. (1993) also found that in a higher demand condition, when participants had to navigate from a map or a text LCD display, the frequency of mirror checks decreased. In this experiment the secondary task competes for capacity with the (highly visual) primary driving task. Interference between the two tasks here can accordingly be expected. As a trade-off the mirror checking task, which is also visual, is the first to 'suffer'.

Self-report measures

Besides measuring how drivers behave overtly through assessing performance, or covertly through monitoring physiological states and reactions (see later), a very important source of information is drivers' self-report: simply asking them how demanding a task was. For this type of measure, standardised questionnaires are typically used. One widely used is the NASA-TLX (Hart and Staveland, 1988). The TLX is a multidimensional scale, measuring several subscales, including experienced time-pressure, frustration and physical load. Separate ratings can be summarised to obtain an overall workload assessment. To achieve this using the TLX, six scales must first be compared with each other for each task element and the operator then has to rate which of the two dimensions contributed most to his or her feeling of workload. This necessitates a total of 15 comparisons before the overall workload rating can be calculated. While the 'traditional' TLX requires this two-pass process, Byers et al. (1989) have proposed a Raw Task Load Index (RTLX) which does not require task paired-comparison weights. The RTLX is a simple average of the six TLX scales. Byers and his colleagues found that TLX and RTLX had comparable means and standard deviations, and correlated above $r = 0.95$, and they therefore recommend the RTLX as a simple alternative to the TLX. Apart from multidimensional scales, unidimensional scales can also be used. In the Netherlands, a unidimensional scale, the RSME (Rating Scale Mental Effort), was developed by Zijlstra (Zijlstra, 1993). Invested effort is rated by an indication on a line. Measuring the distance from the origin to the mark leads to a score. On the RSME the amount of invested effort into the task has to be indicated, and not the more abstract aspects of mental workload. In traffic research the RSME is being increasingly used. For example, using a car phone while driving, or an in-car device that gives feedback on law compliance, have both been found to significantly increase mental workload, as measured with the RSME (De Waard, 1996).

Veltman and Gaillard (1996) compared the NASA TLX multidimensional scale with the RSME in an experiment using a flight-simulator. They found that the RSME was more sensitive than the
TLX. The authors argue that this result may be related to confusion caused by the TLX-subscales. Which rating scale to use depends on what information is needed. A multidimensional scale is probably more diagnostic in the sense that the source of workload can be more accurately traced. If, however, a global rating of workload is required, then the subject's univariate workload rating is expected to provide a measure that is more sensitive to manipulations of task demands than a scalar estimate derived from judgements along several individual workload-related factors (Hendy et al., 1993). Also important is the user-friendliness in the design of self-report scales. If possible the measures should have immediacy and be comprehensible to reduce the need for interpretation and to aid in the precision of measure definition. This is mainly true for unidimensional scales.

Self-report scales have several advantages, the major advantage perhaps being their high face validity. In addition, the ease of application and low cost can be mentioned. Low interference with the primary-task is secured as long as the scale is administered after completion of the task. Delays of up to 30 minutes in workload reporting do not lead to significant error, with the possible exception of delayed ratings after complex multiple-task performance. Other possible limitations of self-report measures include confusion of mental and physical load in rating, the operator's inability to distinguish external demands from actual effort or workload experienced, and the operator's ability to introspect and rate effort invested correctly.

**Physiological measures**

The third source of information about drivers' mental workload is to assess their concurrent physiological patterns during task performance. The advantage of measuring physiology is that it does not require an overt response by the operator. Moreover, most of the measures can be collected continuously, and measurement is nowadays relatively unobtrusive due to miniaturisation. Central Nervous System and Peripheral Nervous System measures are used as physiological indicators. Central Nervous System measures include registration of electrical and metabolic activity of the brain, of which the EEG (Electroencephalogram) is probably the best known example. In the Peripheral Nervous System, Autonomic Nervous System measures include pupil diameter, heart rate and electrodermal activity (EDA).

For the physiological assessment of mental workload, Autonomic Nervous System measures are most common in traffic research, although the EEG, a CNS measure, is frequently used as an indicator of the driver's vigilance. Heart rate is the most popular Autonomic Nervous System measure and will be treated in more detail below. Other frequently used physiological measures in applied fields such as traffic are EDA, hormone levels, and the electrical activity of specific muscles (EMG or Electromyogram). EDA has been found to be a sensitive measure, but has the disadvantage that it is non-specific. In practice this means that the source of a similar skin conductance response can range from a deep breath to a death-threatening situation. The responsiveness to emotional conditions and its global sensitivity are important reasons not to use EDA as a mental workload indicator (e.g., Heino, 1996). In practice, several hormone levels are assessed from blood, urine or saliva samples and are most useful to reflect the integrated effects of stressful situations (which include high workload conditions). EMG
research has had some focus on task-irrelevant facial muscle activity, but results from field trials are not encouraging (De Waard et al., 1995).

The prime measures of heart rate are average heart rate (or IBI, Inter-Beat-Interval, the time between successive heartbeats) and variability in IBI. Average heart rate during performance compared to rest-baseline measurements reflects metabolic activity and has been found to be sensitive both to general alertness level and compensatory effort (De Waard, 1996). Roscoe (1992) claims that the main determinant in heart rate response in experienced pilots, in the absence of physical effort, is mental workload. Not only effort affects heart rate level (e.g., Lee and Park, 1990), emotional factors, such as high responsibility or the fear of failing (in a test), also influence mean heart rate (Jorna, 1993). Other factors affecting cardiac activity are speech and high G-forces that can occur in high-speed flight (Wilson, 1992). In car driving, physical movements seldom disturb average heart rate level, as car drivers simply have little choice other than to remain seated.

When physiological measurements are taken, observations during rest are required to allow for scaling. The reason for this is the 'Law of initial values' which states in part that the range of reactivity is restricted in a condition of high baseline values by a ceiling effect. Participants could also be anxious or reactive, and resting baselines help to interpret comparisons between

![Heart rate chart](chart.png)

Figure 1. Average heart rate of 13 participants while driving along road works. Each point is based on 30 seconds of heart rate data. Just after '70' the road works start, while during the post-rest measurement the car was standing still and participants relaxed.
Human factors for highway engineers

conditions and studies. Compared to a measurement at rest, effects of driving are always found (see De Waard, 1996).

In a typical example, average heart rate and heart rate variability (see later) are calculated over relatively short periods of time, for example 30 seconds (for details, see Mulder, 1992). After this the processing window moves 10 seconds and again averages are calculated. In this way changes during the ride can be made visible. In Figure 1 an example of the results of this method is given. In this figure the average heart rate of 13 participants is displayed. Participants were driving an instrumented car on a motorway while they approached road works (for more details of the experiment see Martens and Brookhuis, 1998). On the x-axis different sections are indicated, the motorway part is a standard dual lane plus emergency lane section. ' 70' indicates the area just before the road works, where the speed limit is lowered from 120 km/h to 70 km/h. Some 10 to 20 seconds after the sign the actual road works begin. At the road works, driving lane width was reduced, and the emergency lane was absent. 'End' designates the end of the road works section, while 'rest' is a post-trial rest measurement where participants sat quietly in the parked car. Just before the start of the road works a heart rate acceleration can be seen, interpreted as a preparatory response. Driving along the road works heart rate stabilises, even to a level below ordinary motorway driving as measured in an earlier part of the ride. From the figure it is clear that, compared with rest, driving a car increases heart rate, but also differences during the ride can be seen (see Brookhuis and De Waard (2000) for another example of these within-journey differences in heart rate, where differences are illustrated between city-driving, driving around roundabouts and on single carriageway through-roads).

In addition to heart rate (or IBI), variability in heart rate (HRV) is an important indicator of mental workload. Increased mental effort coincides with decreased HRV. In general HRV decrease is more sensitive to increases in workload than HR increase, although there are reports of both heart rate and HRV insensitivity (e.g., Wierwille et al., 1985). One cause of mental load having no effect on HRV lies in the global character of the measure and its sensitivity to physical load. Lee and Park (1990) showed that an increase in physical load decreased HRV and increased HR, while an increase in mental load was accompanied by a reduced HRV and no effect on HR.

The third parameter that can be derived from heart rate comes from frequency analysis of IBI. Frequency analysis has a major advantage in that HRV is decomposed into components that are associated with biological control mechanisms (Kramer, 1991). Of the frequency bands that have been identified (see Mulder, 1992), the so-called 0.10 Hz component is related to short-term blood pressure regulation and has been found to be suppressed in conditions of mental effort and increased task demands (Mulder and Mulder, 1981, Backs and Seljós, 1994). The 0.10 Hz component has been found to be very useful in applied research, although there are some restrictions. Most of these restrictions are related to influencing factors, such as physical load, but these are fairly limited in car driving (see De Waard, 1996, for a more complete discussion).

In Figure 2 another example is given of how heart rate measures can be used in mental workload assessment. In the top panel average heart rate is shown, in the lower panel the 0.10 Hz component of heart rate variability. Please note that a decrease in the 0.10 Hz component implies an increase in mental effort. The data were taken from an on-the-road experiment, in which 52 participants completed test rides on a motorway (De Waard, 1991). The test-rides started with a
Mental workload

pre-rest measurement of about 2 minutes. After this, participants could get used to driving the instrumented car while driving over the motorway for some 15 minutes. Data depicted in the figure refer to the journey back to the starting point of the trip. A control section is indicated, on which no special conditions are present. Also indicated is a weaving section, 1.8 kilometres in length, where traffic merges in and out of the main motorway lane(s), and an 800-metre section along a noise screen. Directly after this screen, in a bend to the left, an acceleration lane joins the motorway. Driving over the weaving section and along the noise screen may increase demands in terms of monitoring other traffic’s behaviour. In the right-hand section of the figure, data for the two-minute post-rest are depicted, where participants sat quietly in the non-moving car. Looking at the heart-rate data (upper graph), one of the things that is notable is an overall trend in heart rate to increase during the journey. This increase is most likely related to an increase in traffic density during the journey that occurs on the approach to a relatively large city. Also notable are two peaks in the signal, one at the weaving section, and one at the end, near the noise screen. Both sections are, as said, more complex than, for example, the control section.

The post-task resting heart rate level is comparable to the pre-task resting level, while both levels are significantly below the average task level. Driving a car clearly coincides with increased heart rate. In the lower graph of Figure 2, where the 0.10 Hz component is shown, the same task-rest differences can be seen, a reduction of the 0.10 Hz component during driving compared with rest. During the post-task rest especially, the level is higher, suggesting that participants were somewhat better able to relax ‘when it is all over’ than before the test, as an increase in HRV coincides with reduced effort. The weaving section is again visible in the signal, this time as a sharp decline forming a clear contrast with the normal section that preceded. The 0.10 Hz component is also suppressed near the noise screen. Both events point to the investment of increased mental effort while driving over these sections. This example shows that heart rate and heart rate variability can help to identify locations where drivers ‘have to try hard(er)’.

**SOME REMARKS ON INDIVIDUAL DIFFERENCES AND STRATEGIES**

Driving a vehicle is a task that demands continuous adaptation to a changing environment. A large part of the subtasks that have to be performed, such as lateral position control and speed maintenance, are tasks that are performed automatically, with hardly any driver effort. An important index of performance at this level is the standard deviation of the vehicle's lateral position (SDLP). At irregular intervals the control-level tasks are extended to include manoeuvre tasks, such as overtaking of other vehicles and following of leading cars. These tasks are not automated and require the driver's attention. Indicative measures of performance at this level, which are again performance measures, are delay in responding in car-following and the frequency of mirror checking.

Predicting the effect that a task will have on driver performance and mental workload is very difficult. Firstly, there are individual differences in goal setting and these differences vary from route choice to steering accuracy. Driving is to a large extent a self-paced task. If demands are too high, a slower driving speed can be chosen so as to be better able to deal with these demands (see e.g., De Waard et al., 1997). An elderly driver may prefer to make a detour so that he or she can drive over familiar roads thus facilitating the task through environmental choice. Once the
Figure 2. Average heart rate in beats/minute (upper graph) and the 0.10 Hz component of heart rate variability in arbitrary units (lower graph) while sitting quietly in a car (rest), and while driving on a motorway. Weav. sect = weaving section. noise = section with noise screen

task goals have been set, the task that has to be performed - the task demands - determine task complexity. How difficult a task is, however, depends upon state, context and capacity. This may be lower for the elderly driver as just described. On the other hand a novice driver may
require more effort for vehicle control than an experienced driver. It is however possible to relate driving performance to predetermined critical performance margins, levels above which driving becomes dangerous (see Brookhuis, 1995). As these critical levels denote the change from acceptable to unsafe behaviour, the effort compensation area (where performance level is protected by increased effort investment) is not covered. Therefore in the measurement of mental workload, taking additional relative measures can give a further indication of mental workload. Strictly speaking, workload can only be determined per individual. It is always task X performed by individual Y that leads to a specific performance level. Nevertheless, individuals are not all that different and people often use similar strategies for performance of the same tasks. So, even though not all individuals set exactly the same goal, there are margins that are considered acceptable. Most drivers do not consider swerving or leaving the motorway lane acceptable. Task demands can accordingly be defined in terms of maintaining the vehicle between the lines of the driving lane. For experienced drivers it is not likely that there is much difference in (e.g., self-reported) effort required for the basic task of lateral and longitudinal vehicle control.

The most important element of workload assessment is change. Performance with the use of any device, in any environment under investigation, should be compared with baseline performance, driving without the use of the device, under 'normal' or standard conditions. Changes in mental workload (measures) give a clear indication of what the effects of the changed demands are, incorporating at the same time changes in strategy or altered goals. In the following sections two examples will be given of the effect of road delineation and road layout on mental workload and driving performance. The examples will be illustrated with data collected during test rides over different roads.

**EFFECTS OF ROAD DELINEATION ON MENTAL WORKLOAD**

In Dutch rural areas there are many minor 'B' class roads, mainly used by farm vehicles and private cars. In principle the speed limit for these roads is (by default) 80 km/h. However, a slower speed is usually more appropriate as the lanes are not wide. As a result of the quite narrow asphalt of 4 to 4.5 metres in total, cars damage the road edges or, more seriously, drivers lose control of steering and end up in a ditch or hit a tree on the left-hand side of the road. Official Dutch guidelines for roads of this width outside rural areas are fairly constrained; above a total width of 4.5 metres a dashed centre line is allowed, below 4.5 metres in width no lines are to be painted on the road. Unlike many other countries, edge lines are not found in isolation, i.e., they are only painted in combination with an axis line. For this combination, the road has to be at least 5.8 metres in width. As edge lines help to enhance detection of the road's edges, the Traffic Safety Board of the province of Frisian, in co-operation with the Dutch Ministry of Transport, initiated a project to study the effects of different edge marking on driving behaviour. The study is treated in detail in Steyvers and De Waard (2000). However the main results are discussed below.

Four types of minor rural roads were studied:
1. No road delineation (one lane, not marked)
2. Dashed centre-line delineation (two lanes, centre marked)
3. Dashed edge-line delineation (one lane, edge marked)
4. Continuous edge-line delineation (one lane, edge marked)
Participants were required to drive an instrumented car over all four types of road. Tests were performed during daylight and during the hours of darkness, in the early evening. During the rides, vehicle parameters were measured, such as steering wheel position and lateral position. Subjective judgements such as ratings of invested effort were also collected. In addition, participants' heart rate was recorded to fully enable evaluation of mental effort. The roads had a dashed centre line, no lines at all or edge lines (dashed or continuous). Within-subject comparisons were made between roads, while the ratings with respect to condition (daylight/darkness) refer to between-subject data (see Figure 3). It was found that lateral position choice is affected by delineation. On centre-lined roads, lateral position is more towards the edge than on the other three roads. With respect to driving speed, average speed was highest on the centre-lined road and lowest on the unmarked road.

During darkness the average lateral position was found to be closer to the centre of the road. This is a similar effect to that found for drivers operating under sedative drugs. Swerving, as measured by the standard deviation of lateral position, increased however, which may counteract positive effects of the safer road position. Analyses of the heart rate data, in particular of heart rate variability, indicated that driving during darkness required increased effort investment. The subjective scale of effort, the RSME, refines the picture. People who were unfamiliar with the area had to invest more effort when driving. This was particularly true for the non-marked road during darkness (see Figure 3): driving in darkness while not knowing what to expect was considered very effortful. The visual guidance that delineation gives is very important. This is demonstrated both by driving speed and mental effort. Driving speed is higher on marked roads, while effort investment is highest on non-marked roads during darkness. Delineation on the one hand increases safety by providing guidance, on the other hand it increases driving speed and therefore mobility, but this in turn in general decreases
safety. The choice whether and how to delineate a road is therefore not a simple one and has to be balanced.

**MAKING USE OF MENTAL WORKLOAD IN ROAD DESIGN**

Speeding is a serious problem on 80 km/h speed limit through-roads that are used both by local and inter-regional traffic. Several causes for speeding have been suggested, amongst which an important one is that the road as such is not easily distinguishable from a 100 km/h speed limit road. In a project initiated by the Dutch Ministry of Transport, the road’s layout was adapted to increase class recognition and induce required driving behaviour. Various principles were implemented to achieve this:

- **Instrumental conditioning.** In conditioning use of reward is made to increase appropriate behaviour and punishment is used to suppress unwanted behaviour (see Chapter 4).
- **Mental workload.** Both overload and monotony are undesirable situations. If driving is very demanding, a reduction in speed can be expected to regulate and reduce information input. At the other extreme, to avoid driving being too boring, drivers may speed to stay awake.
- **Information theory.** This theory assumes that drivers try to avoid uncertainty. Reduced visual guidance should therefore reduce driving speed (see also the above-described experiment on road delineation).
- **Tracking.** Increased required effort in lane keeping is likely to result in a slower speed as compensation.
- **Speed perception.** As drivers try to keep subjectively experienced speed at a constant level, changes in perceptual flow may affect speed.
- **Utility and risk.** In a cost-benefit analysis benefits such as journey time are balanced against costs, such as the risk of getting a fine, or an accident.

The main goal of the project was to increase road category recognition, and to decrease speeding. A 'typical' Dutch condition was that the adaptation should not be too expensive. The road surface layout was modified specifically to create discomfort for the speeding driver. Visual guidance was reduced by removal of the white edge lines. To compensate for the removed visual guidance, the centre line was enlarged from 0.1 m to 0.3 m in width. Instead of white edge-lines, 'blocks' of rough-surfaced chippings were positioned on the roadside. The chippings were also placed under the centre line. The length of a block of chippings and the interval between blocks (both 4.0 m) was devised to induce discomfort if a car drives over them at a speed above 80 km/h. While the actual road width was not affected, the width of the 'comfortable', smooth surface structure of each driving lane was decreased as a result of these changes from 2.70 m to 2.25 m. According to the mental load model this reduction is believed to increase mental load especially when speeding. It requires more (mental) effort to keep the car on the narrower lane with the smooth surface. In terms of the utility model, speeding drivers who drive with two wheels over the blocks of chippings will receive unpleasant haptic and auditory feedback. An example of the standard (control) and the adapted (experimental) roads is shown in Figure 4.

Additional adaptations that were mainly aimed at increasing the recognition of road category and speed limit, included a white painted '80' on the road surface after each intersection, and at 500
metre-intervals a 0.75 metre high retro-reflective yellow road side marker. The top of these markers consisted of a red circle with the speed limit (80 km/h) indicated in white (for more details on the road layout, see De Waard et al., 1995). The effects of different road layouts on driver behaviour in general and on driving speed in particular, were evaluated in on-the-road experiments and appraisal studies. Longer-term speed measurements and accident statistics were also recorded and evaluated.

In the on-road experiment (De Waard et al., 1995) driving speed was lower on the adapted, experimental roads compared with regular, control roads. Although the effect on driving speed was not spectacular, a reduction of about 3 km/h, this magnitude of speed reduction has been found to have a measurable positive effect on traffic safety (e.g., Joksch, 1993). During the test rides, drivers’ heart rate was also registered. Analyses showed a marked reduction in the 0.10 Hz peak on the experimental road, indicative of increased mental effort. Apparently driving over the adapted roads still required increased effort, even after slowing down. In principle, equal effort investment would be expected when driving speed is lower, but the fact that driving speed on the adapted road was still above the speed limit may account for relatively increased effort. The road adaptation was also expected to be effective because it would be uncomfortable for speeding drivers, as well as provide speeding drivers with (haptic) feedback. Drivers evaluated the roads on subjective aspects of the adaptations by completing the Road Environment Construct List (Steyvers, 1993). Results of several studies indicate that the adapted roads are perceived as being less pleasant to drive over and increase activation. The reduction in pleasantness correlated with reported driving speed just as expected: fast driving decreased pleasantness.

Driving speed of vehicles was also recorded at different experimental and control sections for over two years. Here a similar 3 to 4 km/h slower average speed was found on the experimental sections. Accident data showed an accident decrease of 20% and a casualty decrease of 35% on the experimental roads compared with the standard, control before-situation. On the control roads both accidents and casualties increased by 8% and 24% respectively, compared with the

Figure 4. Control (left) and experimental (right) rural through-roads
before-situation. In conclusion, the measure has worked, for two years at least. A reduction in driving speed is linked to increased mental effort and annoying feedback when speeding and a reduction in accidents and casualties.

CONCLUDING REMARKS

Three kinds of measure are commonly used to determine mental workload: task-performance measures, self-report measures and physiological measures. All measures have their advantages and disadvantages: specialised equipment is needed for physiological signals, while for the more advanced primary task performance measures, expensive instrumented cars are required. The need for this specialised equipment has made the use of self-report questionnaires very popular. It should be stressed that on their own these reports can indicate mental workload only to a restricted degree. To obtain a complete picture, measures from more than one category are required. An identical performance level may indicate optimal performance, effort compensation or even overload. Only if performance is assessed in combination with self-reports and/or physiological parameters can a conclusion about effort investment and accordingly workload level be made. The divergence of two measures, such as performance measures and self-reports, has frequently been interpreted as problematic. However, with the concept of effort investment and performance protection, dissociation of measures can actually give more information on mental workload (see also De Waard and Brookhuis, 1997). Humans are very adaptable in responding to continuously changing local situations when driving. However, in constructing a road the engineer should be aware of possible effects of road layout on mental workload. Although most drivers can cope easily with changing situations and increases in workload, as was shown in two examples in this chapter, in combination with a decreased capability, workload can become too high.

RECOMMENDED READING


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LEARNING AND DRIVING: AN INCOMPLETE BUT CONTINUING STORY

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OVERVIEW

Learning is something we all readily recognise is necessary for people to be able to drive well and safely, but it is something which must occur if we are to drive at all. Less obvious, but equally important is the fact that we continue to learn throughout our career as drivers, and that we do so as a consequence of the experience we gain from participating in the traffic system. This chapter considers the nature of human learning, focusing particularly on how we prepare people for participating in the traffic system as drivers, and how their performance changes subsequently as a function of driving experience. The implications of this, and the factors which underlie it, are discussed in relation to how drivers are currently trained, and how they are likely to learn having gained a driving licence.

LEARNING: THE BASICS

Although there are inherited biological constraints on the success we are likely to achieve on the vast majority of tasks we perform, skilled performance depends overwhelmingly on learning. For most authors, it is almost axiomatic that skill is learned (e.g., Annett, 1991). Indeed, extensive analyses of highly proficient musicians, for example, conclude that the amount and nature of practice, rather than innate ability, is the major predictor of the level of proficiency people achieve (e.g., Ericsson and Charness, 1994). Thus, there are conceptual and
empirical justifications which support the rather uncontroversial proposal that skilled performers are made, not born. So it is with drivers, although as we shall see, general cognitive or intellectual abilities do contribute substantially to how effectively people learn to drive.

In the subsections which follow I want to outline what I consider to be the fundamental aspects of human learning on which our developing ability to drive is based.

Intentional and incidental learning

Learning results in a lasting change in an individual’s capacity to perform. When we think of our own experience of learning something, we probably remember hours spent revising for examinations, practising what we thought to be likely questions, or repeating poems over and over we wanted to be able to recite, or indeed spending hours acquiring and practising ball-playing skills, perhaps even for years, trying to co-ordinate the timing and shape of a swing with the hitting of a golf ball towards a seemingly impossibly small target. I will return to discussing practice at some length below, but surprising as it may seem, determination to learn, or the intention to learn, is not necessary for learning to occur. This is the conclusion which must be drawn from studies which contrast incidental and intentional learning. In such studies, participants are required to attend to stimuli and some of them are later given an unexpected recall or recognition task. As long as participants attend to the stimuli in the same way, those who attempt to learn in anticipation of a later memory task, and those who do not, both remember similar numbers of items, whether it be words (e.g., Hyde and Jenkins, 1973) or the precise locations of chess pieces from a briefly seen chess board (e.g., Lane and Robertson, 1979). The latter study shows that for incidental learning to take place the stimuli must be attended, processed or perhaps more accurately interacted with in a relevant way. Intentional learning had a considerable advantage where participants were required to count the number of chess pieces of a particular colour on the board, but incidental learning led to similar levels of recall as intentional learning when participants had been asked to determine what the next move for a particular colour should be. It is interesting to consider that carrying out a task which is a natural part of the skill of playing chess, i.e. determine-next-move, has a consequence of leaving behind a reasonably accurate spatial map of the locations of chess pieces, but a task not naturally part of the skill - counting the number of pieces, does not.

Such results have not only been reported in studies where recall or recognition have been tested, but in other tasks where people ultimately learn to perform highly complex sequences of actions - without intending to learn and even without knowledge that a sequence is present. In a task in which participants had to press one of four buttons, depending upon which of four positions on a screen an asterisk was presented, reaction times reduced as they became more practised on the task. This improvement was short lived where the sequence of positions in which the asterisk appeared was random, but participants became quicker and quicker where the asterisk positions formed a sequence, even where thirteen or even fifteen positions were visited before the sequence began to repeat itself (Nissen and Bullemer, 1987). Two crucial additions in this study were that first, if after substantial practice a block of random position trials was introduced, reaction time increased very markedly for the sequence group, but not for the random group. Re-introducing the sequence on the next block of trials resulted in reduced
reaction times for the sequence group, but not the random group. Second, a slight change in the
instructions telling participants to press the button to indicate where the asterisk would next
appear, rather than where it has just appeared, demonstrated that participants in neither group
had any explicit knowledge of the sequence underlying the order in which the asterisks
appeared. Subsequent studies have established that not only can participants not report the
sequence, but having them concentrate on performing another task at the same time (e.g.,
responding when concurrent tones are ‘high’ rather than ‘low’) does not affect how well
participants learn the underlying sequence. Indeed, where the distracting task is itself
sequential, participants learn the sequence inherent in both tasks simultaneously - although they
cannot report elements of either sequence reliably. We seem to be able to learn more than one
thing at a time, but for this to happen the two to-be-learned tasks must be combined or
integrated. It is important to recognise, particularly in a driving context, that this learning only
happens where participants have to generate some response to both tasks. If participants
respond to only one task, only the sequence underlying the performed sequential task is learned
(see Schmidke and Heuer, 1997). What these studies show is that learning proceeds with
exposure to and interaction with stimuli, materials or events. They show that intention to learn,
indeed full attention during learning, is not necessary for highly reliable learning of the basic
properties of the relationship between one event and another. However, it is important to
recognise that intention to learn does have very considerable benefits.

Intention to learn allows us to determine what to attend to and how we engage with what we
attend to. We also know from studies of learning that where the to-be-learned material is
personally relevant, we remember that information more accurately, and for longer, than where
the to-be-learned material is not personally relevant (e.g., see Matlin, 1989). We know that we
learn better by participating in learning, by attempting to resolve problems rather than simply
being provided with the solution (e.g., Slameka and Graf, 1978), and by performing actions
which are to-be-learned, rather than merely watching the performance of others (Blandin,
Lhuisset and Proteau, 1999). We know that learning is more reliable and durable when we
process whatever we need to learn in ways which are relevant to how we will later be assessed
(e.g., Morris, Bransford and Franks, 1977) and when we engage with a task in a relevant way
(e.g., Lane and Robertson, 1979 above).

In short, the point is that learning, even quite complex learning, is possible without the
intention to learn, even without attention during learning. But there are limitations to what can
be learned without attention (see Cowan, 1999), and perhaps more importantly, by having the
intention to learn, we as learners can attempt to ensure that we engage in learning strategies
which optimise our chances of learning successfully (albeit that we may attend to the wrong
aspects of performance with low-level perceptual tasks).

Practice and improvement

As mentioned earlier, practice is crucial for skill to develop. Although it has been known for a
very long time, it is now much more widely recognised not only that practice is a good thing,
but that there is a lawful relationship between the amount of practice an individual has had and
their ability to perform a task. In relation to driving we have shown that success on a task is a
power function of the amount of practice someone has had (Groeger and Clegg, 2000). Although reports of what has been termed the 'power law of practice' are widespread throughout psychologists' studies of psychomotor and other simple learning tasks (see Newell and Rosenbloom, 1981), it is only recently that the power law relationship between practice and successful performance has been demonstrated for more complex tasks such as learning to use a computer-based text editor, proving geometry theorems and solving physics problems (see Singley and Anderson, 1989; Anderson and Fincham, 1994). Our own work, which examines the change in amount of instruction given to drivers by their teacher as they learn (e.g., Groeger and Clegg, 2000), and the number of errors made as a function of the number of hours of driving experience they have had (e.g., Groeger and Brady, in press), represents the most complex task to date in which current level of performance is demonstrated to be a power function of the amount of task experience the individual has had.

The fact that learning is a power function of amount of practice is very important, both in practical and theoretical terms. It means that performance will continue to improve given practice, but the rate of improvement will continually slow. No other mathematical relationship between practice and success would lead to the same conclusion. More is learned from the first ten hours of practice than from the second ten hours, more is learned in the first year than in the second year, and in the first decade than in subsequent decades - but we are always learning when we perform the task. It also implies that performance continually improves but never reaches perfection. In other words, practice makes us better, not perfect!

It is important to realise that with a complex task such as driving, not all the components of the task will necessarily improve at the same rate. In a study in which typists had to learn to use a text editor, Singley and Anderson (1989) showed that while the total time taken to edit a page of text reduced as a function of the number of hours of practice, there was very little improvement in the time taken to press the required keys over time - almost all the improvement was due to a shortening of the time taken to determine what actions (i.e., editing commands) were appropriate. The keyboard skills these typists already had (already being highly practised) were transferred to the new task, and thus improved only very very slowly as the result of the additional keyboard practice they gained within the study. When we have examined rates of improvement in different elements of the task of learning to drive, we see a very large improvement in activities related to car control, but less improvement in ability to position the vehicle appropriately on the road, and very little improvement in ability to determine what is or is not a dangerous situation (see Groeger, 2000). This arises in part, I presume, because some activities are more difficult than others. The same is true when we look at the rate of improvement in driving ability across different manoeuvres, using all the errors made at similar locations. Learner drivers improve more rapidly on some manoeuvres than others, again, presumably, because some are more difficult than others. That is, not all aspects of driving improve at the same pace. Different parts of the task are learned at different rates, implying that driving is not really one single simple task, but several tasks, all of which may need to be performed at the same time. I will return to this issue below, but before doing so I want to address another property of the power-law. The standard form of this power-law relationship, for a task in which performance is measured by the number of errors committed is

\[
\text{Power Law Relationship: Number of Errors} = \text{Initial Level} \times \text{Amount of practice}^{\text{Rate of Learning}}
\]
Initial level is performance on the first trial. Amount of practice is measured in time on task or number of trials. The minus sign preceding the rate of learning reflects the fact that learning will be reflected in a reduction in errors over time.

As described earlier, the curvature of this function is effectively similar to the slope of a straight line, and thus readily provides a 'rate of learning'. Thus, for example, for power functions, the amount of learning on each trial is a constant proportion of what remains to be learned. The way power functions work, if the number of errors halves over the course of N=100 trials, it will take N times N-1 trials (i.e., 9900 trials) for the number of errors to reduce by half as much again. Note also that performance, in this case number of errors committed, not only depends on the amount of practice and rate of learning, but also on something called the ‘initial level’ of performance. One way of thinking about this is that, for a novice driver, this is effectively how well they would perform without ever having driven - what one might call their 'initial ability'. As will be returned to later in this chapter, our recent longitudinal study of teenage learner drivers has shown that some of this 'initial ability' is related to intellectual, personality and motivational characteristics of the learner (Groeger and Brady, 1999), but it might also reflect well-developed psycho-motor skill and co-ordination, perhaps through playing sport or a musical instrument, or through previous experience as a cyclist for example.

As might be expected on the basis of the equation presented above, as more and more experience is gained, the impact of initial ability on performance reduces. Figure 1 presents a hypothetical graph showing the errors a learner might commit on a particular drive, the number of errors they have committed in total, and the diminishing extent to which initial ability contributes to overall performance as the amount of practice or task experience increases. This means that ability to predict driving performance on the basis of general psychometric tests, even if quite good at the outset of training will diminish as the person becomes more experienced. In fact, when we analysed the errors drivers made on each of six observed drives spread evenly throughout their learning period, the number of errors on each drive was reliably correlated with the number of errors on the previous test drive, and on the next drive, but not the observed drive before or after those. In other words, adjacent tests predicted each other, but those more widely dispersed across the learner drivers' experience did not. This is just what we would expect if ability to perform was changing rapidly, which is of course the case according to the power law of practice, at least very early in a driver's career.

The fact that Initial Ability loses its power to predict performance when people are more experienced is also consistent with the work of Ackerman and others (e.g., Ackerman 1988). In a laboratory simulation of an air-traffic control task, they showed that, as specialised task experience grew, the level of skill attained could not be reliably predicted from participants' general ability.

There is another way in which to think about this notion of Initial Ability. Suppose someone learning to drive a car for the first time had substantial experience of go-carting or off-road driving. We would not expect this person to have the same Initial Ability as someone without such experience. That is, just as in the example earlier with regard to text editing, we might expect some of the off-road driver's previous experience to ‘transfer’ from those tasks similar to driving a car, which they have previously performed. This transferable knowledge would
also be reflected in Initial Ability - although it might not necessarily contribute positively, for example the driver may use the enhanced perceptuo-motor skills or speed handling skills in a way inappropriate to the on-road environment. In just the same way we can think about what happens when a new driver, previously confined to wide roads without traffic, encounters a busy city-centre street. Their likelihood of committing an error will be high because they have not been in such a difficult environment before. On the other hand errors would be less likely if their Initial Ability in this new circumstance is higher because of some positive transfer from driving skills that have been acquired elsewhere. Unfortunately, determining what will transfer so as to enhance performance, and what will transfer negatively - increasing the likelihood of error, is difficult to predict. That said, functional similarity between task components (e.g., a need to signal, or to be in low gear), similarity of the order in which components must be performed (e.g., mirror-signal-maneuver), and higher-level similarities between tasks or situations (which arise through the way they have been described by an instructor, or thought about by the pupil) are the main bases on which positive transfer is likely to occur (see Groeger, 2000). Dis-similarities in these respects may lead to no transfer from previous learning, or indeed to negative transfer.

**Different practice regimes and their effects on learning**

Thus far I have presented practice as if it is something which is unitary or homogeneous. In how it is constituted and in its effects it is neither. Practice is the repetition of some previously performed activity. It may be that the same activity is repeated consecutively, with minimal time intervening between repetitions; that the same activity is repeated consecutively but with more substantial periods interpolated between repetitions; that the performance of different
activities is repeated, but the activities practised within any period of practice are not all identical to each other. These are examples respectively of blocked, spaced and distributed practice. The suggestion made earlier, that driving is not a single task but different tasks which vary in difficulty, has a profound influence on the nature of practice when learning to drive, with different kinds of practice given to different tasks. Thus blocked practice, such as repeatedly practising the same manoeuvre during a lesson, might be given to reverse parking, spaced practice would be represented by the spacing between driving lessons, and distributed practice would be given on a training drive by carrying out one manoeuvre (e.g., driving straight ahead), followed immediately by another different manoeuvre (e.g., turning left at a junction), then another (e.g., driving straight ahead) and so on. We rarely if ever learn to drive under blocked practice conditions, since it is virtually impossible to repeatedly carry out one driving manoeuvre without another intervening. Most of the time we spend learning to drive we are effectively performing under distributed practice conditions, with highly variable periods between driving sessions, and unpredictable intervals between the occurrence of similar manoeuvres. It is important to recognise this fact, since the circumstances under which we practice greatly influence the acquisition and retention of skill.

For a very wide range of tasks it has been shown that blocked practice is associated with more rapid learning, but learning which is less durable than distributed practice. That which is quickly learned can also be more quickly forgotten compared with more difficult skills, given the same total amount of practice. Learning under blocked practice conditions also limits the circumstances in which what is learned can later be used successfully. Shea and Morgan (1979), showed more rapid learning with blocked practice than with distributed practice in a task involving route learning through a spatial display. Participants did reasonably well when the retention test comprised blocks of trials similar to the learning phase. In contrast, however, they did much worse when they encountered their learned routes in a random order. This effect is now known as 'contextual interference' (see Immink and Wright, 1998, for an overview). Another group who learned the same spatial task under distributed practice conditions took longer to achieve the same level of performance during acquisition but did far better than those who learned under blocked conditions, whether the routes learned were blocked or randomly distributed when tested in the retention session. It is also important to note that the learning advantage of distributed practice intensified as the interval between the acquisition and retention phase increased.

Recently, Immink and Wright (1998) have reported similar results, but also showing that when learning under distributed practice, learners actually take more time between individual trials. It is presumed they need this in order to decide things such as what level of confidence they must have before responding. Distributed practice suffers where there is restricted time between trials but thrives where additional time is available. This suggests that the advantage that the blocked practiser has at acquisition arises because he or she does not have to invest the additional cognitive effort involved in practising what are in effect retrieval strategies. Doing so, however, confers considerable advantages when the individual has to retrieve what they have learned. Finally, other studies have shown that how well what is learned during training transfers to new situations also depends on the type of practice the learner has had. For example, participants in a speed discrimination study, trained on three speeds, were better able to make judgements about new speeds if the three speeds they learned about were encountered
in a random (i.e. distributed) fashion during practice than if the three speeds were blocked into trials of similar speed (Catalano and Kleiner, 1984).

In short, practice conditions have a profound impact on how rapidly skills are acquired, how well they are retained, and how well what is learned will generalise to new circumstances. This is fortunate for learning to drive. Since driving comprises many different tasks, it follows that the vast majority of on-road experience represents distributed practice - usually practice of particular driving tasks will be separated by days or even weeks (see Groeger and Brady, in press). While skills are less likely to be acquired quickly, whatever is learned is more likely to be retained for longer and, given appropriate levels of similarity between what has been learned and new task circumstances, is more likely to transfer positively. Unfortunately, the impact of spacing on learning is not infinitely elastic. Few opportunities to perform particular tasks, with these opportunities very widely dispersed in time, is not likely to lead to successful retention - this is, I believe, why judgement of hazards and potential danger develops very little while drivers are learning to drive (see Groeger and Chapman, 1996; Groeger, 2000). There is simply not enough opportunity to learn to be safe for most learner drivers.

TRAINING AND LEARNING TO DRIVE

Some years ago Ivan Brown and I caused a measure of consternation by claiming that on the basis of published evidence the case that driver training leads to increased safety was at best ‘not proven’ (Brown, Groeger and Biehl, 1987). In the decade and a bit that has passed since then others have drawn similar conclusions (e.g., Horneman, 1993), and a number of our own subsequent studies have done little to change this conclusion. One of the problems in establishing a benefit of training is that comparison with otherwise similar groups of individuals without training is difficult if not impossible. Certainly impressive studies by Gregersen (1997; 1999) have shown increased safety as a result of large scale changes in the licensing of young drivers, but attributing even these robust effects to differences in the training actually received by drivers is unconvincing, since we know little about what training differences there were. This is, for me, the central problem in demonstrating a benefit from training, or indeed in proposing ways in which the effectiveness of training might be maximised. Even in the United Kingdom, where the accident rate for young drivers is lower than for almost every other European country, driver training is at best rather like a craft which an individual trainer develops over time, rather than a skill that can itself be trained and passed on effectively to others. While training has been shown to be effective in other domains, there is very little evidence which shows that it is so for any aspect of driving.

Differences in learning regimes

If one believes that the driving task to be learned by drivers is similar across the world, it is rather surprising that such radically different practices exist with regard to how drivers are trained. Several countries make it a mandatory requirement that drivers undertake formal training (e.g., Germany, The Netherlands), while other do not (e.g., United Kingdom, Republic of Ireland). Some require that learner drivers only drive with a professional instructor (e.g.,
Germany) while others permit learner drivers to drive when accompanied by a qualified driver (e.g., Sweden, United Kingdom), and others permit conditions in which an as yet unqualified driver may drive alone (e.g., Republic of Ireland). There are, unfortunately, too many differences between countries, and accident involvement and exposure data are too unreliable or inconsistently collected, to permit a comparison which might expose which of these training regimes are associated with greatest safety.

Our own longitudinal study of almost 200 teenagers learning to drive contrasted the learning rates and driving test performance of those learning predominantly with professional driving instructors with those learning predominantly with parents (see Groeger and Brady, 1999; Groeger and Brady, in press). Rigorous psychometric testing and interviewing of participants revealed that those taking largely formal training were not different from those who mainly learned with their parents. Thus any difference was unlikely to be due to some selection bias, such as, for example, less able pupils tending to be taught by driving instructors. Those who made most progress when learning to drive, as assessed by repeated assessments of their driving capabilities by an independent observer, were more likely to pass the state driving examination than not - a result which validates our assessment technique. As anticipated above, the factor which led to most progress when learning to drive was the amount of driving the pupil did, not who was in the role of teacher when they drove. This suggests that taking professional instruction confers little benefit on the learner, but the matter is much less straightforward than that. Close analyses of our data show that less able pupils make more progress with professional instructors than do more able pupils. The reverse is true for those driving largely with parents. Arguably, the less structured driving experience offered by parents who teach their children to drive, provides a challenge which the more able can thrive upon but which impedes the progress of those who are less able. The more programmatic teaching offered by the professional instructors studied, offers less able pupils the support, routine and structure which allows them to develop their abilities while experiencing a level of demand with which they can cope. In contrast, for the more able learner, the inherent structure of the training offered appears to impede the progress they might be expected to make.

Recognising differences in pupils’ ability, and suiting the training regime to that ability would seem to offer a real prospect of improving the effectiveness of training. Ultimately, however, it is hours behind the wheel which count most. Ensuring that there is sufficient practice, increasing the level of difficulty of driving according to the pupil’s ability, reducing the verbal support given as performance improves as well as varying trip or lesson type and length, seem to me to be the characteristics on which successful driver training programmes should be based.

**Learning After Licensing**

Few would draw the easy conclusion that once training has been completed and a licence to drive unaccompanied has been awarded, that learning is complete. However, the research presented earlier which made clear that the acquisition of driving skills is a power function of the amount of practice or experience of driving, has profound implications for this view. Learning will never be complete. Certainly, in the absence of some acquired brain deficit through accident or advancing
years, performance will appear to reach a stable level. In fact, by virtue of driving skills developing as a power function of experience, all skills will be gradually changing, albeit very very slowly and will require very considerable amounts of experience for a change to be discernible. However, as stated above, the skills which comprise driving are not all acquired at the same rate, even though the acquisition of all are best modelled by a power function. In particular, I suggested that appreciation of danger and safe handling of exposure to risk were, according to our studies, the elements which changed most slowly of all during training. In effect, the skills required to be safe hardly change at all during training, because when learning, drivers drive too little to be exposed to risks for which they can develop a competence in handling - and it is only by interacting with and responding to events that we learn effectively. This suggests that safety should increase as a function of time spent driving, although a discernible change will really only be observed some time after people have completed their training. Recent evidence from a large Norwegian study demonstrates this admirably.

Sagberg (1998) reports data from a sample of almost 60,000 drivers, drawn from the Norwegian register of driving licence holders. About half of those who agreed to participate in the study were aged between 18 and 20 years of age, and had held their licences for between 1 and 18 months (N=17,400). The others were a control sample of 24 year old drivers, with at least five years of licenced driving behind them (N=13,200). The groups differed markedly in the number of crashes they reported having been involved in in the previous month - 651 for the novice group and 259 for the others, that is 37.4 per thousand and 19.6 per thousand respectively. Among the novice group, after eighteen months of licence-holding, 45% of males and 32% of females had been involved in an accident. This gender difference is almost entirely explained by the difference between the distance driven by males and females during that period. However, the data which really serve to make the point about the role of inexperience in crash involvement which Sagberg reports are presented in Figure 2. Respondents were asked to

![Figure 2. Young drivers' crash risk by time since licensing, with fitted trendline (after Sagberg, 1988, reproduced with permission from Groeger, 2000)](image-url)
Learning and driving

report the number of crashes, if any, they had had in the previous month, and how far they had driven in that time. As the graph shows, the number of crashes per million kilometres driven reduces as the time for which a licence has been held increases. The rate at which this change occurs slows over time. In fact the relationship between experience and risk reduction is a power function (crash risk = 102.82 x number of months licence held^{-0.327}), which accounts for some 60% of the monthly accident risk variation. Other analyses of the same data show that this is not simply an age (i.e. maturational) effect, but a real increase in safety as a function of increased driving experience.

Elsewhere in this book, and in other sources (e.g., Groeger, 2000), there are numerous reports of studies which show that driving abilities which have been extremely well-learned are nevertheless prone to impairment from other tasks the driver is required to perform simultaneously. Thus, for example, Shinar, Meir, and Ben-Shoham (1998) show that gear-changing interferes with detection of traffic signs, Verwey (1991) demonstrates elegantly that different manoeuvres are interfered with by different secondary tasks, while Duncan, Williams and Brown (1992) show that driving tasks such as deciding when to move away from a stationary position and pulling back into traffic having overtaken are very demanding of attention. These studies are generally taken to reflect the extent to which driving makes demands on our cognitive resources. By implication they show that few, if any, aspects of driving are ‘automatic’, in the classical sense of being capable of being combined with other tasks with little cost to performance. However, these and other studies are important in that they show that quite different types of concurrent task affect different types of driving task - indicating that driving makes quite different demands on our cognitive resources in different circumstances. What emerges in the few studies which have systematically studied it, such as the work of Willem Verwey (op. cit.), is that qualified drivers with more or less driving experience are affected differently by different types of concurrent task.

In short, the environments in which we drive impose demands on our cognitive system, but the demands may be qualitatively different, rather than absent, when we become highly experienced. Such differential patterns of interference demonstrate that the way our brain is used when we drive changes as we become more experienced (see also Posner, DiGirolamo and Fernandez-Duque, 1997). This too, I would suggest, reflects continuing learning, which we must take into account when we teach, assess, or indeed build the physical infrastructure for driving. We cannot however simply assume that continued learning will guarantee a continuing improvement in performance.

RECOMMENDED READING

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BEHAVIOURAL ADAPTATION AND DRIVERS' TASK CONTROL

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INTRODUCTION

It was found long ago that engineering improvements to vehicles and road environments do not necessarily result in intended reductions in the accident toll. Increasing the width of a roadway, decreasing its curvature, improving guidance in low-visibility conditions, all tend to make drivers go faster and be involved in more serious crashes. It is only through speed-limiting countermeasures that the driver's tendency to offset improvements by higher speed can be restricted. But speed is not the only means by which drivers demonstrate this so-called behavioural adaptation. On high-standard roads where the driver's task is especially easy or monotonous, drivers may engage in subsidiary activities, decrease their level of vigilance, or become drowsy. Such adaptations may be risky as well.

An essential feature of driving, as well as of human behaviour in general, is that it is adaptive. Just as our visual system adapts to light conditions to optimize performance, so drivers adapt to road and traffic conditions to optimize their goal-directed behaviour. In the same way, drivers react to changes in the traffic system. Gibson and Crooks noted back in 1938 that when provided with more efficient brakes drivers delay braking accordingly. Therefore, it is usually safe to assume that drivers will respond to changes in road design and traffic management in line with their goals and motives, which in turn may be in conflict with the designer's goals. It would be extremely useful to find a tool for estimating this effect. While not presenting such a
general tool, this chapter aims to provide some insight into the phenomenon of behavioural adaptation in terms of experimental work on driver behaviour and reactions in real-life driving.

**EARLY THEORIES**

Many candidates have been presented to explain the phenomenon of behavioural adaptation. Early research proposed that drivers have a target level of risk they are prepared to accept, feel the risk level of their behaviour and then adjust their driving (primarily speed) so as to maintain this risk level, a process known as risk homeostasis (Wilde, 1982). Such an homeostatic state might be related to an optimal level of physiological activation that is characteristic of each individual and is possibly related to neurotransmitter levels. Another early position was that drivers are threatened in hazardous situations in a way that keeps them away from danger and teaches limits for safe driving. In this view, most of time they control their driving in terms of safety margins rather than subjective risk (Näätänen and Summala, 1976).

For highway engineering, however, we need more predictive and detailed models. We need to begin by answering such questions as why on wider roads people drive faster and allocate more attention to non-driving tasks, why they don't react immediately when they see the first cues of a hazard ahead and ultimately we need to be able to quantify and predict such effects.

**TIME-BASED MEASURES OF CAR CONTROL**

One key for an understanding of behavioural adaptation comes from an idea that is behind one of the basic concepts in traffic engineering - that of sight distance. Along with good preview time, adequate design for any given design speed should provide drivers with sufficient sight stopping distance, a sight distance which makes safe stopping possible within it. This is in line with the traffic rule in several countries that says that drivers should continuously adjust their speed so that they can stop within the available sight distance (note that this rule is not generally complied with in the dark; see Leibowitz, Owens & Tyrrell, 1998.)

The concept of sight stopping distance obviously involves the feature of availability: drivers should always have sufficient time to detect an obstacle in their path, and sufficient time to brake and stop their vehicle safely in front of it. Speed and road environment together determine the time available for drivers at any moment. The corollary is that available time can be thought of as determining speed as well as steering control to guarantee adequate management of the vehicle.

**Lane keeping**

Time-based measures to explain driver behaviour emerged in traffic-psychology theory in the 1970's and 1980's. Currently such measures are being used in intelligent driver support systems. Godthelp, Milgram and Blaauw (1984) proposed that drivers control their lane-keeping task using time-to-line-crossing (TTL) as a control variable. This means that, for every
moment on the road, a driver knows (or he/she has an impression of) how much time it takes before the vehicle crosses the edge or center line and drives off the road. In contrast to earlier vehicle-steering models, time-to-line-crossing implies an important feature of tolerance in lane control. Drivers have quite a lot of tolerance in lane keeping in the sense that, instead of working in a servo-type loop that corrects the course whenever the vehicle deviates from an imaginary driving line, they only have to correct the course when they are too close to driving off the lane. We can think of the road as providing a tube, with the lane edges as immediate limits, and drivers being free to move within that tube. The time-to-line-crossing has an important psychological meaning — availability of time. This available time determines drivers' time-sharing behaviour, the way they allocate time and attention to driving and non-driving tasks.

The available time in lane control is an important basis of behavioural adaptation that connects speed, road width and curvature. In a study with an instrumented car on an open freeway, we asked drivers to sample continuously information from a visual display (target) that was located in different positions within the car (see Figure 1). Cruise-controlled speed varied

![Figure 1](image-url). The location of the visual displays in an on-road task where participants had to react to the braking of the car ahead, while continuously looking at one display in a monitoring task. Reprinted from Summala, Lamble & Laakso, 1998, Accident Analysis & Prevention, Vol. 30, p. 403, by permission of Elsevier Science Publishers)
between 80 and 120 km/h. As expected, the time the drivers allocated to the non-driving (i.e. secondary) task decreased linearly with their speed, reflecting the diminishing time that was available to the driver. The closer to the roadway view the target was located, the more time drivers spent looking at it, utilizing their peripheral vision in lane keeping. It also appeared that road design influenced time-sharing behaviour. On the sharpest curves (curve radius equal to 1000 m) glances to the in-car display shortened substantially. The results indicate that on freeways drivers actually have plenty of visual attention capacity usable for non-driving activities. At 80 km/h, experienced drivers can use 85% of their time for a secondary monitoring task located in the same position as the speedometer. At a speed of 120 km/h, and when the display is located on the passenger seat beside them, 90 degrees from the roadway ahead, they can still spend more than 60% of their time on the secondary task.

A related experimental paradigm, called spare capacity measurement (of mental load), confirms that certain traffic environments and situations require more time and leave less capacity for additional tasks (see Chapter 11). Harms (1991) showed that a mental arithmetic task was performed more slowly by drivers when they passed through a village or a priority crossing, even more so if they had to turn left, a manoeuvre that required more active visual search in both directions.

**Car following**

Another continuous control task in driving is car following, for which a time-based control variable can be defined as well. It was first proposed by Lee (1976) who described a model in which drivers, when following the car ahead, control braking by means of a time-related measure, \( \tau \), or time-to-contact. In this, drivers adjust speed by accelerator and brake application to control the time available to the moment of collision with the rear-end of the vehicle ahead.

More time can be allowed, of course, by choosing a longer following distance (for any given speed). This is functionally useful when the car ahead brakes and the following driver looks directly at the brake lights of the lead car. However, longer distances are not fully functional if the car ahead decelerates without braking. A long headway means slower growth (in rate of increase of visual angle) of the image of the car ahead in the following driver's retina, and longer detection times (Hoffmann & Mortimer, 1996). While reaction time to the onset of the brake lights of the leading vehicle is of the order of 0.7 s, our results show that the detection of similar, unsignalled deceleration requires 1.5 s at a following distance of 15 m, 2 s at a distance of 30 m and 3 s at a distance of 60 m. Even more problems arise if drivers look away from the car ahead, convinced of being able to keep control because of the longer headway. Figure 2 shows that reaction times to the braking of the lead car grow substantially when the distance to it increases.

These results indicate one type of behavioural adaptation. A longer, subjectively safer, following distance may lead drivers to share attention in a way that may actually increase risk. This may be especially misleading for experienced drivers who have learned to use their peripheral vision in maintaining their vehicle in its lane position. They may not realise that
detection of a vehicle ahead using peripheral vision does not improve with normal driving experience (Summala, Lamble & Laakso, 1998). However, increasing following distance is a typical adaptive mechanism when drivers start speaking on a mobile phone or doing other in-car tasks, and similarly when they anticipate deceleration of the lead car (van der Hulst, Meijman & Rothengatter, 1999).

![Distance and speed graph]

**Visual target**

Figure 2. Drivers’ reaction times to the braking of the car ahead at different speed and distance, while they are looking continuously at it (control condition) or at certain targets inside their car. (The data are from Summala, Lamble and Laakso, 1998.) In the search for simple mechanisms behind behavioural adaptation, available time is clearly and necessarily an important determinant of driver reactions in urgent situations. However, the results reported here suggest a more general principle that drivers adjust their behaviour and respond to changes in their environment according to the time available to them. In general, driver reaction times are positively correlated with available time.

**DRIVER REACTION TIMES IN SURPRISE SITUATIONS**

Driver reaction time is a parameter of great importance in road design and traffic management. Among other measures, brake reaction time is used in assessing sight stopping distance. In accident litigation, the legal process often tends to determine whether the participant driver reacted to the impending collision within ‘acceptable’ time, where acceptability is defined in
terms of a certain percentile point in the distribution of reaction times thought to represent the
driver population (or relevant fraction of it) under relevant conditions.

From what was said in the previous section, it follows that whenever driver reaction times are
considered they should be related to the urgency or criticality of the situation, in terms of
available time. Furthermore, it is not at all clear that drivers react to an unexpected obstacle or
other hazards as soon as they detect them. What happens then in real-life conditions?

It is not an easy task to study driver reactions on the road unobtrusively, and in a situation
which is suitably urgent and allows exact measurement of criticality and reactions. It is also not
easy to find real-life situations where urgent situations can be arranged without ethical
problems.

In one study we circumvented these difficulties by positioning a police officer on the road in a
very exact location from which he suddenly became visible to approaching drivers (from
behind a sight obstacle). This allowed the measurement of the exact moment that the driver
could see the police (stimulus) and the onset of brake lights (reaction). The police officer stood
with one hand up signalling a request to stop, thereby forcing drivers to react without any
hesitation.

As expected, the results clearly showed that the faster drivers, who had less time available to
stop in front of the police officer, reacted faster. Reaction time depended on the time-to-
collision fairly linearly, in an adaptive manner. Correspondingly, the variance of reaction times
substantially increased with time available (Koivisto & Summala, 1989). This suggests
differences in detection capabilities, attentional problems and/or response patterns among
drivers that tend to increase with decreasing criticality. For example, the detection of targets
against the background gets more difficult with increasing distance.

Comparisons of young and elderly drivers' reaction times shed more light on the mechanisms
of behavioural adaptation. Olson and Sivak (1986) carried out an excellent experiment in
which they had people of different ages drive an instrumented car over a fixed route on which
an obstacle unexpectedly appeared in the middle of their driving lane, on the far side of the
crest of a small hill. In their measurements, the experimenters were able to separate out
perception and response times. Perception time refers to the detection part of the reaction
process, and is usually defined as the time from stimulus onset (appearance of an obstacle, for
example) to the moment that the pressure on the accelerator starts diminishing. We can also
call it the accelerator response. Response time usually refers to the time interval between the
accelerator response and the activation of the brake pedal, often called movement time. The
point is that the accelerator response might reflect a fairly fast automatic response, while
applying brakes may be more considered (and adaptive), being either delayed or hurried,
depending on the driver and the situation. What is more, drivers who are slower in detection
(perception time) may compensate with faster response times.

Figure 3 shows cumulative distributions for total brake reaction time and its two components.
We can see from the results that, as expected, older drivers have a longer perception time.
Figure 3. Perception time, response time and total brake reaction time for younger (18-40 years) and older (50-84 years) drivers in the surprise situation of Olson and Sivak's (1986) study, in which drivers for the first time encountered an obstacle in their path after a hill-crest. Adapted by Summala, 2000, from figures 1-6, Human Factors, 1986, 28(1), 91-96. (By permission of Human Factors and Ergonomics Society.)
(accelerator response). This corresponds to many results from laboratory experiments that show that reactions are fastest at age 20 years or below, and get slower with age. However, older drivers moved their foot from the accelerator to the brake pedal faster than the younger group and thus compensated for their slower perception times, to such an extent that there is no difference in total brake reaction time. However, we can see further that the distribution of the younger drivers' response times is quite skewed, implying that some young drivers appear to delay their brake reactions. Although there are no steering data available from this experiment to support it, we can assume that some of the participant drivers were searching for an alternative way to avoid the obstacle, especially by steering around it (it did not fill the road entirely). This is an example of adaptive behaviour that is in line with the tendency to maintain progress and avoid speed deceleration.

**Higher goals modify driver reactions**

Interpretation of drivers' performance is not always possible unless we take higher motivational goals into account. While we found that driver brake reactions are typically dependent on available time (urgency of the situation), this is not necessarily the case in all kinds of driver task. In steering responses and lane changes, the situation is quite different. A partial or potential obstruction of the lane ahead appears to trigger a lateral shift in drivers at a similar latency independent of the distance (Summala, 1981). A probable explanation comes from the fact that lane change and lateral shift operations markedly differ from braking operations in that the latter mean slowing -- a condition that drivers feel as punishing. Thus they tend to avoid it. On the other hand, an early lane change may save a driver from slowing down when the lane ends and thus promotes unimpeded progress, and this is why it is reasonable to do it promptly, largely independent of distance. The upper-level motivational factor (maintaining progress) presumably explains two seemingly different behaviours.

**SPEED AND VISUAL SEARCH PATTERNS**

We saw above that driver behaviour in different situations is adaptive and serves a higher-level goal, unimpeded and speedy progress. Secondly we learned that at higher speeds drivers do not allocate attention to in-car tasks to the degree that they do at lower speeds. As a corollary to this, we may hypothesize that at high speeds drivers must be more selective when driving in more complex environments, that they do not spend as much time 'sight-seeing' as at low speeds, and that they must reduce looking at the road-side. Unfortunately, high speed drivers may also change safety-critical routines. Higher speed is expected to change drivers' visual search strategies, simply because they don't have sufficient time to look in all directions and search for all possible dangers. This was illustrated in the results of a study, described below, where we analyzed unalerted drivers' behaviour on the approach to a roundabout. The popular small-radius roundabout is a good design element, and safe in comparison to a normal four-leg intersection, because it has fewer conflict points for motor vehicles to collide, and drivers who approach it must look only to their left for other vehicles, making the driver's task simpler. Unfortunately, this may lead to unfavorable visual search patterns concerning cyclists and pedestrians. This is especially the case with a bicycle track that crosses the roadway.
immediately in front of the roundabout. Cyclists who come from the right and place trust in their priority may be at a very high risk.

In the study, which covered six roundabouts in three countries, we used a stunt bicyclist who approached the roadway either from the left or right on a collision course with approaching cars. Two video cameras monitored approaching drivers, one for speed profile and the other for drivers' head movements. We found that, as expected, drivers with higher speeds looked more to the left for prioritized vehicles and failed more often to yield to the cyclist coming from the right (fortunately the cyclist braked and stopped when he noticed that the approaching driver did not yield to him).

Figure 4. An experimental setup for studying drivers' visual search patterns and yield behaviour in a situation where a stunt cyclist approaches either from the left or right on a collision course. Reprinted from Rasanen & Summala, 2000, Transportation Human Factors, Vol. 2, p. 6, by permission of Lawrence Erlbaum Associates, Inc.
A similar situation occurs at normal street crossings where right-turning drivers look for vehicles coming from the left -- because there are no conflicting vehicles for them coming from the right. At these points they are likely to fail to observe pedestrians and cyclists coming from their right, just in front of the crossing. Speed is again an important factor. A speed bump just in front of a pedestrian/bicycle crossing forces drivers to slow down and, consequently, they have sufficient time to look both left and right and, what is more, if they do hit a cyclist, speed is low enough to reduce the likelihood of serious injuries.

**SPEED, TIME AND THE ACCIDENT PROCESS: A MODEL FOR CAR-BICYCLE CRASHES**

To highlight the role of speed and time in accident causation, as adaptively determined by cognitive and motivational factors, Figure 5 collects together a number of such factors that contribute to car-cyclist crashes at bicycle crossings.

The starting point is that driver behaviour is based on both knowledge of the traffic system that drivers have acquired through experience, and the goals and motives of driving that form the motivational basis of behaviour. These goals have a direct influence on speed choice and the tendency to maintain progress. They also influence (i.e. support selection of) schemas that guide visuo-motor performance: we look where we expect something important or productive to appear, in relation to our present goals (Theeuwes & Hagenzieker, 1993). As noted above, higher speed allows less time and therefore forces more selective visual scanning behaviour, informed by accumulated knowledge as to where dangers are expected to lurk. This process is called *top-down* detection, as it comes from knowledge (and motivational) structures. As reported above, it may lead to failure to detect a cyclist at all. In contrast, detection may be stimulus-driven, where the driver may fortuitously detect a cyclist through his/her peripheral vision or during an occasional glance in the general direction of the cyclist. Such *bottom-up* detection is often too late to enable appropriate reaction. Together with the tendency to maintain progress (avoiding slowing down), it may lead to a priority conflict, where the driver takes priority in violation of traffic regulations. In such a case, it usually depends on the cyclist whether a crash occurs or not.

Unfortunately, the cyclist's expectations may also fail, especially in the case of turning cars. The latter typically slow down, not in order to yield to the cyclist, but to make a controlled turn. This manoeuvre is often then wrongly interpreted by cyclists involved in crashes (Räsänen and Summala, 1998).

**SUMMARY/CONCLUSIONS**

For a responsible road designer and manager, it is safe to assume that drivers do respond to changes in road design and traffic management in line with their own goals and motives, which in turn may be in conflict with the designer's goals. It is proposed in this chapter that drivers adjust their reactions, time-sharing behaviour, and visual search strategies to the time available to them that is determined by speed, road width, curvature, and other design features.
Figure 5. A model depicting the major factors underlying a specific crash type, where a driver who approaches a roundabout or a crossing hits a bicyclist because s/he is looking for vehicles, not cyclists. Reprinted from Summala & Räisänen, 2000, Transportation Human Factors, Vol. 2, p. 31, by permission of Lawrence Erlbaum Associates, Inc.
Such behavioral adaptation tends to be counterproductive to safety. A famous scientist in traffic engineering, Reuben Smeed (1949) even discussed "a body of opinion that holds that the provision of better roads, for example, or the increase in sight lines merely enables the motorist to drive faster, and the result is the same number of accidents as previously". But he also continued, "there will nearly always be a tendency of this sort, but I see no reason why this regressive tendency should always result in exactly the same number of accidents as would have occurred in the absence of active measures for accident reduction".

We know now that Smeed was correct. Highway safety has improved drastically during the last decades in terms of serious accidents per driven miles, driver population, and even in absolute figures. Speed limits that were extensively introduced in the 1970's cut the tendency to raise speeds as a reaction to road improvements, thus making many kinds of improvements more effective (Summala, 1985). Along with new design features and improved traffic management, developments in vehicles' passive safety as well as medicine and emergency services, among others, have contributed to the positive safety development.

However, in designing and managing the road transport system for safe and fluid transport operations, road engineers should be aware of the adaptive nature of driving, and of the general tendency of drivers to react to changes in the traffic system in a way that is not always what designers intended.

**RECOMMENDED READING**


In this chapter, social psychological principles relevant for highway engineers are described. In what way is the content of social-psychology distinct from the content of psychology more generally? The answer lies in the definition of social psychology. Although there has been controversy and debate over the thrust, aims and definition of social psychology, the majority of psychologists operating in this field look favourably on Gordon Allport’s suggestion that their work is an “attempt to understand and explain how the thought, feeling and behavior of individuals are influenced by the actual, imagined, or implied presence of others” (1985, p. 3). The key point of the definition is that it stresses the influence of others on our own individual behaviour. Even when the individual is alone, behaviour may be influenced by perceptions of what others think s/he should do. And clearly, it also implies that our ways of thinking and acting are influenced by others when they are in our presence.

The impact of the wider group on the individual is an important concept for complex transport systems. Social psychology argues that on one level, the explanation for the behaviour of a single driver cannot be comprehensively analysed without viewing that driver as part of a broader group of drivers, continuously interacting and influencing one another. Therefore system design and construction must reflect this understanding and not be based on an erroneous model of humans as abstract rational actors, isolated from their social context and operating on purely ‘objective’ criteria. An interesting example of how the ‘social’ impinges on the ‘individual’ can be found in a study carried out in the 1950s. The researchers showed a video-recording of a particularly rough game between two college American football teams (Dartmouth and Princeton) to the students of the respective colleges. Supporters of each team were asked to comment on the match. The psychologists were amazed by the responses - the
Princeton fans reported seeing a constant barrage of vicious play by Dartmouth players while the Dartmouth fans saw a series of brutal attacks by Princeton players. In other words, the perception of the game, the individual’s response to the game, was first and foremost social. It was group membership, either as a Princeton or a Dartmouth fan, which was the primary influence on perception and the evaluation of the match. It was not the case that people simply or objectively ‘saw what happened’, rather the social context in which they operated and the influence of the others aided the construction of the particular perception they experienced.

In the rest of this chapter, the concepts and models, as well as the supporting empirical research, which have been proposed by social psychologists to explain and predict how the individual is influenced by others, will be outlined. Where possible, the specific relevance of those models and concepts for the highway engineer will be made explicit although this may be at times tentative since behaviour in a given research situation may not always simply transfer to other situations, such as driving. The first concept to be examined is that of ‘social facilitation’, a product of the classical pioneering era of social psychology, which continues to be instructive in research today.

**SOCIAL FACILITATION**

Can we say that people working together can produce more than if they worked separately; in other words is the whole greater than the sum of the parts? There is some evidence that this is the case and that an individual’s performance is enhanced by the presence of others. This has been observed in animals and humans. Chickens, fish and rats eat more if they are near other members of their own species who are eating. Dogs will run more quickly with other dogs than on their own and the same has been noted in horses. It has been shown that students in a class tend to cough more if other students are present and coughing. And people laugh more when others are laughing. During the industrial revolution, shoemakers were noted to work harder when other people were tapping in shoe nails as well. One of the earliest studies in social psychology reported that cyclists tended to go faster when they were being paced by a bicycle which was just ahead of them and they tended to record the slowest speeds when racing a clock on their own (Triplett, 1898). One obvious feature of the presence of others is rivalry when one goes faster in order to defeat the opponent, but it has also been suggested that a process known as social facilitation might be responsible. The idea behind this concept is simply that the visual or auditory presence of another provides an activating stimulus; thus two or more animals or humans together will provide a stimulus towards behaviour both to the other and to themselves, and in this way the rate of output increases. This phenomenon is most clearly seen again in cycling when there are races between two individual cyclists on a track. The normal situation for two cyclists with roughly the same ability is that the person who is ahead in the initial section of the course will be passed in the home stretch since s/he provides a visual and auditory stimulus for the cyclist behind but does not have this stimulus him/herself.

However in other situations, we find that the group or the presence of others can cause a deterioration in performance. This phenomenon is called social inhibition and a good example of this was in a study where subjects read various philosophic arguments to which they then had to think up and write counterarguments. Some of the subjects worked individually and
Social psychological principles

Some in groups. The arguments were evaluated independently by a panel of judges who obviously did not know whether the written counterargument came from the individual or group condition. The judges found the arguments produced individually were overwhelmingly better than the group ones. Another researcher found that subjects learning nonsense word syllables were more successful when working alone than when with other people. We can also find more subtle problems with group performance, especially in how a group fares with decision making. In 1961 the US government decided to send a small group of Cuban exiles to invade Cuba and overthrow Castro with air support from the US Air Force. The Bay of Pigs invasion ended with the Cuban army easily overcoming the invaders in a few days. While it is very easy in hindsight to say that a particular decision was very badly made, it has been recognised by most objective and unbiased observers that this was the case with the Bay of Pigs and that a no-hope mission was very foolishly supported. A psychologist examined all the available documents from this incident and concluded that at certain times a group structure may overwhelm the ability and intelligence of individual members of the group. This process, called ‘groupthink’, referred to the situation where people become so unbalanced by the consensus in a group of like-minded people that they lose a realistic view of the world; so rather than a group providing a stable way of thinking and more intelligent decisions than an individual, this is shown quite often not to be the case, particularly when access to alternative points of view are absent. Similarly, the process of brainstorming, where a group of individuals gather to try to solve problems in an alternative and effective way, has also proved itself to be of rather dubious use.

So how can these research findings be explained, when there are apparently different effects of the presence of an individual? Why does the presence of others sometimes lead to social inhibition and sometimes to social facilitation? An explanation for the apparent contradictory results mentioned above has been proposed. It has been suggested that the presence of others enhances performance on simple well-learned tasks, while on complex, novel tasks the presence of others acts as an impairing force. In other words social facilitation occurs on easy tasks while social inhibition occurs on complex tasks. This is explained in terms of the ‘dominant response’ which can be seen as the natural or almost instinctual response that a person makes in a certain situation. It is the main response in the person’s repertoire for that situation; for example clapping to music might be a dominant response in that situation, which a person could do almost automatically without thinking about it, while juggling would not. It is assumed that tasks which involve the dominant response undergo social facilitation. The presence of others causes arousal and when people are aroused they emit a higher level of the dominant response. On the other hand that higher level of arousal caused by the presence of others means that if the response required is not the dominant or usual or learned one, then social inhibition is caused. This explanation of the interaction between task novelty and impact of the presence of others, while it has been debated and fine-tuned, is broadly the accepted one.

Driving, while a complex skill to master at first, through practice becomes an automatic task in an individual’s repertoire. Therefore, while the novice driver’s performance on the roads is likely to be impaired by the presence of passengers or other motorists, the typical experienced motorist will experience social facilitation in these situations. This however does not necessarily mean a better driving performance - it is more likely that social facilitation will produce a greater rate of response of various motoring behaviours, for example speeding. Of
course, the individual driver may experience the influence of others in a more aware way than
the semi-instinctive model proposed through social facilitation. One of the major areas of
research in social psychology has been into the process of conformity and some of the most
famous experimenters have contributed to research on this topic. Conformity is also relevant to
the way in which people act and a summary of the concept is presented next.

CONFORMITY

In the previous section, the presence of others had an effect that might be called automatic. The
individual driver, in the presence of others, produced a higher output of the dominant response.
However there may also be more considered or self-aware responses to the behaviours of
others that the individual witnesses. The social psychologist Charles Lord has suggested that
one of the overarching themes which emerge from social psychological research is that people
have two main goals in their interaction with the social world - they want to be right and they
want to be liked and these goals are sometimes incompatible. The presence and behaviours of
other people in our environment can contribute to these goals depending on how we choose to
use that information. In essence, this is a decision we make about how we are to be influenced
by others. Psychologists usually distinguish between two types of influence, informational and
normative. These have quite different rationales as well as consequences and both types are
associated with a classic experiment in the body of social psychological research. It is worth
examining each in turn.

Informational influence

When making sense of our environment, we are sometimes faced with very ambiguous
situations. Because we want to be right, if possible, in the decisions we make, then in addition
to our own judgements, we may examine what others think or regard as appropriate in the
ambiguous situation. For example, if the speed limit on a stretch of road is 70 km/h but the
road is possibly icy, then we may decide to drive at 60 km/h. We may also seek to confirm the
validity of our decision however by examining the typical speeds of other drivers also on the
road. If they are driving at around 60 km/h, we may be satisfied that the correct decision has
been taken. However, if they are driving at around 70 km/h, we may wish to reassess our
analysis of the road danger. The experiments which confirmed the degree to which we rely on
others for information were carried out in the mid-thirties. The studies used a phenomenon
called the autokinetic effect which is the apparent (but illusory) sensation that a stationary
pinpoint of light in a darkened room is moving. Participants in an experiment were asked to
judge how far the pinpoint of light had moved after a certain interval of time. Individuals had
to make estimates alone first, where they soon developed a personal mean or average of
movement. These individuals were then brought together in groups and asked to make
estimates. They developed group means quite different from their original personal means and
tended to stick to these new group means quite rigidly. Even when removed from the group
and asked once more to make the assessments individually, they adhered fairly closely to the
group mean they had established. This confirms our reliance on the estimates and information
from others when faced with the need to be ‘right’.
Normative influence

However as was suggested above, we also have a need to be liked, sometimes at the expense of being right. This often means that we will say or do the right things so as to get along better with people in our environment. In order to maintain harmony, many of us, in different situations, are prepared to forego our own valid opinion. This phenomenon was elegantly demonstrated in a well known line-judging experiment. Individuals were presented with a series of slides. On each slide was a target line on the left and three lines on the right labelled A, B or C. The participant had to match the target line with the closest line in length from A, B or C. This task is not difficult and in a control situation, it was found that virtually no errors were made. However, in the experimental situation, it was designed so that individuals were presented with the line-judging problems as members of a group. All the other members of the group were in fact confederates of the experimenter who had arranged to give the incorrect answer on twelve trials. The real participant was placed second from last in group order and therefore had to first listen to the contradictory evidence of others before making public his judgement. It was found that more than three quarters of the people he studied conformed, that is gave the wrong answer, at least once and that over 60% gave the wrong answer on three or more slides. How is the evidence to be interpreted? It is sometimes suggested that since conformity occurred on less than half of all the experimental trials, that what had in fact been demonstrated was that people usually do not yield to normative influence. But this misses the point. In the study, there was absolutely no ambiguity about the correct answer and in interviews after the study, participants admitted that they had knowingly given the wrong answer. The power of this simple experiment is that it reveals the strength of group influence in a measurable way and this in spite of the fact that the group were unknown to the genuine subjects and had no access to any tangible penalty for dissent.

In terms of driving, this evidence allows us to imagine how much behaviour on the road is influenced by others. Returning to the earlier example above, how likely are individuals to drive more slowly in conditions that they know to be dangerous when everyone else is driving quickly? In the study cited above, the controlled environment meant that the subjects would be guaranteed protection from any group response more severe than mild displeasure or surprise. On the roads, other drivers may punish deviant behaviour with the use of gestures, the horn or even aggression. The individual driver may also be threatened with the stigma of being a ‘bad’ or ‘Sunday’ driver. Replications of the work indicate that conformity is culturally universal and may in fact be higher in some cultures outside the USA where the study was originally carried out.

The main lesson from the research on conformity is that those who design roads must remember they are not constructing systems for atomistic individuals operating with their own independent and separate values. Rather one must think in terms of individuals who are constantly monitoring their own performance as well as those of others and using these perceptions and reactions to assess what is appropriate and what is safe. They want to be right in the sense of being safe on the road and good drivers but they also want to be liked by other drivers and to match their own behaviours with their peers. The rules of the road are therefore not taken at face value but negotiated by groups of drivers.
NORMS AND IDENTITY

One problem with discussing conformity with reference to driver behaviour is that it appears to clash with our sense that there are many varied styles of driving on the roads and that psychologists must be able to produce models that capture diversity as well as sameness. It is true that driver behaviours do vary but psychologists have never confused conformity with uniformity. There are predictable differences among various groups of people and differential rates of accident variability. At first glance, these appear to have more to do with demography than psychology since age and sex are so heavily implicated in road accidents. However we should be aware of the important distinction between competence and actual behaviour. Competence on the road refers to the physical and mental capabilities of drivers and is at least partially determined by factors like attentional resources, information processing ability and reaction time. These in turn will be related to experience and also in a non-linear fashion to age. On the other hand, actual driver behaviour is partially determined by people's attitudes and norms. The high accident rates of young males may be caused not only by a lack of experience and exposure but also because their behaviour on the road reflects a set of risk-taking norms that they employ. In other words, there are not only issues of skill to consider when trying to make sense of patterns of road accidents but also issues around the ways in which drivers actually behave.

Let us consider the assessment of behaviour on the road more specifically. Reason et al. (1990) developed a 50 item self-report measure of driver behaviour called the driver behaviour questionnaire (DBQ) in which drivers were asked to report how frequently (ranging from 'never' to 'nearly all the time') they engaged in certain behaviours on the road. A factor analysis was carried out on the items. This statistical technique reduces a large number of items into a smaller number of composite factors. On the basis of this analysis and a further retest by Parker et al. (1995), these researchers distinguished principally between errors and violations. Errors were defined as "the failures of planned actions to achieve their intended consequences" (quoted in Parker and Manstead, 1996; 202) and included such items as misjudging the speed of oncoming vehicles when overtaking another vehicle. Violations on the other hand were "deliberate ... deviations from those practices believed necessary to maintain the safe operation of a potentially hazardous system" (ibid) and included such items as driving very close to the car in front in order to indicate to the driver that s/he should move over to allow the respondent to pass. In essence, the distinction between them captures the difference between unplanned but risky behaviour and deliberate risk-taking.

It was found that, not unexpectedly, less experienced drivers were likely to report a far greater frequency of errors. However, young and male drivers were disproportionally more likely to report higher levels of violations. The analysis by Parker et al. (1995) indicates that number of violations decreases more or less monotonically with age while males report significantly higher levels of these violations compared to females. This suggests that driver performance (his/her capability) and skill are not the only factors linked to accidents. Violations are deliberate cases of risky behaviour. This leads us back to the issue of norms. It appears that certain demographic groups, as a consequence of who they are, deliberately engage in certain types of behaviour. For example, Jessor (1987) found that risk-taking behaviour on the road is linked to risk-taking in other areas of life such as the domain of health where road violators are...
more likely to engage in drug use, general deviance, sexual promiscuity, smoking and alcohol use. West et al. (1993) also found that mild social deviance in general life is correlated with deviance in road behaviour and these in turn are linked indirectly to higher levels of road accident involvement (see also Chapter 16).

How do we summarise what is occurring here? What it suggests is that risk taking is often deliberate. Therefore accidents are not always or the consequence of unintentional risk-taking behaviour - rather they frequently arise when drivers deliberately engage in risky behaviour. Certain groups, especially young males, are primarily responsible for these violations and when added to their already low levels of experience and exposure, they figure disproportionally in road accidents. The problem seems to be that among the norms prevalent for young men is one of riskiness (see also Chapter 16).

Social psychologists have developed the term self-verification as a model for the way in which we interact and behave in front of others. Establishing a consistent identity is a challenge for all individuals and negotiating the environment without a consistent identity is problematic. To deal with this, it is suggested, we engage in behaviours which elicit verification for others of the kind of identity we want to have. For example if we wish to be 'sporty people' then this may involve not only visiting the gym regularly but also carrying about our sports gear and wearing sports clothes and carrying sports-branded bags in order to verify to ourselves and others that we are indeed sporty people. Similarly, with young males, establishing a consistent adventurous, risk-taking identity may involve verifying to themselves and others on the road that they are indeed the violators of 'petty' rules.

The problem for those trying to design safer roads and design out accidents is that such behaviour inevitably runs counter to attempts to increase safety. Since self-verification is about showing to oneself and others that one is a risky person, then improvements to the road environment to enhance safety may elicit riskier behaviour (such as increased speed) to reestablish the driver's identity as a risky one (see also discussion of behaviour adaptation in Chapter 13). It suggests that tackling safety issues on the road means working both on mental (or human) factors as well as on objective environmental factors, because the norms of particular demographic groups create a need to display deviance.

**Norms - not all bad**

So far, norms have been presented entirely negatively, as constructs that endanger individuals and need to be overcome. But this is not the only way in which psychologists model them and more often they are understood as buffers against negative actions. In particular, norms have been conceptualised by social psychologists as the key to blocking the expression of aggressive impulses. The dominant model of aggression was first outlined in the 1930s and called the frustration-agression hypothesis. According to this hypothesis, frustration occurs when people are unexpectedly blocked from reaching a particular goal. They respond to this frustration by expressing aggression, sometimes directed at the source of their frustration and sometimes displacing their aggression elsewhere when the source of frustration is too powerful. For example, people who lose their money in telephones and soft-drink dispensers frequently kick
the machine. Motorists blast their horns at the driver ahead when the car in front does not move after the lights have changed. Environmental discomfort can also decrease tolerance of frustration and hence increase aggression. More violent crimes (but an unchanged number of non-violent crimes) are recorded on exceptionally and uncomfortably hot days in Texas for example. Similarly, in a study of driver behaviour, the hotter the day, the more likely was a motorist to blast the horn at a driver not moving off on green.

However, these kinds of reactions are fairly primitive or immediate reactions to frustration and the evidence also suggests that often when we experience frustration, discomfort or pain, we are able to control our response and engage in an assessment of the situation (e.g., Was the pain caused deliberately? Did I deserve it?). Our norms about controlling our responses can also play a role and often we can control our anger (although we might feel very tempted to release it) because a very strong reaction might appear socially inappropriate. It is in this context that norms play a socially positive role.

Nevertheless there can be “a weakening or removal of inhibitions that normally restrain people from acting on their impulses”, a phenomenon termed ‘disinhibition’ (Lord, 1997, p. 515). Perhaps the best known example involves the use of alcohol which acts to disinhibit normal moral codes and under its influence there is an almost linear increase in people’s tendency to respond to a frustrating catalyst with aggression. In an appropriately motoring-based metaphor, it has been suggested that alcohol facilitates aggression not so much by “stepping on the gas but rather by paralysing the brakes”. The increase in riskiness and aggression on the road as a consequence of alcohol consumption is very well known in this context.

However the notion of aggression and its link to disinhibition of anti-social behaviour is best expressed in the term deindividuation. This refers to the way in which a person is said to lose much of their personal identity and values when part of a crowd. Deindividuation requires anonymity above all else. This may be provided by being in a large crowd, darkness or disguise and allows people to express impulses they normally would not. For example, the brutality of the actions of the white supremacist Ku Klux Klan have been linked partly to the hoods and robes which disguise their identity. In an experimental study, women wearing hoods and in relative darkness were found to deliver higher intended electric shocks than those with name tags operating in full brightness.

What implications are there for aggression on the roads by drivers? Driving, particularly under time pressure, is a potentially inherently frustrating experience especially where unexpected delays occur. Delays, exacerbated by the errors of other drivers, increase the potential for frustration. The media term ‘road-rage’, defined as uncontrolled anger or aggression between road users and sometimes involving violence and injury, reflects the commonness of frustration-aggression in this context. While it is true that attempts have been made to coin other domains of anger such as ‘air-rage’ and even ‘office-rage’ (directed, apparently, at computers), it appears that driving provides one of the most prolific sources of aggression mediated by frustration. Even the perception of poor roads, unclear signalling and unfairness of traffic-light cycle times might add to a sense of injustice for a driver and increase the potential for angry outbursts.
What can designers do to lessen this aggression? First, it is clear that increased discomfort contributes further to aggression and that the provision of air-conditioning and other car comforts can be of real benefit. Second, norms that drivers already have against hurting or abusing others must also be protected against disinhibition or deindividuation. Ways of stressing the identity and individuality of the driver could be developed such as increased visibility of drivers, personalisation of registration plates and perhaps also of the vehicle itself. These factors and others like them can enhance the positive aspects of the group inside the individual - remind her or (more usually) him that he is not just another driver on the road but the same person with the same morality as over breakfast with the family. Given the finding that people in disguise are also easier to aggress against, it is likely that tinted windows or sunglasses when not needed may weaken restraints on potential expressions of hostility. To sum up, the evidence on aggression suggests that drivers are protected from themselves and others by keeping them comfortable, individual and visible.

**CHANGING ATTITUDES AND BEHAVIOUR**

It was noted above that many of the undesirable aspects of drivers' behaviours arose as a consequence of deliberate or intentional acts (as opposed to uncontrollable errors from say lack of experience). The positive aspect of this is that it suggests it might then be possible to change these deliberate behaviours which are under volitional control. There have in essence been two approaches to promoting change in people by social psychologists and both approaches implicate the behaviour-attitude link. The first way involves changing individuals' behaviour with the anticipation of change in the corresponding attitudes relating to that behaviour, which should then sustain the original behavioural change in the long-term. This approach was first developed by Festinger (1957) who suggested that consistency is central to the person. People need to achieve consonance between their attitudes and behaviours. Therefore, if they engage in new ‘discordant’ behaviours, in order to avoid dissonance they will change their attitudes to bring them into line with the new behaviours. They may also need to justify to themselves why they are behaving in a new way (“I'm driving responsibly. Why is that? Maybe it’s because I'm a responsible driver”). Psychologists sometimes use strategies to persuade people to commit themselves to a set of behaviours (e.g., by placing stickers on their car windows or making a public verbal commitment to pursue a course of action). It has been found that the use of car stickers encourages both drivers and their passengers to increase seat-belt use and other researchers noted a substantial increase in seat-belt use with a method that employed both incentives to change behaviour and a personal commitment component.

A more common way to attempt behaviour change however seeks to change an individual’s attitude or feelings first with the assumption that behavioural change will follow from this. The prominent social psychologist Carl Hovland sought with his co-workers to model the process of informational influence on attitude change. The Yale school, as they were known, summarised the process as "who says what to whom with what effect in what context". In other words the key components they suggested that one should consider when evaluating the effectiveness of a message in changing behaviour are the characteristics of the message sender (or speaker), the message itself, the message receiver (or audience), the content of the message and the circumstances in which it was received and sent. Their work, carried out over a number
of decades suggested, for example, that more trustworthy and attractive communicators were more credible, that appeals for moderate attitude change are more effective, especially if the message is fear-arousing and that a medium like television is better for simpler messages while complex messages are more credible or comprehensible when delivered on paper.

Despite these conclusions, media campaigns focusing on driver attitudes often appear to have little or no effect in persuading audiences to change their behaviour. For example, Rothengatter et al. (1989) found that a publicity campaign alone was unlikely to change drivers’ attitudes towards speeding and that only when the threat of increased surveillance was included did drivers’ behaviour begin to alter (and then often without impacting in any way on their attitudes). A problem generally for public health campaigns, beyond the assessment of their efficacy, is finding any real effect after they have been completed. However we know that companies are willing to spend substantial parts of their income seeking to change people’s attitudes towards their goods and services and presumably then their behaviour, so why the skepticism about health messages? There are a number of reasons for this such as the specificity of behavioural change required and people’s mistaken optimism which will be dealt with in more detail. Furthermore, recent research proposes that there are two routes to attitude change. The first route is a peripheral one and here the individual attends to cues which are peripheral to the message such as the appearance of the communicator or the context in which the message is received. Any attitude change that does occur as a consequence of peripheral communication is likely to be temporary and/or superficial. People who are processing the information peripherally are likely to use short-cuts or heuristics rather than a systematic analysis of the communication. On the other hand, people may process information at a much deeper level. This is usually referred to as central processing whereby the person’s attention is entirely focused on the message and any attitude change that arises from this message is likely to be profound and enduring. Deliberation over the communication rather than short-cuts through it are typical in this latter mode of communication. What decides whether we process a communication peripherally or centrally? Cognitive psychologists suggest that human beings are ‘cognitive misers’ and like to avoid heavy intellectual processing demands unless the situation absolutely requires it. Only when a topic is of immediate personal relevance do we have the motivation to process it via the central route.

The consequence for road safety is that because we think safety messages are generally not relevant to us (see below for more information on these kind of biases), we tend to process them only peripherally and our attitudes, if changed at all, are changed temporarily and superficially. Those who are motivated to pay very close attention to messages about road safety already see the topic as having tremendous relevance and are unlikely to need to be persuaded further. In other words, road safety messages tend to preach to the converted. By corollary and perhaps more pessimistically, the consequence of Festinger’s proposal above of people’s need to be consistent suggests that the drivers least likely to attend to safety messages are the riskiest. The principle of selective exposure implies that we selectively expose ourselves to messages that affirm our behaviours and current attitudes and dislike information which makes us feel dissonant or inconsistent. In order to avoid dissonance, it follows, risky drivers will seek to ignore or downplay public messages which challenge their psychological balance. Since “I’m a speeding driver and want to stay alive” and “speed kills” are contradictory messages, the speeding driver will probably simply avoid processing the latter
message at any deep level and continue to engage in the risky behaviour.

**THE THEORY OF PLANNED BEHAVIOUR**

At the core of much social psychological research is the relationship between attitudes and behaviour, alluded to above. In the late 1920s and early 1930s, there was a tremendous sense of confidence that attitudes could be measured and accurate behavioural predictions made since if one knew people's attitudes towards certain objects, issues and behaviours, one could surely anticipate their behaviour. However, research began to be published which suggested that the behaviour-attitude link was not so clear-cut. One researcher travelled around the US in the early 1930s with a young American-Asian couple and frequented a large number of hotels and restaurants. He wrote to these establishments at a later point asking if they would accept guests of Asian (Chinese) extraction. Virtually all of the establishments that responded said they would refuse to accept 'Chinese' guests. Despite some flaws in the design of the study, it sounded a useful note of caution about assumptions of a universal direct link between attitudes and behaviour. Later work looking at the attitude-behaviour link in relation to exam cheating and on attitudes and behaviour towards ethnic minorities further challenged the degree to which the link existed. By the late sixties, it was hinted by some influential writers that social psychology would soon have to abandon its core concept of 'attitude' altogether.

The relevance of attitudes in social psychology has been maintained largely through the development of a new model by Ajzen and Fishbein (1977) and a reconceptualisation of the link between attitudes and behaviour. This model is known as the Theory of Reasoned Action (TRA) and it stresses the principle of compatibility. In other words, if one wishes to know the likelihood of someone engaging in a particular behaviour, one should measure the attitudes specific to that behaviour rather than general attitudes. A good example of this is given by Manstead where he suggests that "if one wants to predict whether or not adolescents will use condoms when having sexual intercourse, it is far better to assess their attitudes to using condoms when having sexual intercourse than to measure attitudes to condoms: clearly one can have positive attitudes to condoms in general, while at the same time having negative attitudes to using them oneself" (1996, p. 13). The Theory of Reasoned Action proposed that the best predictor of engaging in a behaviour was the individual’s intention to carry out that behaviour. The intention in turn was determined both by the attitude towards the behaviour (belief about the consequences of the behaviour and one’s evaluation of those consequences) and the subjective norm. This last is derived from what one thinks other people think one should do regarding the behaviour and also from how motivated one is to comply with other people, particularly those close to one. In summary, the model suggests that an individual’s intention to do something is determined by his/her evaluation of the likely consequences of the behaviour as well as what they think those who are important to them think they should do. Later Ajzen modified the TRA to take account of the role of habit and self-efficacy in determining whether individuals would would chose to engage in a certain behaviours. One might, for example, evaluate smoking as having very negative consequences and also have close friends and family who wish one to stop, and yet one might continue smoking. The problem, Ajzen suggests, is that the force of habit and the fear of not having the strength to desist could maintain the behaviour. This concept Ajzen (1988) defined as perceived behavioural control and he labelled
his revised model the Theory of Planned Behaviour (TPB).

Parker and her colleagues have examined the use of the TRA and TPB to make predictions about behaviours on the road (1992, 1995, 1996). In particular, they have looked at the determinants or predictors of certain driving violations. By identifying those factors distinguishing low and high violating drivers, they hoped that those beliefs and values underlying violations could be targeted in road safety campaigns. For all the violations examined, they found that the model's components all contributed significantly and independently to understanding or predicting intention to carry out the behaviour. These components included attitude to the behaviour (or a small set of beliefs about the consequences of a particular behaviour), subjective norm (or the beliefs an individual holds about the views of a small number of significant others about his/her performance of a behaviour) and perceived behavioural control (or the degree to which the individual felt the performance of the behaviour was under volitional control). The poorest combined variance for any behavioural intention was close following of another car (23%) while 47% of the variance of the intention to speed could be explained. Subjective norm was found to be particularly important in its association with seven of the nine driving violations investigated, suggesting that in order to make sense of and to potentially combat intentionally risky driving on the road, one must remember that the driver is heavily influenced by the expectations of others. Parker and Manstead (1996) note that age-related differences also emerged with regard to determinants of risky behavioural intention and that any road campaign must be sensitive to the age group it is targeting.

Parker et al. (1996) designed persuasive communications (videotapes) based on the TPB which were intended to target beliefs and values which their research had identified as important. After viewing the videotape intended to challenge normative belief, participants were found to have less favourable normative beliefs about speeding, while the tape targeting anticipated regret generated more negative general attitudes to speeding. This style of research by Parker, Stradling, Manstead and others shows that specific social psychological research models can be used to understand driver violations on the road as well as provide the basis for the development of designs for interventions in challenging risky behaviours.

THE CHALLENGE TO RESEARCHERS AND DESIGNERS - DRIVERS' INCURABLE OPTIMISM

The models outlined in the previous section, the TRA and the TPB, locate attitude as central in people's decision-making with regards to certain behaviours. This attitude in turn is defined within the tradition of behaviour analytic models - people do things at least partly because they evaluate the consequences as being of ultimate benefit to them - i.e. the process is to some extent rational. However, there is a different and powerful paradigm within social psychology which does not conceptualise human behaviour as necessarily rational. In fact, a lot of work looking at attributional biases highlight just how irrational humans can be. This is not necessarily a negative characteristic and can have psychological benefits. For example, a well known phenomenon is that of the self-serving bias whereby we highlight our own successes and abilities and downplay our failures. This has been shown to have very positive
consequences in protecting our self-esteem and there is some evidence that self-serving biases insulate people against depression for example. However, a problem arises when we fail to be sufficiently self-critical or to appreciate our flaws. Our undue optimism and self-serving biases are reflected in the way most people regard themselves as funnier than average, as better at getting on with others than average or even better looking than average. More seriously but also well known is the tendency of most drivers to regard themselves as better drivers than average. This is so pervasive that one study found that even drivers who had been hospitalised for their accidents believed themselves to be safer and more skilled than the average driver (Svenson, 1981). Young male drivers are particularly prone to this perception which runs clearly against the road accident evidence.

The problem for interventions such as mass media campaigns to change drivers’ behaviour is that the false optimism that most have (“I’m too good a driver” or “it won’t happen to me”) means they consider that safety advertisements are for other drivers, the bad ones who are below average. But when only 2% of drivers consider themselves to be below average (Reason et al., 1990), it is clear that few will be inclined towards behavioural change in the light of a mass campaign. McKenna (1993) has also examined the biased perception called the “illusion of control”, whereby people tend to believe they are far more in control of their environment than they actually are. He found that most drivers thought they were very unlikely to have an accident when they were driving but far more likely when they were a passenger. What really needs to be challenged is the sense that drivers have that as long as they are behind the wheel of a car, they can handle most eventualities and protect themselves. The problem is that, as was noted in an earlier section, because of our dislike for contradiction or dissonance, we tend to avoid information which challenges views and beliefs that we hold. Therefore through the media we use, through the topics we select and through the friends we select, our rosy world view tends not to be disturbed. This is because the psychological environment we have created does indeed appear to confirm our views, so that optimism becomes reality.

Another aspect of this self-serving thinking arises with the false consensus effect. This bias refers to the manner in which we regard our own views and behaviours as normal and common while contrary views and behaviours are regarded as deviant and extreme. Students in one study were asked if they would be willing to wear a sign advertising a campus restaurant and it was found that those who agreed thought that most others would agree also and that those who did not were frankly odd. Similarly Manstead et al. (1992) found that for a range of errors and mistakes, people who engaged in them regularly tended to rate their frequency among the general driving population as far higher than those who engaged in them far less regularly. This was particularly the case with the more intentional ‘violations’ rather than errors. This study shows that people have a tendency to assume their behaviour is similar to others, possibly because of the naive sampling technique which leads them to believe their own views are really the typical ones.

Bias in attributing causality is also important. Evidence suggests that populations in the Western industrialised world demonstrate a ‘fundamental attribution error’ or ‘correspondence bias’. This bias leads people to overestimate the personal or dispositional factors behind someone’s behaviour while underestimating the situational or environmental cues influencing behaviour. One key exception to the correspondence bias is when we are attributing the causes
of our own behaviour. The term 'actor-observer differences' was coined to describe the tendency we have to assume that our own behaviour is caused by factors in the environment or situational influence, while the behaviour of others reflects something internal or dispositional to the person. An example might be the belief that I got into a fight because I was provoked while he got into a fight because he is naturally aggressive. Baxter et al. (1990) examined the relevance of this bias for driving behaviour. They had participants read a number of short vignettes where the commission of a road violation was described. In some cases, the vignette was personalised so that the reader felt that s/he was the ‘actor’ engaging in the behaviour while in other cases the offender was presented in the third person singular so that the reader felt s/he was observing the act. Having read the vignettes, the drivers had to rank how likely the violation was caused by a number of possible contributory factors. The causes attributed in the 'observer' style vignettes were far more dispositional than in the ‘actor’ style ones and this suggests that while we may be prepared to forgive our own bad driving on the road (since we can see the situational factors leading to it), we are far more critical about the ‘bad’ or ‘stupid’ drivers we observe doing the same things.

**CONCLUSION**

The key message that social psychology sends to those considering designing an environment for drivers is that people are not only and simply information processors, despite the assumptions of more hardline cognitive psychologists. Above all, it must be remembered that humans are almost always motivated and are rarely disinterested. As was noted above, they are motivated to be right and to be liked. This means that they are almost always being influenced by others sometimes quite reasonably to seek information in ambiguous circumstances but sometimes, simply to follow what others are doing. The independent driver is a myth - everyone is monitoring their own behaviour and comparing it to that of others. Even when alone, we are carrying the views of others with us - this can be positive in that it may for example reduce aggression but it may also mean that some act in risky ways because they feel that others will expect them to. Rational messages directed at changing these negative behaviours often fail to work because people may deliberately avoid the message or fail to process it in any meaningful way. And ultimately most of us are both blessed and cursed with an overconfidence in our skills and abilities and our likelihood of overcoming risk. Road designers must bring home the potential precariousness of travelling at high speeds in little more than a metallic capsule, especially to the most self-assured.

**RECOMMENDED READING**

For readers seeking to pursue the themes developed in this chapter, the following provide more detailed information, on social psychology generally, and about social psychological factors related to behaviour on the road.


INTRODUCTION

Traffic accidents form a serious threat to the lives and health of children. In the seventies the truly epidemic aspects of the child traffic accident problem started to get attention on an international scale. In the Netherlands in 1972, for example, one third of child mortality between 5 and 14 years of age was caused by traffic. Dutch longitudinal statistics on fatal child traffic accidents indicate that the fatalities problem has been reduced considerably in the last decades: the number of fatally injured 0-11 year old children dropped from 366 in 1970 to 52 nationwide in 1994.

Nevertheless, the many children that are still injured badly in traffic every day form a problem with a strong emotional impact on children, their peers and their parents. A German study for instance, describes vividly the often long-lasting emotional effects traffic accidents and subsequent hospitalisation can have on children. All children studied showed behavioural disturbances and psychosomatic reactions. These lasted mostly from several months to 2 years, but often even longer. Poorer scholastic performance was very frequently observed as well as school-related anxiety, especially in children with school journey accidents.

In most countries, the blame for child traffic accidents was mainly placed on them, due to their supposedly unpredictable behaviour prior to the accident. In Sweden, however, Sandels (1975) in her famous and most readable book *Children in Traffic* pointed out that, in the light of the children's limited psychological abilities (see Table 1), it would morally be more appropriate to blame the parents, who should protect the children better, and the drivers, who should adapt their speed and attention to the children's behaviour. Several studies describe how inadequate parent protection often is and how inadequately drivers often behave towards children.
Furthermore, Sandels stressed society's moral obligation to make the environment safer for children. One of the aims of the present chapter is to help engineers to do just that. The question is what exactly can be done to prevent child traffic accidents?

One traditionally distinguishes three categories of intervention to further road safety: education, enforcement and engineering. Experiences with education of children as pedestrians (e.g., Rothengatter, 1981) and cyclists (Van Schagen and Brookhuis, 1994) are to some extent encouraging in that behavioural changes can be established both under test conditions and when playing outside unsupervised (Van der Molen, 1983). Establishment of the effectiveness of road safety education in terms of accident reduction is often difficult, but has been confirmed for large-scale child education programmes (Preussler and Blomberg, 1987). However, this does not mean that we can hope to transform young children into safe traffic participants.

Convincing drivers, who may be in conflict with children, to drive at low speeds in residential areas (and to watch out for children carefully there) is not an easy matter either. And although it is generally recognised that human error plays an important role in most traffic accidents, this does not mean that Education and Enforcement are 'the' proper cure; neither is Engineering, due to the fact that people react to changes in the system. Newly acquired road-crossing and bicycling skills through traffic education may, for instance, lead to increased traffic exposure, resulting in a higher traffic injury rate. Making a city bicycle path network may attract more bicycle kilometres that are more risky than driver kilometres. Nevertheless many design measures are reported to have considerable accident reduction effects (Underlien Jensen, 1998).

Countermeasures should be and are in fact developed constantly along all three lines: education, enforcement and engineering. What they have in common is that, whatever the type, successful development of a countermeasure depends largely on good analyses of the problems to be tackled and on evaluation of how people react to changes in the 'person-vehicle-road-environment' system. Methodologically sound evaluations and good cost-benefit analyses of the three types of countermeasures are essential. This chapter deals mainly with problem analyses, i.e., analyses of children's accidents, behaviour and abilities in particular traffic and road environments and offers only a few examples of solutions. It is hoped that after reading this chapter, the engineer will be better equipped to design and evaluate countermeasures as a result of more insight into the young road user problem.

**ACCIDENT STATISTICS AND ANALYSES**

**Aggregated accident statistics**

When children start to use a new traffic mode and their exposure to that mode also becomes high, a peak occurs, due to inexperience and lack of skill. After that peak the accident frequency drops again: partly due to more experience and skill, partly because the exposure to that traffic mode drops and is to an extent replaced by exposure to a new traffic mode. Thus road users experience a rolling peak of vulnerability as they proceed from pedestrian to cyclist to moped- rider to car driver.
Exposure to particular traffic modes at a particular age is greatly determined by the specific society in which a child is raised. Determining factors in The Netherlands are for instance that around the age of 12 children change from visiting a nearby primary school (often within walking distance) to bicycling to a secondary school, often at a considerable distance. At the age of 16 they are allowed to drive a moped and at age 18 they are allowed to start to take driving lessons, which may take a year or so. The accident peaks in 1991 were at age 7 (pedestrians), 12-15 (bicyclists), 16 (moped riders) and 21 (drivers).

As society changes, these peaks may change: in 1972 in The Netherlands the peak for injured pedestrians was very prominently apparent at age 6, because at that time, children generally started at that age to go unaccompanied to primary school, whereas they were mostly accompanied by their mothers to kindergarten before that age. Today however, kindergarten and primary school are integrated and exposure develops more gradually.

Statistics for injured children may also differ considerably from statistics for fatalities. In 1972 the fatality peak for Dutch pedestrians was not at age 6, but at age 3-4; for bicyclists it was not age 12-15, but 7-14. It would appear that fatality peaks occur at a lower age than non-fatal injury peaks, perhaps due to greater vulnerability at a younger age, just as elderly people are more vulnerable at an older age.

The scarce international literature on children's exposure to traffic as pedestrians shows that, apart from age, there are large influences of gender (boys being much more exposed), the type of residential quarter and road type, time of year and car ownership in the family (van der Molen, 1981). It is therefore not surprising that aggregate accident data elsewhere sometimes show very different patterns. An American study from 1985 for instance, reports for child pedestrian injuries in Massachusetts (USA) a female peak at age 6 (as in The Netherlands in 1972 for all children) but for boys the peak started at age 3 and remained at a high level until the age of 13. As found everywhere, boys were much more involved in accidents than girls, probably partly because of their higher exposure.

It should be clear that if countermeasures are considered in a particular country or city, it is important to establish some aggregate statistics for each traffic mode, giving a global idea of the problem at a given age. And the analysis should be representative in time and place in relation to where the countermeasures are to be applied. In this respect it is noteworthy that accident data based on hospital intakes may give an entirely different picture from accident data based on official police records. Accident data obtained by interviews give again an entirely different picture. This problem will be examined in later sections.

**Detailed accident analyses**

The aggregate statistics discussed above do not show us clearly where, how and why the accidents occur and under what circumstances. More detailed accident analyses are therefore needed before countermeasures can be developed sensibly. Snyder and Knoblauch (1971) developed a set of
descriptive models which enable accident studies to search for answers to the following three questions:

1) how do accidents occur? (i.e., what goes wrong in the function/event sequence?)
2) why do the accidents occur? (i.e., what are the predisposing factors?)
3) what other relevant circumstances are there? (i.e., what other target group variables are there?)

A generalized function/event sequence was developed to address the first question. Snyder and Knoblauch consider a traffic accident between a car and a pedestrian (or a bicyclist) as the outcome of a process described as two parallel sequences of information processing and actions by a pedestrian and a driver, who happen to be on a collision course. This model implies that the mere presence of a pedestrian and a driver during a certain period in a particular environment will lead to a collision only when several conditions are satisfied during the process: 1) a collision course if no avoiding action takes place, and 2) the information processing and action sequences of both the pedestrian and the driver fail to result in proper avoidance actions. Failure at any step, or inadequate timing are considered to be "precipitating causes" of the collision (see Figure 1). However, many factors may influence the sequence of events and thus, indirectly the occurrence of a collision.

Four classes of predisposing factors could be distinguished: those concerning the driver, the pedestrian, the vehicle and the environment. In order to facilitate countermeasure identification, the authors developed a causes and countermeasure model.

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Figure 1. Aspects of causal type (Snyder and Knoblauch, 1971)
This model helps to describe causal types, i.e., groups of accidents which are similar with respect to precipitating events, predisposing factors and target groups (human populations and/or kinds of physical behaviour involved in a given type of accident, as shown in Figures 1 and 2). The authors indicate that predisposing factors must be environmental, human or vehicle conditions that actually lead to function failure, while target group variables include environmental, human or vehicle conditions that are only associated with accident involvement. Countermeasures can operate in three ways: (1) reduction or elimination of the predisposing factors or (2) of the precipitating event directly and (3) the interposing of a countermeasure in such a way that precipitating action no longer leads to a crash. Snyder and Knoblauch's models were developed for pedestrian accidents but they can and have been used for car-bicycle and car-car accident analyses as well.

An example of a causal type: accidents of young pedestrians near parked cars

In order to familiarise the reader with these models a concrete example is presented here. In 1975 and 1976, 35 children below the age of 6 were involved in pedestrian accidents in the city of Groningen. Seventy eight per cent of them walked or ran into the road suddenly from behind a parked car.
Figure 3a. Five year old children are unable to perceive oncoming traffic when standing on the pavement or on the kerb

Figure 3b. Only at the outer edge of the parked car can such a child see oncoming traffic and can s/he be seen by this traffic
Function/event sequence. The children did not look for potential danger areas, or if they did, they nonetheless did not perceive the oncoming vehicles; they did not perceive any danger and therefore did not perform any evasive action; the drivers did not look for potential danger areas; or did not detect the children in time; once they had recognized the danger it was too late to perform a successful evasive action, because time is needed to decide and to react and because the braking distances of the vehicles were too long.

Predisposing factors. A predisposing environmental factor was the presence of parked cars; a child factor was his or her lack of height and a vehicle factor was its speed. Figures 3a and 3b clearly illustrate that a child of about 5 years of age is unable to perceive oncoming traffic when standing on the pavement or at the kerb; only at the outer edge of the parked car can such a child see oncoming traffic and can s/he be seen by this traffic.

Target group variables (see Figures 1 and 2). Target group variables were young drivers (who are involved most often), kindergarten children (who are involved most often), parked cars and older parts of the city (where these types of accidents occur most frequently).

Whereas the aggregated accident analyses can show us globally where problems exist, i.e., which age groups, which particular traffic modes, and which locations, the causal type analyses can give clues as to how to attack specific accident types. This is what Snyder and Knoblauch did and described in the 2nd volume of their report.

The establishment of causal types and analyses of precipitating factors and predisposing factors can be carried out at very different levels of sophistication. The level is very much dependent on the level of detail of the available accident data and also on the amount of insight the analysts have into traffic behaviour and into the mental abilities and limitations of the traffic participants. The next part of this chapter is aimed at improving that insight.

**YOUNG PEDESTRIANS**

**Child pedestrian accidents**

The frequency and prevailing causal types of child pedestrian accidents depend very much on gender, age and the circumstances a child is living in. Therefore, an engineer, seeking solutions for these problems, should try to find aggregate and disaggregated accident data that relate specifically to the locations and road users the solutions are to be designed for. Ideally this information should be supplemented with relevant behavioural information about the children and the drivers involved, the latter from accident reports or from separate observation studies in relevant locations and circumstances. Depending on the problem to be solved, the relevant level of analysis may vary from a particular school exit or particular street or school route, to a particular residential area, a city or an entire country. The causal type analysis presented above can always be applied, however.
From an earlier Dutch study of child traffic accidents (van der Molen, 1981), the following variables emerged as contributory factors:

**Predisposing factors**

- **Neighbourhood characteristics**
  - The differences in child pedestrian accident rates (per 1000 children living there) may vary enormously between city areas and also between different neighbourhoods in a city area.
  - We generally found the safest areas to be at the outer edges of the cities, mostly modern neighbourhoods. The most dangerous areas in Dutch traditional cities were those around the city centres, often built shortly before or after World War II, but not yet designed to accommodate the many parked cars of our time.
  - The accident rate per child living in a street increases when the vehicle intensity increases.
  - Accident rates in cul-de-sacs (up to 80 houses long) were relatively low. The shorter the cul-de-sac, the lower the accident rate.
  - Few play facilities and few or small gardens cause children to play outside on the pavement and during play they often dash out from between the cars parked alongside the street.
  - A lack of availability of playgrounds correlates with accident involvement in several studies.

- **Visual obstacles**
  Visual obstacles, most often parked, standing or moving cars are very much involved in accidents (in many studies 40 - 50%) and the more so the younger (and shorter) the children. The percentage of obstacle-related accidents generally peaks around age 3-5.

- **Playing on or near the roadway**
  The percentage of accidents while playing actually on the roadway is generally found to be very low, mostly only a few percent.

- **Journey purpose and school journeys**
  Only a minority of accidents occur while children are 'at play' (in the normal sense of the word), this even with the younger ones (although there is an age effect: younger ones were more frequently playing). Most of them, however, are on a particular journey to or from home, school or elsewhere. Most studies indicate that school age children experience 25-33% of their accidents on their way to or from school.

- **Stepping out of cars and buses**
  In our review we found that 2-3% of child pedestrian accidents in The Netherlands were related to bus stops and 2% while leaving a stopped car. The 6% found by Grayson (1975) in England varied strongly with age: being 13% for the 10-14 year age group, mostly when leaving a bus.
• Time of the accidents and weather
In Amsterdam about half the number of child traffic accidents, reported in 1975, occurred at the morning, noon and afternoon rush hours. Several studies report about 5% of the accidents occurring at dusk or darkness and 5-7% during adverse weather conditions such as snow, hail, rain, mist and glazed frost.

• Road types and vehicle intensities
Despite an increasing radius of action with age, child pedestrian accidents are often associated with low traffic intensities.

• Intersections
The importance of intersections as a problem varies with city size, rises with age of the children, and is also dependent on the definition of an intersection.

Accident event sequences

• Dashing out into the road
In The Netherlands, the most frequent (approximately 70%) causal type of child pedestrian accident is dashing out into the road (whether or not from behind parked cars or obstacles) as compared to playing on the roadway, leaving cars or buses or other pedestrian manoeuvres. Children dashing out are often running, not looking out well or not at all and often appear before the driver from behind a visual obstacle.

• Not stopping before crossing
This is a common aspect of child pedestrian accidents and more so for younger children and boys.

• Not looking out before crossing
Grayson (1975) interviewed accident-involved children and found the following. A complete lack of attention (child did not look at all) decreased with age: 0-4: 82%, 5-9: 62% and 10-14: 37%. This happened more with boys (62%) than with girls (50%), less when a child was alone and more when it was running. A partial lack of attention (child looked but did not see vehicle) increased with age: 0-4: 10%, 5-9: 29% and 10-14: 48%. This happened more with girls (41%) than with boys (26%). Misjudgement (child had seen the vehicle before starting to cross) increased with age: 0-4: 4%, 5-9 and 10-14: 8%, but this was the least frequent cause. Some form of distraction could be identified in 28% of the accidents with 0-4 year olds, but only in 4% of those with 10-14 year olds. Grayson found that a complete lack of attention occurred more often on minor than on major roads.

• Running across
This is a very typical aspect of child pedestrian accidents. Grayson (1975) found in his study that the percentage of accidents in which children had been running across is high and decreased with age: 0-4%: 87%, 5-9: 85% and 10-14: 71%. Boys (86%) had been running more often than girls (75%). In the Skandia study at pedestrian crossings, 60% of the accident-involved children crossed while running.
• Traffic lights
In Sweden, in 1971, the Skandia Insurance Company analysed 30 accidents with traffic lights: 11 times the car went through red and in 5 cases it made a turn through green, while the child had a green light as well. In 15 cases the child walked through a red light. So it appears that traffic light systems should be designed carefully and should avoid giving a green light to possibly conflicting parties.

Child pedestrian behaviour

Child pedestrian behaviour is influenced by many factors. These influences have been reviewed in considerable detail by Van der Molen (1981). As will appear below, traffic intensities have an important influence on traffic behaviour. Generally speaking, child pedestrians behave 'safer' and more normatively when growing older and girls perform better than boys. For a young child to become a proficient pedestrian requires a complex learning process comparable to learning to drive for adults. The complexity and scope of pedestrian tasks has been described by Van der Molen et al. (1981) in their Pedestrian Task Analysis. The scope of this chapter does not allow description of child pedestrian behaviour of all age groups in all tasks. However, how pedestrian behaviour in some basic tasks develops with age can be illustrated by comparing the behaviour of 4-6 year old children with that of adults. Such young children are generally only out alone in relatively quiet streets, not far from home, where it is also where they become involved in accidents. In such quiet streets, unaccompanied children were unobtrusively observed on their way to or from Kindergarten or when playing outside (Van der Molen, 1983). The average traffic intensity in those streets was 30 veh/h, varying from 2 to 200 veh/h. Adults crossing in those streets were observed as well. We wanted to see to what extent children and adults behaved according to a model, proposed by Firth (1982), based on observations in Great Britain in much busier streets.

According to this model adults look both ways during approach to the kerb. They do not stop there and use gaps in the traffic stream cleverly, when walking calmly across. Children do stop at the kerb, look both ways and wait until no more traffic is approaching. Then they cross at a run. However, when we analysed these British studies ourselves, it appeared that for adults the model
Young pedestrians and cyclists

only held in streets quieter than 200 veh/h. In busier streets they did stop at the kerb, often waiting for a suitable traffic gap. Children waited for larger gaps than did adults.

One striking difference between adult and child behaviour, observed in our studies, was that the behaviour of adults was strongly determined by dynamic traffic aspects (i.e., the momentary presence of approaching traffic) but that the children's behaviour was strongly determined by static traffic aspects (i.e., the average traffic intensity in a street). In very quiet streets (less than 1 car/minute), the children seldom (25%) stopped at the kerb. And they seldom (25%) looked out before crossing. The majority of the children paid hardly any attention to the road and their behaviour was not influenced by approaching traffic. In the busier streets (more than 2 cars/minute), however, most children stopped at the kerb and looked out well there, even if no traffic was approaching.

Can children be trained or educated to become better road users in this respect? Large scale applications of child education programmes in the UK and USA have resulted in significant accident reductions in 3-8 year old children (Preusser and Blomberg, 1987). Statistically significant accident reductions were also reported after installing a pedestrian education programme for 6-7 year olds in Atlanta (USA). However, even when education and training of children leads to improved behaviour and accident reduction, this still does not mean that children can be transformed into safe traffic participants: less unsafe is probably the best we may hope for. As will be outlined in the next section, their abilities are too limited in many respects.

Driver behaviour when facing child pedestrians

In a study on conflict avoidance behaviour of drivers in residential areas in Osaka, it was concluded that "drivers usually do not attempt to avoid other traffic participants except when these are crossing in front of them". In line with these findings a study in Nottingham (UK) presented a gloomy picture of driver behaviour in the presence of children. No speed reduction was observed when children were waiting at the kerb to cross, neither was any avoiding action (such as slowing down or veering away) taken unless the child was closer than the stopping distance of the car.

There appear to be four problems with drivers in residential areas: a) they are not sufficiently conscious of the chance and possible severe consequences of colliding with a child; b) they drive too fast given the circumstances and c) pay too little attention to detecting children, and d) when they detect children they too often expect that they will behave safely.

CHILDREN'S ABILITIES AND LIMITATIONS IN TRAFFIC

In order to assess the mental and behavioural demands in traffic for children, elaborate analyses have been made of the extent and contents of all conceivable pedestrian tasks (Van der Molen et al., 1981) and bicycle tasks (Brookhuis et al., 1988). These analyses describe not only the behaviours in particular circumstances that are required for safe performance, but also the necessary knowledge, psychological abilities and judgemental, decision making and motor skills,
necessary for safe performance. The next step was to try to establish which abilities are or can become present in children of a particular age range.

When considering this matter, three important issues must be taken into account. In the first place, children differ with respect to the age at which certain abilities are fully developed. In the second place, (guided) learning can lead to improvements in abilities and in spontaneous performance. Because of that, children may - after proper training and/or through more experience - show abilities and certain behaviours at an earlier age. In the third place, one must realise that, when children have learned certain abilities or behavioural procedures, and can demonstrate these when tested by a trainer or parent, this does not necessarily mean that the child will perform likewise when out alone in the street. In view of the three important issues mentioned above, the figures reviewed by Vinjé (1981) and later empirical research by her and others, should only be used as a global indication of what children may be capable of at a certain age.

Knowledge of traffic concepts and traffic rules

Four to six year olds have limited knowledge of traffic concepts. 'Traffic' does not necessarily include cyclists. 'Street' sometimes means roadway, sometimes includes the pavement. Left and right have not yet always been sorted out. Procedural knowledge is often lacking: proper crossing often means to them running across. Until age 7, it is more important to teach procedural knowledge (when to do what) than formal rule knowledge, which children cannot yet handle well. Children can be taught gradually the use of some simple pedestrian facilities such as crossing sites with good visibility and a safe route to school. Children under 11 seldom showed sufficient knowledge of priority rules to be considered safe when bicycling.

Information processing speed

Information processing abilities develop until about age 15. There are always qualitative and quantitative differences with adult performance. Qualitative because children often lack knowledge of signs, rules and proper procedures and (until about age 11) because of a lack of ability to focus on the relevant information by being easily distracted. There are quantitative differences as well: children have a smaller memory capacity and longer reaction times due to lack of availability of all relevant information. This holds also for secondary school children when in complex or unknown situations on a bicycle or moped. Reaction time to visual or auditory information develops from age 3 until 16. The amount of information children can store in short-term or working memory (i.e. what can be held in mind at any moment in time) improves considerably around age 10-12.

Attention and distractability

For safe behaviour, children need to be able to focus attention on what is important, but often they must also divide their attention on different task aspects. Four year old children can focus attention on one task aspect, but dividing attention on various task aspects becomes better with age. The
most important impediment to safe performance, however, is the distractability of young children. And this does not improve well with age. Children age 10 are hardly less distractable than 4 year olds and resistance to distraction develops up to about age 15. Boys are more distractable than girls. Distractibility becomes less when tasks become easier. Tasks can be made easier by training relevant skills or by better engineering. Motivations other than road crossing are often a predisposing accident factor as they distract the child from the road crossing task. When children are distracted while performing a certain manoeuvre in traffic, their attention is drawn from that manoeuvre to whatever distracts them, while they continue to carry out the locomotor part of the manoeuvre. Distraction constitutes much more of a danger to safe performance than poor basic perceptual and judgemental abilities.

Risk perception

Vinje studied children's risk perception by showing them filmed traffic scenes in which children were involved. When a film scene was suddenly stopped, children were asked what they thought might happen next. The results suggest that children may not always cross safely because of lack of sufficient risk perception, although children age 5 can perceive and anticipate at least some risky traffic situations. Another example is given by Ampofo-Boateng and Thomson, who found that young children were very sensitive to the presence of cars. They would regard a potential crossing site as dangerous if moving cars were visible in the vicinity, even when moving in the opposite direction. Unfortunately, when no cars were immediately visible, children showed a strong tendency to judge the crossing site as safe. Thus, the brow of a hill, a sharp bend in the road or a site where visibility is limited by obstructions, were almost always regarded as safe places to cross the road. Young children only take into account directly visible dangers and they learn to anticipate dangers, only gradually. Thomson, for example, found that only around nine years did children begin to appreciate why a sharp bend or the brow of a hill are dangerous places to cross the road.

Insight into spatial relations around obstacles

Four to five year-old children do not sufficiently understand who or what is visible for whom behind visual obstacles such as parked cars. This lack of insight may lead to choosing inappropriate crossing sites, as has been demonstrated in a study by Demetre and Gaffin. They took 6-year-old, 8-year-old and 10-year-old children to a road and asked them to select one of two equidistant road-crossing locations: one that provided a clear view of oncoming traffic, and one that involved stepping between two parked cars which largely occluded the child and oncoming traffic. The 6-year-olds were essentially random in their choices, 8-year-olds showed a significant preference for the location without parked cars (though highly dependent on their - independent - road crossing experience), and almost all 10-year-olds selected the location without parked cars.

Gap acceptance

Taking an adequate crossing decision and choosing a sufficient gap in the traffic stream remains difficult under the age of 8. Estimating when an approaching car will be nearby is based more on
distance judgement than on speed judgement, which might be dangerous when cars drive unusually fast. Younger children making road crossing decisions generally wait for larger traffic gaps than adults and thus seem to compensate for less skill.

Table 1. Development over the years of abilities and skills that are necessary for safe pedestrian and cyclist behaviour. Figures in the table indicate at which age a particular function or ability is expected to be present in 50%, 50 - 85% or more than 85% of children, based on experimental studies

<table>
<thead>
<tr>
<th>Presence of function or ability</th>
<th>&gt; 85%</th>
<th>50 - 85%</th>
<th>&lt; 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>visual perception</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. peripheral vision</td>
<td>8/9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. movement perception</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. color perception</td>
<td>4/5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>continuing visual search after a car has passed by</td>
<td></td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>auditory perception / location</td>
<td>4/5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>insight in spatial relations</td>
<td>8/9</td>
<td>6/7</td>
<td>4/5</td>
</tr>
<tr>
<td>choosing a crossing site away from parked vehicles if such a site is equally nearby</td>
<td>10</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>making a crossing decision in the presence of traffic</td>
<td>8</td>
<td>6/7</td>
<td></td>
</tr>
<tr>
<td>distance estimation</td>
<td>8</td>
<td>6/7</td>
<td>5</td>
</tr>
<tr>
<td>speed estimation</td>
<td>9/10</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>perception and anticipation of risk</td>
<td>9/10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>identifying a safe place to cross (without training)</td>
<td>10/12</td>
<td>8/9</td>
<td>7/8</td>
</tr>
<tr>
<td>same (after training)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>motor skills</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>stopping (as pedestrian)</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bicycling without starting to sway:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- decelerating</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- keeping a straight course</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- stopping</td>
<td>8</td>
<td>7</td>
<td>5/6</td>
</tr>
<tr>
<td>- looking backward</td>
<td>10</td>
<td>8/9</td>
<td>5/7</td>
</tr>
<tr>
<td>- signalling</td>
<td>10</td>
<td>8/9</td>
<td>5/7</td>
</tr>
<tr>
<td>(= bicycling with one hand on the handle bar)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- bicycling slowly</td>
<td>13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Attentional functions and information processing capabilities will keep on developing until the age of 15. It is difficult to say when these are developed sufficiently for safe traffic participation. Both functions are, like motivation, strongly associated with accidents.
**Motor abilities**

Important is the ability to stop and to suppress the impulse of walking or running ahead. This ability is not present sufficiently below the age of 6 (i.e., in less than 85% of the children) and is nearly absent at age 4. Even in a bicycling country like The Netherlands, experiments show that, until age 9-11, basic motor bicycling skills could / should be improved by training.

**YOUNG CYCLISTS**

**Child Cyclist accidents**

In many European countries, children's bicycling exposure increases dramatically at age 12, when they commence going to secondary school, often at considerable distance from home. During these trips they are probably confronted with many novel traffic situations. Pedestrian and cyclist accidents are greatly and disproportionally underrepresented in police statistics compared with hospital records and these are only the "tip of the iceberg" as there is a large number of accident victims that do not need hospitalization.

**Manoeuvres.** Accidents involving bicyclists are often categorized in several main categories (in this chapter right-hand driving is taken as standard; readers from the UK, Australia, Japan and other countries driving on the left must therefore take this into account). The Dutch bureau of statistics has used the following categories:

1. Crossing traffic (i.e., coming from 2 different roads at an intersection)
   1a) both parties driving straight ahead
   1b) party coming from the right turns left

2. Overtaking traffic (one party coming from behind)
   2a) both parties driving straight
   2b) the party being overtaken turns left
   2c) the overtaking party turns right

3. Meeting traffic on the same road
   3a) both driving straight (head-on collision)
   3b) one party turning left (for instance at a T-junction)

4. Collision with a stationary object or with a person
   4a) with a stationary object
   4b) with a pedestrian or animal

5. Bicyclist dashing out of an exit

6. Single bicycle accidents (skidding, falling etc.).
The Dutch statistics bureau has described how often Dutch children became involved in (officially recorded) fatal and non-fatal accidents of the above categories in 1978. We will refer to these data when discussing the different categories below. For all 6 categories the total number of accidents were for age 0-4: 111, age 5-9: 1030 and age 10-14: 2550.

1. Crossing traffic (i.e., coming from 2 different roads at an intersection). In The Netherlands, this category involved approximately 30% of all child bicycle accidents, with no apparent age trend.

2. Overtaking traffic (one party coming from behind).
   2a) both parties driving straight.
   This category involved approximately 16% of all child bicycle accidents in The Netherlands: age 0-4: 18%, 5-9: 11% and age 10-14: 18%. Trucks and trailers are overrepresented in fatal accidents of this category.
   2b) the party being overtaken turns left and 2c) the overtaking party turns right.
   In The Netherlands this category 2b + 2c together involved approximately 15% of all child bicycle accidents. It generally is the bicycle turning left that is hit from behind and - less frequently - the car turning right hitting the bicycle going straight: in a total of 25 fatal Dutch accidents with 0-14 year old children in 1972, 20 belonged to category 2b and only 5 to category 2c.

3. Meeting traffic on the same road.
   3a) both driving straight (head-on collision).
   In The Netherlands this category involved approximately 8% of all child bicycle accidents.
   3b) one party turning left (for instance at a T-junction).
   This category involved approximately 17% of all child accidents in The Netherlands. The main problem here is bicyclists turning left in front of the oncoming car.

4. Collision with a stationary object or with a person or animal. In The Netherlands this category involved approximately 8% of all child bicycle accidents.

5. Bicyclist dashing out of an exit. In The Netherlands this category accounted in 1972 for about 6% of fatal bicycle accidents until age 14.

6. Single bicycle accidents. This category comprised approximately 7% of all officially recorded child bicycle accidents. In the age group 0-4: 14%, 5-9: 7% and age 10-14: 7%. No fatalities were reported. However, large numbers of cyclist accidents not involving any other vehicle go unrecorded in the accident statistics. Children often lack sufficient manoeuvring skills up to 10. According to a Canadian study from 1970, young children age 5-9 often lose control or fall and the fall-accident risk increases by as much as a factor of 5 for children who cannot properly reach their pedals.

Children as bicycle passengers. The number of children officially recorded as injured bicycle passenger can be estimated at about 6% of all child bicycle accidents.

The driver's point of view. Drivers often complain about the unpredictability of the behaviour of bicyclists. Poor visibility of bicyclists is also mentioned often, especially at night and during rain.
Not only cars collide with bicycles. In Amsterdam, 20% of bicycling accidents, reported in 1975, were with other bicycles and 14% with mopeds. A British study from 1988 reports that about 10% of hospitalised bicycle riders in Oxford clashed with another bicycle.

As regards the state of the art pertaining to child bicycling accidents, there are many data available on the accident sites and manoeuvres involved (as outlined in this section), but information about the function-event sequences leading to the accidents is scarce. The most frequently established causes and relevant behaviours are the following:

- approaching an intersection at too high a speed
- insufficient watching out for approaching traffic
- poor estimation of the chances of conflict
- poor perception by cyclists of the degree to which they hinder other traffic
- wrong position on the road
- faulty assumption that no other traffic is approaching
- not noticing relevant (priority) signs.

From behavioural studies (see next section) it consistently appears that bicyclists look around insufficiently, especially to the rear. Signalling with their arms to indicate a directional change is rare. Looking and signalling is done more for left turns than for right turns and straight crossings, seldomly when swerving around parked cars. Children display more normative behaviour (e.g., slowing down, looking out and giving a signal) in traffic situations that are more busy or complex. The next section will deal in detail with some behavioural studies and the effects of age on child bicycling performance and possible links with accident involvement.

**Young cyclists' behaviour**

According to several studies at the University of Groningen (The Netherlands), child cyclist behaviour appears to be governed by several general principles. Cycling behaviour of children 12 years and older is primarily led by energy-economy principles such as not stopping and choosing the shortest course, a minimum of necessary actions and narrow safety margins. This group uses its own criteria about traffic rules and seems to trust that these are respected by other road users. Young bicyclists up to 12 years of age behave somewhat more carefully but also give the impression that they rely on the anticipating skills of other road users.

**Keeping a straight course.** Fifty per cent did this insufficiently and swayed excessively. There was improvement with age. Boys performed worse than girls.

**Keeping a right hand distance to the pavement shorter than 1 meter.** Forty three per cent rode further than 1 m from the pavement. There was an improvement with age (to 32% in the 15-18 year group). Boys were worse than girls. In young children there is a positive correlation between not following a straight course and driving too far from the pavement.

**Bicycling speed.** As bicycling speed determines the amount of information that one needs to process mentally per second, bicyclists should move more slowly when the situation becomes more complex, especially when they are less experienced. During approach to an intersection, speed at
10 meters from the intersection was unchanged. Slowing down generally started only a few meters before the intersection, the amount of deceleration depending on the complexity of the intersection and on the manoeuvre and traffic intensity. At intersections without priority regulation (meaning that motor traffic coming from the right takes precedence), the average deceleration was approximately 10%. Deceleration at priority regulated intersections was approximately 30% when the bicycle had no priority and only approximately 6% when he or she had priority, independent of age and traffic intensity.

Avoiding obstacles. Fifty seven out of 61 bicyclists swerved around a standing or slowly moving obstacle without looking back or signalling. Although motorised traffic came from behind in 8 instances, the bicyclist involved looked back in only four of these cases.

Right turns. It was only during the last meters before turning that 54% of the children looked left, 26% looked to the right and 29% gave a hand signal. During the turn only 9% looked or kept looking left. Seventy percent of the children took the curve too wide, i.e. more than 1 meter from the pavement. These behaviours during a right hand turn were not influenced by traffic intensities.

Crossing straight. It was only just before or on the crossing that 50% looked left and 46% looked right. While crossing, only 17% looked out any further. In this manoeuvre all age groups performed slightly better when there was more traffic.

Left turns. When preparing for a left turn, half the number of children moved towards the road median and 66% looked back, but only 17% gave a hand signal. The 11-14 year group performed the worst and was also the group with the most accidents.

Left turn tactics. The normative tactic (looking backward, signalling and changing lane position) was seldom used by children, but by 26% of adults.

Negotiating traffic lights. In 28 observations in the study by Brookhuis et al. (1988) traffic was regulated by lights. In the 5 cases that the bicyclist had a green light, none of the children looked around and all of them just went across. In 8 out of 23 red light situations, the child disrespected this and went through it, but always after looking around. Children were stopped after the manoeuvre and were asked questions about it. Many children in the middle- and older-age group seemed to have acted "on automatic pilot", saying they could not remember how they behaved (32%). In the younger age group this was only 12%. Going through a red light was mainly for reasons of economy, just as for carrying out manoeuvres without decelerating or yielding right of way.

Age group differences. The results above can be summarised as follows. The 7-10 year old children do not keep their course very well, but try to be more careful than is true for the 11-14 year group, reflected in lower speeds and more visual search. The 11-14 year group is the least careful. They approach crossings fastest, must then slow down most, but cannot yet oversee the situation quickly enough and show less visual orientation than the other age groups. They are also the most accident involved group.
ENGINEERING AND DESIGN FOR CHILD TRAFFIC SAFETY AND PLAYING POSSIBILITIES

Tackling the problem of child pedestrian and cyclist accidents requires educating and training of children, parents and drivers, but engineering measures are at least as important. As indicated in the introduction, the aim of this chapter is to give the reader insight into and a feel for child traffic behaviour and accidents in the light of children's psychological abilities, and to mention only a few examples of solutions in terms of engineering and design. These solutions are of course covered in detail in many books and guidelines for traffic engineers. Some recent ones will be reported at the end of this section.

Engineering and design for child pedestrian safety

From the section on child pedestrians several leading principles for ideal neighbourhood characteristics and several more specific suggestions for engineering measures emerge:

1. One message for the engineer is clear: avoid visual obstacles wherever children and cars meet regularly. Where this is not always feasible, such as in the new Dutch "woonerf" (residential area traffic calming), cars should proceed slowly and drivers should be trained to look out for children playing.

2. There should be no parked cars or other obstacles to vision where children cross roads, especially at school and playground exits. Bars at the kerb should stop them before crossing. But for many streets this also means that parking alongside the road should be changed to parking in concentrated areas. This will restore mutual visibility between children and drivers and prevent 'dash out' accidents. Parents taking their children to school by car should not be allowed to stop near the school entrance, as they would then introduce visual obstacles at the very place many children are crossing.

3. Parking near pedestrian crossings and near junctions and crossroads should be prohibited and the restriction enforced.

4. In streets where many children reside, cars and especially their speeds should be made completely subordinate to the residential function and the possible presence of children at play. There are many solutions to slowing down traffic in such streets (see below).

5. Traffic calming measures are also indicated for school roads and may be very effective: Anderson and Engel (1994; cited by Underlien Jensen, 1998) report a 82% casualty reduction after implementation of such measures on school roads in Odense, Denmark. For a review of traffic calming schemes in the UK, we refer to Mackie and Webster (1996).

6. In streets where many children live, parking of large vehicles should be avoided and those entering should have sound (or sound as well as light) signs when reversing.
7. Playgrounds should be made available close to the homes of children. Playground availability has been shown to have a favourable effect on child accident frequencies. Redesigning streets into 'play streets' is another option (see below).

8. Building more cul-de-sacs may give children more possibilities to play outside and still have a favourable effect on their accident rate.

**Engineering and design for bicycle safety**

From the Section on child cyclists several suggestions for engineering measures emerge, especially concerning bicycle design and equipment. In general, design measures for cyclist safety may be similar for children and adults.

1. The strategy of avoiding visual obstacles in streets will also prevent cycling accidents with younger children.

2. The design and the technical state of bicycles appears to be very important, as is rider conspicuity.

3. In general, separation of cyclists from heavy traffic, including buses, is preferred. Side mirrors covering 'blind spots' should be obligatory on large vehicles.

4. The severity of accidents with pedestrians and cyclists may be diminished by better design of car front ends.

5. Bicyclists can protect themselves by wearing a helmet.

**New design and redesign of residential areas**

In new residential areas, the basic strategy of road lay-out is an important factor. In many newly built residential areas the road network has been structured in a hierarchical manner according to the traffic stream and residential function. Separation of different types of traffic have often been applied. This has led to situations in which considerably fewer child traffic accidents occur. Examples are for instance The Bijlmer area in Amsterdam and the British 'New Town' Cumbernauld. In existing residential areas this is, however, often not feasible. There, one can have recourse to traffic calming measures and implementation of low speed zones as developed in the Netherlands and legalised in 1976. Several experiments in Europe where large residential areas were redesigned and/or where traffic calming and quietening measures were taken, showed sizable accident reductions.
Differences between residents and the municipal authorities in the experience of traffic hazards

In residential areas accidents are generally not concentrated in 'black spots' but spread over the entire area. This fact, and the phenomenon of considerable underreporting of child pedestrian and cyclist accidents, often gives rise to miscommunication between the local government (who are not aware of an accident problem) and worried residents who experience lack of safety for their children. The subjective experience of unsafely correlates with average speed and with the logarithm of the number of vehicles passing and with official accident records over a period of three years. Having children under the age of 10 increases the experience of unsafely considerably. Local government should consider the complaints about unsafe locations as much as they pay attention to police recorded accidents.

Enhancing possibilities for children to play more and more safely in their living environment

Parents increasingly try to avoid their children coming into contact with traffic. Several studies report that children are accompanied to school and other destinations at an increasingly higher age. Parents also wait increasingly longer before they allow their children to play outside unsupervised. For different age groups of Dutch children, Jansen described in 1997 where they play and what their needs for playing are. Children age 1-3 often play alone where they can be seen from the home. Accompanied they play often at a short distance from the home in a small park, square, playground or sand box. They need wide pavements and back alleys and the possibility of bicycling or tricycling around without the need to cross a road.

Children age 4-6 often play in their neighbourhood, visible from home or from a friend's home. They need free space of 100 - 500 square meters within 100 meters of the home. They move along the pavement and need to cross their street within visual distance of the home.

Children age 6-12 play in their residential area, often hundreds of meters from their homes. From age 8-10, they have a large radius of action, but their own neighbourhood remains the basis from which they approach the wider world. They need free space of 2000 - 3000 square meters within 300 meters of the home, as well as a piece of vacant land of 1000 - 2000 square meters, preferably with natural soil or vegetation and a little hilly. They roam all pedestrian and cycling paths in their neighbourhood and the wider residential area.

Children age 12-18 move to more organised surroundings such as sport clubs. Squares in their own neighbourhood remain meeting sites for hanging around, skating and playing ball games. They need several meeting places of 25 to 50 square meters. They need safe cycling routes to central service areas, and cycling facilities at crossings.

When riding a bicycle, Dutch children age 0-6 may have a broader radius of action than the above data of Jansen suggests. We found that, for cycling accidents with 0-6 year old children in Groningen, in 1978, the median distance from home was 800 m. For both pedestrian and cyclist accidents in Rotterdam, it was reported in 1975 that 50% of children age 0-4 had their accident
within 100 m. of their home, 50% of 5-9 year old children at 200 m. and for the age group 10-14 this was 700 m.

A recent Dutch initiative, taken by the ANO Foundation, is the concept of 'natural play woods': woods of preferably 10 hectares, where city children of all age groups can play in nature, but where supervision is present for their physical and social safety.

It is understandable that parents strive for a better and safer living environment for their children and frequently take action to achieve this. There are many international and national organisations that assist parents in doing so, some of which are mentioned below.

*Growing up in cities* is an international project to involve children in the design of their living environment in large cities. It is sponsored by UNICEF. Address: MOST secretariat UNESCO, Nadia Auriat, 1 Rue Miollis, 75732 Paris (tel: +33 1 4568 3862). For information and workshops in The Netherlands, tel: +31 20 592 9639.

The *International Association for the Child's Right to Play* (IPA) is a Non-Governmental Organisation, but which acts to advise and influence governments. It formulated in 1977 the *Declaration of the Child's Right to Play* in preparation for the *Year of the Child* in 1979. Its aim is to enable children to move easily about the community by providing safe pedestrian access through urban neighbourhoods and better traffic management and to reserve place for play through statutory provision. Secretariat: Nederlandse Speeltuinvereniging (Dutch Playground Society) in Utrecht, tel: +31 (0) 30 2544 880.

In The Netherlands, the foundation *Priority for Children* (in Dutch: *Stichting Kinderen Voorrang*), publishes many studies on child accidents, playing possibilities and on designs to improve the children's situation in these respects. They also publish guidelines for improving school routes, on how to deal with the authorities, action schemes for residents, etc. Unfortunately their brochures are in Dutch only, but translations of their work might be a worthwhile international project. Two recent brochures by Jansen and by Schouten deal with a host of design suggestions for the enhanced safety and playing possibilities of children, both illustrated with photographs and design drawings. The address of the foundation is Eerste Nassaustraat 5, 1052 BD Amsterdam, tel: +31 20 6826322.

**Textbooks and catalogues for engineering and design of countermeasures**

An interesting document for traffic engineers is a report of the so called ADONIS project of the EU transport RTD Programme (Dijkstra et al., 1998; available free of charge). It is a catalogue of measures for pedestrians and cyclists, both for their safety and for promoting walking and cycling and leaving cars at home for short trips. The catalogue includes for pedestrians 33 technical and 9 non-technical measures and for cyclists 38 technical and 22 non-technical measures such as rules and regulations, traffic signals, and public information and education. For pedestrians it is the first comprehensive European catalogue written in English. Each description of a measure is accompanied by illustrations - photos, diagrams of lay-out design, or other road elements - as well as illustrations of public information material. Infrastructure measures are sometimes detailed with dimensions as well. The advantages and disadvantages of the measures in terms of comfort, costs,
road safety, and social safety are described in considerable detail. Sometimes cost estimates are provided. Finally, the names of publications or organisations are listed as sources of further information. Although this catalogue is set up for pedestrians and cyclists of all age groups, several child specific measures are presented as well.

The ADONIS report (Dijkstra et al., 1998) also contains a review of existing catalogues and manuals, which is given here as well:

1. Pedestrian catalogues/manuals.

1a. The Austrian pedestrian catalogue (VCO, 1993) deals with the pedestrian (characteristics, needs, disabilities, emotions), criteria for planning (such as 'the shortest path'), designing and dimensions, crossing measures, relationships with cyclists and public transport, elements related to comfort (protection from rain, landscaping, etc) and rules and regulations.

1b. The Dutch pedestrian catalogue (VBV, 1993) deals with several principles that determine 'practical value' (accessibility, ease of walking, ease of road crossing), 'perceived value' (safety and attractiveness), and 'future value' (changing composition of the population and changes in behaviour). Also dealt with are spatial structure and facilities at the street level, as well as supportive measures such as information campaigns, education, maintenance, and the control of slippery surface conditions.

1c. A comprehensive pedestrian catalogue published in the USA (FHWA, 1989) can be considered as a real design manual. Information about data collection methods are presented as well as the planning and design of footpaths, crossings, and pedestrian zones.

Not mentioned in the ADONIS report, but worth drawing attention to here (and also available free of charge) is Underlien Jensen's (1998) review of some 19 physical safety measures for pedestrians of all age groups with summaries of the estimated safety effects of each. These effects are often considerable, although some measures may have a negative safety effect, thus stressing again the need for careful evaluation. An older but still useful treatise on design for pedestrian safety in the UK was published by Wade et al. (1982).

2. Bicycle catalogues/manuals.

2a. The Dutch cycling catalogue (CROW, 1993; available in English, German and Dutch) is focussed mainly on technical measures. It is organised as follows: design as process, design of a network, road sections, road surface, intersections, cyclists and speed inhibitors, cyclists and unlawful parkers, bicycle storage facilities, temporary measures, furnishing cycle routes, and assessment of cycling infrastructure.

2b. The German cycling catalogue (FGSV, 1996), which focusses on infrastructure measures, deals with legal regulations and design fundamentals. Main items are planning and design of cycling networks, road sections as a part of different road types and junctions of various kinds. Bicycle storage facilities and technical prescriptions for realising cycling facilities are also dealt with.

2c. The Dutch ASVV (CROW, 1996) distinguishes basic information (including documentation and legal regulations), methodology (including analysis methods and resources for designing), facilities (for traffic circulation, technical traffic facilities for special categories and for mixed traffic, and measures at the level of traffic regulations), and special designs (technical designs, facilities for road works, and the management and maintenance of roads).
A recent report (not mentioned by ADONIS) with many countermeasure suggestions for both pedestrians and cyclists (of all age groups) in urban areas is published by the European Transport Safety Council (ETSC, 1999c), Rue du Cornet 34, B-1040 Brussels (tel: +32 2230.4106).

RECOMMENDED READING


Dijkstra, A. et al. (1998). Best Practice to Promote Cycling and Walking. Denmark Ministry of Transport, Danish Road Directorate, Copenhagen. This is the 1st report of the EU transport RTD programme, available free of charge (fax: +45 33 15 63 35).


THE PSYCHOLOGY OF THE YOUNG DRIVER

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THE YOUNG DRIVER PROBLEM: OVERINVOLVEMENT IN COLLISIONS

In Australia, drivers aged 16-24 years comprise about 20% of the driving population but account for around 50% of injury crashes and 35% of fatal crashes (Macdonald, 1994). In the UK, approximately 850,000 new drivers come onto the roads each year. About 170,000 of these drivers have at least one accident in their first year and approximately 11,000 of these accidents result in injury. It is estimated that injury accidents involving young drivers cost circa £1.8 billion, even in 1991 (Department of Transport, Road Safety Division Research Tender Briefing, 1994). In Ireland, about 50,000 new drivers take to the roads annually. Over their first 5 years they have an injury-accident rate about five times that of more experienced drivers. Similarly in the US, other things being equal, the 'just trained' driver is unquestionably the most dangerous. Those who have most recently passed the driving test kill the most other road users and are most likely to kill themselves (Evans, 1991). Evans refers to this seemingly universal phenomenon as "almost a law of nature". One conclusion is inescapable from these observations: driver training, which for most people ceases after passing the driving test, and driver testing, must be failed as methods for ensuring safe vehicle operation. Another conclusion is that learning to be safe may require extensive experience on the roadway after the driving test has been passed and a licence obtained.
Human factors for highway engineers

WHAT ARE YOUNG DRIVERS LIKE?

To begin to understand the problem of young drivers and their accidents, we can first ask what they are like. Are there features which distinguish them from other groups of road users, in particular older drivers, which might explain their increased accident involvement?

Risk life-style

The first noticeable feature is that, amongst young drivers, there is undoubtedly a subgroup of drivers who deliberately take risks. As a consequence they are overinvolved in both traffic violations and accidents. Their risky behaviour is not just confined to roadway use but characterises their life-style as a whole. They are more likely to engage in drug use, heavy drinking and petty crime. These expressions of poor socialisation (i.e. inadequate or incomplete learning of socially acceptable attitudes and behaviour) and risk seeking may well be the result of both personality and environmental factors.

However this group is by no means the entire problem. Only about 15-20% of young male drivers fall into this category, where high risk driving is part of a profile of deviant behaviours. There is no evidence that the majority of young driver crashes arise from intentional high risk or antisocial driver behaviour.

Nevertheless, there are individuals, characterised as sensation seekers, who take physical and social risks to obtain "varied, novel, and complex sensations and experiences" (Zuckerman, 1979). Drivers who score relatively highly on measures of sensation seeking are more likely to commit driving violations, receive higher scores for risky driving and to crash (Jonah, 1997).

Risk exposure

A second characteristic of young drivers is that they are more vulnerable because of the conditions under which they drive. Compared with others, they are more likely to drive vehicles which offer less protection in the event of a collision. They are more likely to drive with a car full of friends, thereby increasing the number of casualties in the event of a crash. They are more likely to drive during darkness and particularly on weekend nights, periods typically associated with a higher incidence of driving with elevated blood alcohol levels (BALs). Late at night there are of course the further risk-contributing effects of drowsiness and the opportunity provided by lower density traffic to drive faster, especially in urban environments.

It is also worth noting that the alcohol-related accident risk of young drivers starts at much lower BALs (20 mg per 100 mL) and rises more steeply than in older drivers. Driving with 50 mg per 100m, the legal BAL limit in many countries, the involvement in a fatal accident of an 18-19 year old is estimated to be almost five times higher than for a 30-34 year old. Alcohol and high speed are associated with 40% of all loss-of-control fatal crashes involving young
male drivers aged 18-21 years (Laapotti and Keskinen 1998). Not surprisingly, young drivers are over-represented in alcohol-related accidents on weekend nights.

Although such factors as these may selectively influence young driver accident rates they do not account entirely for young driver overinvolvement in accidents. In reviewing the evidence, Jonah (1986) concluded that "even when one controls for the quantity and quality of exposure to risk, young drivers are still at greatest risk of casualty accident involvement" (p. 257).

Risk seeking

A third aspect of the young driver problem relates to attitudes to driving and in addition the driver's vulnerability to peer pressure. Evidence suggests that for some young adults, high-risk driving, which they see as a demonstration of superior control skills, is associated with social status and is reinforced by peer influences: significant others in the driver's social group may strongly encourage such driving. It can also be reinforced by the high-risk driving behaviour exhibited by heroes in dramatic film and television. Such fictional representations unintentionally provide a model for young people to imitate, particularly where they identify strongly with the character(s) portrayed.

Overestimation of competence

Fourthly, young male drivers typically overestimate their own competence as drivers and, in the context of an impending collision, overestimate their ability to correct the situation.

Deficiencies in competence

A fifth characteristic of young drivers has to do with identifiable deficiencies in their competence to recognise hazards and hazardous situations. Thus they:

- are poor at identifying distant hazards;
- see less risk in various driving scenarios;
- are more likely to be in driving situations where they may come into conflict with other drivers (e.g. accepting shorter headways and narrower gaps when entering traffic, running amber lights and driving faster).

In other words, young drivers are less able to read the road ahead than the more experienced driver.

Furthermore they often find it difficult to manage and control their speed appropriately. Thus:

- they are less likely to be able to stop within the limits of forward visibility;
- they underestimate the consequences of dangerous driving;
To summarise then, young drivers:

- include a sub-group of high-risk lifestyle individuals;
- tend to drive under more vulnerable conditions;
- are subject to peer pressures to adopt high-risk driving styles;
- overestimate their ability to drive safely;
- are poor at hazard recognition;
- are prone to drive too fast for the prevailing conditions.

These features, in particular the last three, suggest that young drivers are somehow not acquiring a desirable level of competence through their training and supervised experience, prior to obtaining a license. To understand why this may be the case, we need to look more closely at what it is the driver has to learn.

**WHAT IS INVOLVED IN LEARNING TO DRIVE?**

For the young driver, learning to drive is no easy, simple matter. The human brain needs to go through some fairly radical changes before it can be entrusted to guide safely perhaps a ton of metal hurtling at high speed towards a similar object approaching from the opposite direction and before it can control the vehicle like an extension of its own body, like a “wheeled exoskeleton”. What then has to be learned in learning to drive? A useful starting point is the conceptualisation provided by the CHIPS model, a development of an earlier model proposed by Hawkins (1987) which describes the various interfaces between the human operator, the car and its operating environment (see Figure 1).

![Figure 1. The CHIPS model: interfaces with the human operator](image)

CHIPS is an acronym for the environments with which the individual interfaces in the driving task: Cultural, Hardware, Instructional, Physical and Social. The individual is in the centre of the figure and represents the driver. The Cultural environment includes shared attitudes and values relating to roadway use, including safety. Concepts such as care, courtesy and...
the figure and represents the driver. The Cultural environment includes shared attitudes and values relating to roadway use, including safety. Concepts such as care, courtesy and consideration for other road users, as well as individual responsibility, might be included here. The simplest way of representing these cultural elements is in terms of the statement "the way we do things around here". In terms of the culture of road user behaviour, this may be restated as "the way people drive (or behave as pedestrians/cyclists) in this country (or region/city etc)". Cultural values and norms of behaviour arise out of a long process of social learning, involving observation of how others behave and react and feedback on one's own behaviour and attitudes (see also Chapter 14).

The interface between the driver and the Hardware, the machine or car in this instance, focuses on controls and displays. Effective, efficient and safe control of a car requires a skilled performance at this interface and the development of this skill typically follows a pattern characteristic of coordinated visual-motor skills in general:

- gradual transition from conscious, rule-based and discrete acts to relatively unconscious, automatic, coordinated, skill-based acts (from declarative to procedural knowledge);
- associated decreases in the requirement for working memory capacity and release of capacity for higher-order perceptual and judgemental processes;
- associated expansion of the window of planned behaviour.

Research on visual-motor skill acquisition has identified important roles for feedback and for practice. Feedback has a vital corrective function but also a motivational effect on performance (Holding, 1989), while practice facilitates the development of automatic routines for control operations such as changing gear, steering and even activating appropriate switches. Automatisation of operations enables them to be carried out more efficiently and using less mental capacity. Practice effects typically follow a power law (see Chapter 12).

The Instructional environment comprises all those rule-based controlling instructions which direct the decision-making and responses of the driver. Many of these are internalised formal rules and regulations (such as on which side of the road to drive; where not to overtake; when to signal and so on). Some may be described as informal rules arising from guidance provided by an instructor or handbook, or rules based on the individual's own accumulated experience (e.g., to drive more slowly when the road surface is wet). And some instructional control will be situated in the environment, directly telling the driver what to do. A clear example would be electronic traffic signals at junctions and railway crossings and direct instructions from police. The instructional environment is rather like the software in a computer, providing a set of instructions which tell the computer what to do.

Elements of all of these types of 'controlling instruction' will have been assimilated during childhood and adolescence by the driver, even before s/he first takes the wheel of a vehicle, but very many remain to be learned through instruction, training and experience. The seeming universal over-representation of young drivers in crashes, in spite of huge variation in requirements for, and experience of, formal training (see later) testifies to the often painful role of experience in this process. Learning what behaviour is required under what conditions to achieve both satisfactory mobility and a safe outcome is a major challenge and is not helped by
a number of factors such as the probabilistic (as opposed to certain) relationship between the key variables involved (taking a particular corner at 100 km/h may lead to loss of control...or it may not) and the relatively low frequency of occurrence of many hazardous contingencies (such as the roadway beyond a bend being completely blocked by an obstruction).

The Physical environment, in this context the interface between the driver and the road and traffic environment, can at times seriously undermine the ability of the driver to carry out the task safely and the driver needs to learn to recognise particular conditions and their properties. While performance problems caused by such general environmental factors as vibration, noise and extremes of temperature and airflow have been eliminated from modern vehicles, there remain the problems of reduced visibility during hours of darkness and in weather conditions such as fog and heavy precipitation and conditions associated with a decrease in road surface adhesion (rain after a dry spell, loose gravel, wet leaves, frost, ice). More specific environmental learning has to do with interpreting the evolving road and traffic scenario in front of the driver in terms of required control actions (mainly speed and direction), a skill sometimes referred to as “reading the road” or “hazard recognition”. A subtle part of this learning has to do with the management of the driver’s vigilance or attention, not only maintaining a level necessary for the task in hand but also deploying it effectively to sources, and potential sources, of task-relevant information and efficiently: avoiding monitoring of irrelevant sources, avoiding excessive dwell-time on particular sources and switching attention appropriately while undertaking two or more concurrent tasks.

The fifth element about which the driver has to learn is the Social environment, the interface with other road users such as drivers, cyclists and pedestrians, as well, perhaps, as passengers in the driver’s own vehicle. It needs to be recognised that driver behaviour has a strong social dimension, a dimension which expresses how we relate to other people. Do we show off to them, threaten them, bully them, ignore them, compete with them, punish them? Do we show deference or assertiveness, rage or revenge? For a safe and reliable performance, the driver needs to learn to separate the way s/he drives from emotional needs and assimilate the social code of the road of mutual care, consideration and courtesy. We expect this from professional drivers and airline pilots for example. We don’t expect a pilot who has had a row with his partner or boss to take it out on his passengers by flying the plane aggressively or threatening other aircraft in the vicinity. But because roadway use is so unexceptional, so well stitched into the fabric of daily life, we tend to carry over into it ongoing emotional and social needs and fail to recognise the inappropriateness of their expression there.

Indeed the very anonymity and protection offered by the metal capsule of the car may well disinhibit expression of feeling previously restrained for fear of social censure. The driving environment is one which produces a deindividuating effect: drivers are anonymous, largely shielded from the normal social feedback of others, physically protected by the armour of their vehicles and surrounded by similarly anonymous other road users. Such deindividuating conditions predispose even normally socialised individuals to express aggression more impulsively (Festinger et al. 1952). Because driving is very often in large part about how we relate to other road users, and because the road and traffic environment is relatively circumscribed (compared say with the varieties of other forms of social life), anti-social behaviour is that much more conspicuous. This varies from simply ignoring the (social) rules
(e.g., not signalling your intention or not giving way) to behaving in a blatantly aggressive way to others (e.g., ‘cutting up’ another driver or making a threatening gesture). Thus we should not be surprised by the fact that people who are socially deviant in other domains of life behave similarly on the road and as a consequence are over-represented in crashes (see for example West et al., 1993 and Evans, 1991). Similarly, because of their relative immunity to the social consequences of behaviour, it would be expected that individuals low in self-esteem would be predisposed to a higher crash involvement.

So learning to drive is in part also about learning how to relate to other people on the road. But beyond this basic social learning there is the further dimension of communication, knowing what, how and when to communicate to other road users and how to interpret the messages being transmitted from them. Communication modes include indicator lights, brake lights, reversing lights, headlamp flashes, sounding the horn, and making eye-contact and gestures such as waving. More subtly they include the 'posture' of other vehicles, whether nosing out from a parking spot or in terms of their apparent trajectory when moving. The driver needs to learn to interpret these cues appropriately, as well as how to employ them himself or herself.

Learning and experience of the five interfaces described above ultimately enable the development in the driver of:

- skilled routines which operate in an automatic, unconscious way as part of attention, search, decision and control sequences (skill-based learning);
- a large body of rules which specify appropriate responses given particular situation or scenarios (rule-based learning);
- knowledge structures which provide a long-term memory based organisation of knowledge relevant to the driving task and its sub-domains (knowledge-based learning).

At any moment in time these forms of mental representation provide:

- a dynamic mental model of the trajectories of the driver’s own vehicle relative to the road environment and those of other road users (vehicles, cyclists, pedestrians) in the environment;
- a prediction of the imminent outcomes of those trajectories (rather like an internal video sequence which runs ahead of real time);
- response options linked to the various road and traffic configurations.

For the interested reader, further discussion of these features may be found in, for example, Rasmussen (1986), Brown and Groeger (1988) and Brown (1993).

**Learning as a continuous process**

Of course, the task of learning to drive does not start with a blank canvas: it is situated in a life history of the individual in which many relevant elements have already been assimilated. The inexperienced driver will have had varying degrees of direct exposure to the contingencies of driving through his or her active participation in traffic as a pedestrian and perhaps cyclist. S/he
will also have observed events both as a vehicle passenger, a viewer of fictional movies and perhaps also as a viewer of road safety educational films. S/he will also bring to the driving task an acquired knowledge-base derived from experience in environments other than the roadway. That store of knowledge might include the effects of impact with hard objects, characteristics of the trajectories of moving objects, expectations about other people’s behaviour and so on. Such knowledge is important for the development of safe driving because it enables the driver to rule out certain contingencies as improbable or impossible (e.g., “if I apply the brakes I will go faster”) and facilitates the identification of valid contingencies (e.g., “this road surface appears to be greasy: if I brake hard on it, I may lose adhesion and directional control”).

How we behave as drivers on the roadway is also continuously subject to control by its consequences. Responses which are followed by rewarding (i.e. pleasant, desireable) consequences will tend to be strengthened, those followed by punishing (or non-rewarding) consequences will tend to become weakened. Thus if risk-taking achieves desirable rewards (such as the saving of time) this behaviour will be reinforced, a phenomenon described elsewhere as “learned riskiness” (Fuller, 1992). Similarly, rule-following will tend to be abandoned where experience shows the consequences of rule-following are not what is expected. Hence drivers are more likely to ignore speed limits and even traffic signals when streets are deserted, such as in the early hours of the morning, because of the low probability of punishing consequences to these behaviours.

This represents a particular problem for the learning of safe driving in that on occasion (and perhaps frequently) the driver’s internalised safety instructions or rules may be observed to be inconsistent with contingencies as experienced and that when obediently followed the rule actually leads to some negative consequence. An example would be a driver for whom time was valuable who slowed down in a speed restricted area but experienced no safety or other advantage from the behaviour. The rule to reduce speed is here seen to be at variance with the actual contingencies. Under such circumstances one would predict an eventual decrease in the frequency of rule following. The general finding in this area is indeed precisely that: instructions lose their control when there ceases to be a correspondence between instructions and the behaviour-consequence relation (Zeiler, 1978).

The fundamental point however is that driver behaviour, like any other, is continuously being remoulded by its consequences and that this process may undermine as well as strengthen safe procedures (see Chapter 4 on learning for a more detailed exploration of this process and for a discussion of the implications of this kind of theoretical analysis, see Fuller (1991)).

**Learning opportunities**

The fundamental problem for the young driver has to do with learning, from control skills to the vast range of features of the interfaces described in the previous section. Clearly one of the most, if not the most salient problem for the inexperienced driver is the sheer lack of exposure to the contingencies of the driving situation, to the relationships between antecedent conditions, the driver’s responses to them and the consequences of those responses. Adding to this problem
for the inexperienced driver is that many dangerous contingencies have a relatively low frequency of occurrence, yielding little opportunity for learning through direct experience of them. Furthermore, as mentioned earlier, the relationships between the variables involved are typically probabilistic rather than completely predictable. It is hardly surprising, therefore, that the young driver should occasionally get into real difficulties. For young female drivers, for example, fatal loss-of-control episodes are typically associated with slippery road surface conditions (Laapotti and Keskinen 1998).

Compounding the learner's difficulties further are two features of the driving situation which tend to work against the development of safe driving. One is the reinforcement of unsafe behaviour and the other is its complement, the 'weakening' of safe behaviour through either extinction or even punishment (see Chapter 4). As discussed earlier in the context of violating rules of the road, from behavioural theory we can predict that every time a driver takes risks, either knowingly or unknowingly, and "gets away with it" without undesirable consequence, then that behaviour will be reinforced; that is, made more probable in similar circumstances in the future. As Summala (1988) expresses it, "every successfully terminated trip reinforces the (associated) behaviour, which the driver feels safe and rational" (my parenthesis). This is consistent with the report by Brown (1982) showing younger drivers, and particularly males, to have greater confidence in their ability to recover from decision errors than older drivers of both sexes. Brown suggests that because perceptual-motor skills are relatively easily acquired, novice drivers may become overconfident in their abilities to manoeuvre their vehicles and "take on" situations with which they simply cannot cope. Because novice drivers must frequently get themselves into situations requiring rapid responding, it is this feature of driver behaviour which is selected out for early reinforcement. This may explain why young drivers, when judging accident riskiness, emphasise the ability to react quickly in emergencies rather than the ability to drive "defensively" (Finn and Bragg, 1986).

Thus from a learning perspective the inexperienced driver is primarily handicapped by

- inadequate exposure to the contingencies of safe driving;
- discrepancies between experienced contingencies and contingencies as represented in learned 'rules of the road';
- few opportunities to learn directly the relationships between low probability events;
- the reinforcement of unsafe driving behaviour and the punishment or at least non-reinforcement of safe driving behaviour.

Perhaps we should not be surprised then that as the driver discovers what the real contingencies are in the traffic system, the penalty of a road accident must sometimes be paid.

**Hazard recognition**

Because of their inexperience, young drivers have had relatively little opportunity to develop reliable predictive models in their heads of potentially hazardous situations, whether these relate to the behaviour of other road users or to the speed, trajectory and attentional options selected by the driver himself or herself. As a result, young drivers moderate their speed later
than experienced drivers, they slow down in a less smooth and controlled manner and end up with a higher minimum speed. Not surprisingly young driver accidents are characterised by driving too fast for the prevailing conditions. This lack of an ability to relate speed to conditions is also shown up in the relatively high involvement of young drivers in single vehicle accidents. Thus driver training, for example, might well pay more attention to the development of hazard perception skills, including perception of those hazards involved in fast driving. Recognition of this is becoming realised in the form of modifications to training curricula and extensions to driver testing which incorporate hazard perception elements (usually written or computer-based scenarios). Fundamental objectives of such extended training might include:

- relating speed to conditions (e.g., of road surface adhesion; visibility, road curvature and so on);
- correct anticipation of behaviour of other road users (including low probability events);
- ability in forward planning.

These suggestions for a training intervention to deal with particular young driver problems also have implications for highway design. These will be described in the next chapter section.

Learning about human factors

What people do on the roadway, their performance, is ultimately constrained by what they are able to do, their competence; this always sets the limiting conditions for performance. However, human performance, irrespective of the level of competence, is variable and therefore not completely reliable. Performance is variable because it is vulnerable to a wide range of influences such as:

- biological changes (e.g., with age);
- learning effects (e.g., through experience);
- driving task-generated factors (e.g., feelings of boredom, drowsiness, emotion);
- non-task generated factors (e.g., time-of-day, sleep quality and quantity, alcohol, stress, emotion).

As described in Chapters 1 and 6, collectively these influences are known as human factors. Variability of performance arising out of them is a major contributing factor in collisions on the road. But this is not the whole of the picture. What people actually end up doing, their behaviour, is in turn a function of:

- individual values (which provide motivation for particular acts - e.g., desire to show off or drive at high speed);
- social norms (influencing behaviour through group dynamic processes – e.g., pressure to conform to what others are doing);
- the culture of roadway use within which the road user operates, a culture which in turn transmits values, rewards and punishments (e.g., through an enforcement strategy).
Thus quite independent of the quality of training the driver has received, and the level of competence they have and performance they are able to deliver, what s/he actually does on the roadway at any moment of time is vulnerable to a vast array of personal, social and cultural influences. It would seem appropriate for drivers to be made aware of these influences and to become familiar with the potential effects of them on driving safety. Such knowledge does not, of course, guarantee that the driver will become safer, but recognising the problem must be the first step towards a solution. However, systematic learning of human factors, how to recognise their effects and how to deal with them is nowhere part of formal instruction in driver training.

In this context, are there any particular vulnerabilities of the young driver? We have already noted the increased susceptibility to the performance-degrading effects of alcohol and to the motivation for speed for its own sake. The young driver is also more sensitive to social pressures from peers in the same car to drive fast and to enhance his status by 'showing off'. It is also likely that speed adaptation effects will be more pronounced in the inexperienced driver, mainly because of that lack of experience. And a further characteristic of the young driver may be a disposition to 'test the limits' of the system, an observed characteristic of industrial operatives (Rasmussen, 1997). The equivalent in driving might be "seeing how fast she will go" or "seeing how quickly you can get from A to B".

Given these pervasive problems of learning for the young driver, it seems pertinent to ask how different training systems have fared in preparing the driver to survive travelling on the highway.

**SAFETY EFFECTS OF DIFFERENT DRIVER TRAINING SYSTEMS**

In the different European countries, varying requirements for driver training and different training methodologies have emerged. Variations relate to features such as:

- the age at which a driver may drive different types of vehicle (for a car, 16 in Norway, 17 in Ireland and the UK, 18 most other EU countries but 16 in Sweden and France as an accompanied driver under a contracted apprentice system);
- the mandatory requirement for theory and practical training (most countries but not the UK, Ireland or the Netherlands);
- the opportunity to practice with laypersons (not permitted in Germany, Denmark, the Netherlands, Portugal, Greece, Luxembourbg);
- the requirement for practical training and certification of driving instructors (all countries except Ireland);
- the requirement of a probationary period for newly qualified drivers (Germany, Spain, Portugal, the Netherlands).

What is perhaps surprising is that despite these wide variations in training experience, there is no evidence that the differences in national systems produce major differences at the level of national casualty totals (Lynam and Twisk, 1995). No one of them seems to be significantly better at producing safer drivers than any other. From the perspective of accident involvement, young qualified drivers in the EU are more-or-less as good, or bad, as each other.
What may account for this? One reason may be that the focus of traditional systems of training has been mainly to prepare learners to pass the driver licensing examination - the driving test - an examination which in all countries has really only been able to assess basic competence. After this drivers have typically been left on their own. A second reason may be the effect of driver testing. Since there is little variation in what is finally assessed internationally to obtain a full driving license, those who get through are more-or-less equivalent in competence, irrespective of the nature of their previous training. And lastly, the sheer accumulation of experience of driving on the roadway seems to be a key factor in the process of learning safe driving. Appropriate safe behaviour cannot simply be taught - it has to be learned by doing (see Chapter 12) and at present that inevitably means making mistakes on the roadway.

In line with these suggestions are the conclusions of an extensive review of training and licensing systems completed within the EU-funded GADGET (Guarding Automobile Drivers through Guidance Education and Technology) programme (Siegrist, 1999). This concluded that the most effective systems from a safety perspective are characterised by more formal education and training, graduated licensing, increased experience under lay instruction and risk awareness training.

However the problem remains of how the novice driver can continue to learn through trial and error after obtaining a license, but escape the painful consequences of the error element in this process, the problem of further learning through crashing.

**Solutions for the Young Driver**

**Dealing with hazards**

Young drivers need all the help they can get from the highway engineer. Their task is qualitatively different from that of the experienced driver because they have less well developed control skills, they have less of an idea of what speed is appropriate for various conditions of road and traffic and they have a less well developed ability to select what is appropriate from the array of information bombarding them. Thus they are more likely to suffer from an information overload. The implication of this is that at times, critical information may simply be ignored. So what kinds of help can the engineer provide?

The first type of assistance would be to ensure that the driver's attention is reliably attracted to the occurrence and nature of hazards ahead, to ensure that warning information is picked up by the driver. Rumble strips provide a part answer to this, capturing the driver's attention through the three separate modalities of vision, hearing and vibration. Once attention is attracted in this way, then clear signing of the hazard should follow, with high contrast and dynamic warning signs being more reliably detected. A further help to the novice driver would then be to provide clear guidance as to what s/he should do to cope with the particular hazard. This basically means telling the driver where to go and what speed s/he should be going at, perhaps involving directions to SLOW and a reduced speed limit appropriate to negotiating the hazard. Information given well in advance so that it can be picked up leaving enough time for an
appropriate controlled response, even by those driving at excessive speeds, will benefit the information-laden novice and the provision of high skid-resistant surfaces will help where drivers are prone to respond late, for example approaching traffic lights after a fast stretch of roadway.

**Enforcement**

But assisting young drivers to deal with hazards in these ways will not be enough because so often it is the drivers themselves who create the very hazards in the first place. Thus it is not the curve or the junction or the roadway obstruction or the children playing in residential streets that are the real hazards, but the speed adopted by the young driver in approaching them. These are the conditions where enforcement of compliance with safe speeds is appropriate and where traffic calming measures such as humps and ramps and throats and gateways and chicanes and so on can bring the driver's behaviour under control.

A further way of helping inexperienced drivers to 'help themselves' is through modifying their perceptions of the roadway so as to induce heightened attention and vigilance or even perceptual illusions of speed. An example of the latter is the use of transverse lines across the roadway with progressively decreasing intervals between each, yielding the illusion in a vehicle travelling at constant speed of actually accelerating. In many locations, such devices have been shown to slow drivers down and reduce accidents. They should also help compensate for speed adaptation effects.

The point of this chapter, however, is not to tell engineers what to do, but simply to reveal what is known about the psychological characteristics of the young driver and to underline the fact that they need all the help they can get in solving the problem of getting safely from A to B. The implications of young driver characteristics for roadway design are to an extent self-evident. But it will be up to the creative engineer to devise ways of dealing with them, wherever feasible. And one conclusion is fairly certain at least, design solutions for young drivers are likely to benefit all road users and especially drivers who are elderly.

**Recommended Reading**


**INTRODUCTION**

Demographic evolution in most industrialised countries shows a steady increase in the number of people who will be elderly, defined as people who are over 65. For example, the prospect for the EU is about 80 millions of people will be elderly by the year 2020 (Marcellini et al., 1998) with 22 millions of them being between 65 and 79 years old and 22 million being over 80 years old (with two women for every man). Compared with preceding generations, these people will be characterised by the demand for a higher level of mobility. And as the general population ages, the percentage of elderly drivers on the road also increases. In parallel with this, people of all ages, and especially older people, are becoming more dependent on their cars with the increasing trend towards sub-urbanisation. This is particularly the case in the developed nations, where the use of private cars is more widespread.

Engineers and transport authorities often fail to take adequate account of the characteristics of the elderly (drivers or pedestrians) in the design of the road environment. The elderly have age-related perceptual, cognitive and motor difficulties which lead them to avoid complex traffic situations, whether as drivers, public transport travellers or pedestrians, and even to give up driving. In a study of adults from 22 to 92 years, Kline et al. (1992) found that older drivers change their driving habits in response to age-related visual decline. All individuals under 64 years of age currently drove and did so in both day and night conditions; all of the drivers who
no longer drove at all, or who no longer drove at night, were 64 or older. Some of them had
given up driving, invoking reasons of their dislike of traffic or involvement in a traffic accident.
This chapter aims to present recommendations and guidelines for road environment design,
based on the travel needs of the elderly, both pedestrians and drivers, in order to ensure their
mobility and safety.

OUTDOOR MOBILITY OF PEOPLE WHO ARE ELDERLY

Outdoor mobility is defined as the capacity to go outside the home and move in the
surrounding environment. Where freedom to move means both physical and psychological
health and well being, outdoor mobility is a prerequisite for successful ageing. Furthermore,
having a driving licence may have a special significance as a symbol of freedom and
independent life. A survey carried out by Brög et al. (1998) showed that mobility behaviour
patterns are closely connected to the end of active life. Retired people reduce their activity
outside the home and the use of the private car gives way to other modes of transport, such as
walking and public transport. However, this reduction is just partly age-related (decreasing
capacities, end of active life) as architectural barriers and unsuitable modes of transport may
discourage mobility. Carrying out a survey on demand for transport by people who are elderly,
Marcellini et al. (1998) found that:

• people who are elderly consider outdoor mobility very important for their quality of life;
• the decrease of mobility with increasing age does not depend on a decrease of desired
mobility or health problems, but mainly on barriers and hindrances in the environment and
in the transport system.

Two surveys on elderly mobility patterns (Marcellini et al., 1998; Brög et al., 1998) have
shown that walking is the most used mode of travel, particularly in middle-sized towns. This
has positive health benefits in that walking is associated with less osteoporosis, less obesity,
less constipation, fewer hip fractures and less use of prescribed drugs (Waller, 1991). However,
people who are elderly are more vulnerable than other age groups to traffic risks when walking.

AGEING AND FUNCTIONAL CAPACITIES

The ageing process is the result of intrinsic and extrinsic factors conditioning some functional
changes in the organism. Epidemiological data show that these age-related changes occur at
different levels and rhythms leading to a high variability among people who are elderly.
According to Smith et al. (1993), ageing is a progressive and variable combination of
ontogenetic, historical and life events, which result in great individual variability. Even if the
difference between chronological and functional age is now established, the older population is
usually classified into classes of five or ten years, as young-old, old and old-old. Within-person
variability increases with age, such that task performance may vary over time for the same
individual. Another source of variability is between generations, so that today’s drivers who are
elderly differ from those of 20 years ago. These differences relate to economic status,
education, home location and experience as users of new technologies.
The main feature of ageing is the progressive slowness of behaviour, but different systems involved in adaptation show the following characteristics:

- the neuromuscular system changes in ways that influence both cognitive and motor behaviour as well as general well-being. The ability to perform continuous movements or complex skills declines and coordination is disrupted; the control of posture and balance degrades and a loss of motor control is evidenced as well (Vercruyssen, in Fisk and Rogers, 1997);
- loss of muscle strength, endurance and tone, as well as a decrease of the range of joint movements and reaching distances are the major factor responsible for the age-related motor limitations (Vercruyssen, in Fisk and Rogers, 1997);
- step length, step height and walking speed decrease with age and lead people who are elderly to find difficulties in performing daily life tasks, such as pushing buttons, opening doors, using stairs and travelling by public transport (Steenbekkers and Beijsterveldt, 1998);
- age-related loss in the ability to detect, interpret and react to visual and auditory information compromise the performance of a wide range of daily tasks. The response to illumination and colour discrimination declines with age and sensitivity to glare increases as well as the time to recover from glare exposure (Olson, 1988). However, the increased time needed to recognise visual information seems to result mainly from slower information processing than from sensory loss (Stokes, 1992);
- some memory loss and a decrease in ability to learn, particularly self-learning, are the main cognitive age-related changes. However, while working memory processing and episodic memory decline with age, semantic memory and procedural memory remain quite stable. Therefore, successful learning will depend on the interplay of these systems. Moreover, some age-related difficulties in learning ability can be addressed by means of adding a memory aid, providing increased time or more practice. Cognitive deficits can be compensated by means of appropriate strategies based on previous knowledge and/or experience.

Major theoretical frameworks suggest that age decrements in cognition occur as a result of limited mental energy or processing resources, age-related slowing or dysfunctional inhibitory mechanisms. According to Craik and Byrd (1982), the hypothesis of limited processing resources suggests that adults who are elderly show comparative declines on cognitive tasks, due to a diminished pool of mental energy that governs controlled or effortful cognitive processes in working memory.

The second major hypothesis is that age-related cognitive declines are a result of a reduction in information processing speed. Cerella, Poon and Williams (1980) suggested that, due to central slowing, age differences increase with cognitive task complexity, underlying the importance of timing aspects in situations requiring speeded responses. Strategies for reducing age-related differences, such as environmental support interventions, provision of more time for processing events or information and training activities to enhance response speed are strongly recommended for older adults.
Regarding the third theoretical perspective, Hasher and Zacks (1988) suggested that, rather than suffering from decreased processing resources, older adults have inefficient inhibitory mechanisms in working memory, leading them to attend to irrelevant contextual details and to have faulty interpretations of context. As a result, the content of working memory is different for old compared to young adults, with the working memories of older adults containing more irrelevant information which detracts from the processing of target information. The 'failure to inhibit' hypothesis has many implications for the design of the environment and of information for people who are elderly. It should perhaps be assumed that they are highly distractible and may easily be confused by competing sources of information.

The ability to compensate functional losses is often the key to living the later life as a period of continued usefulness, recreation and productivity. Compensation is the reason why some performance decrements in laboratory tests are not replicated in daily task performance. The environmental support hypothesis suggests that age differences decrease on cognitive tasks when encoding and retrieval support is provided, either in the form of contextual cues or through a resource limiting encoding or retrieval operation. Another way is through automatization of the components of complex behaviours, requiring fewer resources to perform them (Plude and Hoyer, 1985).

**TRAVELLERS WHO ARE ELDERLY**

The age-related decrease in cognitive, sensory and motor abilities leads people who are elderly to experience some difficulties in performing tasks related to driving and/or walking. However, these difficulties could be reduced if task conditions could be changed to match the available capabilities of this population.

**Drivers who are elderly**

The emphasis on the elderly driver population could be linked to the statistical predictions which show that it is likely that by 2021, 60-65% of men and 40-50% of woman over 70 years old will have a driving license (Stewart and David, 1996). With the ageing process, most of the important abilities necessary for driving (vision, memory, attention, decision making process) decline (Marin-Lamellet, 1994). As a consequence, the mobility of drivers who are elderly tends to decrease and they develop some specific strategies to compensate for their deficits.

Although there are well-recognized declines and changes in visual functioning with age, their contribution to the problems of older people on tasks in the natural environment, including their driving, is less known (Kline et al., 1992). Wood (1993) attempted to explain the elderly driver's performance and accident characteristics by reference to three kinds of visual impairment: cataracts, visual field restriction and monocular vision. By using goggles, the authors simulated these visual impairments in two groups of subjects, young and elderly, who had normal corrected vision. Driving performance was assessed on a closed-road circuit, free of other vehicles. The results indicated that cataracts resulted in the greatest decrease in driving performance, followed by visual field restriction, even though all drivers satisfied the visual
requirement for driving. The effect of visual impairment on driving performance was greater for the older subjects.

Nevertheless, research work is progressively taking into account cognitive and psycho-sociological factors. As an example, Baldwin et al. (1995) tried to assess the age difference in mental workload capacity in a driving simulator environment with the use of a subsidiary mental arithmetic task. The results indicated that as steering task difficulty was increased, verbal response latency on a concurrent mental arithmetic task increased more for the older subjects than for the younger. Moreover, the authors stated that the secondary mental arithmetic task did not interfere with steering performance. This seemed to indicate that older subjects kept their priority to the driving task when they had to deal with another concurrent task. However other work using a simulated driving task showed that uncertainty concerning the location of relevant information slowed decision-making speed proportionally more for older subjects than for younger ones (Ranney et al., 1992).

An interesting approach has been used by Taranek et al. (1993) and McCoy et al. (1993) to evaluate drivers in the situations that are most often associated with older-driver accidents, left turns at controlled intersections in urban areas. Results showed that among vision factors, sensitivity of depth perception and peripheral vision (right field) were significantly correlated with the driving performance of the elderly subjects. Perceptual abilities seemed to have a greater impact on driving performance: some older subjects had good vision but a lack of ability to use it effectively. Concerning other cognitive dimensions, it appeared that language skill, orientation, memory, attention and the ability to follow verbal instructions were most highly correlated with driving performance. Decrements in range of motion did not appear to be correlated with driving performance. The authors explained this by pointing to the fact that, in their driving situation, traffic density was low, inducing few lane-changes, passing or collision avoidance manoeuvres. These results have been used to design countermeasures to address the problems of older drivers, such as:

- physical therapy (home based exercises designed to improve posture, trunk rotation, neck and shoulder flexibility);
- perceptual therapy (home based exercises, 20 min four times per week for 8 weeks);
- driver education (safe driving for mature operator programme);
- traffic engineering improvements (signs, pavement markings and traffic signal displays).

Using the same route to test the effects of these countermeasures on driving performance, it has been shown that the combination of perceptual therapy and driver education provide the greatest improvement, followed by the combination of traffic engineering improvements with driving education and either physical or perceptual therapy. However, the differences observed were not statistically significant. The authors concluded that this new approach is promising and should be extended by using a different sample of older drivers (more representative of the older population) and more extensive traffic engineering improvements.

Among drivers who are elderly, different durations of driving experience and different attitudes towards driving risks are of course possible. Drivers who are elderly present the greatest variability of any age group, in terms of performance in various measures of cognition, vision
and response time. Their age-related perceptual and cognitive difficulties lead to changes in their driving habits and often to giving up driving, which affects their own mobility. Self-decision to stop driving has been found to be related to sex and health status of the driver (Hakamies-Blomkvist and Wahlström 1998). Men who are elderly tend to find it more necessary to drive and to stop driving later than women. Men who have voluntarily stopped driving are typically in poorer health than those who continue. However sooner or later elderly drivers are faced with an increase in the level of accident risk, due to their difficulties in the detection and information processing of road signs in a functionally useful time.

**Drivers who are elderly and accident involvement.** In most industrialised countries, the accident rate as a function of age shows a U shape curve which is higher for the younger age groups, then decreases and finally increases again for age groups over 60. This increase is maintained, even taking exposure into account, because elderly drivers tend to drive less. Age comparisons of fatality rates, however, must take into account the greater fragility of people who are elderly.

Driving accident patterns of drivers who are elderly are well documented and differ significantly from those of younger drivers. When involved in accidents, drivers who are elderly are more often considered as responsible (Fontaine and Gourlet, 1992). They are rarely involved in speed violations or alcohol driving. Their main areas of accidents are at intersections and more generally complex traffic conditions. Vehicles of these drivers are more often hit than hitting. These accidents occur less in night-time conditions, which reflects the fact that elderly drivers drive less at night due to visual difficulties, as well as having less of a social requirement.

After the age of 55, adults begin to have more traffic convictions and accidents per miles driven. Based on the use of mileage as a measure of exposure to risk, drivers who are elderly are commonly accepted to have higher accident rates than middle-aged drivers. Their accidents tend to occur during merging in traffic, turning across traffic and in relation to refusal of right of way priority. In right handed driving countries, the left turn is particularly difficult and data indicate that elderly drivers at fault were hit by a vehicle coming from the right in 59% of the cases and by a vehicle coming from the left in 41% of the cases. Observations made in Japan (a left handed driving country) at different simple intersections did not show differences in attention allocated (visual behaviour) to oncoming traffic by elderly drivers compared with others. However, they needed more time to complete the turning manoeuvre, allowing potential conflict with rapidly approaching vehicles (Keskinen et al., 1998).

Problems in making rapid and safe turning manoeuvres could be due to a lack of sensitivity to the speed of oncoming vehicles, basing judgement on the acceptance of physical separation, irrespective of speed (Staplin, 1995). Drivers who are elderly could also have difficulties in negotiating intersections due to a decrease in their working memory abilities. The complexity of an intersection could result in an overload of the driver and as a consequence, lead to risky decision-making. To reduce this, it is suggested that drivers be provided with cues that could be used to better prepare their action (Guerrier et al., 1999). In another intersection study reported by Garber (1991a) the following conclusions were drawn. Drivers who are elderly:

- have significantly higher involvement ratios than other age groups;
• have higher involvement ratios at intersections outside cities than within cities;
• when involved in a crash, are more likely to have committed a traffic violation, and this likelihood increases with age;
• are more likely to commit a traffic violation at an intersection, during a turning manoeuvre (left-turns) and at yield right-of-way, than other age groups;
• are more likely to commit a traffic violation at intersections controlled by stop signs than at any other type of traffic control.

Pedestrians who are elderly

Due to the age-related biological changes that affect movement, such as decreases in muscle mass, bone density, number of nerve cells, strength and energy, people who are older have to walk slowly and sometimes using a cane. Reduced speed of walking is adopted to compensate for changes in visual and balance abilities as well as a reduction of the available strength of the lower limbs. The length of stride is generally reduced and pedestrians find it difficult to adopt a steady walking rhythm. The reduction of walking speed seems to occur spontaneously, allowing elderly pedestrians to deal with unexpected environmental events more effectively (Ferrandez, 1989). In a recent survey, it was shown that after 70 years old, a quarter of the men and 40% of the women experience difficulties in walking (Hjorthol and Sagberg, 1998). They also find standing uncomfortable and tiring. However in the younger population of elderly people, a reduction in the average number of long walks can be observed. This is due to an increase in the use of private cars (Oxley, 1998).

Three types of problem can be identified for pedestrians who are elderly:

• considering near-side only: due to cognitive workload, problems in processing all the relevant information at the same time. They might check first one side of the road and then the second, once they have arrived at the middle of the road. Such a strategy is very time consuming and could often lead to a situation where the pedestrian will be only at the middle of the road when traffic re-starts from traffic lights;
• following other pedestrians with a reduction in the level of awareness;
• confusion at junctions: at complex junctions with cadenced traffic lights, pedestrians who are elderly could have difficulties understanding the logic of the crossing. As a consequence they might then decide to cross at another point (not protected) or to follow other pedestrians without checking if it is safe, or try to cross when they think they are allowed to do, but inappropriately.

Pedestrians who are elderly have a greater tendency to take the shortest path and will not systematically use pedestrian crossings. It seems that some pedestrians who are elderly have difficulties in seeing the crosswalk signals from the opposite side of the street. Most of them avoid rush hours, dusk and night for crossing. Even if it seems that they have enough time to cross the street with walking signals, they feel quite anxious and increase their walking speed as much as they can. But doing this, they also increase the risk of falling (Bailey et al., 1992). Sometimes a lack of knowledge of the meaning of flashing crossing signals is also observed;
pedestrians who are elderly tend to go back instead of continuing to cross (Bailey et al., 1992). However a history of driving experience can increase the pedestrian's 'road sense' (Packham and Silcock, 1998; Nagayama and Yasuda, 1996).

Pedestrians who are elderly and accident involvement. Pedestrians who are elderly are less involved in pedestrian-vehicle crashes than other groups and particularly children, but when they are involved in a crash they are more likely to be killed (Zegeer, 1993). That is why the rate of fatal accidents of elderly pedestrians is higher than in other groups (Marcellini et al., 1998). Most statistical data show an increase in fatalities after 75 years of age (Zegeer, 1993).

Crashes involving elderly pedestrians can be explained by different factors such as (Bailey et al., 1992):

- the influence of glare which can prevent reading crossing signals;
- the difficulties in extracting relevant noise from the street which will result in lower detection of oncoming traffic, especially from behind;
- the general slowing of behaviour which could lead them to a long decision time before crossing or difficulties in setting up the crossing strategy.

When studying accidents in Paris of pedestrians who are elderly, it appears that conflicts occur mainly with cars (59%) followed by two-wheeled vehicles (28%), commercial vehicles (8%), public transport vehicles (3%) and lorries (2%). Main causes of the 566 elderly pedestrian accidents registered in Paris in 1996 were:

- the pedestrian did not respect the crossing rules;
- crossing out of time (with traffic lights);
- violation of the pedestrian right of way by drivers;
- manoeuvres of vehicles (U turn);
- violation of red light by drivers;
- various other reasons (e.g., alcohol, speed).

In the USA, Zegeer (1993) indicated that the main sources of crashes with pedestrians who are elderly involved turning and reversing vehicles. Some surveys showed that due to their decrease in walking capacities, pedestrians who are elderly tend not to go to intersection crossings, even if most of the time they are protected intersections with crossing signs. This is due to the fact that the protected crossing is either too far or it is too complex to set up the crossing strategy (Baltes, 1998). In a Swedish study, elderly pedestrians were asked to cross a street at fast, very fast and normal speeds. The results indicated that 90% of the subjects crossed the street at a speed lower than 1.2 m/sec, some of them crossing at a speed lower than 0.7 m/sec. In terms of reference, it is worth noting that some official traffic engineering recommendations are to take a speed of 1.2 m/sec as the basis for crossing time.
TRAVEL NEEDS OF PEOPLE WHO ARE ELDERLY

Travel needs depend on the road user’s goals and on limitations in moving around. The primary goal is reaching a destination, but other conditions are required, particularly safety and comfort, and these are thus the secondary goals. The travel needs of a particular group can be identified by comparing these goals with their functional characteristics (motion, sensory, psychological and communication limitations). Identification of the travel needs of people who are elderly is based on their difficulties in performing a set of tasks related to driving and/or walking. Considering the purpose of this book, environment-related tasks are the relevant ones in which to identify the needs of the concerned population to reach their destination safely.

Environment-related tasks while driving and walking

The difficulties experienced by drivers who are elderly in performing certain strategic and tactical tasks enable us to identify their needs in order to continue driving and satisfy their mobility goals safely. Identified needs for each environment-related sub-task and the corresponding areas of difficulty include the following:

1. Vehicle control involving the following sub-tasks:
   - Road-related tasks - intersections (road crossings, T junctions, roundabouts), narrow or sharp curves, driving onto and off motorways, road works, railroad crossings, driving on flyovers, bridges, and tunnels;
   - Traffic-related tasks - car-following, overtaking, entering and leaving traffic, lane changing, reading road signs;
   - Roadside service - contacting breakdown service, changing a wheel.

2. Trip information is required particularly to:
   - Determine whereabouts – people who are elderly may have some difficulties in hearing and understanding announcements, identifying visual displays, detecting arrival point, reading maps;
   - Changes in regular travel schedule - getting information on route changes, and changing route (road works, traffic jams) constitute areas of difficulty.

3. Environmental conditions – dealing with particular environmental conditions such as:
   - Weather, sometimes imposing increased difficulties to see, read, understand signs and audible information in degraded visual and sound conditions;
   - Night driving, imposing increased difficulties resulting from visual deficits and greater sensitivity to glare as well the need for more time to recover.

4. Parking – the identification of parking areas and the payment system, as well as appropriate manoeuvres, represent areas of difficulty for drivers who are elderly.
Regarding pedestrians who are elderly, their travel needs are identified on the basis of their difficulties in walking resulting from a considerable decrease in their physical and sensory abilities, as well as unsuitable walking conditions. Moreover, older people are more vulnerable and, usually they feel unsafe when crossing a street even with traffic lights. Therefore, the following areas of difficulty have been identified in relation to the performance of some specific tasks involving walking:

1. **Street crossing**, imposing increased difficulties at unprotected street crossings, as well as at protected street crossings (traffic lights);

2. **Pedestrian areas**, where irregular pavements, difference in levels, stairs (step length and height, total distance by stairs), ramps (straight or in curve), barriers (parked cars, objects on street), string beans and escalators can represent increased difficulties;

3. **Access to parking areas**, particularly underground or silo parking having unsafe access for pedestrians;

4. The use of public transport imposes some difficulties related to the infrastructure, such as walking distances and access to vehicles. The following areas of difficulty have been identified:
   - **Bus and tram stops**, as well as metro and railway stations sometimes make access to vehicles very difficult for people who are elderly, resulting from large gaps, high steps and inadequate ramps;
   - **Intermodal trips** impose mode transfers where the walking distances can be excessive for the concerned population; moreover, string beans and escalators can impose increased difficulties as well if their speeds are too high.

**Travel needs of drivers who are elderly**

Considering the age-related decreasing abilities of the driver who are elderly, the following areas of difficulty with typical current road environments have been identified. These take into account the driver's remaining capacities, their perceptions of task complexity and their compensatory strategies.

1. **Regarding intersections** (road crossings, T junctions, roundabouts) drivers who are elderly require:
   - Controlled intersections (traffic lights);
   - Adequate road-side information;
   - Roadway design which makes the task easier.
2. Regarding driving onto or off motorways, drivers who are elderly require:
   - Advance information with adequate size for legibility;
   - A road design allowing an increase in the distance to get into traffic lanes;
   - Separated slip-roads to drive onto/off the motorway in order to avoid conflicting traffic situations.

3. Regarding road works, drivers who are elderly require advance and clear roadside information.

4. Railway crossings should be avoided and replaced by flyovers; at existing railway crossings, clear and early warnings are required.

5. When following a car, overtaking, entering and leaving traffic, lane changing, as well as driving on flyovers, bridges and tunnels, drivers who are elderly require:
   - Good visibility;
   - Clear information (e.g., road signs, unambiguous one/two flow signs and pavement markings).

6. When contacting breakdown services or changing a wheel, people who are elderly require increased safety conditions to accomplish these tasks (e.g., space and protection from traffic).

Travel needs of pedestrians who are elderly

The identified difficulties of elderly pedestrians in meeting their outdoor mobility needs allow us to define the following requirements for the improvement of the environment:

1. Regarding street crossings, pedestrians who are elderly require:
   - Protected street crossings;
   - Frequent protected street crossings;
   - Enough crossing time allocated to cross safely.

2. Regarding pedestrian areas, pedestrians who are elderly require:
   - Smooth and level pavements (given adequate width);
   - Reduced difference in levels (sidewalks);
   - Absence of barriers;
   - Ramps provided with handrails, particularly in curves;
   - Lifts or smooth ramps instead of stairs;
   - Adequate length and height of steps.
3. Pedestrians who are elderly require good accessibility and safety at underground parking and silos.

4. Regarding the use of public transport, people who are elderly require:

- Reduced intervals between bus/tram stops and metro/railway stations;
- Lifts instead of stairs and escalators;
- Appropriate length and height of steps;
- Reduced walking distances;
- Appropriate speed and design of escalators and string beans.

In order to respond to all these identified needs of drivers and pedestrians who are elderly, specific recommendations are proposed in a later section of this chapter. However, there is a lack of accurate specification on many issues. This strongly suggests that people who are elderly should be routinely included in future highway design studies.

**INFORMATION REQUIREMENTS AND ROAD SAFETY**

In order to make appropriate decisions and to perform the task safely and efficiently, the driver needs information from the vehicle and the road environment. The three levels of the driving task - navigation, manoeuvring and control - should be considered in identifying driver information needs. The special needs of people who are elderly concern mainly information on "where he or she is", "how far he or she is from the next decision point" and "what he or she has to do there" (e.g., turn left/right or go on). The time of presenting the information, its repetition and aids for decisions in more complex situations should be matched to the person's memory, attention, response times and spatial representation deficits.

The two primary ergonomic approaches to the design of a system consist in adapting the system and/or the environment to fit the user's needs according to criteria of safety, efficiency and comfort and modifying the user to interact easily and safely with the system through training. Both approaches are important in providing maximal benefit to users, in terms of adequate human-machine interfaces. The enormous variability among people who are elderly is a major difficulty in this design process.

The decline in the sensory and psychomotor capacities of the elderly is reflected in difficulty in discriminating relevant information and in the need for more time to process it. Advanced Transport Technology (ATT) can be of great help in driving but it is bringing about important changes in the driving task and the road environment. If we still take into account that drivers who are elderly are not familiar with modern information technologies and have difficulties in self-learning, we can easily understand that using ATT can be a factor increasing the complexity of the driving task. These systems provide relevant information for travellers, either drivers or public transport users, aiming to improve safety, efficiency, economy and the environment of all modes of transport. In-vehicle systems, such as route guidance, collision avoidance, reversing aid and emergency alert systems, as well as dynamic information systems, may become factors creating important changes in the driving task and road environment. Although guidelines have been and are being produced for designing systems to fit drivers who
are elderly, there is a neglect of the possibilities offered by training in enabling such drivers to engage safely and effectively with developments in modern transport technologies.

**Drivers who are elderly and advanced transport technology**

Information technologies are more and more present in the transport domain either inside vehicles or in the road environment. The new trends in driving aid technologies could provide an opportunity for elderly drivers to continue to drive without restrictions. However, there are very few data available regarding their needs in relation to on-board telematic services, the behaviour of these drivers when using on-board telematic services and also the benefits that drivers who are elderly could draw from these telematic services. The EDDIT Project has tried to fill this gap and conducted tests in Europe involving almost 400 drivers over 60 years old. These tests have been carried out on public roads, driving simulators and on private roads (Oxley 1996).

**Route guidance systems**

Driving an unfamiliar route, along unknown roads means drivers may have a requirement for navigational information. This activity can be very attention demanding and drivers who are elderly experience difficulties in doing it while driving. This is why they prefer familiar roads and avoid unfamiliar areas. From the work conducted by the EDDIT project, with four route guidance systems under real road traffic conditions (Oxley et al., 1994a, 1994b; Marin-Lamellet et al., 1994), it can be said that:

- Drivers who are elderly found the technological aid useful for them and said that they could go out more often in unfamiliar places more easily;
- Hazardous situations were observed in complex junctions where the information presented was difficult to understand;
- The effect on the activity of driving appeared to be limited mostly because no handling of the system was necessary when driving (programming the destination was made when the car was stopped). However, observations showed that handling an information system (road traffic) with a keyboard while driving was a very dangerous task for drivers and particularly for drivers who are elderly;
- Most of the drivers were obliged to increase their level of concentration but small distractions were generated by the systems;
- Vocal instructions were particularly appreciated by the drivers who are elderly.

In the context of the guidance driving aid, the EDDIT project also carried out some generic work in a driving simulator context. The presentation of guidance instructions with a Head Up Display versus a dashboard display was explored, as well as the interaction between age and the size and the complexity of guidance symbols (Marin-Lamellet et al., 1994; Marin-Lamellet et al., 1995). The results obtained showed that the Head up Display improved the reaction time of the elderly subjects in the simulator context and that audible cues were particularly useful for them. Furthermore, the results confirmed that people who are elderly take in and process
complex visual information in a less efficient way than young adults, and also that the difficulties encountered were increased by the complexity of the driving task.

Reversing aid systems

Drivers who are elderly increasingly experience difficulties during reversing manoeuvres. This is due to reduced physical suppleness with age, restricting neck and torso movements, but also to reduced lateral field of vision. Consequently, elderly drivers usually need more space to park their car, and they have a higher accident rate than other drivers when parking. Trials done by the EDDIT project (Barham et al., 1994a, 1994b) showed that reversing aid systems were useful and easy to use by most of the participants. Some difficulties were encountered during the first trials as it appeared necessary to obtain familiarity with the system distance indications.

Night vision enhancement system

For most elderly drivers, driving at night is very difficult due to the age-related reduction of visual acuity with low luminance. Relevant objects when driving (pedestrians, road panels, roadwork signs and landmarks) cannot be seen clearly in darkness; older drivers are also particularly sensitive to glare. The EDDIT project tested a system using infrared technology (Oxley et al., 1994) in which a camera mounted at the top of the windscreen projected the forward image as a Head-Up Display. The assessment was carried out on a restricted track. The subject’s task was to detect various objects situated around the road, i.e. pedestrians, dummies and road signs, while driving the car once with the system off and once with the system on. The results indicated substantial improvement in the distances at which drivers were able to detect pedestrians and certain road features. The subjects found the system easy to use and the Head-up Display easy to read. It should be stated that the trials were not carried out on a winding road or in heavy traffic and more work is needed on the viability of this type of support system.

Collision avoidance (T-junctions and turns across traffic)

The reports of accident characteristics of drivers who are elderly show that they have a high accident rate at junctions, especially when the driver has to turn across traffic from a major road into a minor road or to turn out of a minor road into a major road. With this in mind, the EDDIT project developed and assessed a prototype of a decision aid system which can be used in this context. The interface for the driver was in the form of a green (safe gap) or red (unsafe gap) light. Considering the early stage of design of the prototype system and the potential risk of the situation, it was decided to conduct the evaluation on a driving simulator.

The results showed that such a system reduced the number of unsafe gaps accepted by the drivers; however, it should be stated that for some subjects their definition of a safe gap was not the same as that of the system, which produced potentially dangerous situations. Consequently further development should adapt the system to the performance of the
individual rather than be set at a notional safe time. Most of the subjects who participated found the system useful, easy to use, and thought that it could modify their driving behaviour.

Other advanced transport technologies are under development such as Intelligent Cruise Control, a device that automatically regulates speed and distance between vehicles in a highway context. It is possible however that the use of such a device by drivers could lead to a large decrease in attention level. Another concept of advanced transport technologies that could be potentially useful for elderly drivers concerns emergency aid, in particular a system to detect a problem at the driver level (drowsiness or heart stroke for example) and to take over safe management of the car. This kind of advanced technology is highly safety critical and will need further development before being put into use.

The EDDIT trials showed a high degree of willingness from drivers who are elderly to consider the use of Advanced Transport Technologies. Even if more work is needed on this issue, there is every reason to suppose that well designed telematic systems could be useful for them and will lead to an increase in their safety and mobility on the road. The TELSCAN project has followed on from this work and produced a handbook of ATT design guidelines taking into account the characteristics of potential users who are elderly (Nicolle et al., 1999).

Cognitive plasticity in the older person

Due to a generation effect, some people who are elderly are not used to advanced technology, and this may lead them to avoid and even reject new technological systems. Such an attitude can lead to learning difficulties. Learning performance and learning aptitude decline with age, particularly when the information presented increases in complexity or when the speed of presentation is beyond the control of the subject. However, according to Stokes (1992), some disabilities of people who are elderly are more related to under-stimulation than to the loss of intellectual capacity.

One of the solutions for reducing cognitive demands and improving the cognitive performance of older adults is through training interventions. Others include restructuring the cognitive information and molar changes in the environment (Park, 1992). However, all these solutions must be taken into account together, in order to design training programmes compatible with the cognitive changes related to the ageing process, and be based on a cognitive ageing framework to solve real-world problems for the elderly.

Van Zoomeren (1987) proposed a theoretical framework of attention, and defined it as a cognitive state with two interdependent dimensions: selectivity, which refers to limited information processing resources, and intensity, which is the dimension of alertness. The age differences in the domain of selectivity, particularly those concerning divided attention, likely contribute to age decrements in a broad spectrum of cognitive activities, including learning, memory and problem solving. The empirical data show that people with attention impairments have difficulties in selecting relevant information, particularly when a lot of information is presented at a high rate. Even when all information is relevant, their limited resources lead to errors and omissions. Moreover, different studies report a proportional increase in age
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decrement under increasing task complexity. Considering that automatic processing does not demand significant attention resources and is either based on inborn mechanisms or is the result of learning, training for people who are elderly should integrate effective learning of daily living activities, particularly those concerning mobility: the use of public transport and car driving. At the same time, training should develop the ability to anticipate events in order to optimise the use of their limited processing resources and avoid too much information processing simultaneously.

Cognitive training

Cognitive training directed to a driving context could be seen as a way of improving mobility and safety of people who are elderly, based on the state of the art in cognitive training research. Willis (1990) states that the most important result of cognitive training research is the identification of the plasticity of adulthood cognitive functioning. Numerous studies have reported significant improvements in the performance of adults over 60 years by means of behavioural interventions, as well as the possibility of halting the decline of cognitive performance of the healthy elderly by means of cognitive training. According to Park (1992), cognitive training, as well as interventions at the environment level, can reduce cognitive demands and improve cognitive performance. Baltes et al. (1986) noted that although fluid intelligence abilities decline with age, there is a certain amount of cognitive energy or capacity held in reserve by both young and elderly adults. The concept of reserve capacity is the focus of cognitive training research to restore reserve capacities to enable improvements in cognitive behaviours.

Life-span development in the later years shows a trade-off between a loss in creativity and a gain in wisdom, which is explained by the age distribution of fluid versus crystallised intelligence. The first one, fluid intelligence, entails the abstract capacity for problem solving (creativity), while crystallised intelligence involves the acquisition of practical experience and expertise (wisdom). With optimal training or under suitable conditions, the reserve capacity can be expressed as plasticity and used, thereby increasing cognitive performance above observed baseline levels. The finding that individual behaviour can be modified significantly in the elderly through cognitive training has indeed been used to demonstrate the existence of a reserve capacity. In this context, the usefulness of cognitive training and its relevance become more evident regarding the cognitive difficulties of elderly people when using new systems, as well as their acceptance of change and adaptation to these systems.

Drivers who are elderly should be encouraged to up-date their driving-related knowledge by means of specific training programmes. Actually, training could constitute a way of allowing people who are elderly to keep driving safely and be aware of their own limits. The EDDIT project training experiment (Simoes et al., 1994) has shown that cognitive training activities can provide a cognitive stimulation which slows down the decrement in capacities related to the ageing process. The design of cognitive training should prepare people to deal with complex tasks in complex environments. Therefore, a driving context-oriented training programme should focus on knowledge-based activities as well as on skill and rule-based activities.
According to Dreyfus and Dreyfus (in Olsen and Rasmussen, 1989), this means that 'know-how' is no more enough and training should extend to the 'know-that'.

To take an example of context-oriented training to drive a vehicle equipped with ATT systems, such a training could focus on integrating activities at each of the levels of the driving task:

1. Regarding the strategic level, (navigation) it should integrate knowledge-based activities allowing for:
   - a more rapid and effective understanding of displayed messages;
   - the development of the senses of direction and distance;
   - the development of spatial knowledge representation (cognitive maps);
   - the representation of routes having the characteristics of reversibility, transitivity and flexibility.

2. Regarding the tactical level (rule-based), the training should focus on the interaction with other road users, using displayed messages to anticipate their behaviour;

3. Regarding the operational level (skill-based), the training should integrate the learning of the control of any system used.

Recent developments in cognitive training research stress the fact that computer-based systems are bringing about substantial changes in tasks, imposing new skills that demand adequate training methods. According to Bainbridge et al. (1989), the impact of new technologies on training is twofold: first it results in skill demands that emphasise the importance of cognitive skills, and second, new technologies provide new tools for training and more control over training. Cognitive training research suggests that the design of training programmes adapted to people who are elderly and to different travelling contexts using telematics, should take into account the following:

1. Even if computer tasks are not familiar to the elderly, at each stage of the training programme, learning should be supported by pre-existing knowledge, because this is likely to be more successful than training people in completely new tasks;
2. Learning materials should be well-elaborated and people should be encouraged and helped to establish links between information that they are learning and pre-existing knowledge;
3. In order to maximise possibilities for transfer, a training programme should be varied in terms of types of stimuli and materials used in training, most of them being related to the context addressed and the learning skills required;
4. Pictorial forms should be used as stimuli in training materials, as they allow for easier information processing;
5. Implicit memory being intact in the elderly, implicit memory skills should be used in training;
6. The training programme should develop the subjects' capacities for selecting relevant information, and anticipating events and relevant information, in order to ease decision making;
The training programme should provide for the acquisition of adequate compensatory strategies to be used in the subject's daily life.

In the USA a mature driving improvement programme was established in California in 1987. Participants are entitled over three years to receive auto insurance premium reductions (Janke, 1994). The course curriculum includes:

- Strategies to compensate visual and audio impairments;
- Precaution measures to prevent or offset the effects of fatigue, illness and medications on driving performance;
- Updates on rules and efficient driving techniques under current road and traffic conditions;
- Planning travel time and selecting routes for safety and efficiency;
- Decision making in dangerous, hazardous and unforeseen situations.

Additional suggestions have been proposed by Janke (1994), such as recommendations for periodic medical and vision examinations, caution in terms of leaving enough distance between cars in order to give more time to react to evolving traffic situations, avoidance of high-risk situations, as well as an incitement to assess periodically their own perceptual and psychomotor skills in order to detect declines and, if possible, compensate for them.

**RECOMMENDATIONS FOR THE IMPROVEMENT OF THE ROAD ENVIRONMENT**

As the driver is a component of the driving system, his or her characteristics should be taken into account in the design of the different components of the roadway system. Therefore, the following recommendations for road environment improvement consider both categories of travellers discussed in this chapter (drivers and pedestrians who are elderly), whose needs have been identified in relation to an inventory of areas of difficulty in performing driving and walking-related tasks. The best general recommendation that could probably be formulated is to include in every traffic study centred on the design of the road environment a sample of road users (drivers and pedestrians) who are elderly.

**Enhancing the driving context**

Aiming to meet the identified needs of drivers who are elderly and their requirements for safe and comfortable driving, a set of recommendations for road environment improvement are presented below (Staplin et al, 1998; CEMT, 1991).

1. Regarding intersections (road crossings, T junctions, roundabouts) drivers who are elderly require:
   - Controlled intersections: traffic lights are better than right of way or yield;
Elderly drivers and pedestrians

- Adequate roadside information: to reduce confusion at an intersection approach, the use of a separate signal to control movements in each lane of traffic is recommended. A minimum letter height of 150 mm is recommended for use on post-mounted street name signs; for overhead mounted street signs, a minimal height of 200 mm is recommended;
- Roadway design easing the task: for example, skewed intersections should be avoided, right angled being better; a minimum brightness contrast ratio of 2 between the painted edge of the roadway and the road surface if lighting is operated (contrast of 3 if no lighting).

2. Regarding driving onto or off motorways, drivers who are elderly require:

- Advance information with adequate size, lighting and glare protection;
- A road design allowing an increase in the distance to get into the traffic lane;
- Separated slip roads to drive onto/off the motorway in order to avoid conflicting traffic situations.

3. Regarding road works, drivers who are elderly require advance and clear roadside information.

4. Railway crossings should be avoided and replaced by flyovers; at existing railway crossings, clear and early warnings are required.

5. When following a car, overtaking, entering and leaving traffic, lane changing, as well as driving on flyovers, bridges and tunnels, drivers who are elderly require:

- Good visibility;
- Extended use of 'overtaking zones' on two-lane roads;
- Clear information on, for example, the length of two-lane road sections.

6. Regarding traffic-related tasks, the major recommendations concern the required information (in due time, correctly located, having adequate dimensions and contrast, according to environmental conditions), as well as training programmes to improve driving ability. The required information (static and/or dynamic) should take account of the position, direction, identification and functioning/rules. Moreover, Advanced Transport Telematics might one day provide most of the remaining identified information needs of drivers who are elderly, but training programmes should be introduced to enable an efficient use of these systems.

Enhancing the walking context

To ensure safety and mobility of pedestrians who are elderly, their needs regarding walking and the use of public transport should be taken into account. These needs could direct in a general way the design of the road and pedestrian environment (Marcellini et al., 1998, Steenbeckers and Beijstervedt 1998, CEMT 1999, Johansson 1993).
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1. Regarding street crossings, pedestrians who are elderly require:
   - Protected street crossings, with stop lines placed 2 m before the pedestrian crossing;
   - Increased duration of the red light period of traffic light systems;
   - Car traffic calming areas;
   - More safety islands for pedestrians (when crossing wide streets);
   - Enough crossing time allocated to cross safely: walking speed has been found between 0.7 m/s (average men and women over 80 years old) and 1.0 m/s (average men and women from 65 to 69 years old); a speed of walking of 0.85 m/s for the calculation of the duration of crossing signals could be recommended. Lower walking speed values should be taken into account if elderly people use walking aids; in this case more time is required.

2. Regarding pedestrian areas, pedestrians who are elderly require:
   - Smooth and level pavements, gradients of 2.5 % maximum (1% is never an obstacle);
   - Reduced difference in levels (side walks);
   - Separate lanes for pedestrians and cyclists;
   - Ramps provided with handrails, particularly in curves;
   - Lifts instead of stairs;
   - Adequate length and height of steps: the following average values should be considered for the design of steps: 18 cm (men and women over 80 years old) and 19 cm (men and women from 65 to 69 years old).

3. Pedestrians who are elderly require good accessibility and safety at underground parking and silos.

4. Regarding the use of public transport, people who are elderly require:
   - Reduced intervals between bus/trams stops and metro/railway stations;
   - Lifts instead of stairs and escalators;
   - Appropriate length and height of steps,
   - Reduced walking distances and provision of benches for resting every 70 meters;
   - Appropriate speed and design of escalators and string beans: for example, enhancing the border of steps by colour painting and increasing the lighting at the departure and arrival zones.

According to Oxley (1998), improvements of the environment to take account of the identified needs of pedestrians who are elderly will be obtained by increasing the number of pedestrian-only areas and of various safety measures such as protected crossing zones and measures to reduce vehicle speeds.

In addition to street crossings, as well as access to public transport and public spaces, speed of walking and comfortable step length and height should be taken into account in the design of
public spaces related to public transport use. Steenbeckers and Beijsterveldt (1998) propose a set of design guidelines based on measures of walking speed, step length and height. Step length, defined as the distance covered while taking one step, has been found to vary between 43.8 cm (average men and women over 80 years old) and 52 cm (average men and women from 65 to 69 years old). No significant difference has been found between comfortable step height ascending or descending. The following guidelines have emerged from the above measures:

- To determine the walking space required to walk behind a carriage, to pass through a revolving door or to be covered by taking one step, the average values constitute a reference point and the smaller values should be used;
- Regarding step height, the lowest height found is not comfortable for all subjects, so that adjustability is desirable where possible. Moreover, a flight of stairs should be regular, inducing a certain rhythm of body movement.

CONCLUSIONS

Road environment improvement is a major requirement to satisfy the mobility and safety needs of people of all ages. A system designed according to the special needs of people who are elderly could be user-friendly to all users. Thus, the increasing number of people who are elderly in all developed countries, as well as the increasing number of drivers over 60 years old, are not the only reasons why a system's design should take their special needs into consideration. The information provided to the road user (driver or pedestrian) is a further major factor for safety in the elderly, as is the ease of complicated manoeuvres by means of good intersection design. Finally, the use of telematics could be of great benefit, assuming good ergonomic design and the provision of adequate training interventions.

RECOMMENDED READING


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Imagine this. You are sitting in your office and have to be at a meeting 60 km away by 15.00 hrs later that day. You tell your computer where you want to go, your desired arrival time and that you want to use the company car. Instantly reviewing possible routes and their speed restrictions, likely congestion, roadworks in progress and expected weather conditions it replies that you will need to depart by 14.00 hrs to give a 95% chance of arriving on time. You accept this. At 13.59 you step into your vehicle which has already emerged from the underground car park and is waiting for you. A voice asks you to confirm your destination and on hearing your agreement the vehicle sets off, leaving you to continue with your work, access audio or visual entertainment, eat, sleep or whatever is possible in the confined space of the vehicle. You decide that today you will ride facing the rear and swivel your seat around to watch a wide-screen movie. At 14.55 your vehicle pulls up at your destination.

You have not been driven there by a chauffeur, however. Your vehicle has been entirely controlled by advanced transport technology (ATT), utilising such elements as satellite navigation, external vehicle speed control, lateral positioning and headway control and automatic collision avoidance, all situated within a network transport management system. Far-fetched? Perhaps for the moment, but the fact of the matter is that the required technology is just about already with us. ATT is on the march and is likely to change the nature of driving so radically that we may not even recognise it.

We have to an extent grown used to the task of driving changing, slowly but continually, as road and vehicle designs have evolved. Salient historic examples are respectively the introduction of motorways and the replacement of cable and drum brakes with hydraulically
operated disks. More recently we are witnessing the development of self-explaining roads (see Chapters 5 and 9) and traffic control systems which can add some 'intelligence' to the road environment and to vehicle functionality.

Intelligent Transport Systems (ITS) or User Services are based on intelligence placed at the roadside and in the vehicle (ETSC, 1999b). To date at least 32 separate applications have been identified. Some examples are navigation systems in the car and variable directional signs along the roadway. These can guide traffic, can reduce uncertainty in finding the optimal route, and can remove instabilities (e.g., traffic jams) in the traffic flow. Drivers can be equipped with reversing aids, night vision enhancement and emergency alert systems. Vehicle-to-vehicle interaction such as distance keeping can change from being performed manually by the driver to being performed more or less automatically.

Intelligent Transport Systems have varied aims including the improvement of safety, efficiency, economy and the environment. ERTICO is the European organisation which aims to promote ITS. Its optimistic vision of the potential advantages of ITS includes:

- a 50% reduction in fatalities;
- increased survival rates of crash victims by 15%;
- reduced travel time by 25%;
- decreased city centre pollution by 50%;
- reduced public transport delays by 50%;
- reduced freight and fleet operational costs by 25%.

ITS will also:

- provide for automatic monitoring and charging for road utilisation costs;
- enable rational car use through vehicle sharing;
- support intermodality between private and public transport;
- enable comprehensive management of the road network, including access control.

The European Transport Safety Council (ETSC, 1999b) concludes further that gains in safety from ITS could be significant. On motorways, injuries and fatalities could be reduced by 10-15% with the implementation of motorway control systems, driver and vehicle monitoring systems, collision avoidance systems, incident management and automated speed enforcement. On other rural roads, intelligent speed adaptation and automated speed enforcement could produce injury reductions of 30% and 20% respectively. Finally in urban areas, collision avoidance, intelligent speed adaptation and urban traffic control could produce a potential injury reduction of 30%. Nevertheless it should be cautioned that at present there is not a sufficient empirical basis to evaluate the effects that all of these systems might have on road safety.

What is more certain is that with such developments the role of the human driver will progressively change from being the active controller of the vehicle to being more of a passive systems monitor. This implies an increased emphasis on higher level cognitive activity, coupled with a decrease in the number and nature of control operations.
We can conveniently conceptualise the effects of many elements of current ITS applications in terms of the Task-Capability Interface model described earlier in Chapter 1. At the heart of that model is the idea that the outcome of any transaction between the driver and the road and traffic system is a result of the relationship between the demands of the driving task and the driver's available capability. We can represent this relationship over time as in Figure 1 below. Up to point 't', capability exceeds demand and a safe outcome pertains. However at point 't', demand momentarily exceeds capability and loss of control ensues.

Many components of ITS involve a transfer of driving task elements to automatic or semi-automatic systems, thereby reducing, or at least changing task demand. For example, current ITS applications could affect the various elements which together determine the driving task as follows:

- road: variable message signs which display information about road incidents, weather conditions and temporary speed restrictions. These will have the effect of reducing driver uncertainty and the likelihood of selecting an inappropriate speed or level of vigilance;
- vehicle: the capture, hold and display of critical information in the vehicle, rather than its brief presentation as the driver approaches and then passes a roadside display, will avoid the driver 'missing' critical information;
- road user: the provision of proximity or collision warnings, headway information, enhancement of conspicuity, ramp metering and flow control, will all potentially make adjustment to the presence of other road users easier;
- road positioning: the provision of lateral positioning guidance will facilitate this task element;
- speed: intelligent speed adaptation (external vehicle speed control), will limit speed options available to the driver and enable avoidance of too high a speed for the prevailing conditions.
Beyond these assistive technologies, complete transfer of elements of the task to automated control are possible, including speed, headway, lateral positioning and collision avoidance.

On the capability side of the model, current ITS applications relate in particular to the management of the human factors element in the determination of capability. These include:

- monitoring of driver state, such as of impairment due to drowsiness and drugs;
- transcending visual limitations through vision enhancement (night vision and reduced daylight vision);
- enhancing reliability of predictions through traffic information and variable message signs (see 'road' measures above);
- modifying motivation to commit violations through automatic violation detection and enforcement.

The reader is invited to consult GADGET (1999) for further description and discussion of these ITS elements.

It is natural to construe such ITS applications to the driving task and the driver as both reducing task demand and enhancing driver capability, thereby increasing the margin between demand and capability as represented in Figure 1 and increasing safety. But this would be rather too naïve a conclusion. Providing the availability of more information to the driver will certainly change the nature of the driving task and may even increase task demand. Hence its introduction needs to be managed in a way which takes full account of our understanding of the cognitive processes involved in driver information sampling and decision making (see Chapter 3). But if through ITS the task is made easier, will compensatory behaviour emerge, as described in Chapter 13? Will there be a loss of predictability of the behaviour of other road users as they variably take up the new technologies? Will there be difficulty in utilisation of ITS for different sections of the road-user population (e.g., see Chapter 17)? Will ITS induce a loss of skill in both experienced and novice drivers? What happens in the event of ITS failure in terms of road users' situation and system awareness, when they are 'out-of-the-loop'? Will there be increased collisions (rather than the expected reductions) because ITS encourages more traffic, more road use under hazardous conditions, a redistribution of traffic onto less safe roads (or roads which become less safe because of this redistribution) or more simply because it provides a compelling distraction?

Apart from road building, the highway engineer is in the business of providing relevant road positioning, route guidance, manoeuvring, regulatory and control information to the road user. To the extent that this information is supplemented, amplified, replaced or becomes invisible through ATT, not only the driver's task but also that of the highway engineer will change. In the long term ATT may provide for a much more efficient distribution of vehicles over road space, possibly enabling reduced carriageway numbers and width requirements, enabling provision of light-vehicle only roads and traffic lanes, a reduced requirement for all road-side information and controls and perhaps a massive increase in system efficiency and safety.

The move to this 'golden' future, however, will be preceded by a potentially very difficult transition period, particularly if developments are left solely up to market forces. There will
inevitably be a mix of vehicles on the roadway with varying degrees of assistive and/or externally controlled features as well as vehicles being driven independently; there will be a lack of standardisation in subsystem functionality; there will be a loss of predictive reliability of other vehicle behaviour; there will be 'adaptive' changes in road-user behaviour. The implications for highway engineering are very unclear during this period but, as represented in Figure 2, they will become the more compelling as levels of driver support and control develop and as levels of penetration of ATT in the system approach saturation.

Figure 2. Increasing implications for highway engineering as technology shifts from assistive to controlling and from low penetration of the system to high penetration

Thus in both the short and long-term the consequences of the development and application of ATT and ITS are uncertain. And hanging over the entire enterprise is the over-riding question of acceptability: the issue of the potential loss of freedom of the road user, the freedom to control directly the motion of a piece of moving machinery, just about when and where and how we want.
**GLOSSARY**

0.10 Hz component. The variation in heart rhythm with a cycle of 10 seconds that serves as a physiological indicator of mental effort. It is a narrow band (0.08-0.12 Hz) within the total spectral energy band range.

Accommodation. Is the process by which the image is focused on the retina. In degraded conditions of vision (night, fog), a special case of accommodation error arises from the fact that the eye tends to slip into a relaxed state of 'dark focus accommodation'.

Active failures. Errors the driver commits directly in his interaction with the system, of which he forms a part, and whose effects are felt almost immediately.

Actor-observer difference. The correspondence bias (see glossary entry) is much smaller, sometimes even nonexistent, when people explain their own behaviour than when they explain another person’s behaviour.

BAL. Blood alcohol level.

Behaviour adaptation. A change in behaviour, usually to some safety intervention, which may negate some or all of the intended safety benefit.

Behavioural adaptation. Tendency of drivers to react to changes in the traffic system, whether they be in the vehicle, in the road environment, in road or weather conditions, or in his/her own skills or states, in accordance with his/her motives; terms sometimes also
used: behaviour feedback, risk compensation and risk homeostasis, with somewhat different emphases.

Capacity. Available mental processing capability to perform a task.

Categorization. The act of putting events, objects and ideas in categories. Categories are specific real-world classes which can be identified by a list of distinguishing features (e.g., birds have wings, feathers, etc).

CHIPS. Acronym for model which describes the various interfaces between the driver, the vehicle and the road and traffic environment - Cultural, Hardware, Instructional, Physical, Social environments.

Cluster analysis. Method to group items together on the basis of their subjective similarity, leading to a dendrogram structure.

Cognition. The process of knowledge acquisition and its use.

Cognitive training. Training interventions aiming to improve individuals’ cognitive performance using cognitive tasks as simuli.

Conspicuity. How salient an object is in its own environment; how much an object stands out from the rest of the environment.

Contrast sensitivity. A measure of the limits of visibility for low contrast patterns (how faded can an image become, before it is invisible).

Contrast. Between two adjacent regions is their relative luminance levels.

Correspondence bias. A tendency to assume that a person’s words and deeds correspond with that person’s underlying traits, attitudes, and intentions, even when the words or deeds were facilitated by situational constraints.

CR, Current road. A road design based on existing design guidelines.

Declarative knowledge. Knowledge (factual) about the world and its functional properties.

Deindividuation. Losing track of a personal identity, often as part of a crowd, so that personal responsibility for the consequences of actions is lessened.

Discriminative stimulus. An event which signals the relationship between a response and its consequences.

EEG, Electroencephalogram. Record of the electrical activity of the brain cortex. Appears as a sinusoidal waveform ranging between 1.5 and 40 cycles per second (Hz) and producing a voltage between 10 and 200 microvolts.
Effort. Conscious energy expended in order to maintain a desired level of task performance.

Episodic memory. The ability to recollect specific events from one's personal past.

Expectation violation analysis and review. A process "designed to identify expectancy violations, pinpoint their sources, and develop information displays to restructure violated expectancies or structure appropriate ones. The analysis and review is initiated by first reviewing the area upstream and downstream of a problem location or assessing a road segment as part of general surveillance. This general review provides an understanding of the land-use, geometric design, traffic operational procedures, and traffic control devices which serve to structure driver expectancies. Once this understanding is obtained, and/or unidentified problems found through routine surveillance, a detailed analysis is then performed" (Alexander and Lunenfeld, 1986, p.28).

Explicit memory. Memory involved in remembering a prior experience.

False consensus. A tendency to view our own actions and choices as more common than they are, or at least as more prevalent than they are viewed by other people who choose differently from us.

Fovea. Is a small region in the center of the retina, about 2 degrees in diameter that contains exclusively cone-shaped photoreceptors (cones), and is responsible for highest spatial acuity. Rod-shaped photoreceptors (rods) are located everywhere in the retina, except in the fovea. They are used for vision at low levels of illumination.

Foveal vision. The image being looked at falls on the fovea of the retina, a central area in the retina of densely packed cone cells, which mediate the vision of details and colour. It corresponds (in experience) to the clear part of the image of any fixation.

Fundamental attribution error. A tendency to underestimate the power of the situation (relative to dispositions) when making causal attributions.

Global optical flow. Visual coherent motion pattern of all the objects in the visual field due to self-motion. In common language this phenomenon is defined as apparent motion because even static objects seem to move in the eyes of the observer; however in perceptual terms this sort of visual motion is quite real and provides a major source of information about our own displacements and about the structure of the environment.

Goal setting. The level of task performance that one tries to attain or maintain.

Groupthink. Group members seek concurrence, consensus and unanimity more than they seek the best possible alternative.

Holistic information. The overall information content instead of the specific features.
HR, Heart Rate. physiological indicator of both physical and mental workload.

HRV, Heart Rate Variability. (Ir)regularity in IBI, reflecting a person’s sensation of workload.

IBI, Inter-Beat-Interval. The time between successive heartbeats, relates to \( HR = \frac{60,000}{IBI} \), IBI in milliseconds, HR in beats/minute.

Illumination. Is the amount of light falling onto a surface. It refers to the lighting conditions in the environment and to how the objects are struck by photons, directly from light sources or indirectly from reflections by other objects.

Implicit memory. Also called perceptual priming, involves cognitive representations and expresses itself in cognition rather than in behaviour.

Information processing. Information moves toward some goal by going through a series of stages.

Itinerary approach and global safety approach. These differ from the blackspot approach (or analysis of local malfunctions, i.e. at a specific site) insofar as they take into account broader analytical units (different sections of road, of a town or of a county). These approaches combine accident analysis and observation of user behaviour. The itinerary approach involves spotting the repetitive aspects of the malfunctions observed and thereby highlighting those that are common to the particular itinerary. The global safety approach draws on different analytical tools, such as the categorisation of roads across a network, accident scenarios and the geographical location of accidents.

Latent failures. The negative products or results of strategic decisions made in the organisational and directive spheres of the system. They can reveal their presence when they are combined with active failures, creating a potentially conflicting or dangerous situation and increasing the risk of an accident.

Lightness constancy. Refers to the ability to perceive the constant reflectance properties of surfaces, despite changing conditions of illumination.

Lightness. Is the perception of a surface's reflectance.

Local optical flow. Visual motion pattern due to the displacement of an object. If the observer is also in motion the local optical flow will be the combined result of the global optical flow with the specific visual dynamic pattern of the object.

Luminance. A measure of the amount or intensity of visible light energy emitted or reflected from a given source or surface.

MDS, Multidimensional scaling technique. Used to determine the similarity between members of a set of stimuli.
Memory representations. The mental function of retaining information about stimuli, events, images, ideas, etc. after the original stimuli are no longer present.

Memory. The notion of human memory comprises different systems: refer to episodic, semantic, procedural, explicit, implicit and working memory.

Mental image. Our 'visual' representation of an object or event when it is absent, as opposed to perception that requires the physical presence of an object in the visual field. Mental imagery and perception share many psychological functions and brain structures, however the former seems to be much more demanding and requires more mental resources.

Mental workload. Proportion of the mental capacity required for task performance.

Myopia, or nearsightedness. Is a condition in which people can see well at short distances, but cannot focus properly on distant objects.

NASA-TLX. see TLX.

Negative transfer. The carrying out of the wrong procedure having switched task, such as the type of car you are driving.

Night myopia. Is a similar effect to myopia observed in conditions of night vision.

Normative influence. Because people want to be liked and to maintain social harmony, they sometimes comply with the majority's 'norms' or standards for acceptable behaviour.

Official road categories. Categories as intended by current design principles.

Optical flow. Visual motion pattern produced by any kind of displacement in the visual field of the observer. The optical flow can be imagined as an array of vectors distributed in the visual field, each one representing the motion of a point or object in three-dimensional space (see also global and local optical flow).

PASAT, Paced Serial Addition Task. Demanding secondary task.

Perception time in driver reactions. The time that elapses from a stimulus change (eg., appearance of an obstacle) to the detection of it and the start of the possible response (eg., release of gas pedal), also detection latency.

Photopic conditions of vision. Are viewing conditions under a high level of illumination (eg., normal daylight), in which the cones in our retina are active and colour is perceived.

Picture sorting task. Putting road scene pictures together in piles on the basis of their subjective similarity, providing the input for a cluster analysis.
Power law. Law which, in the context of training, states that increments in performance (speed, strength, accuracy etc) are equal to the amount of practice raised to a power (such as squared or cubed).

Procedural knowledge. Knowledge about how to do something which controls the execution of the act.

Procedural memory. The influence of earlier experiences on present performance, suggested by Tulving as a third system supporting semantic memory which in turn supports episodic memory.

Psychophysics. A branch of psychology. It includes behavioural studies of quantitative relations between people's perceptual experience and physical properties of a stimulus.

Reflectance. Refers to the fraction of incident light that is reflected by a surface.

Response time. Usually refers to the time interval between the accelerator response and the activation of the brake pedal, often called movement time.

Risk homeostasis. The idea that road users make behavioural choices so that they maintain a target level of experienced risk.

RSME, Rating Scale Mental Effort. Self-report measure of mental effort.

RTLX, Raw TLX. Modified simpler version of the TLX self-report measure of workload.

Saccade. The movement of the eyes; a jump from one fixation point to another fixation point.

Schema. A cognitive mental representation that is abstract and that can serve as a guide for action, as a structure for interpreting information, as an organized framework for solving problems.

Scotopic conditions of vision. Vision under low levels of illumination when rod activity dominates vision, particularly at night (night vision).

Script. Individual's knowledge of events in terms of appropriate behaviour to be carried out. Scripts also specify the setting or circumstances.


Secondary task. Added task to increase task demands, used to determine available capacity.

Segmentation. Perceptual differentiation between two or more optical flows.
Self-serving bias. People tend to attribute their own successes more to internal-stable causes and their own failures to external-unstable causes than they would when making attributions about other people.

Self-verification. Getting other people to verify what we believe to be true of ourselves.

Semantic memory. General knowledge about the world acquired through learning.

Sensory input. Information received by the sense organs.

Sensory-motor performance. Motor (i.e. movement) performance which is essentially controlled by afferent (sensory) and efferent (motor) mechanisms.

SER, Self-Explaining Road. A road design that automatically evokes correct expectations in road users.

Social facilitation. Animals and human beings intensify their behaviour when others of their species are present.

Speed adaptation. An illusion involving speed underestimation, arising from prolonged periods of driving at a high speed.

Stimulus control. A shift in the immediate control of behaviour to an antecedent event (discriminative stimulus).

Task demands. Once the goal has been set, a property of the task; what has to be attained by task performance.

Three-term contingency. The functional relationship between antecedents, behaviour and consequences.

Time-based measure. A control variable used by drivers that is given in time rather than distance (eg., time-to-collision, time-to-line-crossing, time-to-stop-line).

Time-to-Collision (TTC). Stands for the time required for two vehicles to collide, if they maintain their speed and path. TTC can also be applied for potential conflicts between vehicles and pedestrians or stationary objects. It has the advantage of combining into a single variable both velocity and distance. It is one of the most popular time-related measures of road user behaviour.

TLX. Self-report measure of mental workload.

Top-down processing. Expectations people have based on thoughts, goals or memory.

Working memory. The concept refers to the process and structures involved in simultaneously holding information (perceptual and from long-term memory) in mind and using that
information in order to perform specific tasks. Sometimes called short-term memory. Memory of short duration (usually only a few seconds) and limited capacity (about 7-9 'chunks' of information).
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