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Assessing and enhancing the capabilities of young novice drivers to anticipate latent hazards in road and traffic situations

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Dit proefschrift is tot stand gekomen met steun van de Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV. Hiernaast hebben het Centraal Bureau Rijvaardigheidsbewijzen CBR en het Human Performance Laboratory van de Universiteit van Massachusetts Amherst UMASS mensen en middelen beschikbaar gesteld voor onderzoek.

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ISBN: 978-90-73946-09-5

RIJKSUNIVERSITEIT GRONINGEN

HAZARD ANTICIPATION OF YOUNG NOVICE DRIVERS

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Proefschrift

ter verkrijging van het doctoraat in de
Medische Wetenschappen
aan de Rijksuniversiteit Groningen
op gezag van de
Rector Magnificus, dr. E. Sterken,
in het openbaar te verdedigen op
woensdag 30 november 2011
om 16.15 uur

door

Willem Pieter Vlakveld

geboren op 17 mei 1953
te Hilversum

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Preface

Although at moments during this PhD-project I felt lonesome, you never do research completely on your own and I would like to thank the people and institutes that made this fascinating journey through the land of science possible.

First, there were the guides I had in this land of science. These were my three supervisors: Prof. dr. W.H. Brouwer, Prof. dr. D.L. Fisher and Prof. dr. K.A. Brookhuis. Wiebo, discussions with you were always very stimulating and you made me acquainted with the intriguing world of cognitive neuropsychology. Your wise words kept me on track and it was your idea to expose novice drivers to hazardous situations in a driving simulator. Don, your hospitality and your openness to share knowledge are special. You hardly knew me and asked me to stay with you and your family in your family vacation home in Vermont. Thanks to the stimulating discussions with you, but also thanks to the creativeness and skilfulness of all the other people of the lab, I was able to run a unique experiment. Of the people of the lab, I especially would like to thank Sandy Pollatsek, Matt Romoser and Hasmik Mehranian. Karel, your share in this project was only at the end, but thanks to your comments, the final version has improved considerably.

Foremost, I would like to thank SWOV. When I started this project, I was fifty-three years old. Research institutes that not only facilitate older employees to realize a PhD project, but also encourage them to do so are very rare. I especially would like to thank our managing director Prof. F.C.M. Wegman. Fred, to my opinion you have succeeded in creating the right climate for scientist to grow and develop. Second, I would like to thank the Ministry of Infrastructure and Environment that showed interest in the development of hazard perception tests and funded SWOV to carry out research on this topic. The third institute I would like to thank is CBR (the Dutch driving license authority). The various task to measure hazard anticipation used in this PhD project, were made by CBR in close co-operation with SWOV. CBR also facilitated the experiments, recruited part of the participants and rented the eye tracking equipment.

I am very grateful for what the mentioned institutes have done for me, but it is the people in these institutes that really matter. Marjan Hagenzieker, you persuaded me to start this project. En route, during my few moments of despair, I sometimes hated myself for having given in so easily. Now of course, I thank you for the fact that you believed in my capabilities and have stimulated me to do all this. Divera Twisk, you were my fellow traveller. You were involved in almost all the important steps of this project. I had told you that I was impressed by the work of Don's human performance laboratory at the University of Massachusetts in Amherst. When we were attending ICTTP in Washington, you suddenly proposed not to fly immediately back home and to take me to Amherst first instead. You had to take me there, as I cannot drive. You also stimulated me to ask Don if I could work in his lab for a couple of months. I am very grateful for the fact you did this and for many things more. Saskia de Craen and Maura Houtenbos, we did not work together in the studies presented in this thesis, but I would like to thank you for your dissertations on adjacent subjects that have inspired me a lot. Saskia, I also thank you for the fact that I could make use of your participants when you were conducting one of your own experiments. Michelle Doumen, thank you for helping me with the experiments in which use was made of an eye tracker. Two trainees of SWOV also helped me to conduct the experiments: Suzanne van der Sluis and Bas Tabak. I still feel a bit ashamed about the tedious work I asked you to do for me. Of my colleagues at SWOV, I finally would like to thank Marijke Tros. The content of this book may have its flaws but thanks to your work, it looks perfect. Of the people of CBR, I would like to thank René Claesen, Theo van Rijt and Rumy van den Heuvel for their enthusiasm and commitment. During the first year of this project, I have spent much time at CBR and it felt as if we were colleagues. I would also like to thank Jörgen Langedijk and Carolien Bijvoet for the wonderful animation videos they have made.

First of all, this project was intended to proof my qualities as a scientist. At the moment I am writing this preface, I do not know yet whether I have been successful in this or not. Regardless whether I will pass or not, I do hope the results will help to reduce the crash rate of young novice drivers. In this thesis, road safety is discussed scientifically with lots of figures, but let us not forget that each young victim is a personal tragedy and that we (the society and the young people they themselves) have to do our utmost best young lives are not lost on our roads. For myself, now this project has ended, I do hope to have some time to go out sailing again.

Willem Vlakveld
Utrecht, September 2011

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1. General introduction

1.1. Hazard anticipation

For experienced drivers, driving is almost as natural as walking. Although it may feel easy for experienced drivers, driving is a complex task. Drivers have to perform various complex motor tasks such as steering, braking, and gear shifting to keep the appropriate trajectory and speed. What the appropriate trajectory and speed are depends on the intentions of the drivers, the road and traffic situation, the status of their own vehicle (e.g. the speed) and their own personal status. Their own status is determined by their competences (e.g. skills and abilities), their personality and their state of mind at that moment in time (e.g. drowsy or vigilant, being under the influence of psychoactive substances such as alcohol or not, distracted or attentive, emotionally aroused or not, etc.). Drivers have to monitor the traffic situation, the status of their vehicle and their own status permanently. With her or his intentions in mind (e.g.: 'I want to arrive somewhere in time and in good health.'), the general expectations about what can happen (e.g.: 'I am driving on a motorway, so I expect no oncoming traffic.'), and what the driver thinks others are expecting of her or him (e.g. that the driver obeys the rules of the road), a driver scans the environment. When doing so drivers sometimes detect elements in the traffic scene that could intervene with their intentions. This for instance, may be another car on collision course not showing any apparent speed reduction that has no right of way. Drivers have to recognize what these possible hazardous situations are and predict how the traffic situation can develop. Based on these predictions, the drivers may sometimes experience feelings of risk. In order to reduce these feelings they take actions to avert a possible threat (e.g., they reduce their speed).

This is to say that they anticipate a possible hazard. All this most of the time is done effortlessly.

The above description is neither a complete description of the driving task nor a model of this task. The intention here is to indicate that, although experienced drivers seem to execute the driving task effortlessly, the driving task is in fact very complex as often subtle judgements and predictions are made about the intentions and actions of other road users in relation to one's own. In the studies that are presented in this thesis, not all the mentioned aspects are investigated, but only those that are related to the detection of hazards and the reactions on hazards. For better understanding of this general introduction, hazard anticipation can preliminary be described as encompassing the following aspects:

- Detection and recognition of potential dangerous road and traffic situations;
- Prediction of how these latent hazards can develop into acute threats;
- Feelings of risk that accompany these predictions of acute threats;
- Selection and execution of actions that enlarge one's safety margin and reduce one's feelings of risk.

A theoretical framework of hazard anticipation is presented in Chapter 3.

1.2. The crash rate of young novice drivers

This thesis is not about hazard anticipation in general, but about the hazard anticipation of young novice drivers. In this thesis, young novice drivers are car drivers under the age of twenty-five. In developed countries, traffic is the primary cause of death of persons between 15 and 24 years of age. 35% of all fatalities in this age group are caused by traffic crashes (OECD, 2006). In the Netherlands in 2008, 23.4% of all car drivers involved in severe crashes[1] were drivers between 18 and 24 years of age. Of all licence holders, only 7.8% was in this age range. This over-representation of young novice drivers in severe car crashes is not unique for the Netherlands. In OECD countries[2] in 2004,

[1] In this thesis, severe crashes are crashes that resulted in at least one fatality or at least one person injured with an injury rated as two or more at the Abbreviated Injury Scale (MAIS2+). Victims can be the driver her- or himself or her or his passenger(s). Victims can also be the driver/rider or passenger(s) of the other vehicle involved in a crash or a pedestrian involved in the crash.

[2] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands,

27% of all driver fatalities were drivers younger than twenty-five years of age, whereas the proportion of persons older than the minimum age for driving, but younger than twenty-five in the population was 10% (OECD, 2006). Young male drivers are more overrepresented in severe crashes than young female drivers are, even when controlled for exposure. Figure 1.1 shows the average annual number of severe car crashes per distance driven (number of severe crashes per billion driver kilometres) by age of female and male drivers in the Netherlands over the period 2004 to 2009.

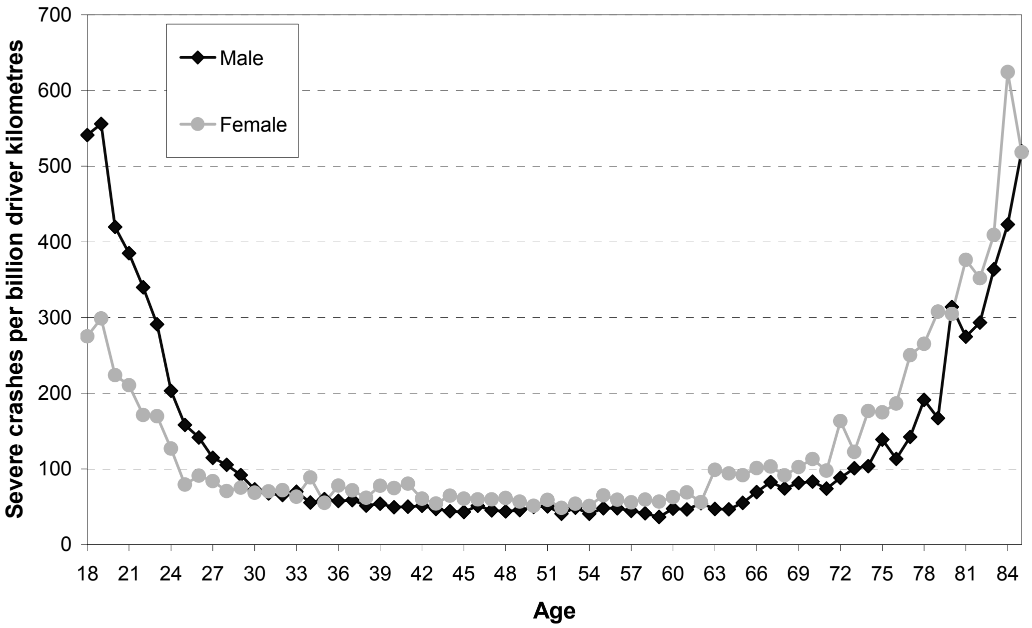

Figure 1.1. Average crash rate of female and male drivers by age in the Netherlands over the period 2004 to 2009. Source: Ministry of Infrastructure and Environment / Statistics Netherlands.

The licensing age in the Netherlands is 18. Figure 1.1 shows that the crash rate is highest for the youngest novice drivers. The crash rate is in particularly high for young male drivers. The crash rate of both young male and female drivers decline rapidly in the first years after licensing, but after the age of 30, the decline is modest. After about 60 years of age, the crash rate starts to rise again. This rise in crash rate is at first very modest, but after the age of 75 the rise in crash rate is quite steep. The U-shape of Figure 1.1 is not unique for the Netherlands. In most countries, reliable exposure data (annual mileage) of drivers are not available. When no reliable exposure data are

New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom and the United States.

available, the crash rate of drivers by age cannot be determined. Elvik et al. (2009) were able to compare crash rate by gender and age for the state Victoria in Australia, the United States, Sweden, Norway, Denmark and the Netherlands. The authors conclude that the function of crash rate by gender and age were remarkably similar in all the mentioned countries. All had an U-shape. Young male drivers had a higher crash rate than young female drivers and after the age of about 30 women had a slightly higher crash rate than men.

When novice drivers grow older and when they gain experience the crash rate declines. Do we have an indication which part of this decline can be attributed to age (e.g. maturation of the brain) and which part can be attributed to experience? From 1990 to 2009 a periodical survey was conducted on behalf of the Dutch Ministry of Infrastructure and Environment. The survey was called the 'Periodiek Regionaal Onderzoek Verkeersveiligheid' (PROV) (Periodical Regional Traffic Safety Survey). Each time approximately 8000 respondents completed the questionnaires, of which about 6000 were car drivers. Data obtained from the surveys of 1990, 1991, 1992, 1993, 1994, 1995, 1997, 1999 and 2001 were combined (Vlakveld, 2005). Although a part of the questions was different each time the survey was conducted, most of questions remained the same over the years. Among the questions that remained the same, were the questions:

- What is your age?
- Do you have a driving licence and if yes, how long are you in the possession of your licence?
- Did you drive a car in the past 12 months?
- What was your annual mileage in the past 12 months?
- In how many crashes[3] were you involved as a car driver during the past 12 months?

In the combined database, 316 car drivers were 19 years of age and held their licence for 12 months. Of these 316 novice drivers, 53 had reported crash involvement as a car driver in the past 12 months. The mean reported annual mileage of the 316 drivers was 6,253 km. Therefore, the crash rate of this group of young novice drivers was 26.8 (self-reported) crashes per (self-reported) million driver kilometres. In the database, 359 drivers were 2 year in the possession of their licence and were 20 years of age. These respondents

[3] In this survey a crash was defined as a crash in traffic that has resulted in material damage, at least one injured person or a least one fatality.

reported 73 car crashes during the past 12 months and their mean annual mileage was 12,006 km. This is a crash rate of 23.2. (self-reported) crashes per (self-reported) million driver kilometres. The same can be done for drivers that passed the driving test at 18 and were 21 years of age, and so on. Figure 1.2 shows the crash rate of drivers that passed the driving test when they were 18 years of age by the number of years the driving licence was possessed.

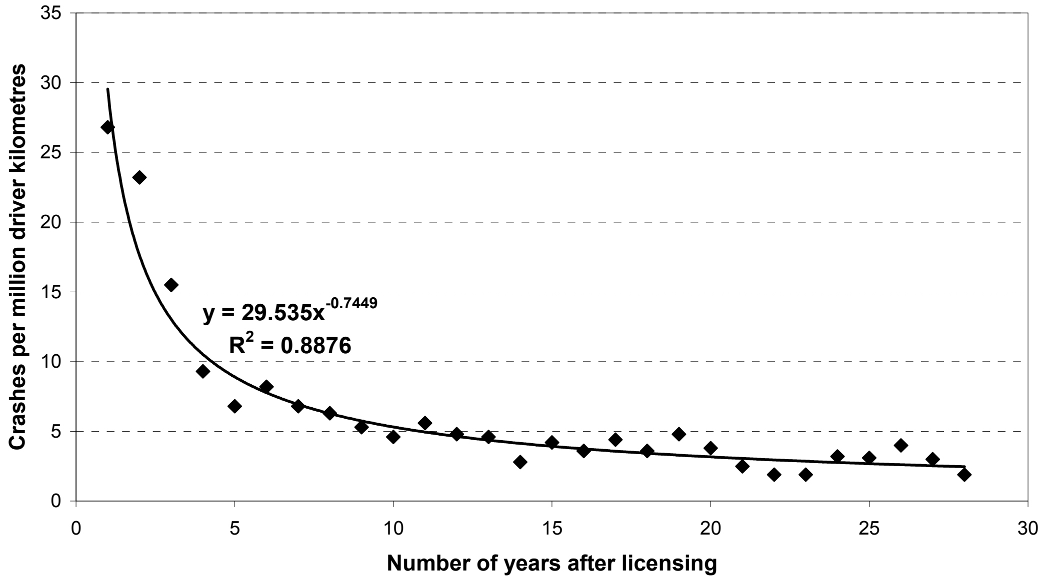

Figure 1.2. Crash rate by number of years after licensing of drivers that passed the driving test when they were 18 years of age. The curve is the trend line with the best fit. Source: Vlakveld, 2005.

Figure 1.2 shows that the crash rate of drivers that pass the driving test soon after they have reached the age limit (18 years of age in the Netherlands), decreases strongly in the first years after licensing. After about 5 years, the decline in crash rate slows. A steep decline in crash rate in the first period after licensing for young drivers was also found in the UK, the USA and Norway (Maycock, Lockwood, & Lester, 1991; McCartt, Shabanova, & Leaf, 2003; Sagberg, 1998).

In the Netherlands, not everyone starts to drive immediately after having reached the minimum age. From the same database, a similar trend line as in Figure 1.3 could be inferred for drivers that passed the driving test when they were: 21 years of age, between 23 and 27 years of age and between 30 and 40 years of age. The results are shown in Figure 1.3. Only the trend lines are represented.

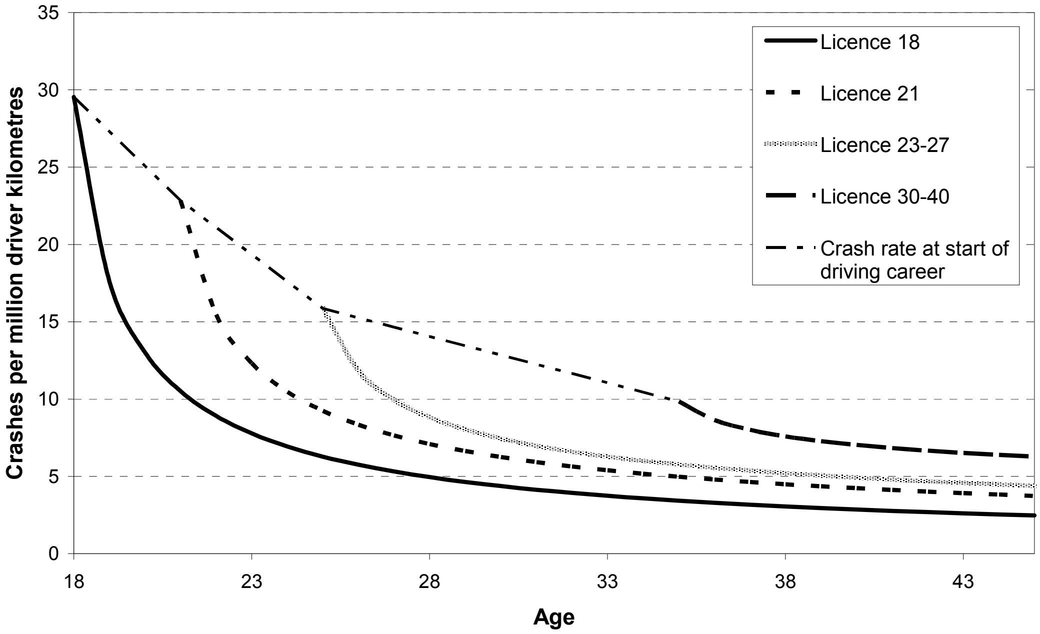

Figure 1.3. Crash rate of novice drivers after licensing of drivers that commenced driving early in life and drivers that commenced driving late in life. Only the trend lines are represented. Source: Vlakveld, 2005.

Figure 1.3 suggests that decline in crash rate is caused both by the mere fact that people grow older (maturation, transition from adolescence to adulthood) and the accumulation of driving experience. When one assumes that the age affect is represented by the line that connects the crash rates at the start of the driving career on the different ages, approximately 40% of the reduction of crash rate is caused by age and approximately 60% is caused by experience. However, people are free to choose when to start with their driving career. There was no random assignment. It is possible that people that decide to start their driving career later in life are more cautious than people that start to drive early in life. Another confounding factor may be that people before they start to drive gain traffic experience in another role (e.g. as a passenger, as a moped rider or as a bicyclist). Differences in personality and traffic experience in another role may have been the cause of the relatively low crash rate at the very beginning of their driving career of drivers that start to drive late in life and not so much the fact that they were more matured. More attempts have been made to make a distinction between the age effect and the experience effect (Levy, 1990; Maycock et al., 1991). One the basis of a comparison of the fatality rates of young novice drivers between States in the USA with an age limit of 15, an age limit of 16 and an age limit of 17, Levy (1990) concluded that the age effect is of more importance than the experience effect. On the basis of a survey in the UK with respondents that started their driving career at different ages, Maycock et al. (1991) assessed that during the first years after licensing; the decrease in crash rate is for 59% due to experience, for 31% due to age factors and for 10% due to unknown factors. It could be that the younger the licensing age the larger the age effect on crash rate is. This could explain that a larger effect of age was found in the USA than in the UK and the Netherland, as the age limit is lower in the USA than in Europe. After having reviewed 11 recent studies on the effect of age and experience on crash rate, McCartt et al. (2009) concluded that the effect of experience on the decline of crash rate is somewhat stronger than the effect of age on that decline.

1.3. The problem

Is there a relationship between the high crash rate of young novice drivers and poor hazard anticipation? This was the guiding question of the literature reviewed for this thesis. This question was also a research question of the research presented in Chapter 5. A second question was: if hazard anticipation improves with age and culminating experience, are there certain aspects of hazard anticipation that predominantly improve with experience and are there certain aspects of hazard anticipation that predominantly improve with age (i.e. maturation of the brain)? The high crash rate of young novice drivers is not a new problem. Studies on this topic in the past decades have been numerous. Hazard anticipation is not a new subject either and has also been studied thoroughly during the past thirty years. However, to date, a broad cognitive-neuropsychological approach on hazard anticipation and young novice drivers was missing. The word cognitive implies learning and neuropsychology implies (dis)ability (functions and impairments). In terms of learning, hazard anticipation is a skill that is mastered with culminating experience. In neuropsychological terms, hazard anticipation is an ability (e.g. weighing of risks) that improves as the brain matures with age. This thesis is intended to bridge the gap between cognitive psychology and neuropsychology with regard to hazard anticipation. Although the guiding questions were fundamental, this thesis primarily is an attempt to contribute to the applied sciences. In order to contribute to the applied sciences two questions were leading for the research conducted in this thesis. These two questions are:

- Based on knowledge about cognitive-neuropsychological processes involved in hazard anticipation, can different aspects of hazard anticipation be tested in such a way that these tests are suitable for incorporation in for example the driving test?

- Based on the knowledge about the cognitive-neuropsychological processes involved in hazard anticipation, can hazard anticipation be trained?

1.4. Outline of the thesis

The first three chapters (including this general introduction) provide an introduction, an overview of the 'young novice driver problem' and a theoretical framework of hazard anticipation. In Chapter 2, an overview is presented of factors that indirectly have an influence on how young novice drivers anticipate hazards in traffic. In Chapter 3, a cognitive-neuropsychological framework of hazard anticipation is introduced that has been the theoretical basis for the empirical studies reported in the Chapters 4, 5 and 6. In Chapter 4, an exploratory study about the differences between young novice drivers, older novice drivers and experienced drivers in hazard anticipation is presented and discussed. Based on the results of this exploratory study two hazard anticipation tests have been developed that are presented and evaluated in Chapter 5. Chapter 6 is about the development and evaluation of a simulator-based hazard anticipation training. In the last chapter of this thesis (Chapter 7), an overview of the key findings is provided and the results are discussed in the light of the theoretical framework (presented in Chapter 3).

2. Determinants that influence hazard anticipation of young novice drivers

2.1. Introduction

The types of crashes in which young drivers are involved, differ from the types of crashes older, more experienced drivers are involved. Young novice drivers have relatively more single-vehicle crashes (mostly due to loss of control), head-on collisions and crashes on intersections (Clarke et al., 2006; Harrison, Triggs, & Pronk, 1999; Laapotti & Keskinen, 1998; McKnight & McKnight, 2003). Young novice drivers share the overrepresentation of crashes on intersections with drivers of 70 years of age and older.

In this chapter, the literature is reviewed about the underlying causes of the high crash rate of young novice drivers and the types of crashes in which they are involved. In particular, those studies are reviewed about determinants that indirectly affect hazard anticipation. A taxonomy for the classification of the different studies about the 'young novice driver problem' is presented in Section 2.2. In the subsequent sections, the studies are discussed along the hierarchical structure of this taxonomy. Of almost each determinant mentioned in the taxonomy, a literature review can be written that is as comprehensive as this complete thesis. Therefore, the overview of underlying factors presented in this chapter is limited in detail. The emphasis of the literature reviewed in this chapter is on the cognitive-neuropsychological aspects of being a young novice driver. Of other determinates only the most important aspects are reviewed.

2.2. A taxonomy to classify studies on young novice drivers

The young novice driver problem is not a new problem. In the past decades a wide range of aspects have been examined. According to the literature many different factors contribute to the high crash rate of young novice drivers and their overrepresentation in particular types of crashes. In Figure 2.1 a systematic overview is presented of these factors.

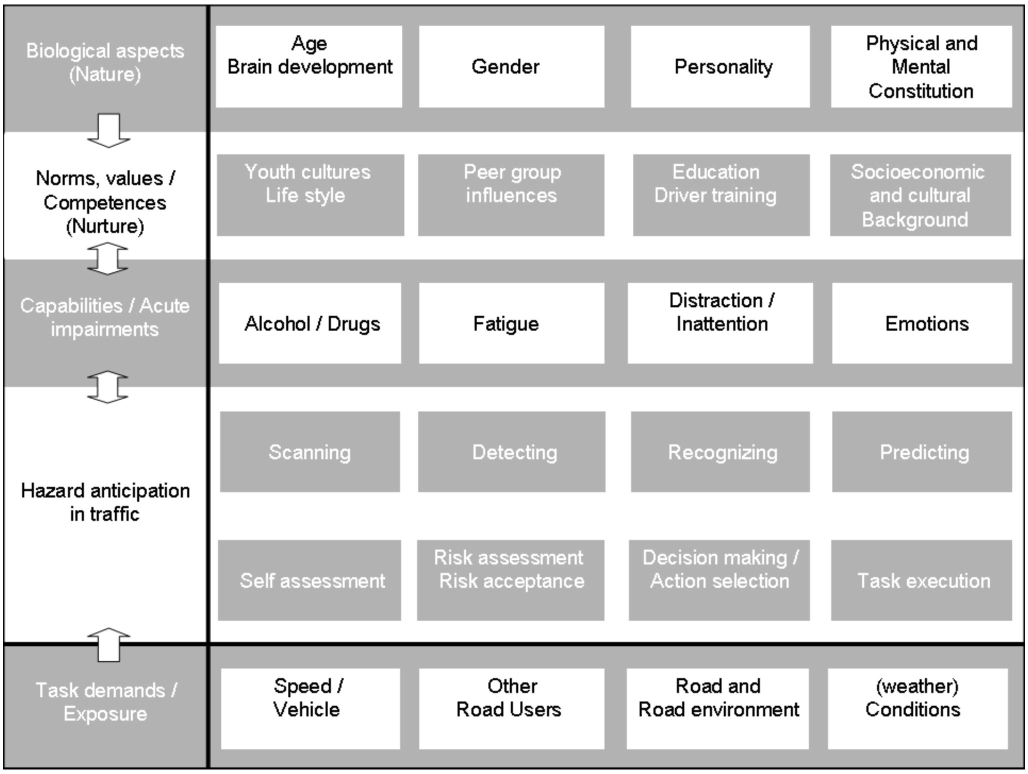

Figure 2.1. Factors that influence the crash rate of young novice drivers.

The leftmost column of Figure 2.1, presents the categories of which the literature was reviewed. At the top are the biological aspects, in particular those that are characteristic for adolescence and young adulthood. Below this category are the social and cultural factors that are characteristic for adolescence and young adulthood. Both the biological factors and the social and cultural factors are constituent for not only traffic behaviour, but also for what one does in other aspects of life. The third category from the top concerns the transient factors that reduce instantaneous driving capabilities. The fourth category comprises factors that are relevant for hazard anticipation, which is the topic of this thesis. Michon (1979) has distinguished three cognitive control levels that characterize the traffic task: the *strategic level*, the *tactical level* and the *operational level*. The strategic level includes, planning of a trip, choice of the mode of transportation, choice of route and time of driving. An example of a strategic choice is taking the short route through the village instead of taking the longer but easier route around the village. On the tactical level drivers choose their cruising speed and headway (the time interval between the car ahead and the own car). This implies considering manoeuvres such as overtaking or not in various road and traffic situations. Choices at the tactical level do not include the fast reactions in case of acute dangers but rather the choices for actions to keep a safety margin that is large enough to avert a crash should a hazard materialize. Choices on the operational level concern the second-to-second execution of basic lateral and longitudinal control tasks of driving (steering, braking, gear shifting) required to keep the car in lane and to avoid crashes. Although hazard anticipation on the strategic level does exist (e.g. 'It snows and it is dark. As I am an inexperienced driver and not used to drive in these dangerous conditions, I will not take the car but will take the train instead.'), hazard anticipation on the strategic level will not be discussed in this thesis. This thesis is about hazard anticipation on the tactical level. The operational level is only relevant as far as decisions made at the tactical level require the execution of task in relation to the appropriate course and speed. However, the reflexes at the operational level in cases of immanent threats (e.g. hard braking when a child that was not expected suddenly crosses the road a few metres ahead from between parked cars), is not discussed in this thesis. As this chapter is about the underlying factors that affect hazard anticipation of young novice drivers, hazard anticipation itself is not discussed in this chapter, but will be discussed in the next chapter (Chapter 3). The fifth category is about the task demands and exposure to specific road and traffic situations. How difficult the driving task is depends on the speed and the vehicle type one is driving, the behaviour of other road users in the vicinity of the driver, the road and the road environment (e.g. an intersection or a motorway) and the (weather) conditions (rain, fog, day and night).

The four factors in the column to the right of each category in Figure 2.1 are factors that are supposed to be constituent for that specific category. In order to keep the taxonomy convenient, only four factors are mentioned for each category. There is not necessarily a direct relationship between a factor in a particular layer and the factor directly underneath or above this factor in another layer. Although there are no relationships between the boxes to the left in one layer and a box directly underneath or above in another layer (e.g. between 'Peer group influences' and 'Fatigue'), there are relationships between the layers at the categorical level (the most left column). The idea is that drivers have to balance their capabilities (a product of biological aspects, social and cultural aspects and possible temporarily reduction of their capabilities (e.g. due to fatigue) on one hand and the risks and/or complexities of the tasks they undertake in traffic (the task demands) on the other. This balancing is accomplished via hazard anticipation (see Chapter 3).

2.3. Biological aspects (Nature)

2.3.1. Age, risk taking and brain development

This thesis is about young novice drivers under the age of 25. The age limit for driving differs from country to country and can differ within one country (different age limits in different states). For most European countries solo driving is allowed when one is 18 years of age or older and after having passed the driving test. In the Unites States of America, Canada, Australia and New Zealand the age limit for solo driving is around 16 or 17 years of age. In terms of human development, the period between 16 to 24 years of age covers the second half of adolescence and the first year or two of young adulthood. Most drivers start their driving career when they are adolescents. In the Netherlands of those that passed the driving test from 2000 to 2007, 70% was younger than 21 years of age (source: the Dutch driving license authority CBR). Adolescence is the transitional stage in human development between childhood and adulthood. Adolescence starts with the onset of puberty. Puberty is the period of development through which its passage endows an adolescent with reproductive competence. Sexual maturity requires activation of gonadotropin-releasing hormone and elevated secretion of gonadotropins and sex hormones (testosterone and oestrogens) (Susman & Dorn, 2009). These are the neuroendocrine processes. The neuroendocrine processes not only lead to physiological changes, but also to behavioural changes (Spear, 2000). Elevated levels of testosterone have been particularly associated with risk-taking in older male adolescents. In girls, elevated testosterone levels have been associated with the tendency to affiliate with deviant peers (e.g. Vermeersch et al., 2008). Although in various studies a relationship between testosterone and risk taking has been found, there are also studies in which no relationship was found (e.g. Booth et al., 2003). Growth spurt begins in girls at age 12 (menarche starts around age 12.5) and growth spurt starts in boys around age 14 (Susman & Dorn, 2009). The moment where adolescence ends and where young adulthood starts is less clear. By age 16, girls have usually reached full physical development. For boys this is around age 22. Adolescence however is not merely a period of physiologic transition it is also a period of socio-behavioural transitions that encompasses the entire second decade of life and the first years of the third decade of life. According to Arnett (2002) adolescence is characterized by a number of psychological phenomena that can stimulate risky driving behaviour: the power of friends, the optimism bias and mood swings. In the literature, novelty-seeking and sensation-seeking are also mentioned as characteristic of adolescence that have an influence on risky driving behaviour (Jonah, 1997). Adolescents form cliques (small, closely-knit groups of friends) that are the basis for their leisure lives. Especially among boys, in order to alleviate boredom and/or to impress friends, young people are inclined to show risky driving behaviour (e.g. show how fast they can drive or how quickly they can pass another car). These friends can also encourage the driver to take risks. The group of friends is a realm away from their parents that offers the opportunity to try out activities that are forbidden by their parents. There is however not much evidence that the optimism bias is more present in adolescents than in adults, as was concluded by Arnett (2002). Optimism bias is the tendency to view the likelihood of negative events as higher for others than for oneself. An example of the optimism bias is a driver that overestimates her or his own skills and/or underestimates the risks. Arnett (2002) concluded on the basis of three studies that young drivers view their risk of a crash resulting from various dangerous driving behaviours as lower than that of older drivers. However on the basis of the studies mentioned by Arnett, the results of other studies and the results of her own research, De Craen (2010) concluded that the studies on this topic are inconclusive. The conclusion of the majority of studies is that when one is asked to compare oneself with the 'average driver', young drivers overestimate their skills *less* than experienced drivers do. However when asked to compare yourself with other drivers of the same age and experience, De Craen (2010) found that young drivers tend to overestimate their skills *more* than experienced drivers do. Horswill et al. (2004) however found no difference between young novice drivers and older more experienced drivers when they had to compare themselves with their peers. Finally, when a comparison was made between self-assessment and the assessment by driving examiners of the these drivers in a test drive, De Craen (2010) found that there were more novice drivers with high scores on self-assessment (i.e. they thought that they were good drivers) and low scores awarded by driving examiners after a test drive, than there were experienced drivers with high scores on self-assessment and low scores on the test drive. In general one can conclude that both young novice drivers and older, more experienced drivers often overestimate their driving skills, but that young novice drivers more often do so on the basis of a wrong assessment of their own capabilities than older, more experienced drivers.

Although adolescents show more often risky behaviour than adults, they do not appear to reason differently about risks than adults. After having presented an overview of the literature about decision making, rationality and risk taking, Reyna & Farley (2006) concluded that when asked to think about risky acts, adolescents are not more irrational or deficient in their reasoning about risks than adults. Reyna & Farley also concluded that there was no proof that adolescents are more likely to believe in their own invulnerability and that adolescents on average are risk-averse when asked to reflect on risky acts. However, Reyna & Farley also mention that results indicate that the capacity to override risk-taking impulses, when in emotionally charged situations, seems to be less developed in adolescents than in adults. An explanation why adolescents take more risks, but in general do not reason differently about risks when they have the time to think and are not aroused, may be found in brain development.

Structural brain development

A possible explanation for the risks adolescents take is that the brain works differently in adolescents than in adults. In this section, the structural differences (differences in size and composition of brain regions between adolescents and adults) are highlighted and in the next section, the functional differences (differences in how brain regions interact when performing certain tasks) are highlighted.

Recent longitudinal studies on brain development in which brain scans were made at regular intervals, using Magnetic Resonance Imaging (MRI), show that brain anatomy continues to develop until well into the third decade of life (Blakemore & Choudhury, 2006; Giedd, 2004; Gogtay et al., 2004; Lenroot & Giedd, 2006). The major findings of these studies are that the volume of white matter increases in a linear way during childhood and adolescence and the total volume of white matter does not start to decline before the fourth decade of life (Lenroot & Giedd, 2006). White matter indicates myelinated axons. Myelination speeds up transmission between neurons and thus improves information processing. In contrast to white matter, the total volume of gray matter tends to follow an inverted U developmental course with volumes peaking at different ages in different lobes. For instance, frontal lobe gray matter reaches its maximal volume at 11.0 years of age in girls and at 12.1 years of age in boys. Temporal lobe cortical gray matter peaks at 16.7 years of age in girls and at 16.2 years of age in boys. Parietal lobe cortical gray matter peaks at 10.2 years of age in girls and at 11.8 years of age in boys. After a peak in a lobe, the volume of gray matter gradually declines. The DorsoLateral Prefrontal Cortex (DLPFC) is in particular slow in loss of gray matter and continues to lose gray matter well into the third decade of life (Giedd, 2004). The DLPFC is a region of the Pre Frontal Cortex (PFC) and is involved in impulse control, judgment, planning and decision-making. The PFC that consists of various sub-areas such as the DLPFC is essential for what are called the executive functions. Executive functions refer to the regulation of planning and social behaviour in situations when 'automatic' responses are inadequate such as when persons are planning tasks, weighing risks and other tasks related to decision making. The executive functions and the PFC are discussed in more detail in Chapter 3. Decline in gray matter is associated with 'dendritic and axonal arborisation'. This process is also referred to as 'synaptic pruning'. A reduction in gray matter is not a symptom of the decay of the brain, but of the development of the brain; it helps the brain to operate more effectively. In contrast to white matter, gray matter contains neural cell bodies and mostly does not contain myelinated axon tracks. The neurons in cortical gray matter process the information originating from the sensory organs or process information from other gray matter (e.g. information from long term memory) in order to create a response to stimuli from the sensory organs or other gray matter. Dendritic and axonal arborisation (synaptic pruning) makes this information processing more effective. Especially the late maturation of the PFC and in particular the late maturation of the DLPFC have tentatively been associated with the high crash rate of young novice drivers (e.g. Isler, Starkey, & Drew, 2008).

Brain function during adolescence

Casey, Getz, & Galvan (2008) noted that risk-taking during adolescence is probably not solely the result of the late maturation of the PFC. Although subcortical areas do not seem to mature markedly during the second half of adolescence (the period in which adolescents start to drive), certain subcortical areas in adolescents show different activities (increased activity or decreased activity) compared to adults when participants of both groups have to perform tasks such as gambling tasks when situated in an MRI. Research in which participants have to perform task that do not require head movements while situated in an MRI, is called functional Magnetic Resonance Imaging (fMRI). In fMRI use is made of the fact that oxygen in blood changes the magnetic resonance slightly. An area of the brain that is active has blood with more oxygen than an area of the brain that is inactive. According to Casey et al. (2008) risk-taking in adolescence is the result of the differential development of the subcortical bottom-up limbic reward systems and the top-down control systems that are mainly located in the PFC. Limbic system is a word that sometimes is used to denote subcortical areas that among others play a role in experiencing negative emotions (the amygdala), feelings of anticipated pleasure (the nucleus accumbens), motivation (the gyrus cinguli anterior), long term memory storage (the hippocampus) and regulation of emotions not involving top-down control by the PFC (the hypothalamus). The gyrus cinguli is actually not considered to be a part of the limbic system, but is closely related to the limbic system. The limbic reward systems mature fast after the onset of puberty and the PFC matures slowly and continues to mature throughout adolescence and early adulthood. The result of this being developmentally out of phase of already matured limbic system and a still immature PFC is among others a heightened responsiveness to incentives and a relatively weak impulse control. The increased activity in some parts of the limbic system during adolescence is probably due to the neuroendocrine changes, especially because of the secretion of dopamine (Chambers, Jane R. Taylor, & Potenza, 2003). Figure 2.2 shows the model of the different functional developmental trajectories of the limbic system and the PFC that may be the underlying cause of the tendency to take risks in adolescence as assumed by Casey et al. (2008).

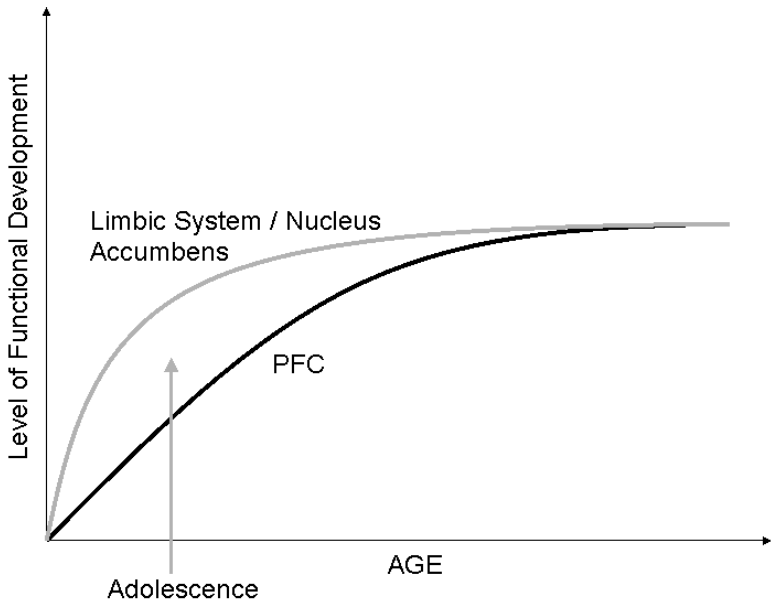

Figure 2.2. Model of the different developmental trajectories of the limbic system (e.g. the nucleus accumbens) and the PFC that may be the underlying cause of the tendency to take risk in adolescence (adapted from Casey et al., 2008).

The gap between the fast functional development of the bottom-up limbic system and the slow development of the top-down control regions of the PFC presumably peaks around 16 years of age, but it takes years after this peak before the gap has completely disappeared (Steinberg, 2008). The slow disappearance of the gap is supposed to be caused by the improving functional connectivity between the limbic system and prefrontal regions over time and the maturation the PFC (Casey et al., 2008).

After a review of the literature of studies applying fMRI about risk taking of adolescents, Barbalat et al. (2010) postulated that risk-taking behaviour of adolescents arises from three different decision-making biases: risk aversion, loss aversion and intertemporal choice. Risk aversion means that when people have to choose between two rewarding options, they will usually prefer the more certain option even when the reward of that option is possibly lower than that of the more risky option. Although adolescents in general are also risk averse, they are less risk averse than adults. When performing gambling tasks, adolescents showed less activation than adults in the anterior insula (region of the brain involved in negative emotions such as fear and disgust), the anterior cingulate gyrus (region of the brain involved in assessing the salience of emotions and the processing of motivational information) and the Orbito Frontal Cortex (OFC) / Ventromedial Prefrontal Cortex (VMPFC) of the PFC (Bjork et al., 2007; Eshel et al., 2007). Persons with lesions in the OFC and/or VMPC have difficulties with empathy, control over emotions and the weighing of risks (see Wallis, 2007 for a review).

Loss averse means that people are generally more sensitive to the possibility of losing something than gaining something (Tversky & Kahneman, 1981). Barbalat et al. (2010) suggested that adolescents may be less loss averse than adults as they are less affected by anticipated punishment than adults. The neural substrate for this phenomena are hypo activations in regions involved in negative emotions such as the amygdala or the insular cortex of the brains of adolescents during tasks when losses are anticipated (Bjork et al., 2004). Not only when losses are anticipated, but also when gains are anticipated adolescents show lower activation in various subcortical regions than adults, most importantly in the nucleus accumbens (Bjork et al., 2004). The lower activation or no activation in adolescents of various subcortical regions in mainly the ventral striatum when anticipating gain or loss compared to adults is in support of the hypothesis of Spear (2000) that adolescents require more intense stimuli to experience positive or negative feelings than adults. This for example implies that they have to drive faster than adults do in order to experience the same amount of pleasure from driving fast. The third aspect mentioned by Barbalat et al. (2010), intertemporal choice, means that direct reward is preferred above long term reward. Thus, a girl may not wear a helmet when riding on a moped because a helmet will ruin her hairdo. This is considered to be more important than the fact that the helmet protects your head in case of a crash. When in an fMRI study both adolescents and adults were asked if they considered it a good idea to swim with sharks, both groups responded that this was not a good idea. Adolescents however needed more time to reach this conclusion than adults and while thinking about an answer, adolescents showed relatively greater activation in the right DLPFC than adults (Baird, Fugelsang, & Bennett, 2005). The relatively greater activation of the DLPFC during the task indicates that adolescents in away are more rational than adults when thinking about swimming with sharks. Adults 'feel' negative emotions (activation of subcortical areas) and without much thinking (little activation of the DLPFC required) immediately decide that swimming with sharks is a bad idea. How this may function is elaborated in Chapter 3 when the somatic marker theory (Damasio, 1994) is discussed. Adolescents on the other hand probably first 'think' that swimming with sharks could be exiting, but in the end come to the conclusion that the negative aspects (being eaten by sharks) outweigh the positive aspects (activation of the DLPFC). In this task, adolescents showed greater activation in the DLPFC whereas this region of the brain is not yet fully matured.

Keating (2007) mentioned the maturational gap caused by the difference in functional development of the socio-emotional circuits of the brain and the control circuits of the brain that is assumed by Casey et al. (2008), as a possible cause of the high crash rate of young drivers.

Although recent studies applying fMRI have resulted in intriguing new insights in why adolescents tend to take more risk than adults, Paus (2009) noted that these results have to be interpreted with caution. There is a confounding interaction between age and performance. When studying age-related changes in brain activity during the performance of a certain task, how do we know that the brain activity is different because of the performance or that the performance is different because of the brain activity?

2.3.2. Gender

Male drivers aged 18-24 are more often involved in severe crashes per distance driven than female drivers in that age group (see Figure 1.1). Based on data from the Netherlands, Figure 2.3 shows how many times more young male drivers and young female drivers are involved in fatal crashes per distance driven than drivers aged 30-59 of both sexes over the period 1987 to 2008.

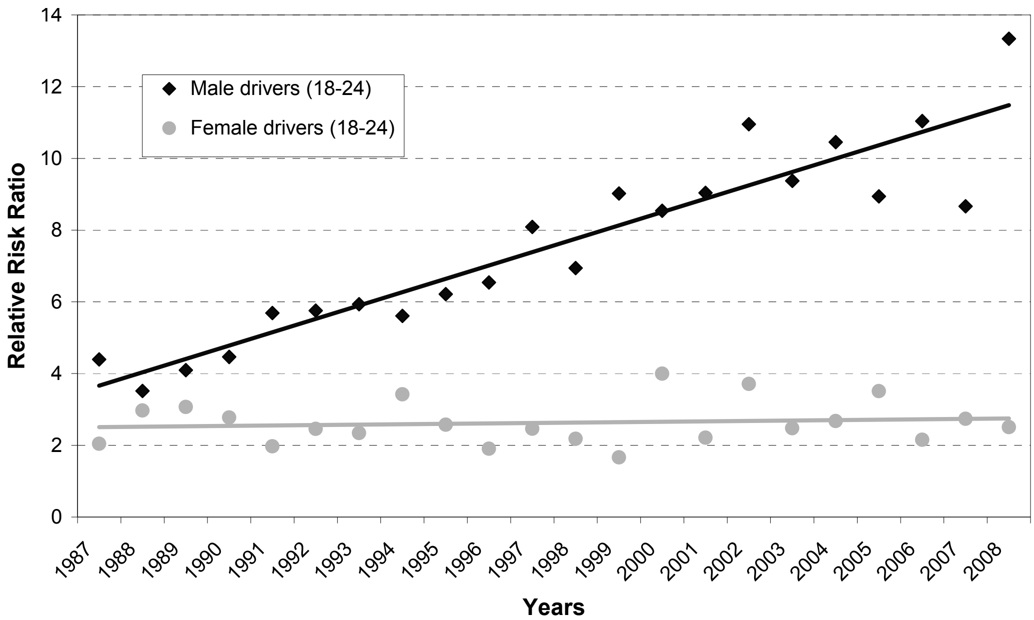

Figure 2.3. Annual relative fatal crash risk ratio from 1987 to 2008 of male drivers and female drivers aged 18-24 with the fatal crash rate of middle-aged drivers of both sexes (aged 30-59) as reference. Source: Ministry of Infrastructure and Environment / Statistics Netherlands.

In 1987 the fatal crash rate (involvement in crashes that result in at least one fatality per billion driver kilometres) of young female drivers (aged 18-24) was twice the fatal crash rate of middle-aged drivers of both sexes (aged 30-59). In this year, this relative risk ratio was 4.4 for young male drivers (aged 18-24). In 2008, the relative risk ratio of young female car drivers was 2.5 and 13.3 for young male drivers. In all years, the risk ratio of young female drivers was lower than the risk ratio of young male drivers and remained more or less constant over the years (slightly more than 2 times the crash rate of middle-aged driver). In contrast, the risk ratio of young male drivers has increased over the years. It seems as if generic road safety improvements over time (safer cars, safer roads) have had less impact on young male drivers than on young female drivers in the Netherlands.

Drivers can have a crash in which no other road users are involved (e.g. when they drive against a tree). This type of crash is called a single-vehicle crash. A driver can also collide with another car. These are the car-car crashes. And a driver can collide with other types of vehicles, including pedestrians. These are the car-other type of vehicle crashes. In a fatal single-vehicle crash, a driver can kill her or himself and/or her or his passenger(s). In a car-car crash the fatalities can be in the other car, the own car or in both. In a car-other vehicle type crash the fatalities can be in the own car, the other vehicle or in both. Fatal crashes are crashes with at least one fatality. Table 2.1 shows the degree in which young male drivers cause more physical damage to themselves and other road users than young female drivers do. Using Dutch data from 2004-2008, the fatality ratios (number of fatal crashes per distance driven) for young males drivers were divided by the fatality rates for young female drivers. This relative fatality ratio (young male driver/young female driver) is presented for single-vehicle crashes, car-car crashes and car-other type of vehicle crashes. Table 2.1 also presents the relative fatality ratios of being killed by young male drivers in car-car crashes and car-other type of vehicle crashes.

Table 2.1. Relative fatality ratios of young male drivers over the years 2004-2008 of various types of car crashes. Source: Ministry of Infrastructure and Environment / Statistics Netherlands.

Crash type in which the driver and or her or his passenger(s) is killed	Relative fatality ratio[4]
1. single-vehicle	8.5
2. car-car	2.2
3. car-other type of vehicle	1.2
Crash type in which the driver kills persons in other vehicles and or pedestrians	
1. car-car	7.4
2. car-other type of vehicle	4.1

Table 2.1 indicates that controlled for exposure it was 8.5 more likely that the young driver in a fatal single-vehicle crash was a young male driver (aged 18-24) than a young female driver (aged 18-24). And controlled for exposure it was 7.4 more likely that the young driver (aged 18-24) was male that collided with another car in which at least one other person was killed. These differences are quite dramatic and cast serious doubts on the fitness to drive of young males. This is of course a major impetus for the research carried out in this thesis.

An in-depth analysis of fatal crashes in which young male and female drivers (aged 18-21) were the culpable party was conducted in Finland (Laapotti & Keskinen, 1998). Of the 413 fatal crashes included in that study, 338 times a young man was the driver and 75 times a young woman was the driver. The percentage 'loss-of-control' crashes was about the same for young male and young female drivers (65.7% and 64.0% respectively). When a driver loses control the driver can run of the road (and hit a tree) (a single-vehicle crash), but the driver can also hit another car or another type of vehicle or a pedestrian (car-car crash or car-other vehicle type crash). For young male drivers, most of the times a loss-of-control crash was a single-vehicle crash (in about 75% of the cases) and for young female drivers a loss of control crash was most of the times a car-car or a car-other vehicle type crash (in about 65% of the cases). Typically, young male drivers' loss of control crashes

[4] Fatalities per distance driven of young male drivers divided by fatalities per distance driven of young female drivers

took place in the evening and at night. The speed was often much too high (in 83% of the cases) and in about half of the cases the young male driver was under the influence of alcohol. The loss-of-control crashes involving young female drivers most of the times occurred in daylight. In 40% of the cases, the young female driver drove too fast and in 6% of the cases, the young female driver was under the influence of alcohol. Young female drivers had significantly more loss-of-control crashes on slippery roads than young male drivers. The results suggest that for young male drivers, loss-of-control is more often the result of risk taking behaviour (speeding, driving while under the influence of alcohol) and for young female drivers more often the result of poor vehicle handling.

Structural brain differences

Could the differences in crash rates and types of crashes between young female drivers and young male drivers be caused by differential developments of their brains? Differences in behaviour between young females and young males may be caused by cultural differences (the way boys and girls are educated and socialized), by biological differences and of course by a combination of the two. In this section, the biological differences will be discussed and in the section about lifestyle (Section 2.4.1) the cultural differences will be discussed.

There are some quantitative differences between the average adult brain of females and the average adult brain of males, but there is also considerable variance within each sex and consequently there is a substantial overlap between brains of men and women. Overall, the total cerebral volume is on average about 10% less in adult females than in adult males. Adult females have less gray matter and less white matter than adult males, even after accounting for sex differences in overall body height and weight. When however expressed as a percentage of total brain volume, sex differences in the volume of white matter disappear. Whether this is also the case for gray matter is inconclusive (Paus, 2009). Only a few regions are on average larger in the male brain than in the female brain, including the amygdala and the hippocampus. There are however also a few regions that are on average lager in the adult female brain than in the adult male brain, including the OFC, the anterior cingulate gyrus, the posterior cingulate gyrus (has a memory related function and gets activated by emotional stimuli), the inferior frontal gyrus (plays a role in inhibition and risk aversion) and the corpus callosum (the connection between the right and left cerebral hemispheres) (Paus, 2009).

When do these sex differences emerge? The total brain volume peaks in girls around age 10.5 and in boys around age 14.5. After this peak the decrease in total volume is somewhat stronger in females than in males (Lenroot et al., 2007). White matter increases throughout adolescence until middle adulthood with males having a slightly steeper rate of increase during adolescence (Lenroot & Giedd, 2010). Gray matter peaks for boys and girls at different ages in different lobes (see Section 2.3.1). After these peaks, the volume of gray matter declines (synaptic pruning). This decline is somewhat steeper in girls than in boys (Lenroot & Giedd, 2010). These different peaks and the subsequent decline in gray matter suggest that during the first years of adolescence girls are ahead in cortical maturation, but that this sex difference gradually disappears in the later stages of adolescence (around 16 years and older). Not only do the cortical areas develop at a different pace in boys and girls during adolescence, some of the subcortical regions show different patterns of development during adolescence as well. After a review of the literature Lenroot & Gied (2010) concluded that most consistently differences in development during adolescence have been reported for the basal ganglia, the hippocampus and the amygdala. The basal ganglia play an important role in action selection, procedural learning and movement control. The basal ganglia function in close cooperation with the PFC (the executive functions). In cooperation with the PFC, the basal ganglia influence motivational processes (cooperation between basal ganglia and cingulate cortex), social reactions (cooperation between basal ganglia and the OFC) and planning (cooperation between basal ganglia and the DLPFC) (see Brouwer & Schmidt, 2002 for an overview). In cooperation with the hippocampus, the amygdala performs a primary role in the formation, storage and recall of memories associated with emotional events (McGaugh, 2000; McGaugh, McIntyre, & Power, 2002). It would seem likely that the subtle differences in development between girls and boys during adolescence are related to the different neuroendocrine processes in boys and girls during puberty. According to Paus (2009) it is difficult to ascertain that this relation exists as the age-related changes in hormone levels are very complex. However, Lenroot & Giedd (2010) noted that although a direct causal relation is difficult to proof, there are some associations between sex steroid levels and the development of certain brain regions. Different brain regions have a different number of sex steroid receptors. Brain regions that show a different pattern of maturation in boys and girls during adolescence also show differences in populations of sex steroid receptors with more oestrogens receptors in brain regions that are larger in females and more androgen receptors in brain regions that are larger in males.

Research suggests that dopaminergic activity peaks during adolescence and that dopaminergic activity potentially fuels an increase in sensation seeking (Chambers et al., 2003; Spear, 2000). Scores on the sensation seeking questionnaire developed by Zuckerman, Eysenck, & Eysenck (1978) correlate with risky driving behaviour and even with crash involvement (see Section 2.3.3). Romer & Hennessy (2007) found that throughout adolescence the scores on a subset of four questions of the sensation seeking questionnaire (I like to explore strange places; I like to do frightening things; I like new and exciting experiences, even if I have to break the rules, and I prefer friends who are exciting and unpredictable) were higher for boys than for girls, but that the peak in sensation seeking was earlier for girls than for boys (see Figure 2.4). The maximum was for boys at age 18.5 and for girls at age 16. In contrast with most questions of the sensation seeking questionnaire, the subset of questions used by Romer & Hennessy (2007) is not 'age biased'. When for instance asked to agree or disagree with the statement 'I like 'wild' uninhibited parties', people can change their opinion as they grow older not because of a decline in sensation seeking but because parties no longer are part of their lifestyle.

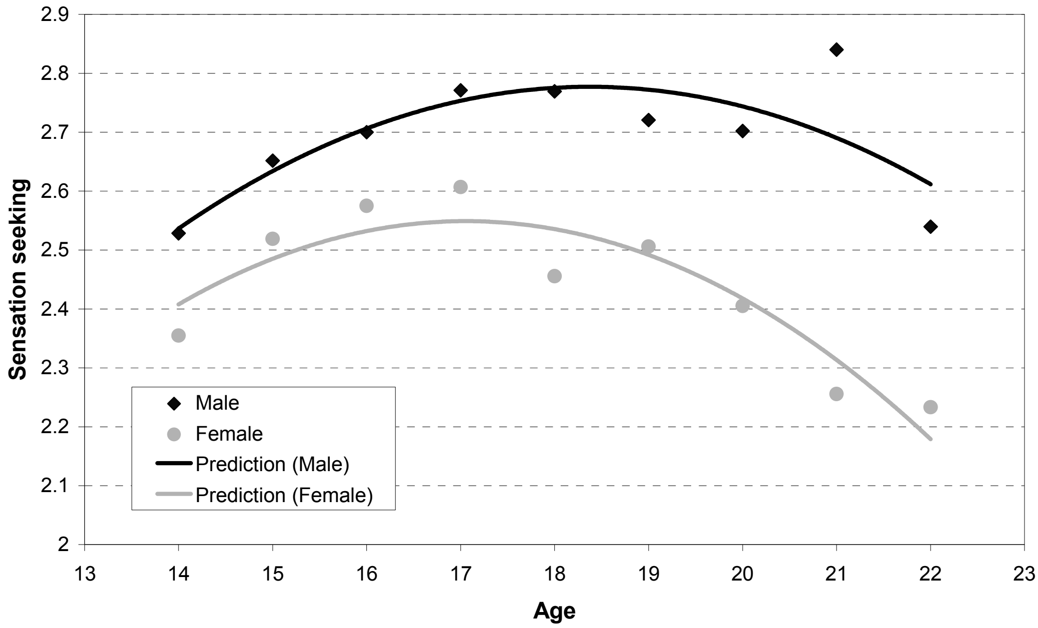

Figure 2.4. Sensation seeking as a function of age and gender (adapted from Romer & Hennessy, 2007).

Functional brain differences in boys and girls

Studies using fMRI on differences in brain activities between boys and girls when performing tasks related to risk perception and risk acceptance, are rare. Only fMRI studies could be found on differences in brain activities between boys and girls when exposed to pictures of faces with particular emotional expressions, such as angry faces. An angry face is another threat than a car on collision course. However, in a certain way critical traffic situations are threatening social interactions and it could be that a car on collision course and an angry face elicit similar emotions of fear. When exposed to an angry face or exposed to threatening situations activation could be observed in the amygdala, the OFC and the basal ganglia (Adolphs, 2002). These brain activities when exposed to angry faces were slightly different for adult males than for adult females (e.g. McClure et al., 2004). McClure et al. (2004) found that when exposed to angry faces, relative engagement of the right OFC and the left amygdale was greater in adult females than in adult males. If this difference in brain activity when exposed to angry faces also applies to adolescents, is inconclusive. Killgori, Oki and Yurgelun-Todd (2001) studied developmental changes in neural responses to angry faces in boys and girls ranging from 9 years of age to 17 years of age. Fearful facial expressions resulted in activation of the left amygdala in all subjects. However this activation got lower as girls grew older and remained the same for boys as they grew older. Girls also showed greater activation of the DLPFC as they grew older than boys did. In contrast to these results McClure et al. (2004) did not find differences in regional brain activities between boys and girls when exposed to angry faces.

Differences between boys and girls when exposed to stressful situations have also been studied. This was not done by using fMRI, but by measuring differences in secretion of glucocorticoid between boys and girls when exposed to stressors (see McCormick & Mathews, 2007 for an overview). In order to cope with stress, animals (including humans) produce glucocorticoids (corticosterone, cortisol and cortisone) that in the brain are secreted by the adrenal glands. Glucocorticoids increase the availability of energy substrates that enables the organism to cope more effectively with stress. Through actions in the brain, glucocorticoids promote goal-directed behaviour and facilitate the formation of memories and thus shape behavioural and psychological reactions to similar stressors in the future (McGaugh, 2000). This implies that drivers may learn from events in traffic (risky situations) that induce arousal (see also Section 3.10). However, prolonged exposure to high levels of glucocorticoids has a damaging effect on the nervous system (Henckens et al., 2009). The secretion of glucocorticoids is under the control of what is called the Hypothalamic-Pituitary-Adrenal (HPA) axis. The HPA axis can be activated by a wide variety of stressors. An important role of the HPA response to stressors is to restore the physiological balance to prevent overreaction of defence mechanisms to stress. How the HPA axis functions depends to a large extend on sex hormones (testosterone and oestrogen). There are marked differences in the production of sex hormones between boys and girls from puberty on. This could be the cause that in females there is an increased response of the HPA axis to stress with advancing age after the onset of puberty, while in males the response is decreased, possibly associated with increased testosterone levels (McCormick & Mathews, 2007).

Considering the mentioned structural and functional differences between women and men that start to emerge at the onset of adolescence and continue to develop well into the third decade in life, both young male drivers and young female drivers probably take more risks in traffic than middle-aged drivers due to brain development. As the brains of young female drivers mature faster than the brains of young male drivers, this tendency to take risks is stronger in young males than in young females.

2.3.3. Personality

Most young drivers will not experience a severe crash in the first years of their driving carrier. In the Netherlands in 2008 less than one per thousand of the licence holders (for a car) aged 18-24 was involved in a severe crash (crashes that result in at least one fatality or one person so seriously injured that hospitalization is required), source: Ministry of Infrastructure and Environment / Statistics Netherlands. Could it be that young drivers with certain personality traits are more risky drivers than young drivers with other personality traits? Ulleberg (2001) found that there were two groups of young drivers (aged 18-23) that reported risky driving behaviour. The first high-risk group consisted mostly of young men who had low levels of altruism and anxiety and high levels of sensation seeking and irresponsibility. These young drivers showed risky behaviour not so much, because they were angry with other road users but because dangerous driving was considered thrilling and because they did not care so much about the wellbeing of others. The second high-risk group also scored high on sensation seeking, but in contrast to the first group, this group had high scores on aggression, anxiety and driving anger. These young drivers seemed to tolerate little from other road users and got angry easily. What both groups had in common was their high scores on sensation seeking. Jonah (1997) reviewed forty studies on the relationship between sensation seeking and risky driving. In the vast majority of these studies there was a correlation of $r = .30$ to $r = .40$ between scores on sensation seeking and (self-reported) risky driving behaviour. Seven studies reported significant differences between high and low scores on sensation seeking and crash involvement. According to Zuckerman (1994) sensation seeking "is a trait defined by the seeking of varied, novel, complex, and intense sensations and experience and the willingness to take physical, social, legal, and financial risks for the sake of such experiences" (p. 27). The sensation seeking scale of Zuckerman has four dimensions. These dimensions are:

1. Thrill and Adventure Seeking (TAS);
2. Experience Seeking (ES);
3. Boredom Susceptibility (BS), and
4. Disinhibition (Dis).

The strongest relationship with risky driving behaviour was found with TAS (Jonah, 1997). As already mentioned in Section 2.3.2 (Figure 2.4), girls scored lower on a subset of questions of the sensation seeking questionnaire than boys (Romer & Hennessy, 2007). The peak in sensation seeking on this subset was for girls around 16 years of age and for boys around 18.5 years of age. After this peak, sensation seeking gradually decreased. Although Romer & Hennessy (2007) used a subset of questions of the sensation seeking questionnaire that was probably not age biased, one can argue that lifestyle may still be a confounding factor. However when using the Need Inventory of Sensation Seeking, a questionnaire in which respondents are not asked to agree or disagree with activities, but are asked for a global need of stimulation (e.g. 'I like feeling totally charged'), participants scored substantially lower the older they were (Roth, 2009).

Sensation seeking is considered to be closely connected with the motivational brain circuitry. According to Chambers, Jane R. Taylor, & Potenza (2003) both dopamine pathways and serotonin pathways affect the motivational brain circuitry. Dopamine release into the striatum[5] operates like a general 'go' signal whereas serotonin has an inhibitory effect. CerebroSpinal Fluid (CSF) concentrations of dopamine and serotonin decline

[5] The striatum is a sub cortical region that functions as an intermediate between the PFC and the basal ganglia and plays a role in both planning of movements and in executive functions. In humans the striatum is activated by stimuli associated with reward, but also by aversive, novel, unexpected or intense stimuli, and cues associated with such events.

during childhood and decrease near adult levels around age 16. Although both decrease, the rate of dopamine to serotonin increases throughout adolescence. In combination with a still immature PFC, this may promote sensation seeking. Because of maturation of the PFC, sensation seeking will finally decline despite there is proportional more dopamine than serotonin.

Personality traits can be associated with subtle difference in brain structure. In a study conducted by Gardini, Cloninger, & Venneri (2009) eighty-five young adult participants completed the Thee-dimensional Personality Questionnaire (TPQ) and had their brain imaged with MRI. The three scales of the TPQ are novelty seeking, harm avoidance and reward dependence. High scores on novelty seeking (a scale that is closely related to sensation seeking) were positively correlated with gray matter volumes in frontal and posterior cingulated areas. These areas are involved in directing visual attention to the periphery of the visual field and implicit attention. Novelty seeking implies not only a tendency for risky activities, but also preference for perceptually rich stimuli. Harm avoidance is a scale that also is relevant for road safety as cautious drivers have a lower crash rate than reckless drivers (Evans & Wasielewski, 1982). High scores on harm avoidance were negatively correlated with gray matter in the OFC. High scores on reward dependence that could have a relationship with susceptibility for peer pressure (see Section 2.4.2) and the preference for immediate rewards (e.g. the pleasure felt when driving fast is more important than the increased possibility of a crash when driving fast), were negatively correlated with gray matter in the striatum and the limbic areas.

Instead of investigating the relationship between a certain specific personality trait and crash rates such as sensation seeking, one can also study the relationship between personality profiles and crash rate. In order to measure profiles, questionnaires are used that measure the dimensions of the 'big five' in personality traits. These dimensions are:

1. **Openness to experience**: Persons that are curious and that are open for new ideas score high on this scale. Other characteristics of a person that scores high on this scale are: mostly appreciates art, shows emotions and likes adventures;
2. **Conscientiousness**: Persons that score high on this scale have a tendency to show self-discipline, act dutiful and aim for achievement. They also like to plan their activities and do not often show spontaneous behaviour;

3. **Extroversion**: Extrovert persons are energetic, optimistic, out-going, self-confident and have a tendency to seek stimulation in the company of others;
4. **Agreeableness**: Persons that score high on agreeableness are friendly and compassionate. They are cooperative rather than suspicious;
5. **Neuroticism**: Persons that score high on this scale are sensitive and nervous. They feel insecure and vulnerable.

Robins et al. (2001) found that from 18 to 22 years of age, the rank order of the scales of the big five of most participants in their study remained stable. This is to say that if for instance a participant had higher scores on conscientiousness than on neuroticism at 18 years of age, this participant had also higher scores on conscientiousness than on neuroticism at 22 years of age. However, the mean-levels on agreeableness and on conscientiousness increased from 18 to 22 years of age and the mean-level of neuroticism declined. Clarke & Robertson (2005) conducted a meta-analysis on the relationship between accident involvement (of all ages and not only car crashes) and the big five personality dimensions. Only low conscientiousness and low agreeableness correlated with accident involvement and these correlations although statistically significant were still rather weak. Agreeableness and conscientiousness are also the two scales of which Robins et al. (2001) had found that they increase from late adolescence to young adulthood. This could partly explain the lower crash rate of persons that start to drive in their twenties compared to people that start to drive at 18 years of age (see Figure 1.3).

2.3.4. Physical and mental constitution

Young persons in general are in good health. Their visual acuity and reaction times are better than the visual acuity and reaction times of older persons. Young persons need less practice to acquire complex motor skills, including vehicle handling. The older one starts to learn to drive, the more hours of driving instruction are required to pass the driving test (Maycock & Forsyth, 1997). Although young people possess physical advantages over older people, some mental disorders have a higher prevalence in young people than in older people. Mental disorders that initially occur in childhood with a high prevalence in adolescence and that may continue in adulthood are various types of autism (Autism, Asperge Syndrome, Pervasive Developmental Disorder Not Other Specified (PDD-NOS)) and Attention Deficit Hyperactivity Disorder (ADHD). In the Netherlands 7.8 % of men and 1.8 % of women between 18 and 24 years of aged are diagnosed as having ADHD in some degree (De Graaf, Ten Have, & Van Dorsselaar, 2010). The exact prevalence of the various types of autism in the Netherlands is not known. In the UK 1.16 % of a cohort of 56946 children between 9 to 10 years of age was diagnosed as having some type of autism. The male to female ratio was 3.3:1 (Baird et al., 2006).

The various types of autism are denoted as Autistic Spectrum Disorders (ASD). Individuals with ASD have difficulties in processing social information and do not communicate very well. Autistic children often show restricted and repetitive behaviour. ASD is the result of divergent brain development in which many parts of the brain and brain systems get affected. In order to anticipate future events, drivers have to predict what other road users in their vicinity will do. Drivers with ASD may have difficulties in doing this (due to difficulties in processing social information). Only one study on this subject could be found (Sheppard et al., 2010). In this study, the hypothesis was that drivers with ADS have poor hazard perception skills where the hazard is a human being (pedestrian or cyclist), but not where the hazard is a car (in which the driver is not visible). To test this hypothesis, adult participants (with and without ASD) watched video clips taken from the driver's point of view. In these clips, a hazard developed, but the clips never ended in a crash. Participants were asked to press a button as soon as they had detected a developing hazard. When the button was pressed, the screen froze and the participants were asked why they had pressed and what could happen in the clip. In half of the clips the hazard was a human being (pedestrian, bicyclist). These were the social hazards. And in half of the clips the hazard was a vehicle in which no person was visible (the instrumental hazards). Participants with ASD identified fewer social hazards than the comparison participants, but were not different in identifying instrumental hazards. When hazards (both social and instrumental) were identified, the reaction times of the ASD group were longer than of the comparison group. The slower reaction times can have been caused by poor hazard perception skills, but also by impaired strategic planning of motor skills of persons with ASD.

Inattention, hyperactivity and impulsivity are the main characteristics of ADHD. Neuropsychological findings suggest that these behaviours result from underlying deficits in executive functions such as deficits in response inhibition and delay aversion. The total brain volume of patients with ADHD is lower than that of matched controls. The differences in volume are the most pronounced in the PFC and the cerebellum. Not only the total volume is less in these brain areas, but also the distribution of gray and white matter is different. Probably the basal ganglia (in connection with the PFC) also have an important function in the development of ADHD. However, MRI-studies about differences in the basal ganglia in persons with ADHD and persons without ADHD are not conclusive. Despite this fact, people with damage to the basal ganglia (because of a stroke) develop ADHD later in life (after the stroke) (Krain & Castellanos, 2006). The effect of ADHD on road safety has received much more attention of researchers than ASD. According to a meta-analysis in which thirteen studies were included, the odds ratio for being involved in a car crash of young drivers diagnosed with ADHD was 1.88, 95% CI [1.42, 2.50] (Jerome, Segal, & Habinski, 2006). Drivers with ADHD are more often inattentive, adhere less to the rules of the road, show reduced inhibition and are more easily distracted than non-ADHD drivers (Barkley & Cox, 2007).

2.4. Norms Values / Competences (Nurture)

2.4.1. Youth cultures / Lifestyle

A car is not only a means of transportation (getting from A to B in a relative fast, safe and comfortable way). There are additional motives for driving. Møller (2004) explored these additional motives for young drivers. She distinguished four different psychosocial motives that were mentioned by young drivers in a focus group. These psychosocial motives were: *visibility* ('See me driving like Michael Schumacher in this fast car'), *status* ('My friends will respect me now that I have a car' and 'I'm king of the road in my own car'), *control* ('It gives me a kick to be in control of this car when I drive fast') and *mobility and freedom* ('Now that I have a car I can go whenever and where ever I want' and 'I can enjoy myself with my friends in my car'). According to the Problem Behaviour Theory (PBT) (Jessor, 1987) motives for in this case risky driving are also motives for other deviant behaviour such as unsafe sex, smoking, alcohol consumption and illicit drug use. Although these activities are perceived as deviant behaviour by society, they can be functional in the life of adolescents (e.g. explore roles, attitudes and values and becoming independent of parents). PBT categorizes motives for reckless behaviour in three systems. The first system is the perceived environment system. This includes for instance peer group pressure. The second system is the personality system (i.e., feelings and perceptions about the self that promotes tolerance of deviance) and the third system is the behavioural system (other risky behaviour than the risky behaviour of study). In PBT, risky driving behaviour is considered as symptom of a syndrome. This syndrome is a problematic adolescent lifestyle. Shope, Raghunathan, & Patil (2003) found that drink driving and involvement in alcohol-related crashes were predicted by friends' support for drinking, susceptibility to peer pressure (perceived environment system) and tolerance of deviance (the personality system). Also a preference for some types of leisure time activities has been found to be related to self-reported risky driving behaviour (Møller & Gregersen, 2008; Møller & Sigurðardóttir, 2009). These activities could be characterized by low structure and high impulsivity such as playing PC-games, visiting fitness centres and partying with friends. Gregersen & Berg (1994) asked drivers that were 20 years of age in a questionnaire about their lifestyle, driving behaviour and crash involvement. They distinguished four lifestyle profiles with a crash rate that was 1.5 times the average crash rate and two lifestyle profiles with a lower crash rate than average (.75 times the average crash rate). The first high-risk group (10% of the respondents) was predominantly male. They were rarely active in sport, liked to consume alcohol, were interested in cars and liked to drive for fun. The second high-risk group (5% of the respondents) could be characterized as young urban professionals (yuppies). The young drivers in this group had a high annual mileage and although driving in the first place was considered as a means of transportation in this group (fast and comfortable), the type of car mattered to them (status). The way they were dressed and cultural activities also were important to them. Just like the first group, they liked to consume alcohol, but unlike the first group they did not drive for fun. 62% of this group was male. The third high-risk group (2% of the respondents and mainly male) did not consume alcohol and were not much socially engaged, but had strong additional motives for driving (i.e. showing off, pleasure, sensation seeking). They also were interested in cars and drove often at night. The fourth and last high-risk group (4% of the respondents and 61% male) did not drive a lot, were not socially engaged, but when they drove additional motives were very important to them. The first low-risk group was large (23% of the respondents) and predominantly female. The young drivers in this group rarely drove, did not consume alcohol and scored a little higher than average on culture and social engagements. This group was not interested in driving and in cars. The second low-risk group (6% of the respondents and 68% female) was active in sport did not consume alcohol and was not interested in clothes, movies and cars. For this group, driving had nothing special. In contrast to the first low-risk group however, they liked to drive to parties.

2.4.2. Peer group influences

In adolescence, reckless behaviour most of the times does not take place if a person is alone. The general opinion is that especially during adolescence peers promote and reward (with praise and esteem) each other's reckless behaviour. One explanation could be that reckless behaviour promoted by friends fortifies the bond between these friends. Arnett (1992) however warns for causal interpretations. It could be that adolescents like everybody else choose their friends on the basis of characteristics they have in common. A common characteristic could be sensation seeking. If this is the case, reckless behaviour is not so much the result of group dynamics, but the result of a common trait in members of the group.

Passengers can strongly influence the behaviour of the driver. They can distract the driver (e.g. by having a conversation with the driver) and they can also stimulate certain driver behaviour. They can encourage the driver to take risks (e.g. 'Show us how fast this car is'), but they can also reduce the risk taking tendencies of the driver. The latter is the case when a passenger makes the driver feel that she or he is responsible for the life of the passenger. In various studies not conducted in Europe it was found that crash rate increased in the presence of passengers (e.g. Chen et al., 2000; Doherty, Andrey, & MacGregor, 1998; Preusser, Ferguson, & Williams, 1998). The more occupants in the car and the younger the age of the driver, the higher the crash rate was (Williams, 2003). However in two studies carried out in Europe (Spain and Sweden) no increased crash rate was found when young drivers were in the presence of passengers (Engström et al., 2008; Rueda-Domingo et al., 2004). The licensing age in the United States, Canada, Australia and New Zealand often 16 is and in some states even younger. In most countries in Europe, the licensing age most often is 18. The difference in results could have been caused by the age of the novice driver. However, it is not only the age of the driver that matters but also the age of the passenger(s) and the gender of both the driver and the passenger(s). Chen et al. (2000) found a higher crash rate for both young male novice drivers and young female novice drivers only when the passenger was male. Simons-Morton, Lerner, & Singer (2005) observed cars that left parking lots. They identified the gender of the driver and passenger if present and assessed their ages. Young novice drivers of both sexes drove faster than the general traffic and followed other vehicles more closely. This effect was stronger for young drivers (of both sexes) in the presence of a male teenage passenger. When young novice male drivers drove in the presence of a female teenage passenger, headways were longer. A problem with all studies about the effect of passengers on crash rate is reliable exposure data. What is the mileage of drivers with passengers in their cars? On the basis of an incomplete dataset -the data only provided mileages of drivers driven with members of their household as a passenger- Ouimet et al. (2010) have assessed crash rate by age and sex of the driver and age and sex of the passenger. The highest crash rate was found for young male drivers (15 to 20 years of age) with young male passengers (16 to 20 years of age). This crash rate was 9.9 times the crash rate of young male drivers without a passenger, 95% CI [9.1, 10.8]. With a young female passenger (16 to 20 years of age) these young male drivers had a relative risk of 3.3, 95% CI [2.9, 3.7]. Young female drivers (15 to 20 years of age) driving with a young male passenger (16 to 20 years of age) had a crash rate that was 4.1 times their crash rate when they drove without a passenger, 95% CI [3.4, 4.9]. When young female drivers drove with a young female passenger (16 to 20 years of age) their relative risk was 4.4, 95% CI [3.8, 5.0]. When young drivers of both sexes drove with passengers over 35 years of age, their crash rate was considerably lower than their crash rate without a passenger. From these results, it can be concluded that peer pressure to take risks and/or distraction is present when young drivers drive with passengers of the same age. This is especially the case when young male drivers drive with young male passengers. Whereas passengers of the same age increase the crash rate of young drivers, older passengers (35 years and older) seem to have a protective effect on young drivers.

2.4.3. Education and driver education

In this section, a distinction is made between general education and driver education. In the first section, the effect of general education on crash risk is discussed and in the second section the effect of driver education on crash risk is discussed.

General education

In a Swedish study a rather weak correlation between the level of education, school performance and crash rate was found (Murray, 1998). The lower the education level and the lower the school performance, especially in science, the higher the crash rate was. In the United States, Bingham, Shope & Tang (2005) found that young drivers that were less academically educated tended to show slightly more driving problems, including drink driving. In Section 1.2 the Dutch periodical survey 'PROV', is mentioned. In this survey, respondents also were requested to indicate the type of education they have had. From the same combined database as referred to in Section 1.2 can be deduced that car drivers younger than 25 years of age with lower vocational education had annually 12.5 self-reported car crashes per million kilometres driven. For the group of young drivers with secondary education but no academic education, this crash rate was 15.2 and for the group of young drivers with academic education this crash rate was 16.0. The differences between the groups were statistically not significant, $F_{(2,4996)} = 0.13$, $p = .87$. The three groups did not differ in age (mean age in each group was 22), but the group with lower vocational education held their licence on average almost a year longer than the group with academic education. This might explain why academically educated novice drivers had a higher (although not significant) crash rate than novice drivers with lower vocational education. Considering the mentioned studies and the result of PROV, it seems that the level of general education may have a small impact on crash rate with higher levels of general education having a slightly lower crash rate, but the results are inconclusive.

Driver training

In contrast to what most people think, evaluation studies and meta-analyses have shown that formal basic driver training in order to pass the driving test does not result in a lower crash rate after licensing than informal training (learning to drive by self-training and training by family members or friends) (e.g. Christie, 2001; Elvik et al., 2009; Senserrick & Haworth, 2005). Driver training programs are difficult to evaluate with crash rate as the dependent variable, as crashes are rare (implying very big samples) and random assignment of participants to a control group and an experimental group is difficult to realize. However, Elvik et al. (2009) noted that a number of well-controlled studies have been carried out and especially these studies show no effect of formal basic driver training. Traditional driver training in order to pass the driving test is about vehicle handling, applying the rules of the road and mastering basic traffic situations. In traditional driver training not much attention is paid to the factors mentioned in Figure 2.1 such as hazard perception, risk assessment, risk acceptance, self-assessment, the effects of fatigue and distraction, etc., that cause the high crash rate of young novice drivers. It could be that future basic driver training in which these factors are addressed, will have a positive effect on the crash rate of young novice drivers after licensing.

In the Netherlands, learner drivers cannot gain experience by driving with lay instructors such as parents before licensing. One can only drive with a certified driving instructor in order to train for the driving test. On average learners need 40 hours tuition behind the wheel from a certified driving instructor to pass the driving test in the Netherlands (Hazevoet & Vissers, 2005). It is impossible to master a complicated task like driving in 40 hours fully. The high crash rate at the beginning of one's driving career and the steep decline of the crash rate in the first years after licensing (see Figure 1.3) seems to illustrate this. Based on a theory about three staged acquisition of motor skills by Fitts & Posner (1967), Anderson (1982) has developed a theory on the acquisition of cognitive skills. His theory is on cognitive skill acquisition in general, but can be applied to learning to drive. Anderson assumed that there are three stages in skill acquisition. These stages are: 'the declarative stage', the 'knowledge compilation stage' and the 'procedural stage'. At first (during the declarative stage), performance is relatively unstable, as possible strategies are tested and rejected. During this stage, the learner focuses consciously on isolated components of the driving task. For example, while learner drivers are in the declarative stage when they change gear (in a car with manual transmission), they have to think about each subtask step by step. For instance: 'First I step on the clutch pedal, and then I move the stick with my hand to the position of the next gear, after this I slowly release the clutch and in the meantime slowly push with my other foot on the accelerator.' Verbal mediation (sometimes spoken aloud) can help to perform the task at this first stage of skill acquisition. When a driver at this stage also has to perform another task not related to driving (for instance talking with a passenger), task performance on the driving task deteriorates considerably. After enough practice, one reaches the knowledge compilation stage. During this stage, elements of the skill get chunked together and verbal mediation of performance is far less. Associations between action patterns in familiar conditions have become stronger. Without a thorough analysis, familiar situations are recognized and a set of rules for that situation is applied. However, at this intermediate stage, a secondary task not related to the driving task, will still interfere with the driving task. Because the chunks of skill elements are not very elaborate yet and not always well suited to the situation, driving in the knowledge compilation stage still requires frequent monitoring and this can be hampered by the secondary task. Finally, after months to years of practicing the procedural stage is reached. At this stage, the parts have become compiled into procedures that are executed in a seemingly effortless manner without much awareness of the separate elements of the skill. Verbal mediation at this stage is very scarce and task performance is highly consistent. Learner drivers at this stage no longer need to think about the sequence of actions for gear shifting. Easy secondary tasks that are totally different from the driving task (for instance talking with a passenger) can be executed at this stage, without or little interference with the driving task. Although at the procedural stage, gear shifting is executed effortlessly and without much thinking, even for the most experienced driver this task never gets fully automated (Groeger & Clegg, 1997) and at some moments attentional monitoring is required to check if task performance develops according to plan (Reason, 1990). Anderson's theory of skill acquisition is based on his Adaptive Control of Thought (ACT) model about mental representations and behaviour. This model has changed considerably over time. In its latest version (ACT-R 5.0) (Anderson et al., 2004) this model contains four modules. Firstly, a visual module for identifying objects. The occipital lobe of the brain fulfils a dominant role in this module. Secondly, a manual model that controls the hands. The motor cortex and the cerebellum are important for this module. Thirdly, a declarative module for retrieving information that is stored in long term memory. The hippocampus and the temporal lobe are important for this module. And fourthly, a goal module for keeping track of current goals and intentions. Several regions of the brain are active in this module, but most importantly the DLPFC. Coordination between the modules is achieved through a central production system. Input for this production system is not directly delivered by the modules, but by buffers of the modules. The reason is that because of limited capacity, the central production system can only deal with information of the modules that is relevant. For instance, people are not aware of all the information in the visual field but only of the object they are attending to. Similarly, people are not aware of all the information in long-term memory but only of what is currently retrieved. The central production system (located in parts of the basal ganglia of the brain) can recognize patterns in the various buffers and make changes to these buffers by matching, selection and execution. As a consequence of development in the ACT-model, the status of the procedural stage has changed. Originally, skill performance at the procedural level was considered as fast, effortless but also as rigid. In the latest ACT-model model, performance at the procedural level can be flexible. Karmiloff-Smith (1992) takes as an example a piano player. Piano playing is not the same as driving, but both are complex perceptual motor skills. When one is learning to play the piano, initially there is a period during which a sequence of separate notes is laboriously practiced (the declarative stage). This is followed by a period during which chunks of several notes are played together as blocks (the knowledge compilation stage), until finally the whole piece can be played more or less automatically (the procedural stage). Karmiloff-Smith (1992) calls the procedural stage based on the older versions of the ACT-model 'reaching behavioural mastery'. However, when this stage is reached the learner can still not start in the middle of the piece or play variations on the theme. She thinks that the performance at the procedural stage is generated by procedural representations that are simply run off in their entirety (see the concept of schemata in Section 3.4). It is only later after more practicing but also because of rethinking of what one is actually doing, that one can interrupt the piece and start at for instance the third bar without having to go back to the beginning and repeat the entire procedure from the beginning. The ability to play variations on the theme requires even more practicing and rethinking. Karmiloff-Smit (1992) hypothesised that this is not because of improvement in behavioural mastery but because of improvement of the mental representations that generate the skills (i.e. improvement in schemata). This is what she called the process of 'representational redescription'. Suppose that based on simple representations a driver applies her or his skills more or less automatically and unexpectedly a dangerous situation occurs. Then the driver may start to rethink why she or he has applied these skills. The result of this rethinking is that her or his mental representations (schemata) that generate automatic task execution become more elaborate and flexible. Studies on differences between experts and novices in detection and recognition tasks have shown that experts can see patterns and perceive the underlying structure of a situation that novices cannot. When however confronted with completely novel situations in which even the elaborated schemata of experts are not of any help to comprehend the situation, detection of patterns by experts can be worse than detection of patterns by novices (see Chi, 2006 for an overview). Experts spend proportionately more time on how a novel situation can be comprehended with existing knowledge and much less time in implementing a strategy for the solution than novices. This is relevant for hazard detection. The differences between novices and experts with regard to the detection and recognition of potential hazards are discussed in more detail in Chapter 3.

The conclusion of the theory discussed so far is that generally not all topics relevant for safe driving are addressed in basic driver training. Furthermore, of the skills that are learned such as manoeuvring the vehicle and mastering common traffic situations, skill performance may look like as if the procedural stage is reached, but this is probably not true. Of what is described by Karmiloff-Smith (1992) as the process of 'representational rediscription' has presumably not yet started when learner drivers pass the driving test.

2.4.4. Socioeconomic and cultural background

There are not many studies about the SocioEconomic Status (SES) of the family young novice drivers come from and their crash risk. In a longitudinal study about lifestyle factors and crash rate in New Zealand, Begg, Langly & Williams (1999) did not find the SES of parents to be an important predictor of crashes. However in an Australian study Chen et al. (2010) found that whereas the overall annual crash rate for young novice drivers (17 to 25 years of age) decreased significantly over time (from 1997 to 2007) it did not decrease significantly in rural areas with low SES. Drink driving, speeding, and non-use of seatbelts in the young novice driver population remained high in these areas over time. Sweden is probably the only country in the world where the relationship between SES of the parents and the number of crashes young novice drivers have, has been studied frequently (Hasselberg & Laflamme, 2003, 2008; Hasselberg & Laflamme, 2009; Laflamme et al., 2005; Murray, 1998). All these Swedish studies indicate that the higher the SES of the parents of the young novice drivers is, the lower the number of severe crashes of the young novice drivers was. In one of the Swedish studies besides the SES of the parents the country of origin of both the parents (second generation) and of the young novice drivers themselves (first generation) were studied (Hasselberg & Laflamme, 2008). In contrast to SES, no relationship was found between country of origin and injury rate. This was true for the first generation from both other Western countries and none Western countries and the second generation from both other Western countries and none Western countries. A serious limitation of all the mentioned Swedish studies is that none of the results were controlled for exposure. It is very likely that the annual mileages are different in each group. And it is also very likely that the lower the SES of the parents, the less protection the cars in which the young novice drivers drive, will offer.

2.5. Capabilities/Acute impairments

2.5.1. Alcohol and drugs

If two people with different body weight and sex consume the same amount of alcohol, their Blood Alcohol Concentration (BAC) will not be the same. If a heavy but not fat man consumes the same quantity of alcohol as a light woman (and both are no regular drinkers), the man will be slightly less adversely affected than the woman. The reason for this is that alcohol dilutes itself in the water volume of the body and muscle tissue contains more water than fat tissue. On average men have more muscle and less fat than women. Because equal amounts of alcohol (e.g. glasses of beer or glasses of wine) can result in a different BAC, in this section only the BAC is mentioned.

Alcohol affects all three cognitive control levels that characterize the traffic task (the *strategic level*, the *tactical level* and the *operational level*) that were distinguished by Michon (1979).

Steering corrections in order to keep the vehicle in the proper position in the lane are executed on the operational level. Louwerens et al. (1985) found that on average the ability to keep track started to deteriorate notably (i.e. drivers started to sway) from a BAC of 0.6 g/l on and got worse the higher the BAC was. Craig, Lees & Edwards (2005) presented an overview of the deterioration of task performance due to alcohol on the operational and tactical level. With regard to the operational level, reaction times on a visual detection task (e.g. braking after one sees that a lead vehicle brakes suddenly) appeared to get significantly longer from a BAC of 0.8 g/l on. With regard to the tactical level, they reported that a secondary task (e.g. talking with a passenger) had a negative effect on peripheral search when alcohol was consumed (a significant effect from a BAC of 0.3 g/l on). Craig, Lees & Edwards (2005) also found studies that showed that visual search in general decreased with increasing BAC. In these studies, it was found that the higher the BAC was the more drivers started to stare straight ahead and no longer searched for information about potential hazards that were not located in the forward roadway. Finally, they found studies that showed that information processing decreased when BAC increased.

Alcohol probably affects the strategic level considerably too (Kelly, Darke, & Ross, 2004). When one is drunk and still decides to drive in spite of her or his incapacity, this is a risky choice on the strategic level. Drunk people tend to do this because already moderate doses of alcohol have a strong motivational and emotional impact. People get euphoric and inhibition gets less stringent. Because of this effect of alcohol, drivers also lose their calibration skills on the tactical level. Poorly calibrated drivers overestimate their skills and underestimate the dangers. This can result in more risk-taking behaviour in traffic.

Because of the effects of alcohol on all three levels of cognitive control of the driving task, it is no surprise that epidemiological studies have shown that the crash rate increases exponential with increasing BAC-levels (Borkenstein et al., 1974; Compton et al., 2002).

The increase of crash rate with increasing BAC-levels is substantially steeper for young drivers than for middle-aged drivers (Peck et al., 2008;

Preusser, 2002). The crash rate of drivers that were 21 years of age and younger with a BAC-level of 0.5 g/l (the legal limit in most countries) was more than twice the crash rate of drivers with a BAC-level of 0.5 g/l that were over 21 years of age (Peck et al., 2008). There are several possible explanations for the fact that alcohol has a more deteriorating effect on young novice drivers than on older, more experienced drivers. Firstly, the tolerance for alcohol may be lower because they are not yet accustomed to alcohol. Secondly, because various subtasks of the driving task are not yet executed fully automatically, the mental work load when driving is higher for young novice drivers than for older, more experienced drivers (De Waard, 2002; Patten et al., 2006). As more mental workload is required for the performance of the basic driving task, young novice drivers have to allocate more of their limited attentional resources to perform the basic driving task. Alcohol impairs information processing and in this regard has a more deteriorating effect on tasks that require much attention than on tasks that require little attention. Thirdly, young drivers may tend to show more risk-taking behaviour under the influence of alcohol than older, more experienced drivers do. As is already mentioned, even low quantities of alcohol can give a feeling of euphoria and decrease (social) inhibition. The brain of adolescents is not yet fully matured (see Section 2.3.1). This makes inhibition of impulses and the weighing of risks more difficult for adolescents than for adults. Because of the effect of alcohol on the brain, executive functions may deteriorate more in adolescents than in adults and this may result in more risk-taking behaviour by young novice driver than by older, more experienced drivers when under the influence of alcohol.

In the Netherlands, driving under the influence of alcohol is not a typical young novice driver problem. In fact prevalence of drink driving was slightly lower in the age group of drivers between 18 and 24 years of age than in older age groups (DVS, 2009). Despite the relative low prevalence of young motorists (drivers of cars, and riders on mopeds and motorcycles) that drink and drive in the Netherlands, young male motorists (between 18 and 24 years of age) were overrepresented in severe crashes that were alcohol related. Although this group represented only 4% of the total Dutch population in 2002, they accounted for 23% of the in-patients and fatalities due to alcohol-related crashes (Mathijssen & Houwing, 2005).

Alcohol is not the only substance that affects driving performance and behaviour. Other (illicit) substances frequently combined with driving are cannabis, cocaine, opiates and stimulants (amphetamine and designer drugs such as ecstasy (MDMA)).

In laboratory studies and simulator studies, the effect of delta-9-tetra-hydrocannabinol (THC) -the psychoactive component of cannabis- on driving performance has been clearly demonstrated. THC impairs lane keeping (steering), attention, reaction time, short-term memory, hand-eye coordination, decision making and concentration (e.g. Ramaekers et al., 2004). Despite these impairments until recently, there was no epidemiological proof for a heightened relative crash rate when driving under the influence of cannabis (see EMCDDA, 1999, for an overview). Initially it was considered that although cannabis does affect the basic driving skills it does not impair the calibration skills. This is to say that drivers under the influence of cannabis compensate for the impairments, for example by driving more slowly and by avoiding risky traffic situations (e.g. Krüger & Berghaus, 1995). This may be partly the case, but in older epidemiological studies, drivers were tested on the presence of an inactive metabolite of THC in their urine. This metabolite of THC can be present days after THC has been active in the brain. In more recent epidemiological studies presence of the THC itself in blood was directly measured. From these studies it can be concluded that high doses of THC do increase the crash rate (see Drummer, 2009, for an overview).

Cocaine, amphetamine and ecstasy make users more energetic and alert. Negative effects (mostly in a later phase) with regard to amphetamine are: delirium, panic, paranoia, impulsive behaviour and aggression. Negative effects of cocaine are headaches, panic attacks and nausea (Shinar, 2006). MDMA (ecstasy) causes mild hallucinogenic effects, increased tactile sensitivity and emphatic feelings. Brookhuis, De Waard, & Samyn (2004) found that MDMA had only modest effects on the basic driving skills on the operational level. However, MDMA did affect the tendency of drivers to take risks. In a simulator drive, while crossing a priority road with oncoming traffic from left and right and while turning left with approaching traffic, participants when under the influence of MDMA accepted smaller gaps than when they were sober. Some epidemiological evidence exists that amphetamine increases crash rate (Drummer, 2009), but for cocaine and MDMA to date, clear evidence of an increased crash rate on the basis of epidemiological field studies is not available. There also is no epidemiological evidence that opiates increase crash rate. In order to improve our still limited knowledge about the effects of especially drugs on crash rate, the European project DRUID (Driving under the Influence of Drugs, Alcohol and Medicines) was started in 2006. This project is not yet completed. The aim of DRUID is to gain new insights with regard to the real degree of impairment caused by psychoactive substances and their actual impact on road safety. Despite the fact that to date for some illicit drugs no clear negative effects on traffic safety have been found, it has been demonstrated that combined substance use, especially the combination of alcohol and illicit drugs, leads to an substantially higher crash rate (Mathijssen & Houwing, 2005).

In contrast with drink driving, prevalence of illicit drug driving was found the highest in the youngest age group of motorists (motorists between 18 and 24 years of age) in the Netherlands, but illicit drug driving was only slightly less in the group of motorists aged 25-34 (Mathijssen & Houwing, 2005).

2.5.2. Fatigue

Fatigue has been defined as a state of reduced mental alertness that impairs performance during a range of cognitive and psychomotor tasks, including driving (Williamson, Feyer, & Friswell, 1996). The terms sleepiness and drowsiness are often used as synonyms for the word fatigue, especially when reference is made to the neurobiological processes that regulate the circadian rhythm and the need to sleep (Dinges, 1995). Fatigue can be caused by time on task and the complexity of the task, but also by lack of sleep. Lack of sleep can be chronic when during a long period, the daily quality of sleep has been poor and/or the daily quantity is not enough. Lack of sleep is acute when task performance is impaired due to one bad and/or short night. Driver fatigue can also occur when a person drives at moments when she or he is normally asleep (e.g. nighttime driving). During a 24-hour cycle, the human body has greater need for sleep at some moments (especially between midnight and 4 a.m.) than on others. The 24-hour cycle of the body is called the circadian rhythm. Finally, drowsiness, but not fatigue can occur when the driving task is monotonous. This is sometimes called driving without attention or highway hypnoses. Driver fatigue can cause crashes because of deficits in attention, vigilance and information processing. When one falls asleep behind the wheel, failure to perform the driving task is complete.
A recent naturalistic driving study that was called the '100-Car Naturalistic Driving study', has revealed that drowsiness was a contributing factor in 13% of the crashes and in 12% of the near crashes (Dingus et al., 2006). In a naturalistic driving study, participants drive in instrumented cars. Participants know that they are driving in instrumented vehicles, but these instruments (e.g. cameras) are not visible or hardly visible and are unobtrusive. In a naturalistic driving study, participants are not instructed to use the car in a particular way. It is the intention to observe driving behaviour in daily life. In the '100-Car Naturalistic driving study', car

performance and driver behaviour was recorded of hundred instrumented cars over a period of a year. It was possible to analyse what the driver did just prior to 82 crashes and 761 near-crashes and how the traffic situation developed in these situations. Some of the most common unambiguous behavioural signs of sleepy driving are: single or repetitive head drops (called micro-sleeps 5 lapses of R500 ms), heavy eyelids with frequent eye closures, and yawning (Powell & Chau, 2010). In 13% of the crashes and 12% of the near-crashes, the drivers showed severe visible symptoms of drowsiness just prior to the crash. In a follow-up study it was analysed what the relative risk of certain behaviour was by comparing how often drivers manifested certain behaviour (in this case the visible symptoms of sleepy driving) in general and how often they manifested that behaviour during the short period prior to the crash or near crash (Klauer et al., 2006). From the data could be inferred that drowsy drivers are between four and six times more likely to be involved in a crash than attentive drivers.

In the '100-Car Naturalistic driving study', no distinction was made between young novice drivers and older, more experienced drivers with regard to drowsy driving. There are indications that drowsy driving is more common among young drivers than among older drivers (Barr et al., 2011). Young drivers are also more involved in fatigue related crashes than older, more experienced drivers (McCartt et al., 1996; Pack et al., 1995; Sagberg, 1999). This could be because fatigue itself deteriorates the performance of the driving task of young novice drivers more than it affects the driving task of older more experienced drivers. It could also be that young drivers choose to drive longer without a rest than older drivers do. Smith et al. (2009) made young novice drivers (aged 17-24) and older, more experienced drivers (aged 28-36) complete a video-based hazard perception test at 03:00 a.m. (higher sleepiness) and at 10:00 a.m. (lower sleepiness). In this test, participants watched videos that were taken from the perspective of a driver. In these videos, conflicts developed (e.g. a lead vehicle that brakes due to a blockage further ahead, or a car that pulls out from a row of parked cars when the driver of the video passes the parked cars). Participants had to press a button as soon as they detected the developing hazard. As in earlier studies in which this type of test was applied (McKenna & Crick, 1997; McKenna & Horswill, 1999), response latencies (the time between the first sign of a developing conflict and the time the button is pressed) were significantly longer for the young novice driver group than for the older, more experienced driver group (both in the lower sleepiness condition and in the higher sleepiness condition). However, the response latencies were about the same in the lower sleepiness condition and the higher sleepiness condition for the older, more experienced drivers, but were significantly longer in the higher sleepiness condition than in the lower sleepiness condition for young novice drivers.

Figure 2.5 shows the annual crash rate (number of severe crashes per billion driver kilometres) over the years 1999-2008 during daytime (06:00 a.m. - 09: p.m.) and during nigh time (09:00 p.m. - 06:00 a.m.) for young drivers (between 16 and 24 years of age) and middle-aged drivers (between 30 and 59 years of age) in the Netherlands.

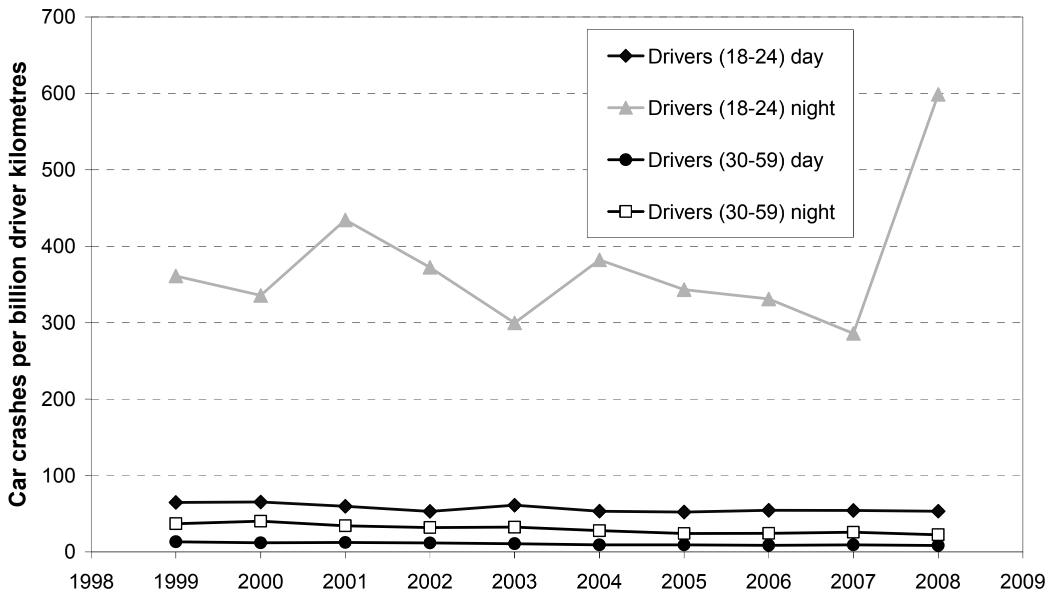

Figure 2.5. Average annual number of severe crashes per billion car kilometres of young drivers (aged 18-24) and middle-aged drivers (aged 30-59) during day-time (06:00 a.m. - 09:00 p.m.) and during night-time (09:00 p.m. - 06:00 a.m.) over the period 1999-2008). Source: Ministry of Infrastructure and Environment / Statistics Netherlands.

From Figure 2.5 can be inferred that the crash rate during nigh time for young novice drivers is on average 6.5 times the crash rate during daytime. For middle-aged drivers the crash rate during night time is on average 2.9 times the crash rate during daytime. Not only the crash rate is substantially higher for young novice drivers during the night, young novice drivers also drive relatively more often during the night. They especially drive more often very late at night and very early in the morning. In the Netherlands the proportion of the total annual mileage that is driven between midnight and 05:00 a.m. of young novice drivers (aged 18-24) is about two times this proportion of middle-aged drivers (aged 30-59) (Source: Statistics Netherlands). The crash rate during night time is not only high because of fatigue. It is also high because driving under the influence of psychoactive substances (alcohol and illicit drugs) is more frequent during the night time than during daytime. Another cause is impaired vision during hours of darkness. In darkness, other road users without lighting (pedestrians, animals, parked vehicles, bicycles without lighting) are more difficult to detect because of little contrast with the environment. Visibility while driving at night can also be temporarily impaired by glare from oncoming headlights. While driving at night especially young novice drivers also drive more often with passengers of their own age. These passengers, especially when they are drunk, can motivate the driver to take risks (see Section 2.4.2) and can distract the driver. Based on a case-control study in New Zealand, Keall, Frith, & Patterson (2005) concluded that almost half the night time crashes of drivers younger than 20 years of age was alcohol related. Although a substantial part of the night time crashes involving novice drivers seem to be alcohol related, fatigue is probably also a risk factor on its own. Horne & Reyner (1995) found that drivers under 30 years of age (especially men) were in particularly prone to sleep-related crashes in the very early hours of the morning. Typical sleep related crashes are single vehicle crashes or head on collisions that are not alcohol or drug related, with mostly no passenger in the car, in mostly good road and weather conditions and in which the driver has made no evasive actions (e.g. braking) to avert the crash at the last moment (Van Schagen, 2003). Groeger (2006) supposed that drowsy driving is more common in young drivers not only because they drive relatively more frequent late at night, but also because of their sleep patterns and the quality of their sleep. As teenagers grow older they go to bed later, but they have to wake up as early as before. Self-reported need for more sleep is the highest around 15 years of age, but is still relatively high at the age of 21. Sleep structure also changes markedly across adolescence and early adulthood, with among other changes, a considerable reduction in the amount of slow wave sleep. According to Groeger (2006) this may be one of the causes that waking up not feeling refreshed is high between 16 and 23 years of age. The effect of sleep loss and changes in the quality of sleep may not only result in drowsy driving, but may also hamper learning to drive as newly acquired procedural skills require sleep in order to consolidate (Walker, 2005).

2.5.3. Distraction/Inattention

Lee, Young, & Regan (2008) mentioned 14 different definitions of driver distraction. What these definitions have in common is that they describe a source of the distraction. This source can be an object (e.g. a billboard), a person (e.g. a passenger or a pedestrian on the sidewalk), an event (e.g. a low flying airplane that is landing) or an activity of the driver (e.g. mobile phone use while driving). The source of distraction can be within the driver her or himself (e.g. when the driver is absorbed in thought or is daydreaming), inside the vehicle (e.g. a wasp in the car or crying children in the backseats) or outside the vehicle (e.g. a billboard or a remarkable pedestrian on the sidewalk). The driver can be compelled by the source and cannot ignore to pay attention to it (e.g. a crash in the opposing lane) or the driver voluntarily chooses to do something (e.g. calling up someone with his cell phone). In many definitions, distraction is related to attention (e.g. 'distraction occurs when attention is withdrawn from the driving task'). Due to distraction, attention can be disturbed, diverted or misallocated. Finally the outcome of distraction can be described in terms of impaired behaviour of the driver (e.g. delayed response or no response) or impaired capabilities of the driver (e.g. diminished situation awareness, diminished hazard anticipation, degraded decision making). The outcome can also be described in terms of car performance (e.g. disruptions of speed and lane maintenance) or in terms of road safety (e.g. increased crash risk). An overview is presented in Table 2.2.

Table 2.2. Elements of distraction (Lee et al., 2008).

Source	*Location of Source*	*Intentionality*	*Process*	*Outcome*
Object	Internal activity (e.g. daydreaming)	Compelled by source	Disturbance of control	Delayed response
Person	Inside vehicle	Driver's choice	Diversion of attention	Degraded longitudinal and lateral control
Event	Outside vehicle		Misallocation of attention	Diminished situation awareness
Activity				Degraded decision making
				Increased crash risk

Considering the good aspects and the limitations of the 14 mentioned definitions of driver distraction, Lee et al. (2008) proposed the following definition:

"*Driver distraction is a diversion of attention away from activities critical for safe driving toward a competing activity*."

Note that this definition of driver distraction excludes drowsy driving or driving without awareness when the workload is low and the driving task is monotonous (see Section 2.5.2). According to the definition distraction is about diverted attention and not about diminished attention (e.g. because of fatigue or highway hypnoses). Note also that the definition includes poorly timed driving activities such turning on the wipers when immediate action is required to avert a crash. The competing activities in the definition can refer to interactions with equipment (both driving related and not driving related) in the vehicle, passengers, food, thoughts (of the driver her or himself) while the traffic situation is safety critical or developing into a safety critical situation. Being captured by objects, persons and events outside the vehicle not related to the safety of the traffic situation is also a 'competing activity'.

One of the most remarkable results of the '100-Car Naturalistic driving study' (Dingus et al., 2006 see paragraph 2.5.2 for a description of this study) was that in nearly 80% of the crashes and 65% of the near-crashes distraction was a contributing cause. However, distraction in this study also included drowsy driving and 'non-specific eye glance away from the forward roadway'. These non-specific eye glances could be the result of internal distraction (e.g. when the driver is absorbed in her or his own thoughts), but could also be the effect of highway hypnoses. The first is included in the definition of distraction, but the latter not. When drowsy driving and non-specific eye glances are excluded, still in nearly 68% of the crashes and 35% of the near-crashes distraction was a contributing factor. Some types of distraction are more risky than others. Klauer et al. (2006) made a distinction between moderate secondary tasks and complex secondary tasks. Moderate secondary tasks were: talking and listing to a hand-held cell phone, inserting/retrieving a CD or cassette, reaching for a not moving object, combing or fixing hair, other personal hygiene (but not applying make-up), eating and looking at external objects. Complex secondary tasks were: dialling a number on a hand-held cell phone, locating/reaching/answering a hand-held device, operating a Personal Digital Assistant (PDA) or smart phone, reading, reaching for a moving object, insect in vehicle and applying make-up. On the basis of the data of the 100-Car Naturalistic driving study, Klauer et al. (2006) could calculate the likelihood of an at-fault crash or near crash when engaged in moderate secondary tasks or complex secondary tasks compared to non-distracted driving. The Odds Ratio (OR) for moderate secondary tasks was 2.10, 95% CI [1.62. 2.72]. The OR for complex secondary

tasks was 3.10, 95% CI [1.73, 5.47]. Preliminary results of another naturalistic driving study with heavy vehicles and lorries have revealed that typing, reading and sending text messages on a cell phone or a smart phone while driving is in particular dangerous (VTTI, 2009). It was found that while texting the occurrence of a 'safety-critical event' was 23 times higher than during non-distracted driving.
Figure 2.6 shows the crash rate (crashes per million driver miles) of attentive and inattentive drivers prior to the crash per age group in the 100-Car Naturalistic driving study. Inattentive drivers did not pay attention to the developing hazardous traffic situation in the 3 seconds before the crash because they were distracted (in accordance with the definition) because they were drowsy or because they glanced in non-specific directions away from the developing hazard.

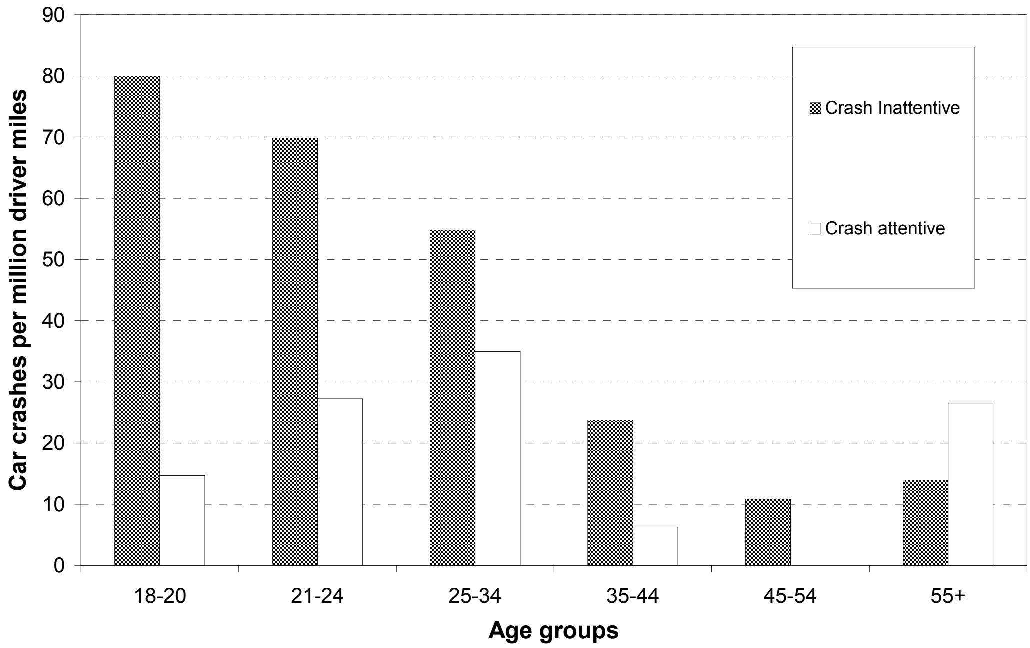

Figure 2.6. Rate of inattentive and attentive crashes per million miles driven per age group (adapted from Dingus et al., 2006).

The crash rates of inattentive crashes declined, as drivers were older (until the age of 54). And the crash rates of attentive crashes increased as drivers were older (till the age of 34). After having analysed more than 5000 crash reports Stutts et al. (2001) found that of all age groups, young drivers (under 20 years of age) had the most distraction-related crashes. They especially were more involved in distraction related crashes because of secondary tasks involving equipment not related to driving such as adjusting the radio, cassette or CD-player. Klauer et al. (2006) divided the population of drivers in the 100-Car Naturalistic driving study in a group of drivers that had a high involvement in crashes or near crashes and a group of drivers that had a low involvement in crashes or near crashes. The average involvement was 3.6 crashes or near crashes. The mean age of the high involvement drivers was 30 and the mean age of the low involvement drivers was 37. This difference was significant. Figure 2.7 shows the frequencies of safety-critical events due to distraction of high involvement drivers and low involvement drivers per age group. The youngest drivers not only had the most safety-critical events, but also more often belonged to the group of high involvement drivers.

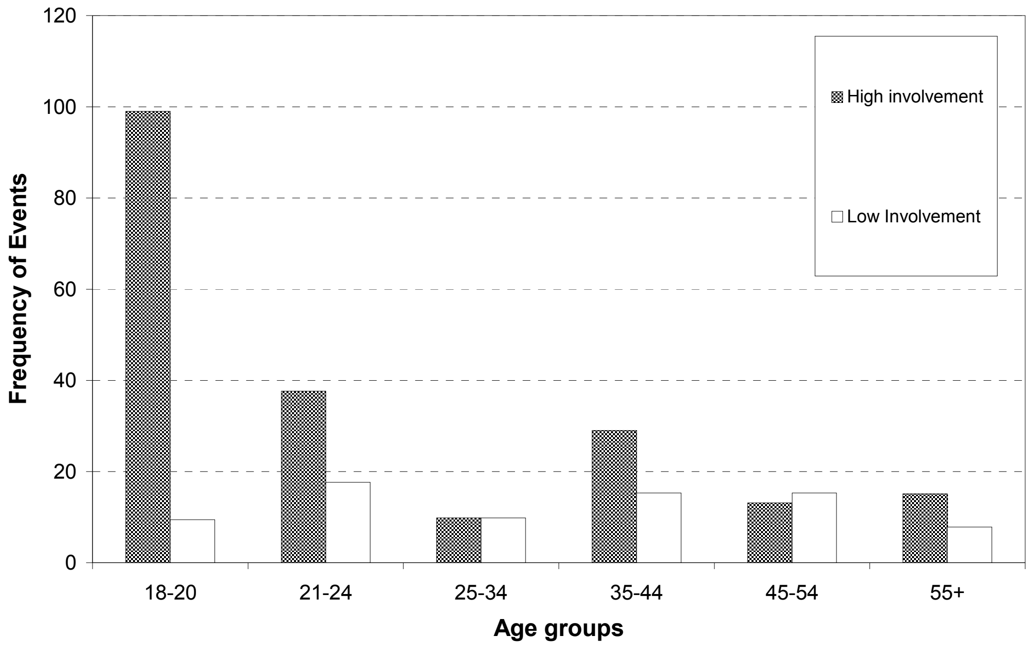

Figure 2.7. Number of safety-critical events of high involvement drivers and low involvement drivers per age group (adapted from Klauer et al., 2006).

A possible explanation for the high involvement of young drivers in distraction related crashes is that they more often engage in secondary tasks than older drivers, especially with cell phones and smart phones. A second explanation could be that as the basic tasks for operating the vehicle are not yet fully mastered (not yet completely executed at the procedural stage) and still require mental workload, the disruptive effect of secondary tasks is greater for novice drivers than for experienced drivers. A third possible explanation could be that novice drivers lack the skills to assess whether the traffic situation is safe enough to engage in secondary tasks or not. This latter possibility is closely related to the hazard anticipation.

2.5.4. Emotions

As in other domains of life, drivers experience emotions when certain events take place. A driver may be angered by another driver when she or he thinks that this other driver interrupts her or his goals or creates a hazardous situation. Drivers also experience fear when they are aware of the hazards in traffic. Many drivers even experience fear or anxiety in situations when the risk is low (e.g. Taylor, Deane, & Podd, 2007). These drivers have driving anxiety, fear of driving or even driving phobia. On the other hand, drivers can experience joy and excitement when they drive fast and think that they still control the vehicle. Mesken (2006), after having reviewed studies about the effects of emotions on driver behaviour, concluded that traffic situations can elicit emotions and that particularly negative emotions such as anger and hostility are related to risky driving and affect general task performance. In contrast to feelings and moods, emotions are related to a particular event or object (Mesken, 2006). You are afraid of something, angry at someone or sad about something. According to Frijda (1986), cited in Mesken (2006), an important characteristic of emotions is that the events or objects that evoke emotions have personal relevance. When for instance personal goals are interrupted by someone, you can get angry at that person. You not only get angry, but you also want to do something about it (e.g. hit that person). This is what Frijda calls action readiness; the tendency to act as a response to the emotion-evoking event. This action readiness can be so comprehensive that all other intentions (e.g. to drive safely) are overruled. This is what Frijda calls the control precedence of emotions. Arnett, Offer, & Fine (1997) distinguished state factors and trait factors of emotions. Trait anger for instance is the disposition of a person to experience anger. Some persons get angry sooner than others do. State anger is the experience of the emotional state itself that is caused by a certain event. It could be that trait factors are stronger during adolescence and young adulthood than in childhood or adulthood.

Adolescence has long been characterized as a time of increased emotionality. Aristotle already described youth as 'passionate, irascible, and apt to be carried away by their impulses' (cited by Larson & Lampman-Petraitis, 1989). The notion that adolescence and young adulthood is a period of turmoil was rediscovered in the second half of the 18th century. In 1774, the novel 'Die Leiden des jungen Werther' (The sorrows of young Werther) was published. In this novel by Goethe the young man Werther is depressed because the girl he loves marries someone else. Eventually he commits suicide. This novel is seen as a typical product of the 'Sturm und Drang' (storm and stress) period. Sturm und Drang was both a movement of German writers in favour of emotions, subjectivity and nature at the beginning of Romanticism and a denotation of turmoil in young adulthood. Goethe also wrote the phrase 'Himmelhoch jauchzend, zu Tode betrübt' (Up one minute, lost to death) which is often used to describe the mood swings of adolescents. If all adolescents and young adults experience more storm and stress than they experience at other ages is questionable (Arnett, 1999). However, there is evidence that dysphoric states such as sadness, anxiety, irritability and restlessness are more common in adolescence and in young adulthood that in all other stages of life (see Petersen et al., 1993 for a review of the literature). The effect of this on driver behaviour is not known. There are studies in which a relationship between negative moods and risky driving were observed for drivers in general (see Mesken, 2006 for a review of the literature). One study could be found that showed this relationship for young drivers (Arnett et al., 1997), but no studies could be found that has examined if negative moods while driving resulted more often in risky driving behaviour in young drivers than in older drivers.

2.6. Task demands

So far, the literature has been reviewed about aspects of the young novice drivers themselves, but could it also be that they have a higher crash rate because they more often drive in circumstances that are riskier for all drivers? Driving to a certain extent is a self-paced task. The task demands are largely determined by the driver her- or himself. This is to say that drivers chose to drive with a certain speed and to a certain extent, chose to drive in particular types of cars. They also decide where and when to drive and whether or not to put their safety belts on. In this section on task demands only the consequences of the facts that young novice drivers more often expose themselves to dangers than older, more experienced drivers, are discussed. The reasons why they expose themselves more often too dangerous traffic situations compared to older, more experienced drivers has been discussed in the previous sections of this chapter. The precise taxonomy of Figure 2.1 will no longer be continued. This is to say that in the remaining part of this chapter speed and vehicle, other road users, road and road environment and (weather) conditions will not be discussed in separate sections, but will be discussed in one section named 'exposure'.

2.6.1. Exposure

In Section 1.2, the Periodical Regional Traffic Safety Survey (PROV) of the Dutch Ministry of Infrastructure and Environment was introduced. One of the questions in this questionnaire was: “How fast do you drive on roads with a speed limit of XX km/h when there is no congestion on moments that you do not pass another vehicle and the weather condition is good?” Figure 2.8 shows the self-reported speeds of female and male drivers per age group for motorways with a speed limit of 120 km/h.

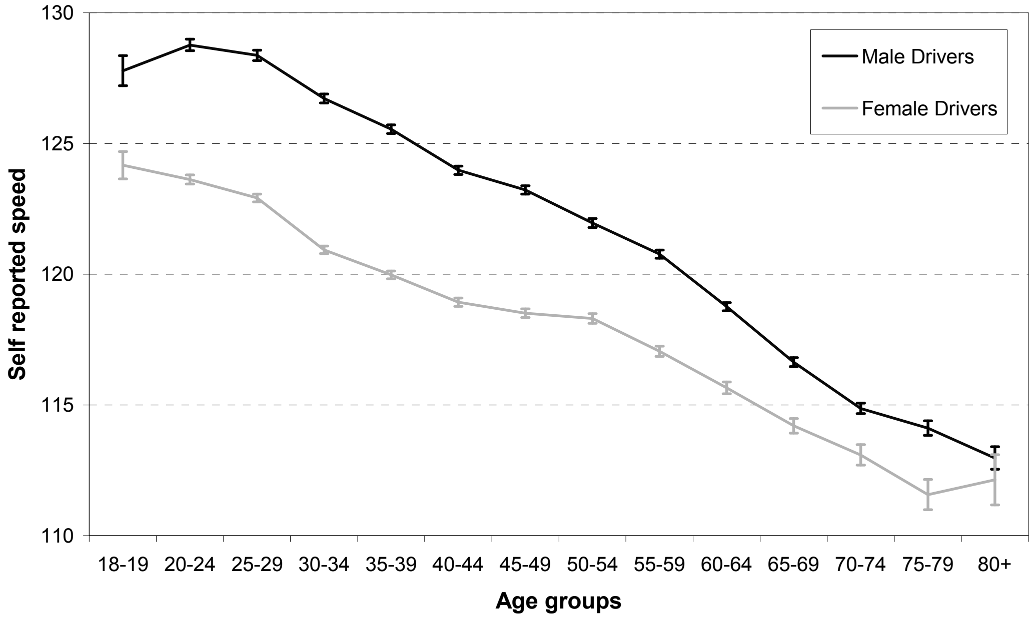

Figure 2.8. Self-reported speeds in good weather and traffic conditions on motorways with a speed limit of 120 km/h for female and male drivers per age group. Error bars indicate +/- 1 standard error. Source: Ministry of Infrastructure and Environment.

The results in Figure 2.8 are based on the combined data of 10 surveys with about 6000 car drivers as respondent each between 1990 and 2005. The self-reported speed on motorways was lower for females than for males and decreased with age. Note that the self-reported speed of 18-19 year old male drivers was lower than the self-reported speed of 20-24 year old male drivers. For female drivers, the average self-reported speed on motorways was no longer above the legal limit from the 35-39 age group on. For male drivers this was the case from the 70-74 age group on. Figure 2.9 shows the same results as Figure 2.8, but now for main rural roads with a speed limit of 80 km/h.

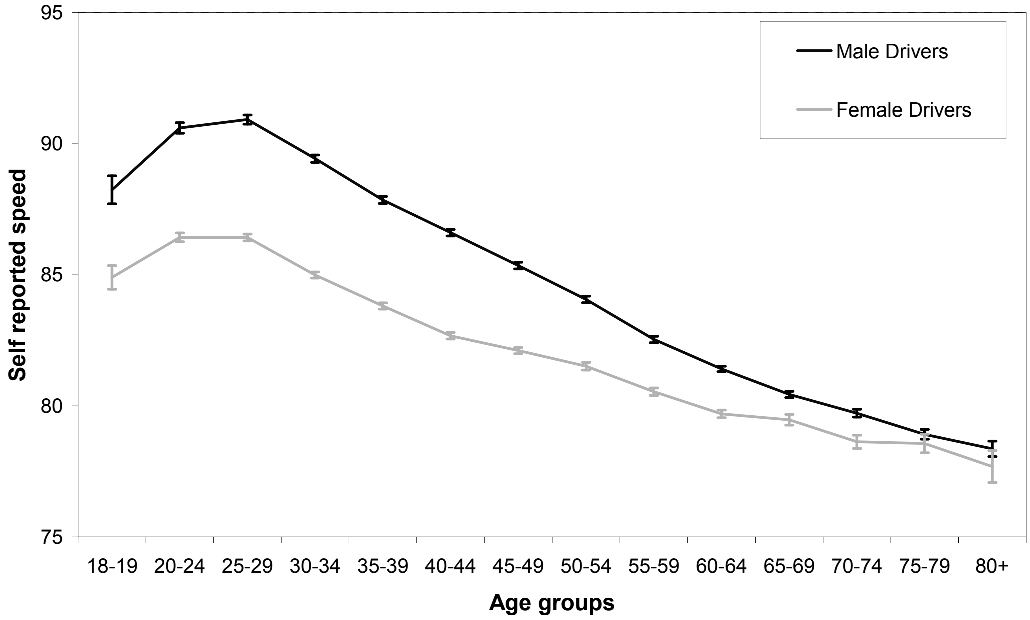

Figure 2.9. Self-reported speeds in good weather and traffic conditions on main rural roads with a speed limit of 80 km/h for female and male drivers per age group. Error bars indicate +/- 1 standard error. Source: Ministry of Infrastructure and Environment.

Figure 2.9 shows that the average self-reported speed on main rural roads of female drivers was lower than the average self-reported speed of male drivers. For both young 18-19 year old female drivers and 18-19 year old male drivers the self-reported average speed was lower than for 20-29 year old drivers of the same gender. Female drivers in the 60-64 age group were the first with an average speed under the legal limit. For the male drivers this was the 70-74 age group. Figure 2.10 shows the same results as Figure 2.8 and Figure 2.9, but now for urban roads with a speed limit of 50 km/h.

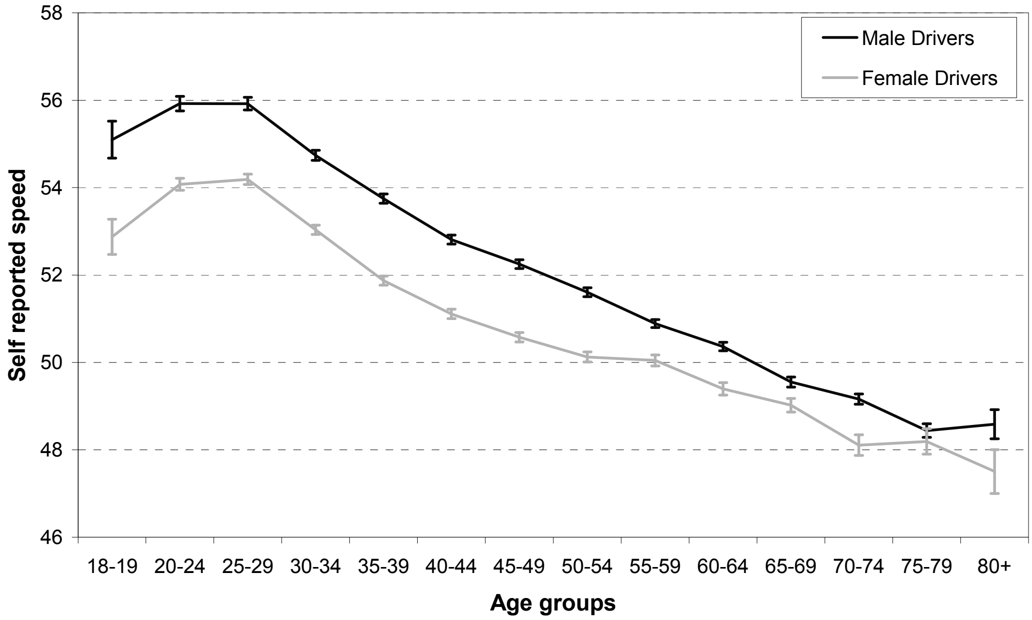

Figure 2.10. Self-reported speed in good weather and traffic conditions on urban roads with a speed limit of 50 km/h for female and male drivers per age group. Error bars indicate +/- 1 standard error. Source: Ministry Infrastructure and Environment.

Figure 2.10 shows a similar pattern as the Figure 2.8 and 2.9. Note that the average self-reported speed for both 18-19 year old female drivers and 18-19 year old male drivers was lower than for the 20-29 year old drivers of the same gender. In a longitudinal study in which novice drivers at regular intervals had to report their speed in the first two years after licensing, De Craen (2010) found that in the Netherlands self-reported speeding in urban areas increased significantly in the first two years after licensing. Clark, Ward, & Truman (2005) after having analysed 3437 accident reports, found no significant differences in the number of crashes due to speeding between 17-19 year old drivers, 20-22 year old drivers and 23-25 year old drivers in the UK. However, Clarke et al. (2005) did not make a distinction between speeding and driving too fast in the given conditions (e.g. driving too fast in a curve). McKnight & McKnight (2003) made this distinction and, after having analysed more than 2000 crash reports in two States of the USA, they concluded that 16-19 year old drivers did not crash very often because of speeding (driving over the legal limit) but because of driving too fast for the circumstances (e.g. driving too fast in a curve). The results of the study of McKnight & McKnight (2003) indicated that the youngest novice drivers had crashes not so much because of deliberate reckless driving, but because of poor hazard anticipation. This is to say that in general they did not recognize the hazards and did not feel risks. The conclusion of McKnight & McKnight

(2003) that especially for the youngest novice drivers it is not so much deliberate risk taking, but rather poor risk assessment and poor hazard anticipation that make novice drivers crash, was reconfirmed in a recent study in which 5470 crash reports involving 15-18 year old drivers were analysed (Curry et al., 2011).

Not all cars offer the same protection to the occupants of the car in case of a crash. In older vehicles with less advanced passive safety features, such as seat belt reminders, headrests, airbags, etc., drivers and passengers run a greater risk to get injured or to die in a crash than drivers and passengers in newer cars with more advanced safety features. Not only the safety features and how old the car is determine the consequences of a crash, but also the mass of the car. In a car-car crash, the occupants of the heavier car are better protected than the occupants of the lighter car (Van Kampen, 2000). Cammisa, Williams, & Leaf (1999) found that in the USA teenage drivers were more likely to drive in older and smaller cars than drivers in other age groups. Research by Williams et al. (2006) confirmed this result for the USA. Ferguson (2003) found that the older and the smaller cars was in which young novices drove, the higher the risk was of getting injured in a crash. This study was conducted in the USA, but similar results have been found in Germany and Australia (Schepers & Schmid, 1996; Watson & Newstead, 2009).

In Figure 2.11, the number of 18-24 years old car occupants that died in a car crash in 2008 by day of the week and hour of the day in Europe is represented.

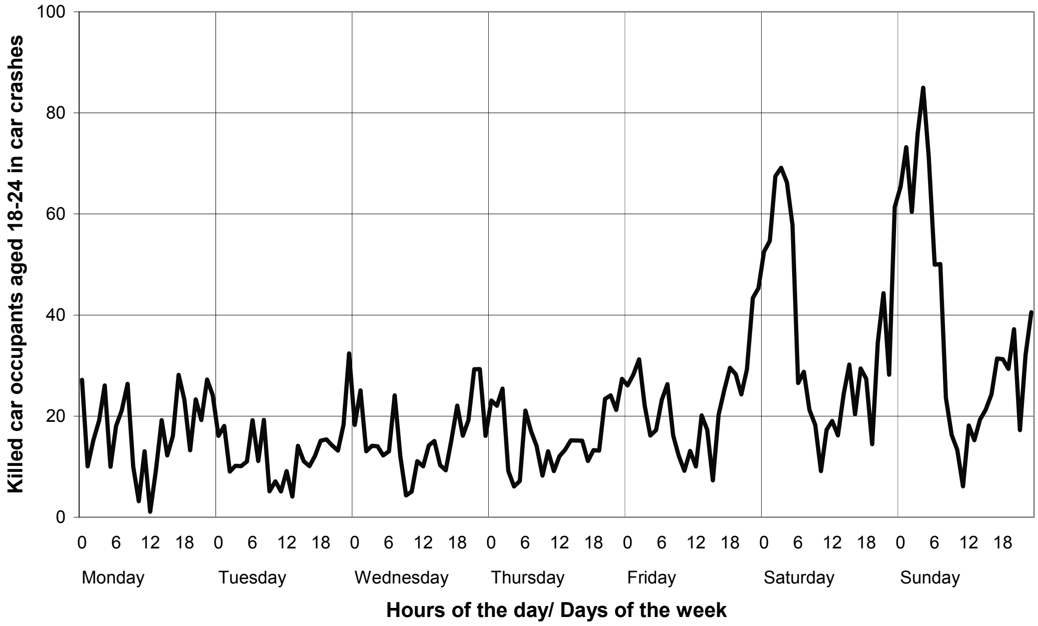

Figure 2.11. 18-24 year old car occupants killed in car crashes in Member States of the European Union except Germany in 2008, per day of the week and hour of the day. Source: CARE (EU road accident database).

The number of fatalities was in particular high on the night from Friday to Saturday and on the night from Saturday to Sunday in the first hours after midnight. As already mentioned in the Sections 2.5.1, 2.5.2 and 2.5.3 factors like drink and drug driving, fatigue and driving with peers as passengers contribute to this high number of fatalities in weekend nights. It is however also caused by exposure. Young drivers drive relatively more often late at night and driving in darkness is more difficult for all drivers than driving during daylight (Keall et al., 2005).

Finally, recent studies about self-reported seat belt use and age no longer show substantially higher percentages for young drivers that do not use seat belts than for middle-aged drivers (SARTRE 3, 2004; Zandvliet, 2009). In the USA in 2008 the observed rate of occupants that used her or his seat belt was 83% (NHTSA, 2008). In the Netherlands in the same year 95% of the drivers of cars (not including vans), 94% of their front seat passengers and 81% of their back seat passengers used their seat belt (DVS, 2008). Despite the relative high percentage that used the seat belt in the USA (83%), the percentage of car occupants killed that did not wear her or his seat belt was high (51%). This percentage was hardly any different for young drivers and middle-aged drivers (NHTSA, 2008). The relative high percentages of killed car occupants that did not wear a seat belt, despite the high percentage that wears a safety belt, implies that raising the percentage from say 90% to 100% still is an effective road safety measure.

2.7. Conclusions

The high crash rate of young novice drivers is a universal and multifaceted problem. It cannot simply be reduced to only a lack of skills due to inexperience or to only the propensity to take and accept risks due to their youthfulness (i.e. immaturity of the brain). Inexperience and youthfulness are interrelated and embedded in a social context. In the present chapter, an overview was presented of the many facets of the young driver problem that affect their ability to anticipate hazards in traffic. Hazard anticipation itself was not discussed. The theoretical background of the psychological aspects of what they do in traffic (information processing and calibration) (see Figure 2.1) and in particular hazard anticipation, is the central theme of the next chapter. In the present chapter, a distinction has been made between biological facets (i.e. age and sex) and sociological facets (i.e. youth culture, peer pressure). This could leave the impression that 'nature' and 'nurture' are completely distinct. In reality the two are strongly intertwined, youth culture and peer contact provide the situation in which the bodily and brain developments can be applied and personality characteristics and cognitive function determine the preference for and selection of situations to be in. For example, during adolescence their peers (see Section 2.4.2) influence what young drivers do. The fact however that peers are so important for adolescents is partly caused by their brain development (e.g. Spear, 2000). The specific exposure in situations further triggers and shapes the bodily functions, with learning processes and habit formation allowing for finer adjustments between nature and nurture. In this chapter, the distinction between 'nature' and 'nurture' was only made in order to classify the many aspects of the young driver problem. Besides the biological and sociological facets of the young driver problem, acute impairments of one's driving capabilities were discussed (alcohol, drugs, fatigue, distraction and emotions). Finally, the effects of exposure to dangers in traffic were discussed.

The present chapter was intended to provide an overview of factors of which young novice drivers differ from older, more experienced drivers and that influence driving behaviour, in particular hazard anticipation. The determinants of driving behaviour discussed in this chapter indicate that there are many underlying causes why young novice drivers are probably less well equipped to detect and recognize possible hazards in traffic and to predict how traffic situations can develop into acute threats. The discussed determinants also show that the ability to assess and weigh risks that merit a response, especially in situations that are emotionally charged and in which there is no time for reflection as is often the case in traffic, is probably less developed in young drivers than in older drivers.

3. Driving and hazard anticipation: a theoretical framework

3.1. Introduction

This chapter provides the theoretical background of this thesis. Hazard anticipation in traffic is not a new subject. Many different definitions of what mostly is called hazard perception have been proposed in the past decades. In Section 3.2 some of the most cited definitions are discussed and a new definition is presented. Models on driving behaviour tell us which processes take place when a driver anticipates hazards. How some existing models on driver behaviour explain hazard anticipation is discussed in Section 3.3. As none of the existing types of models covers all aspects of the definition, a neuropsychological framework on hazard anticipation is introduced in Section 3.6. In preparation of the presentation of this framework the concept of schemata is presented in Section 3.4 and Norman & Shallice's model on willed and automatic control of behaviour (1986) is explained in Section 3.5. The framework that is presented in Section 3.6 was originally proposed to provide insight in the impaired everyday cognitive functioning deficits in patients with dementia, taking into account the interplay between impaired general cognition and impaired social and emotional functions (Brouwer & Schmidt, 2002). In Section 3.7 the meaning of attention in the driving task is discussed within the context of this framework. Based on the framework, the hypothetical differences in hazard anticipation between novice drivers and experienced drivers are discussed in Section 3.8. Empirical evidence for the framework in relation to hazard anticipation is presented in Section 3.9. In Section 3.10, the last section of this chapter, is discussed how hazard anticipation skills are possibly learned and how acquisition of these skills may differ from the acquisition of 'normal' motor skills.

3.2. Hazard anticipation

A hazard is something (a situation, action or object) that *can* cause adverse effects. According to Mills et al. (1996), in traffic a hazard is "any aspect of the road environment or combination of circumstances which exposes an individual to an increased possibility of an accident". Hazard and risk are not the same. A risk is the likelihood that a hazard will cause its adverse effects. This risk can be objective and subjective. Brown & Groeger (1988) used an objective definition of risk. According to these authors, risk is "the ratio between some measure of adverse consequences of events and some measure of exposure to conditions under which those consequences are possible." Armsby, Boyle & Wright (1989) used a subjective definition of risk. These authors defined risk as "the level of danger associated with a hazard, as perceived by the individual". Consider a driver that passes a stationary bus at a bus stop. This is a hazardous situation, because passengers that have left the bus may cross the road just in front of the bus. No driver will know the exact objective risk of this hazard. The probability that a passenger crosses the road just in front of the bus may be low, but the consequences are serious. In these situations, drivers probably do not assess the risk but feel the risk. This is to say, they feel an anticipatory emotion that things may go wrong (Loewenstein et al., 2001). Drivers that pass the bus without reducing their speed and without looking just before the edge of the bus in order to catch a glimpse of a pedestrian that could cross the road as early as possible, do not show anticipatory actions. They may not have anticipated the possible pedestrian because they have not recognized the hazard. These drivers do not expect that pedestrians may cross the road in front of the bus. It may also be that drivers are vaguely aware of the possibility of a pedestrian who could cross the road, but they feel no anticipatory emotions that are strong enough to elicit actions. Finally, it could be that drivers are aware of the risk, but are of the opinion that pedestrians should obey the rules of the road. If pedestrians cross the road just in front of the bus, it is their fault. In the first situation lack of what is mostly named 'hazard perception', is a cognitive problem (the hazard is not detected and not recognized). In the second situation, lack of hazard perception is an emotional problem (no or too little feelings of risk) and in the third situation, not anticipating the hazard, is a motivational problem (no willingness to take account of road users that do not obey the rules of the road). Whether young novice drivers predominantly do not see potential hazards or predominantly do not feel the risks and/or are not motivated to anticipate hazards is subject of study in Chapter 4.

Lack of hazard perception skills is considered as one of the main causes of the high crash involvement of young novice drivers. Already in 1964, Spicer (cited in Pelz & Krupat, 1974) found that young accident-involved drivers were less able to detect hazardous elements in filmed traffic situations than accident-free drivers. Different definitions of hazard perception have been proposed in the past decades. Some definitions that are regularly cited are:

- The process of identifying hazardous objects and events in the traffic system and quantifying their dangerous potential (Deery & Love, 1996);
- The ability to detect a hazards, to assess the risk involved in the detected hazard, to assess one's own ability to deal with the detected hazard and to compare the results of the two assessments in order to determine whether or not one can cope with the hazard (Brown & Groeger, 1988);
- The ability to anticipate traffic situations of which there are two separable components; the degree of perceived hazard associated with the situation, and the perception-reaction time to the perceived hazard (Sagberg & Bjørnskau, 2006);
- The ability to read the road and anticipate forthcoming events (Horswill & McKenna, 2004);
- Processes related to:
  - Hazard detection (being aware that a hazard may be present);
  - Threat appraisal (evaluating whether the hazard is sufficiently important to merit a response);
  - Action selection (having to select a response from one's repertoire of skills); and
  - Implementation (performing the necessary actions involved in the response that has been selected) (Grayson et al., 2003);
- The process of discovering, recognising and reacting to potentially dangerous situations (Engström et al., 2003)

Two components recur in most definitions: the ability to anticipate road and traffic events and the ability to assess risks. Perception is just one aspect of hazard perception. It is not only the recognition of a possible hazard but it are also the preparatory actions (e.g. speed reduction and 'keeping an eye on something or someone') that allow for a timely intervention (e.g. braking) to avert the crash, should the recognized possible hazard materialize. Instead of hazard perception, it would be better to use the words hazard anticipation. Anticipation means that drivers have to be aware of what can happen and take actions in order to be prepared for possible negative events to come.

Drivers are aware of hazards when they can detect them in an early stage of development, recognize them and predict how they may develop. These three abilities are also present in the theory of 'situation awareness' (Endsley, 1995). Endsley (1995) described situation awareness as 'the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future'. Within the model of situation awareness there are three levels: perception (level 1), comprehension (level 2); and projection (level 3). In terms of hazard anticipation, level 1 would be the ability to perceive a possible hazard. A driver actively searches for stimuli that could intervene with her or his goals. Perception means that stimuli in the environment draw the attention[6] of the driver because they give her or him a vague notion that they have meaning (i.e. could intervene with her or his goals such as to arrive somewhere in good health and in time), without exactly knowing what. Level 2 in hazard anticipation would be the recognition of the situation. For the understanding of the present situation, the driver retrieves from semantic memory knowledge such as rules of the road and from episodic memory past experiences in situations like this. For the understanding of the present situation, the driver also assesses the speed and direction of other road users in the scene. Level 3 would be driver's prediction about the development of the recognized traffic situation. These predictions are also based on knowledge stored in declarative memory and assessment of elements in the present situation (e.g. speed and direction of other vehicles in the scene). Although three levels are distinguished in situation awareness, these levels are interrelated. Being aware of the situation is the same as having a holistic comprehension of the situation. Strictly speaking, level 3 does not include the anticipatory actions themselves (e.g. looking in a particular direction based on expectations or reducing speed).

A weakness in the theory of situational awareness is that the emphasis is on cognition, although it recognized that situational awareness is holistic and that the three levels are interrelated. A cue is perceived and the awareness of this cue results in the retrieval of declarative knowledge from semantic and episodic memory. This knowledge is processed in working memory and predictions are made. What is missing is the possibility of an

[6] The concept of attention is elaborated in Section 3.7 and in Section 4.1.6 of Chapter 4 a model about attention is presented. In general, attention is the selective processing of information of certain aspect of the internal and/or external environment, while ignoring other aspects. Attention has to be sustained. Persons can direct their attention towards something, concentrate their attention on something and the attention of a person can be captured by something.

immediate and automatic anticipation on hazards without involvement of working memory. In this 'automatic mode', that probably is the default option, the traffic situation is not analysed but the situation evokes an emotion (possibly because of threats experienced in similar situations in the past). This emotion in combination with the situation automatically triggers a schema (mental representation) and on the basis of this schema actions are carried out at the procedural level (Anderson et al., 2004 see also paragraph 2.4.3), without or almost no explicit awareness. A driver can look in a certain direction from where a hazard may materialize and reduce her or his speed without knowing that she or he is anticipating a hazard. If because of these actions at the procedural level, feelings of risk do not decrease, the driver then can switch to the explicit mode, as described by the theory of situational awareness. How all this could function is elaborated in the Sections 3.4, 3.5, 3.6 and 3.7 of this chapter. For now, it is important to define hazard anticipation in such a way that the role of emotions in hazard anticipation and the possibility of an automatic mode of hazard anticipations are not excluded. To meet these requirements hazard anticipation is defined as:

> *The detection and recognition of road and traffic situations that could increase the possibilities of a crash, including the prediction of how these situations can develop into acute threats. The feelings of risk that are evoked by these predictions and the execution of actions that will reduce the feelings of risk and will ensure a safety margin that is large enough to avert a crash should the latent hazard materialize. Hazard anticipation can range from 'automatic' to 'controlled'.*

Note that in this definition hazard anticipation is not about the detection and recognition of imminent threats, but about the detection and recognition of latent hazards. This thesis is not about the late detection of acute hazards (e.g. a child that crosses the road just in front of the driver) and the reflexive responses of drivers in these emergencies (e.g. hard braking). It is about the early detection and recognition of possible hazards (e.g. a possible child (not visible to the driver) who may cross the road from between parked cars); including the anticipatory actions that create a safety margin large enough to avert a crash should the latent hazard materialize. With regard to the possibility of a child who could cross the road from between parked cars, the anticipatory actions could be looking between the gaps of parked cars and speed reduction. A latent hazard is a possible hazard that not necessarily will develop into an imminent threat. Four types of latent hazards can be distinguished:

1. Possible other road users on collision course that are hidden from view. Objects such as large vehicles (e.g. lorries and buses), parked cars, building, trees, bushes, etc. can obstruct the view. The hidden possible other road user will only become visible at the last moment before a crash. A child that may cross the road from between parked cars is a latent hazard that belongs to this category. This type of latent hazards are named *covert latent hazards* in this thesis;

2. Visible other road users that, due to evolving circumstances in the environment, might act in such a way they may move into the driver's pathway. This includes for instance a car that is waiting in a row of cars that may pull out of this row into the other lane (e.g. because the driver in this car gets impatient). An approaching driver in this other lane that does not consider that this could happen may collide with the car that pulls out. These types of latent hazards are named *overt latent hazards* in this thesis;

3. Signs and precursors of hazards further ahead. For instance, this includes an intersection just after a curve in the road with dense vegetation on both sides of the road. The intersection only becomes visible when the intersection is near and the stop sign at the intersection only becomes visible at the very last moment, as the sign is partly hidden by vegetation. Drivers that do not notice the warning sign 'stop sign ahead' before they enter the curve, may drive too fast and will detect the intersection too late. These drivers also will not search for the stop sign at the intersection and possibly will not stop at the intersection. Signs can be traffic signs (e.g. warning signs), but can also be actions of other road users not being an overt latent hazard themselves. The actions of these road users can predict hazardous actions of other road users that are near to the driver. For instance, braking lights of cars in the distance may indicate that the lead vehicle just in front of the driver, will brake soon too. These types of hazards (official and unofficial warning signs and action by other road that announce latent hazards) are named *precursors of hazards* in this thesis.

4. Indications of circumstances that can cause loss of control. These indications can be in the environment (e.g. a wet surface or a curve), but can also be internal (e.g. feeling drowsy, being distracted). These hazards are named *loss of control hazards* in this thesis.

The emphasis in this thesis is on covert latent hazards and on overt latent hazards. A choice for these two types of latent hazards was made as both covert latent hazards and overt latent hazards involve the anticipation of what other road users may do. Precursors of hazards are only present in Chapter 6 and loss of control hazards are not discussed in this thesis. A latent hazard can also be a mixture of the four distinguished types of latent hazards. For example, a visible pedestrian on the pavement that walks towards the road and then disappears behind a parked car, is an overt latent hazard that turns into a covert latent hazard.

To explain the definition of hazard anticipation, take the following overt latent hazard as an example: A driver is driving in an urban environment. On the pavement on both sides of the road, this driver sees pedestrians (*perception*). In the opposite direction, this driver sees a bus that stops at a bus stop (*perception*). The driver *recognizes* this situation and knows from past events and probably also from her or his own experience as a pedestrian, that pedestrians on the pavement may suddenly start running and crossing the road in order to catch their bus (*prediction*) (see Figure 5.2). This driver slows down a bit (if this is possible) and searches for pedestrians that start to run on the pavement (*anticipatory actions*). Because of these anticipatory actions, the driver enlarges her or his *safety margin* in such a way that she or he can take evasive actions (e.g. brake) should a pedestrian start running and crossing the road in order to catch her or his bus. If the driver in this situation does not enlarge her or his safety margin, this can be because she or he has not detected and recognized the latent hazard. If this is the case, the driver cannot predict what may go wrong. It can also be that she or he realizes that a pedestrian can start to run and cross the road, but *feels no risk* and/or is of the opinion that no anticipatory actions are required because it is their fault when they will be hit (lack of *motivation*). Some drivers will routinely search for running pedestrians on the pavement and will routinely decrease speed (*automatic* hazard anticipation) and some drivers have to think first before they do this (*controlled* hazard anticipation).

3.3. Models of driving behaviour and hazard anticipation

How does the definition of hazard anticipation in Section 3.2 fit with existing theories of driving? Numerous driving models have been developed (e.g. Fuller, 1984, 2000, 2005, 2007a; Näätänen & Summala, 1974; Summala, 2007; Vaa, 2007; Wilde, 1982). Michon (1985) arranged models about driving along two axes. The horizontal axis is behaviourally oriented vs. psychologically oriented and the vertical axis is taxonomic vs. functional. Only the functional models are relevant in relation to hazard anticipation because functional models try to explain driver behaviour (Ranney, 1994). Behavioural oriented models that are functional are the information processing models. The in Section 3.2 mentioned model of situation awareness (Endsley, 1995), is an example of an information processing model. Perception, comprehension and projection are three different levels of information processing in situation awareness. Information processing models are typically represented as a sequence of stages such as; perception, recognition, prediction, decision, response selection and task execution. Usually, a distinction is made between automatic processing of information and controlled processing of information. Automatic processing of information hardly requires conscious attention, whereas controlled processing of information requires conscious attention. Information processing models try to explain (maximal) driver performance (what a driver can do).

Psychologically oriented models that are functional are the motivational models. These models are based on the assumption that driving is largely a self-paced task. Within certain limits, drivers are free to choose their speed, their route (e.g. to reach their destination they can take the route with the many intersections, but they can also take the slightly longer route with only a few intersections) and to carry out certain manoeuvres or not (e.g. overtake another car or not). Because the driving task is largely self-paced, drivers themselves chose the amount of risk they are willing to take. In all motivational models, risk is not a calculated risk of the driver, but a feeling of risk. Besides motivational models based on risk or threat (e.g. Fuller, 1984; Näätänen & Summala, 1974; Wilde, 1982), motivational models have been proposed that are based on task difficulty (Fuller, 2000, 2001, 2007a), pleasure (Rothengatter, 1988), discomfort (Summala, 2007) and best feelings (Vaa, 2007). In contrast to the information processing models, motivational models are especially made to explain driver behaviour (what a driver actually does).

In the following sections one recent information-processing model, one recent motivational model and a somewhat older mixed model are discussed in more detail in relation to hazard anticipation.

3.3.1. Model of information processing in driving and the role of expectancy

Houtenbos (2008) has developed a model about the interaction of a driver with other road users. This model is derived from the theory of situation awareness (Endsley, 1995) and from more general information processing theories (Wickens & Hollands, 2000). Figure 3.1 presents her model from the perspective of one road user.

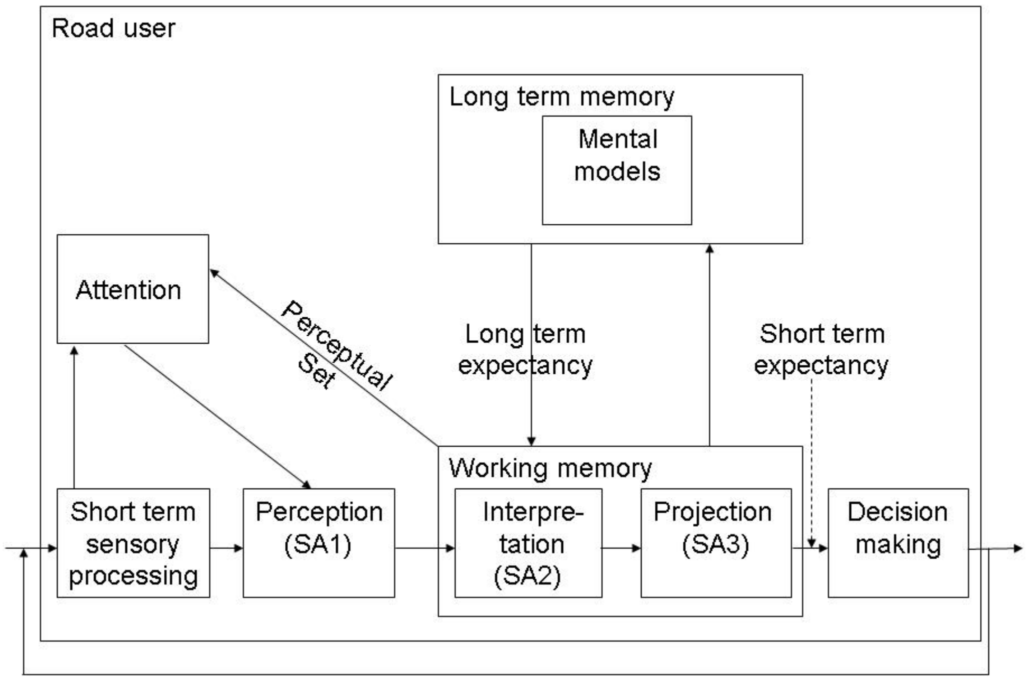

Figure 3.1. Model on the interaction between road users (from the perspective of one road user), based on theories about information processing and situation awareness (Houtenbos, 2008).

Stimuli from the environment are first very briefly pre-attentively processed. This is called 'short term sensory processing'. What is perceived (Situation Awareness level 1 (SA1)), depends (partly) on the focus of attention of the driver and this focus of attention is determined by the drivers comprehension (interpretation) of the present situation (Situation Awareness level 2 (SA2)) and the projection of this situation in the near future (Situation Awareness level 3 (SA3)). These processes take place in working memory. What is processed in working memory is fed by perception (SA1) and by general expectations about the behaviour of road users stored in long-term memory. Houtenbos (2008) calls these general expectations 'long term expectancies'. Thus the perception could be: “There is this bicyclist at about 50 meters away from me.” And the long term expectancy could be that bicyclist in particular situations tend to cross the road without turning their head. The next step is to realize that this is such a particular situation. The result is what Houtenbos (2008) calls a 'short term expectancy'. In the used example the short-term expectancy is: “This bicyclist that is about 50 meters away from me, given the particular circumstances, may cross the road without turning his head.” The short-term expectancy is depicted in Figure 3.1 by a dotted arrow. The reason is that it was a hypothesis. The results of her studies confirmed this hypothesis. Based on the short-term expectancy, the driver takes anticipatory actions. Because of these actions, the traffic situation alters and information processing starts all over again.

The driver behaviour model of Houtenbos (2008) clarifies what could go on in drivers with regard to the first part of the definition of hazard anticipation: the ability to detect and recognize latent hazardous situations and to predict how these situations can develop. However, feelings of risk and the motivations of the driver that are relevant for risk assessment (the second part of in the definition of hazard anticipation) are no explicit components of the model. In her model, also no distinction is made between automatic processing of information and controlled processing of information.

3.3.2. Task-difficulty homeostasis model

The task-difficulty homeostasis model (Fuller, 2007a) is the latest version of a motivational model developed by Fuller about driving behaviour that started as the 'task-capability interface model' (Fuller, 2000, 2005). Fuller (2005) argues that it is not so much subjective risk estimates as proposed by Wilde in his Risk Homeostasis Theory (1982) that influences driver behaviour, but rather subjective estimates of task difficulty. Drivers do not like the feeling of being out of control and subjective risk estimates are only one of the two elements that could lead to the experience of being out of control. The other element according to Fuller is the assessment of one's own capabilities. Figure 3.2 depicts the complete task-difficulty homeostasis model.

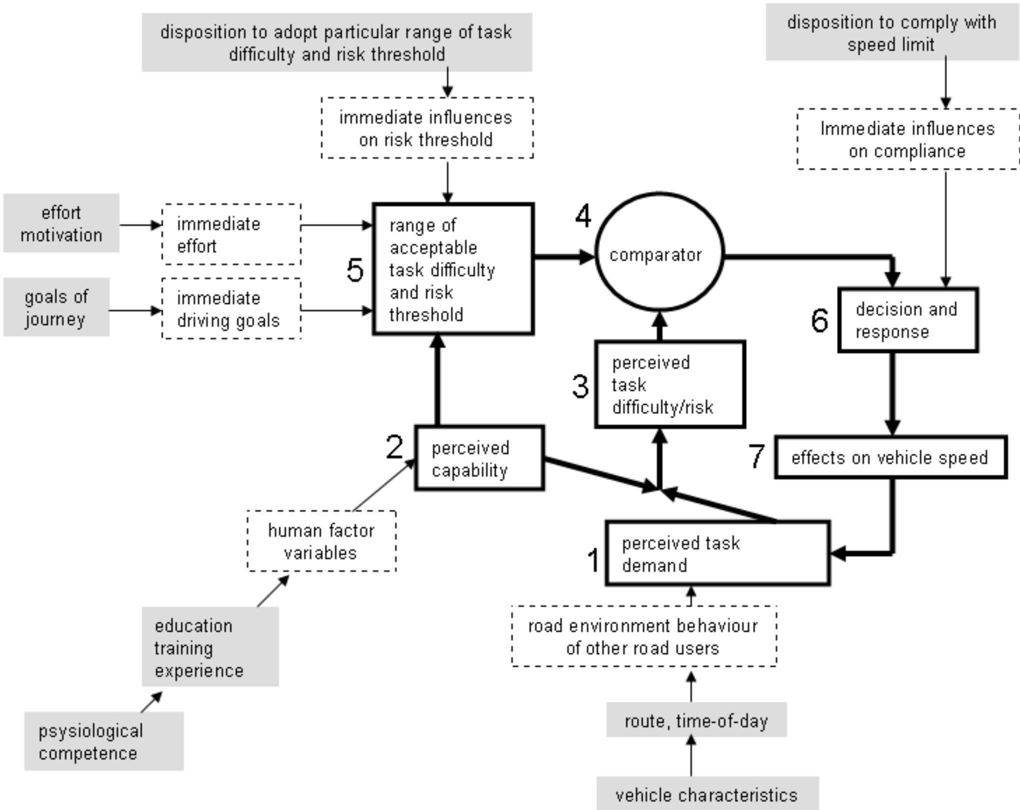

Figure 3.2. Fuller's task-difficulty homeostasis model (Fuller, 2007a).

Fuller assumes that drivers try to keep the complexity of the driving task within a certain range of task difficulty they feel at ease with (5). The task difficulty the driver perceives (3), arises from the perceived task demands to master traffic situations at a certain moment in time (1) and her or his perceived capability to cope with that task (2). The perceived task difficulty (3) and the feeling of risk are the same. The perceived task demands are determined by the traffic situation, the weather and road conditions and the vehicle. If a driver starts to drive faster, the task demands will increase. The perceived capability (2) depends on the competences of the driver (the result of her or his physical and mental constitution and her or his skills that are acquired by training and experience) and the transient impairments of these competences such as fatigue, distraction and the influence of alcohol and drugs. Fuller calls these transient impairments 'human factor variables'. Whether the perceived task difficulty/risk merits an action that will reduce the task demands, depends on the range of task difficulties that are acceptable for the driver (5). Only when the perceived task difficulty is above the limit that is considered as acceptable (determined by the comparator (4)), actions are executed (mostly reduction of speed) (6 and 7) that will reduce the task demands. The range of acceptable task difficulties / risks is not fixed. This range depends on the rather permanent dispositions of the driver (her or his norms and values and whether she or he is a risk avoider or a sensation seeker) and temporary motives (e.g. whether the driver is in a hurry or not). The core of Fuller's task-difficulty homeostasis model is calibration. Figure 3.3 presents an adaptation of what is considered as Fuller's concept of calibration.

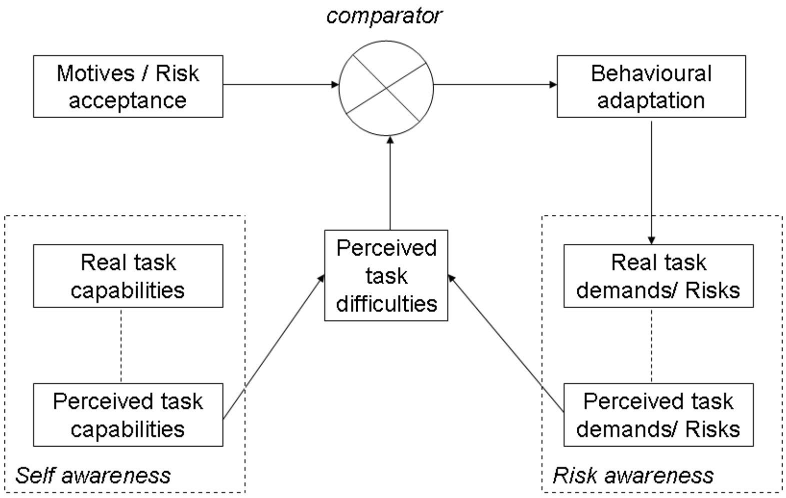

Figure 3.3. Calibration (adapted from Fuller, 2007a).

To a certain extent, drivers can determine how difficult and/or risky the driving task is. When for instance a driver begins to drive faster, the task will usually become more complex and risky. Normally a driver does not want to exceed her or his own abilities and experience feelings of loss of control (Fuller, 2000, 2001, 2005, 2007a). In order not to lose control, the driver balances the task demands and her or his capabilities. This balancing of capabilities and task demands based on self-assessment and risk assessment is called calibration (De Craen, 2010; Fuller, 2007a; Mitsopoulos, Triggs, & Regan, 2006). A driver does not balance task demands/risks and capabilities, but balances perceived task/demands and perceived risks. When both the perceived capabilities completely coincide with the real capabilities and the perceived task demands / risks completely coincide with the real task demands / risks a driver is well calibrated. This is the case when in Figure 3.3 both the boxes of 'Real task capabilities' and 'Perceived task capabilities' overlap and the boxes of 'Real task demands /risks' and 'Perceived task demands / risks' overlap. Such a driver does not underestimate or overestimate her or his own capabilities and does not underestimate or overestimate the risk in the traffic situation.

The task-difficulty homeostasis model can be seen as possible functional architecture behind the second part of the proposed definition of hazard anticipation (the ability to realize/feel the risk involved in a latent hazardous and the motivation to take anticipatory actions). However, no distinction is made between an automatic mode and a controlled mode of hazard anticipation. The task-difficulty homeostasis model also does not offer a possible explanation for the first part of the presented definition of hazard anticipation (the skill to detect and recognize latent hazards and to predict how the situation can develop) as the information processing models do. Another limitation of motivational models in general is that no tests can be executed to falsify the theory (Popper, 1959). Supposed internal mechanisms regulate the behaviour of which the effects cannot be measured separately. A motivational model can explain why a certain driver starts to drive faster in a particular situation and the same model also can explain why the same driver slows down in that particular situation, if this would be the case (Michon, 1985; Ranney, 1994). This is to say every type of behaviour fits the theory and because of this, no accurate predictions can be made about how a driver will be have in certain circumstances.

3.3.3. The zero-risk model

Näätänen & Summala (1974) have developed a model on driver behaviour they themselves call a motivational model, but can be conceived as a hybrid model that has information processing elements and motivational elements. The authors assume that driving most of the times is a self-paced task where drivers proactively control the driving situation, based on their expectations of how things will develop in the near future. As long as the expectancy of risk in the near future is below a certain threshold, drivers will not experience risk. In fact, drivers normally tend to avoid any risk experiences (Näätänen & Summala, 1976). In a recent version of this model, the concept of risk is substituted for discomfort as in Fuller's task-difficulty homeostasis model (see Section 3.3.2) (Summala, 2007). Figure 3.4 shows the zero-risk model.

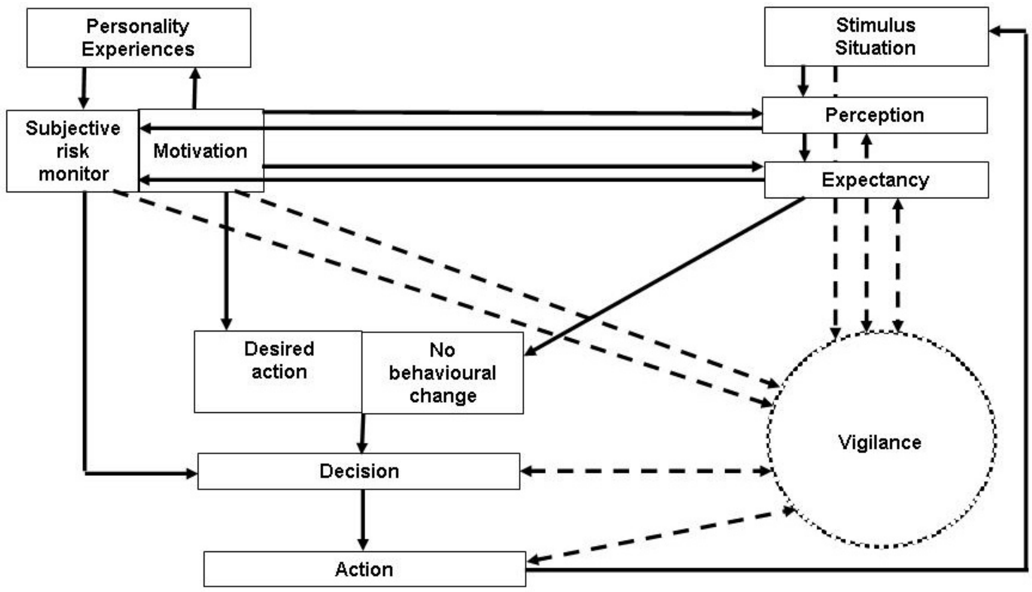

Figure 3.4. Zero-risk model (Näätänen & Summala, 1974).

In the zero-risk condition (the default condition for drivers), drivers perceive the traffic situation (Stimulus Situation → Perception). They recognize the situation (not a separate box) and make predictions about the traffic situation in the near future (Perception → Expectancy). Based on what they expect, action is considered (Expectancy → Desired action / No behavioural change) in order to keep the zero-risk condition. They then take the decision whether to take action or not. In case the decision is action, they also decide what type of action (Desired action / No behavioural change → Decision). Thereafter the selected action is executed (Decision → Action). The traffic situation changes because of this action and the loop starts all over again (Action → Stimulus Situation). In the zero risk condition when a driver does not experience fear, the boxes 'Perception' and 'Expectancy' are influenced by the motivations of the drivers. If for instance drivers are in a hurry, they accept smaller safety margins. Because of this change in risk acceptance, they 'see' no risk where they normally would and also predict no hazards where they normally would. Sometimes the traffic situation is such that the threshold of risk expectancy is transcended and drivers do experience fear or discomfort (e.g. an approaching vehicle on collision course). When this happens, the 'subjective risk monitor' is activated. Because of this, drivers get more vigilant and start to take controlled actions in order to avert a crash. How drivers exactly switch from the zero-risk mode to the risk mode remains rather vague.

In the zero-risk model of driver behaviour, both the first part of the definition of hazard anticipation (the skill to detect and recognize latent hazardous situations and to predict how these situations can develop) and the second part of the definition (the ability to realize/feel the risk involved in a latent hazardous situation and the willingness to take actions in order to reduce the feelings of fear) are addressed and placed in a functional framework. The model also makes a distinction between controlled and automatic processing of information (Shiffrin & Schneider, 1977). In contrast to the task-difficulty homeostasis model (see Section 3.3.2), self-awareness is not an explicit element in the zero-risk model. This can be considered as a weakness of the model. On the other hand it could be that the role of self-awareness in driving behaviour on the tactical level (decisions about actions to take when in traffic) (Michon, 1979) is overestimated in Fuller's task-difficulty homeostasis model. Michon (1988) takes as an example a flute player. When a flute player while playing, constantly is thinking about her or his own capabilities, her or his performance will decrease. It could be that self-awareness is rather an implicit element in risk awareness on the tactical and operational level and not so much something that is explicitly balanced with risk awareness as is depicted in the model on calibration in Figure 3.3.

Of the three models briefly presented above, the zero-risk model on driver behaviour (Näätänen & Summala, 1974; Näätänen & Summala, 1976) offers the best framework for the comprehension of hazard anticipation as it a combination of the information processing models and the motivational models. In the zero-risk model, also a distinction is made between controlled and automatic processing of information. However, how drivers precisely switch from the automatic mode to the control mode remains rather unclear. It also remains unclear what processes take place in the brain during hazard anticipation. In Section 3.6 a neuropsychological framework that was developed by Brouwer & Schmidt (2002) is presented. This framework is an elaboration of Norman & Shallice's model on willed and automatic control of behaviour (Norman & Shallice, 1986) and contains elements of the zero-risk model (Näätänen & Summala, 1974; Näätänen & Summala, 1976). This framework was originally developed to provide insight in the various causes of aberrant everyday (executive) functioning in different categories of neurological patients. For example, both patients with mild Alzheimer's disease (AD) and mild FrontoTemporal Dementia (FTD) are often unfit to drive, but the underlying mechanisms may be quite different. In AD patients slowness and the ability to divide attention when dealing with non-routine elements in the driving task appear to be the most problematic. In patients with FTD, poor monitoring of the risks involved in road and traffic situations and inhibition of on-going behaviour is more conspicuous. In this thesis, the framework is used to provide insight in the cognitive and neuropsychological processes that take place during hazard anticipation. Using this framework, possible differences between young novice drivers and older, more experienced drivers in hazard anticipation are explained (in Section 3.8). In preparation of Section 3.6, the concept of schemata is clarified in Section 3.4 and Norman & Shallice's model on willed and automatic control of behaviour is discussed in relation to hazard anticipation in Section 3.5.

3.4. Schemata, controlled behaviour and automatic behaviour

Shiffrin & Schneider (1977) distinguished *controlled* from *automatic* processing in visual search. At the controlled level, mental effort is required to perform the (visual) task. Controlled task performance is explicit, conscious, planned, but also slow and error prone. Automatic task performance is rapid, undemanding and unconscious, but is also inflexible. In the automatic mode, a task can be performed in parallel with another task that only requires automatic processing if both tasks use different input and output modalities without a substantial loss in performance on either task (Wickens, 1984). When processing information automatically, a visual stimulus generates a response, without or with very little conscious attention. In their classic study, Shiffrin & Schneider (1977) found that participants confronted with a new (visual) task first operated on the controlled level and started to process the visual information automatically after massed practicing in situations in which the same stimulus always leads to the same response. The distinction between controlled processing and automatic processing has resulted in many theories about dual-processing in different domains of psychology (see Evans, 2008 for a review). Even dual-processing of risk assessment has been proposed (Slovic et al., 2004). In the automatic mode, risk is a feeling (Loewenstein et al., 2001). It enables fast reactions to dangers. In the controlled mode, risk assessment is analytic and slow. Norman & Shallice (1986) developed a model about the role of attention in controlled and automatic behaviour. They tried to explain what for instance goes wrong in the brain when someone is on his way to visit a friend on a Sunday, but instead drives to his office when the first part of the route to the friend and the route to the office is the same. This is what Reason (1990) has called a capture slip. Norman & Shallice (1986) also wanted to offer a possible explanation why patients with frontal lobe disorders have special difficulties in performing new complex tasks and have problems with error correction.

A crucial element in the model of Norman & Shallice (1986) is the concept of *schemata* (plural of schema in Greek). According to Shallice (1988), at its lowest level a schema is a mental representation of a sequence of well learned actions. They help to do something when particular circumstances arise. When a driver approaches an intersection and the traffic light turns red, the schemata for braking in cases a traffic light turns red, will be activated and will help the driver to perform the sequence of actions. The schemata that control steering a car require visuo-spatial and manual processing systems and appropriate recognition systems. Connected low level schemas constitute high level schemata. These high level schemata are mental structures that organize our knowledge and enable us to make assumptions about something we perceive. They help us to cope with the world without too much mental effort. If we would have to think all the time about everything we do and would have to weigh all the time all possible actions before we decide to do something, we soon would be exhausted. Schemata influence our selective behaviour, as we are more likely to notice or react to things that are anticipated by our schemata. Wrong activated low-level schemata or not well-elaborated high-level schemata can lead to a misinterpretation of the situation. In police crash reports, the at fault driver that did not gave way at an intersection, often states that he stopped, looked and started to drive again and then collided with the motorcyclist he did not noticed before. These drivers claim that they were completely surprised by the motorcyclist although they had looked in the proper direction (Brown, 2002). These are the so called 'looked-but-failed-to-see' accidents (Crundall, Clarke, & Shahar, 2011). Martens (2007) assumed that in cases like this, the driver may have had wrong expectations about what could happen because not all proper low-level schemata were activated. In this particular case, the schemata activated by the driver may not have included the possibility of motorcyclists that have right of way, as the presence of a motorcyclist is a rather rare event. On the other hand, well-elaborated schemata can also help the driver to detect possible hazards. If for instance an experienced driver passes a parked bus at a bus stop, her or his schemata may help her or him to expect passengers that may cross the street just in front of the bus, although she or he has not seen a passenger (yet). At the highest level schemata are 'scripts' (Abelson, 1981; Schank & Abelson, 1977) or 'Memory Organisation Packets' (MOPs) (Schank, 1982). One such a script or MOP could be 'the driving along a motorway' script or MOP. This script is a conceptual structure of how to behave (stereotypic sequences of action) (e.g. driving at a relatively high speed in the same direction as the other vehicles) and what to expect (e.g. no passengers that cross the road, no oncoming vehicles) when driving on a motorway.

3.5. Norman & Shallice model and driving

The model of Norman & Shallice (1986) is based on two assumptions:

- *Routine actions are based on schemata*. The selection and activation of schemata for routine actions is decentralised and thus require no central control. The relatively automatic selection, activation and inhibition of low-level schemata in routine situations, is called *Contention Scheduling* (CS). Stimuli in the perceived situation trigger schemata and schemata can switch each other on and off. The latter is called lateral facilitation and inhibition of schemata. The combined automatically activated low-level schemata and the automatically inhibited low-level schemata from the selected dominant high-level schema for a particular moment in time. These high-level schemata constitute the 'default option' for action in familiar situations;
- *Non-routine actions require conscious interference in the more or less automatic process of contention scheduling*. In non-routine situations schemata have to be inhibited that were selected by the Contention Scheduler (CS) and other schemata have to be activated that were not activated by the CS. This requires conscious attention and is carried out by a system that is called the *Supervisory Attentional System* (SAS).

Figure 3.5 is a simplified representation of Norman and Shallice's model on willed and automatic control of behaviour.

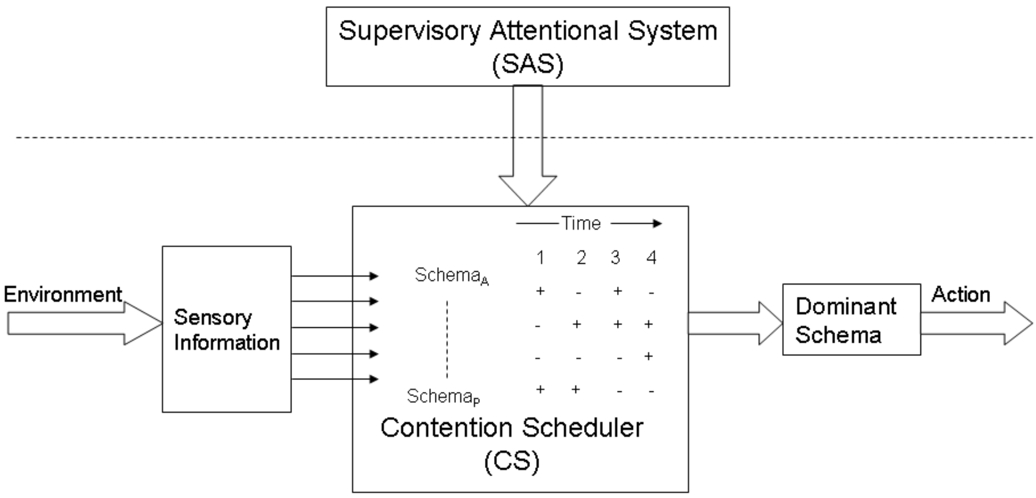

Figure 3.5. Simplified schematic representation of Norman & Shallice's model on willed and automatic control of behaviour (adapted from Norman & Shallice, 1986).

Drivers perceive the environment (the road, the (weather) conditions, other road users, the status of their vehicle (speed and direction), but also their own internal status (constitution, skills, feelings and emotions)). This is depicted in Figure 3.5 by the box 'Sensory Information'. Schemata are automatically triggered when certain conditions are met. One schema can also select or inhibit another schema (lateral facilitation and inhibition between schemata). The automatic process of the selection of schemata is called, as already is mentioned, contention scheduling (CS). In Figure 3.5 schemata that are activated at a particular moment in time (e.g. at moment 1) are marked with a '+', those that are inhibited at that particular moment in time are marked with a '-'. The selected lower schemata constitute one overarching dominant schema for that moment in time. The selected dominant schema structures what in this case the driver perceives, recognizes and expects. This enables the performance of certain actions.

In contrast to the CS, the SAS reflects explicit thoughts about the environment and internal states of in this case the driver. It is involved in the genesis of willed actions and required situations when the outcome of the CS is unsatisfactory. According to Shallice (1988), the SAS is invoked when coping with new situations, when (deliberate) decisions have to be made between various options, in overcoming temptation or in dealing with danger. The SAS operates indirectly by modulating activation within the CS. This is to say that the SAS activates schemata (turn a - into a +) or inhibits schemata (turn a + into a -) within the CS. This consciously turning off and on of schemata requires attention. For Norman & Shallice (1986) attention is only associated with top-down activation and inhibition of schemata, but not with the selection of the dominant schema.

A limitation Norman & Shallice's model on willed and automatic control of behaviour is that the effects of motivation and emotions on the functioning of the SAS are mentioned, but not explained. It also remains unclear how the dominant schema at a particular moment in time are selected and how the SAS gets activated. A third limitation is the rather limited view on attention. Attention is only the product of the SAS that manifests itself in the top-down modulation of schema activation and inhibition.

3.6. An adapted framework for the driving task

Based on Norman & Shallice's model on willed and automatic control of behaviour (1986), Brouwer & Schmidt (2002) have proposed a framework in which the mentioned limitations are met. Besides Norman & Shallice's model, Brouwer & Schmidt made use of elements of the zero risk model on driving behaviour (Näätänen & Summala, 1974) (see for a description Section 3.3.3). A description of the framework is also presented in Koerts, Leenders, & Brouwer (2009). It is called a framework and not a model because it is composed of general claims about cognition and it is insufficiently specified in order to derive falsifiable predictions from it in order to validate a theory (Popper, 1959). Here the framework is used to describe the possible process of hazard anticipation in young novice drivers and older, more experienced drivers. Figure 3.6 presents the framework.

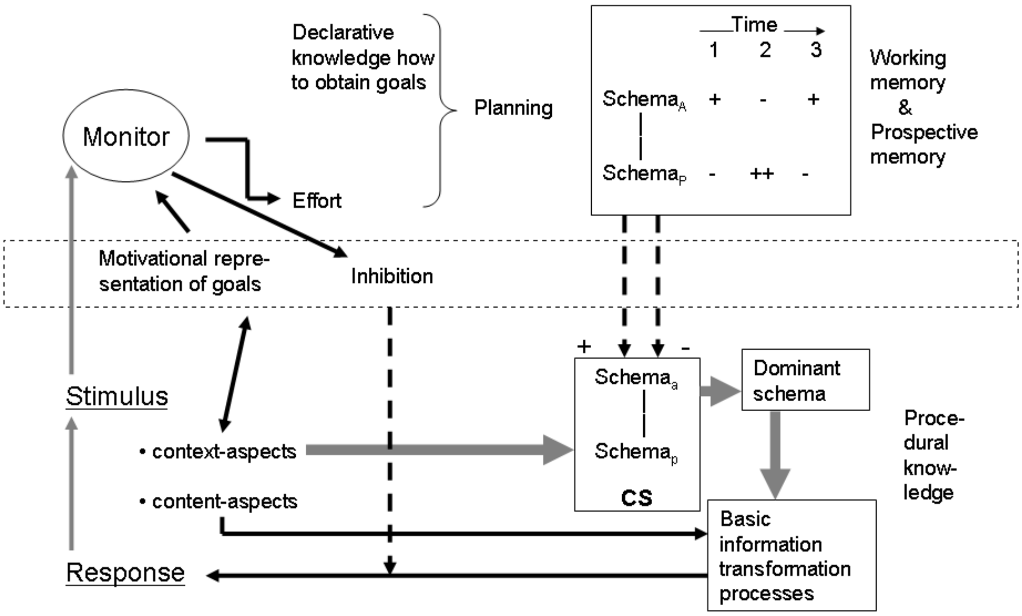

Figure 3.6. Schematic representation of automatic and controlled behaviour (adapted from Brouwer & Schmidt, 2002).

The bottom half of Figure 3.6 describes automatic processing in routine situations. In contrast to the model of Norman & Shallice (1986) the sensory information is subdivided into context aspects and content aspects. What is context and what is content is not a characteristic of the stimulus itself, but depends on the mapping between stimulus characteristics and schemata. As in Norman & Shallice's model, the basic assumption is that all behaviour is caused by the unfolding of schemata in interaction with external and internal stimuli. When a driver approaches an intersection, the perceived intersection (external) and the awareness that she or he is driving (internal) are the context and the perceived elements in the traffic scene of the intersection (e.g. moving vehicles) constitute the content. As in the model of Norman & Shallice (1986) schemata are activated and inhibited in the CS. The perceived information elicits triggers that energize schemata (the processes of contention scheduling) and schemata can also activate and inhibit each other (lateral facilitation and inhibition between schemata). This results in the selection of the dominant schema for a particular moment in time. The dominant schema, if appropriate, helps the driver to 'read' the traffic situation and to predict and defuse the hazard, because it specifies where and when to look and what to do then. These interpretations based on the dominant schema and the actual information about perceived own speed and direction and the perceived speed and direction of other road users, are processed in order to select a response (e.g. braking). The box 'basic information transformation processes' in Figure 3.6 depict this processing. The response will cause an altered traffic situation. This is a new stimulus and the loop of contention scheduling and the lateral facilitation and inhibition between schemata starts all over again. The described process in the bottom half of Figure 3.6 is what Shiffrin & Schneider (1977) called automatic.

However, when the situation is new, or when a decision has to be made between several response options, or temptation has to be overcome[7], or when the situation is dangerous, reliance on contention scheduling alone is no longer sufficient and information has to be processed in a controlled manner (Shallice, 1988). How do drivers know/feel that contention scheduling alone, in which no activation of the SAS is required, will for instance lead to a dangerous situation and that the SAS has to be activated? According to Menon & Uddin (2010), two regions of the brain play an important role in the bottom-up detection (that is to say from the CS) of salient events on one hand and the activation of what they call the Central Executive Network (CEN) and the Default Mode Network (DMN) in the SAS on the other hand. This two regions that are important in the detection of salient events, are the insula and the anterior cingulate cortex. Together they form a Salience Network (SN). Especially the insula responds strongly to deviant stimuli embedded in a stream of continuous stimuli. The region in the PFC that has a dominant role in the CEN is the DLPFC, which is involved in planning and active maintenance of information in working memory and for judgement and decision-making in the context of goal directed behaviour. The region in the PFC that has a dominant role in the DMN is the VMPFC. The VMPFC is associated with social cognitive processes related to self and others (e.g. Bechara et al., 1997; Damasio, Everitt, & Bishop, 1996). Weighing of risks is an important function of the DMN.

The top half of Figure 3.6 represents an elaborated version of the SAS and comprises both the CEN and the DMN. The monitor depicted in the upper left corner of Figure 3.6 can be interpreted as the SN. This monitor has a similar function as the monitor in the zero-risk model on driving behaviour of Näätänen & Summala (1974). The monitor that switches on the SAS not only reacts on the salient bottom-up information (e.g. how dangerous the traffic situation is), but also takes into account the motivations and emotions of the driver. If for instance, a driver is in a hurry or the driver has extra motives for driving (e.g. to impress her or his friends by driving fast or the

[7] For instance the temptation of a sure immediate reward (the feeling of pleasure when driving fast) opposed to an uncertain long term reward (e.g. when you don't speed the likelihood to get involved in a crash is smaller).

feeling of pleasure, a driver may experience when driving fast) (see the Sections 2.3.1, 2.3.2 and 2.4.4), the monitor will not switch on the SAS, even when the SN has recognized salient events. On the other hand, when a driver suffers from driving phobia, the monitor will switch on the SAS even when there is no objective danger. The goal a driver may have is to reach her or his destination in time in a comfortable and safe manner. If a situation is sensed that threatens the realisation of this goal (e.g. the possibilities of a crash), on-going behaviour must be interrupted. This process is depicted in Figure 3.6 by the arrow from the monitor to 'inhibition' and the dotted arrow from 'inhibition' to the arrow from 'Basic information transformation processes' to 'Response'. The next thing is to select an action that averts the threat. This requires a representation of the situation. Ultimately, this is a dominant schema that differs from the automatically selected dominant schema by the CS. Suppose that a driver is approaching an intersection and the traffic light turns yellow, this situation automatically triggers the default schema 'decelerate in order to stop before the traffic light'. Now also suppose that the driver is in a hurry. The yellow traffic light now is a salient event that interrupts her or his goal (to arriving somewhere in time). The monitor inhibits the on-going behavioural intentions (actions for decelerating) and switches on the SAS. The SAS intervenes in the CS and the default dominant schema 'decelerate in order to stop before the traffic light' is changed into the dominant schema 'accelerate in order to pass the intersection before the traffic light turns red'. The interference of the SAS in the CS is depicted in Figure 3.6 by the two vertical dotted arrows between the box in SAS that depicts the representation of the CS in SAS and the real CS. The framework on automatic and controlled behaviour of Brouwer & Schmidt (2002) also sketches how the SAS develops the attentional interferences for the CS. Once the monitor triggers the SAS and the ongoing behaviour is inhibited, drivers retrieve information from declarative memory about how the interruption of their goals (e.g. not having a crash) can be prevented. This declarative knowledge from long-term memory has to be adapted and scheduled in working memory and prospective memory. This scheduling and planning is depicted in Figure 3.6 by the box that looks the same as the box that depicts the CS in Figure 3.5. The box in the top half of Figure 3.6 that looks like the CS is not the CS itself but a mental representation of the CS by the driver of the schemata that have to be inhibited or activated in the real CS. This planning and scheduling takes effort and the driver must be willing to do so. If for instance a driver is tired, she or he will not be able to realize the required effort. Although there are two extremes of action regulation: automatic action regulation (depicted in the bottom half of Figure 3.6) and (consciously) controlled action regulation (depicted in the top half of Figure 3.6), Brouwer & Schmidt (2002) stress that action regulation is not an all or nothing matter. It is assumed that in all activities there is a mix of automatic and controlled regulation. However, for experienced drivers the part in the mix of automatic regulation is supposed to be larger than for novice drivers.

3.7. The framework, attention and driving

In his book 'The Principles of Psychology' (1890), William James wrote: "Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration of consciousness, are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called *distraction*, and *Zerstreutheit* in German." Although according to James everyone seems to know what attention is, many different concepts of attention have been developed. Eysenck & Keane (1995) noted with regard to the scientific definitions of attention that a concept that is used to explain everything will turn out to explain nothing. Different cognitive functions have been distinguished that are linked to different areas of the brain which all are labelled attention. For example, Posner & Petersen (1990) made a distinction between (a) attention as orienting to sensory events; (b) attention as detecting signals for focal (conscious) processing, and (c) attention as maintaining a vigilant or alert state. According to Posner & Petersen for each of these three modes of attention, different circuits in the brain are active. In addition, the cognitive tests to measure for instance selective attention, focused attention and divided attention differ too (e.g. the Stroop-test and complex reaction-time tests). Brouwer (2002) noted a discrepancy between the commonly accepted important role of (visual) attention in driving, the fitness to drive of persons with mild dementia and the scores of these persons on tests such as the Stroop-test. These persons usually score far outside the normal range on these tests, but occasionally official driving experts of the Dutch driving licence authority (CBR) assess these persons as perfectly safe drivers, even in complex driving situations during test drives. Brouwer (2002) also noted that if driving demands a lot of attention how can it be that there are examples of somnambulism where drives drove long distances while being asleep (sleep driving instead of sleepwalking) and not causing an accident. Brouwer (2002), like Norman & Shallice (1986) assumes that attention is an inherent part of the processes involving the activation and inhibition of anticipatory mental representations, i.e. schemata. In both the model of Norman & Shallice (1986) and in the framework of Brouwer & Schmidt (2002), attention is seen as the immediate cause of task performance. However, unlike Norman & Shallice (1986), Brouwer (2002) does not consider attention as a prerogative of the SAS only. Triggered by context and content aspects schemata unfold as patterns of selective attention. Attention both is present in bottom-up processes in the contention scheduler and in top-down processes. It is possible to be attentive as a driver and to anticipate hazards without conscious awareness of these hazards. In this way in familiar driving situations, even if they are complex, persons with mild dementia can cope with these situations and anticipate the hazards in these situations. In Section 4.1.6 a model of attention and eye movements is presented in which four attentional processes are distinguished. These processes are: processing information in working memory, top-down sensitivity control, competitive selection and automatic bottom-up filtering of salient stimuli. This model explains how anticipatory eye movements are possible without conscious awareness of hazards. This is to say possible hazards that are not processed in working memory.

Groeger (2000) has described how schemata and attention could work in driving. These descriptions are based on a theory about the working of the SAS that was developed by Stuss et al. (1995). According to Stuss et al. (1995) the SAS can not only energize and inhibit schemata in the CS, the SAS can also make adjustments in contention scheduling, monitor schema activity and carry out logical operations with regard to the connection between activated and inhibited schemata at a particular moment in time (i.e. if this schema is activated then that schema has to be inhibited). By doing so it can *sustain* attention, *concentrate* attention, *share* attention between different tasks, s*uppress* the execution of task elicited by the CS, *switch* attention, *prepare* for attention in case of an intended action in the future (prospective memory) and *set* a script (e.g. driving along a motorway). In this thesis as is assumed by Brouwer (2002), attention is inextricably connected with processes around schema selection and attention is not limited to the functioning of the SAS only. For Norman & Shallice (1986) and Stuss et al. (1995) attention can only be top-down. This however does not alter the here below presented examples about schemata, attention and driving Groeger (2000) has made based on the model developed by Stuss et al. (1995). The examples are:

- A driver *sustains* attention by keeping the schemata activated for events that occur only occasionally. Hazard anticipation requires the permanent activation of schemata for rare events. Occasionally drivers on the left lane of a motorway (in countries with right-hand traffic) at the very last moment realize that they have to take the exit in order to leave the motorway. These drivers may have been so busy with overtaking other vehicles that they have forgotten to think about to exit the motorway in time. Sometimes these drivers suddenly may move to the right at the very last moment without proper visual search, in order not to miss the exit. When you as a driver on the right lane of the motorway who continues straight, has not sustained the schemata that recognizes and predicts this possibility, the car that moves to the left at the very last moment in order to exit the motorway, will surprise you. This is an example of an overt latent hazard;

- When a driver is on a busy stretch of motorway and drives rather fast, she or he has to *concentrate* carefully on what the traffic ahead is doing (e.g. weaving between lanes or braking);
- If the driver is talking to a passenger she or he has to *share* her or his attention between the driving task and the conversation task;
- When a driver is talking to a passenger she or he has to *suppress* her or his inclination to make eye-contact with the passenger as she or he has to keep her or his eyes on the road;
- The driver has to monitor the traffic situation ahead, but also the traffic situation behind. She or he *switches* her or his attention from the traffic situation ahead to the traffic situation behind by looking in the rear-view mirror;
- All the time the driver is driving on the motorway she or he has to be *prepared* to take actions when she or he sees the sign of the required motorway exit (prospective memory). This being prepared to leave the motorway also means that when approaching the exit the driver has to suppress her or his inclination to overtake other vehicles in time;
- When staring to drive on the motorway the driver has to *set* the 'driving along a motorway' script in order to enable her or him to select the proper underlying schemata in certain situations.

3.8. The framework and the supposed differences in hazard anticipation between young novice drivers and older, more experienced drivers

Figure 3.7 shows the framework for novice drivers and Figure 3.8 shows the framework for experienced drivers.

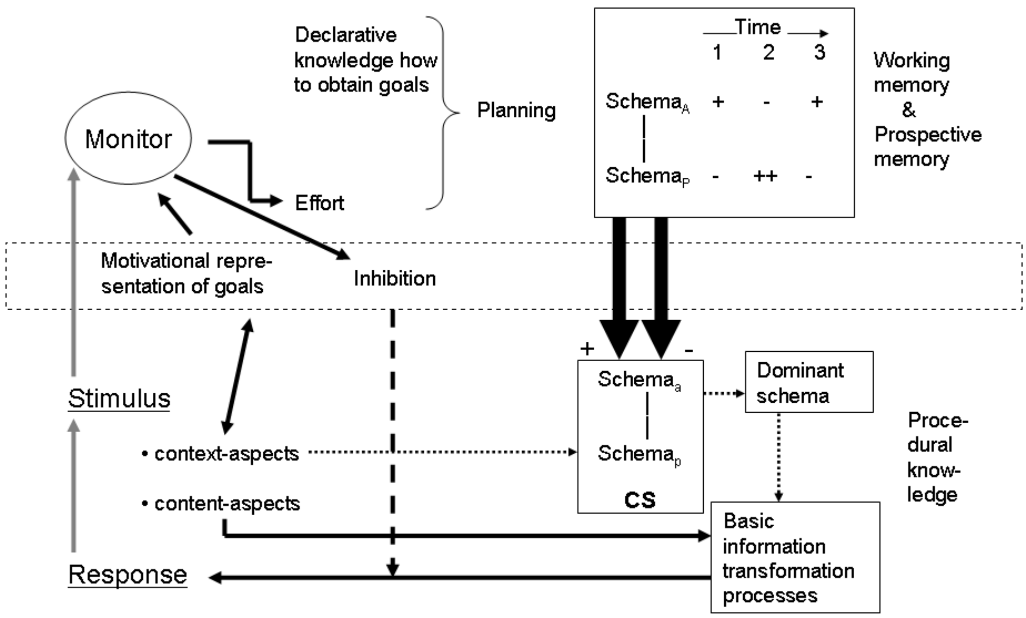

Figure 3.7. Schematic representation of automatic and controlled behaviour of novice drivers (adapted from Brouwer & Schmidt, 2002).

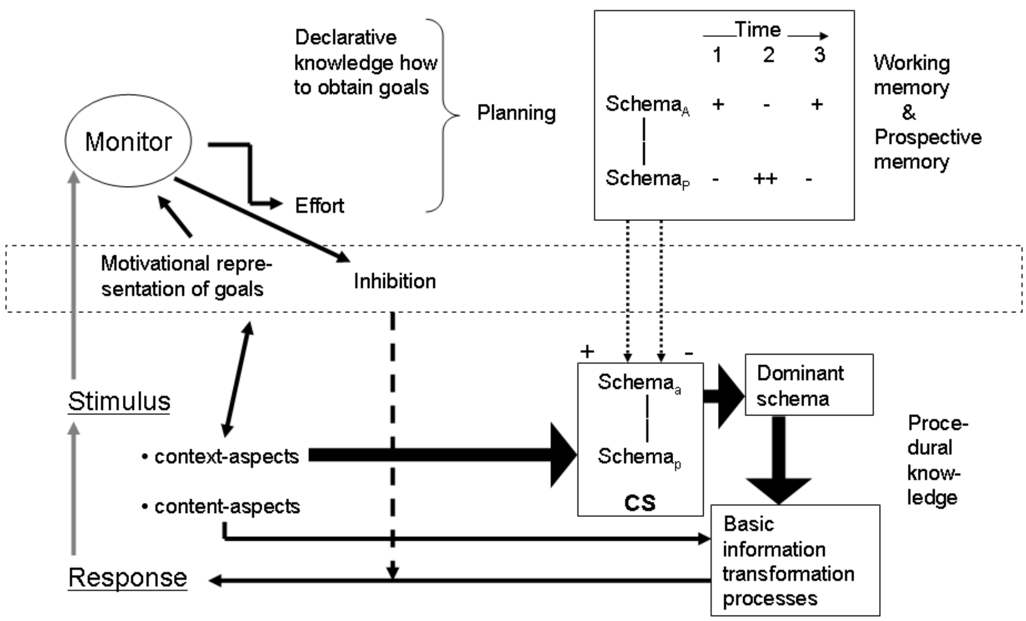

Figure 3.8. Schematic representation of automatic and controlled behaviour of experienced drivers (adapted from Brouwer & Schmidt, 2002).

Based on the framework, the processes hazard anticipation are sketched for respectively experienced drivers, novice drivers with no hazard anticipation skills and novice drivers with some hazard anticipation skills in the Sections

3.7.1, 3.7.2 and 3.7.3. This is done for the scenario in which a driver wants to turn left at an intersection, while an opposing lorry is waiting to make a left turn (see Figure 3.9). The driver of the car that wants to turn left cannot see possible oncoming traffic from the direction of the question mark because the lorry blocks the view.

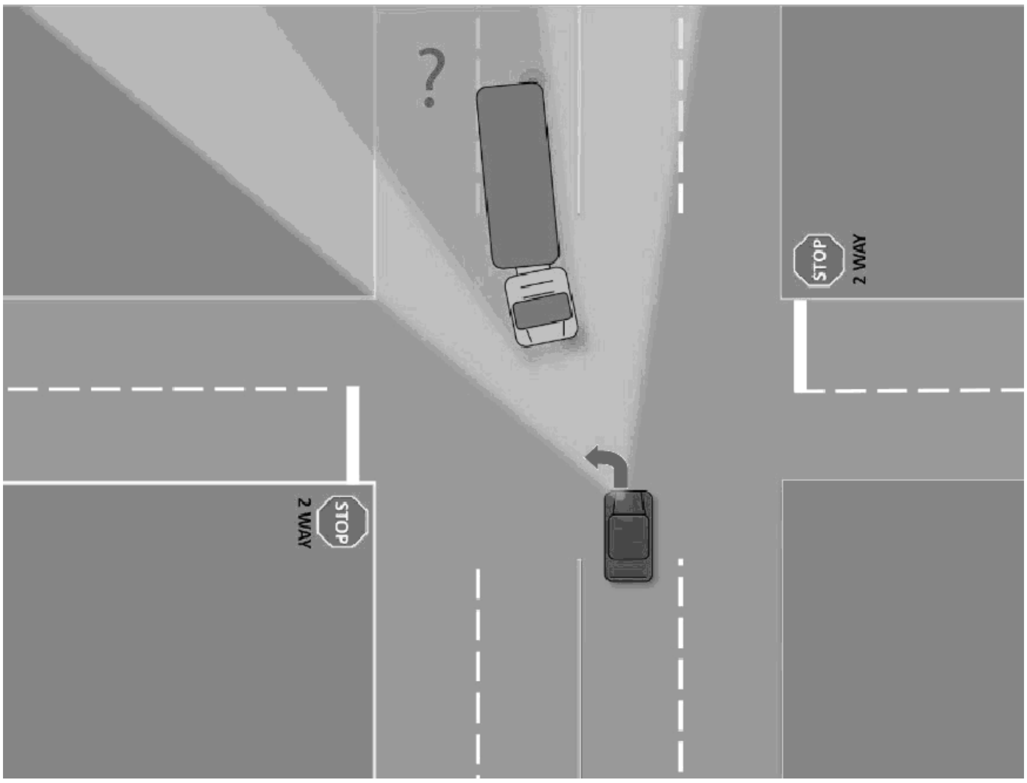

Figure 3.9. The driver of the car wants to turn left, but cannot see possible oncoming traffic because the lorry blocks the view.

3.8.1. Hazard anticipation of an experienced driver

The experienced driver perceives the traffic situation (both the context aspects and the content aspects) and automatically activates the dominant schema 'turning left at an intersection'. Because of her or his selected elaborated dominant schema 'turning left at an intersection' (developed by experience), this driver immediately 'sees' that the opposing lorry that waits to turn left, blocks her or his view on possible oncoming traffic in the lane to the right of the lorry. This 'seeing' of a threat (oncoming traffic that she or he cannot see) is not reached by explicit logical reasoning, but is an immediate gut feeling for the particular threat that the experienced driver has developed. It is the gist of the situation that she or he perceives immediately. A comparison with chess players may provide insight in how experienced drivers could perceive a latent hazard. Master chess players appeared not to consider more moves and most of the times even considered fewer moves than weak novice chess players. Master chess player also appeared not to be more intelligent (measured by an intelligence test) than weak novice chess players. However, after just a glance of 5 s on a complex configuration of pieces on a chessboard, master chess players were much better than novice chess players in reconstructing that configuration by heart. This was only the case when the configuration glanced at could have been an existing configuration in a game. When the pieces were randomly placed, masters even performed slightly worse than beginners (De Groot, 1965, 1966) (see also Section 2.3.3). Another well-known fact is that the difference in performance between master chess players and novice chess players gets more pronounced the more the game is played under time pressure. It could be that chess experts have developed schemata for the solution of many chess problems just as experienced drivers have developed many schemata that allow for a quick and holistic appreciation of the situation in order to anticipate latent hazards. The process of seeing/feeling the latent hazard by experienced drivers is depicted by the three thick arrows in the bottom half of Figure 3.8. Because of this sensitivity for latent hazards, the experienced driver will look to the right (right of the opposing lorry) while slowly turning left in order to detect an oncoming vehicle as early as possible. By performing these anticipatory actions, he or she will avert a collision if oncoming traffic really shows up.

3.8.2. Hazard anticipation of a novice driver not activating the SAS

A young novice driver may just as the experienced driver, drive in 'the automatic mode'. As her or his dominant schema selected by the CS of 'turning left at an intersection' is simple and does not include the possibility of oncoming traffic that is hidden from view, this driver does not turn slowly and does not look into the lane to the right of the lorry in order to detect hidden oncoming traffic. If oncoming traffic does show up, this driver will detect the hazard too late and the result will be a crash. Although the lorry blocks her or his view on possible oncoming traffic, this is not sensed as a deviant situation that requires attention and the monitor does not activate the SAS. The still deficient functioning of the CS in novice drivers is depicted by the three dotted arrows in the bottom half of Figure 3.7.

Once having experienced such a critical event that hopefully has resulted in only a minor crash or even better a near crash, the novice driver may have learned from this threatening situation. If the novice driver does not attribute the cause of the crash to the other driver, i.e. that the novice driver does not think that she or he is not to blame and that the crash was caused because the other driver behaved unsafe, the novice driver may have learned from this critical event. The next time this novice driver encounters a similar situation she or he may probably not automatically anticipate the covert latent hazard as an experienced driver (described in Section 3.8.1), but may feel so uncomfortable in this situation that she or he this time may switch on SAS as is described in the next section.

3.8.3. Hazard anticipation of a novice driver activating the SAS

A perhaps somewhat older and more cautious, but still inexperienced novice driver with a low threshold to activate the monitor, also drives in 'the automatic mode'. Just as was the case with the more confident young novice driver, the automatically selected dominant schema of this novice driver does not include the possibility of oncoming traffic that is hidden from view. However, in this case the novice driver has a vague notion that she or he is not fully in control of the situation because of this lorry. This vague notion bubbling in the Salience Network (SN) (Menon & Uddin, 2010) now switches on the SAS. The novice driver stops before she or he turns (inhibition of on-going task performance) and retrieves knowledge about rules of the road and what his driving instructor has told her or him about the dangers of negotiating an intersection from long term memory. She or he now in her or his working memory explicitly deduces from the perceived situation and her or his retrieved declarative knowledge that oncoming traffic may suddenly appear in the lane to the right of the lorry. The SAS finally reschedules the activated and inhibited lower schemata in the CS in such a way that the selected dominant schema of turning left at an intersection incorporates the possibility of oncoming traffic that is hidden from view. This process is depicted in Figure 3.7 by the two thick black arrows from the box with the representation in the SAS of the CS in the top half of the figure to the real CS in the bottom half of the figure. The cautious novice driver now proceeds in the same way as the experienced driver. This is to say that she or he will turn slowly while searching for oncoming traffic and will not have a crash when oncoming traffic does appear.

Each time this driver encounters similar situations the schemata will elaborate and will get more refined. Ultimately, this driver will have learned to anticipate this type of a covert latent hazard automatically as is described in Section 3.8.1 for experienced drivers.

3.9. Some preliminary evidence in support of the framework

Measurement of brain activity while driving in the real world accurate enough to determine which brain regions are active when performing certain tasks in traffic is not possible. These activities of brain areas can be measured when a driver is 'driving' while she or he is situated in an apparatus for functional Magnetic Resonance Imaging (fMRI), or even better in an apparatus for MagnetoEncephaloGraphy (MEG). MEG is better because MEG has a higher temporal resolution than fMRI and task demands in traffic can change within milliseconds. Driving simulation while situated in an apparatus for fMRI or MEG is very basic. In an apparatus for fMRI drivers have to lie down and cannot move their head. As they cannot move their head, they can only watch projected (animated) video clips, taken from the driver's perspective of what is happening straight ahead. Only with their fingertips they can execute actions such accelerating, braking and steering, but they cannot steer with a steering wheel or use pedals (e.g. Spiers & Maguire, 2007). In an apparatus for MEG drivers can sit, use a steering wheel and use the pedals, but they cannot freely move their head (Fort et al., 2010). A small number of neuro-imaging studies have used driving simulation to examine brain activity during driving (Bowyer et al., 2009; Calhoun et al., 2002; Callan et al., 2009; Fort et al., 2010; Horikawa et al., 2005; Mader et al., 2009; Spiers & Maguire, 2007). In these studies with mostly small samples, no distinction was made between young novice drivers and older, more experienced drivers. In fact, in all the mentioned studies the participants were experienced drivers. While driving in normal circumstances (i.e. there are no immediate or latent hazards), the mentioned studies indicate, that participants showed more activity during driving than during rest periods in the parieto-occipital cortices (play a role in the accurately locating of visual objects). Increased activity while driving was also found in the cerebellum (plays a role in motor control and the timing of actions) and cortical regions associated with perception and motor control, such as the parietal and sensorimotor cortex. However, no increased activity was found in the PFC. No activity in the PFC is in support of the existence of a CS as the default option for driving for experienced drivers. When confronted with imminent hazards that required instant action such as swerving, the experienced drivers also showed heightened activity in the insula, the anterior circulate cortex (the insula and the anterior circulate cortex play a role in bottom-up salience detection (Menon & Uddin, 2010)) and the posterior circulate cortex (presumably plays a role in understanding how other people act). However, for experienced drivers even in circumstances with imminent hazards, no increased activity was found in the PFC (Spiers & Maguire, 2007). This also is in support of the existence of a CS and is also in support of what is described in Section 3.8.1 about how based on the framework experienced drivers may anticipate familiar hazards without involvement of SAS. Only one neuroimaging study could be found about brain activities during simulated driving in situation with a latent hazard (Callan et al., 2009). Callan et al. (2009) conducted an experiment in which fourteen drivers between 21-46 years of age and with at least 3 years of driving experience, watched an animated clip from the driver's perspective of the situation that is depicted in Figure 3.9. In this scenario, the driver turns left at an intersection while, the view on oncoming traffic is blocked by an opposing lorry. As this experiment was conducted in Japan, which has left-hand traffic, the driver in the clip turned right. The experiment here is described for right-hand traffic. The participants watched this clip while lying in an apparatus for functional Magnetic Resonance Imaging (fMRI). Participants had to imagine that they were the driver. The clip stopped and the screen turned black just at the moment where the driver in the clip is about to turn left. Participants could indicate with their left hand it they would move forward in this situation (make the turn) or not. Participants viewed versions of the clip with the opposing lorry and without the opposing lorry and no oncoming traffic. Data about the decisions of the participants were not provided in the study. However, another group of participants (outside the scanner) indicated that they felt more anxiety in the situation where the view was blocked by the lorry than in the situation the view was not blocked by the lorry. Significantly greater brain activity was found in the anterior circulate cortex, the insula, the amygdala, the inferior parietal lobule, the hippocampus and the caudate, but again not in the PFC. These results confirm what is described in Section 3.8.1, about how, based on the framework, experienced drivers may anticipate known latent hazards. The SN (salience network) is active in the situation of the blocked view (i.e. increased activity in particular in the insula), but the SAS is not switched on. The risk is probably immediately subconsciously felt, after which the CS automatically selects the elaborate dominant schema. This enabled recognition and anticipation of the latent hazard without influence of the SAS.

The involvement of the PFC and in particular the DLPFC when driving, was studied by Beeli et al. (2008). In this study male drivers between 20 and 30 years of age (mean age was 24.7) drove in a simulator while the DLPFC was externally activated or inhibited by a 'transcranial Direct Current

Stimulation' device (tDCS). This device contains small electrodes that deliver directly constant, low current to a particular brain area. In half of the group, the right DLPFC was activated and inhibited during the drive and in half of the group, the left DLPFC was activated and inhibited during the drive. The authors mention that participants could vaguely notice that the tDCS was switched on, but could not discriminate whether the tDCS was set on activation or set on inhibition. Before and after the simulator drive in which the tDCS was switched on (part of the time activating and part of the time deactivating), participants drove the same scenario. In the pre-drive, they were equipped with the tDCS that was switched off and during the post-drive they drove without the device on their head. No differences were found between activation and deactivation of the right DLPFC and the left DLPFC. When the DLPFC (either the right or the left) was activated, participants kept a significantly larger distance between the own car and the lead vehicle and made significantly less speed violations in the built-up areas, compared to the situations where the tDCS was set on inhibition or was switched off. Moreover, marginal significant differences were found in average speed and engine rpm when the tDCS was activating instead of inhibiting or switched off. There were no significant differences between the inhibiting situation and the switched off situation. The authors indicate that given the size of the electrode, other regions of the PFC may have been stimulated besides the DLPFC, in particular the VMPFC or the OFC. Whether other regions were stimulated or not, this study indicates that, an active PFC makes drivers more cautious in normal driving conditions. The authors do not mention if there were particular hazardous situations in the scenario.

As presumably, experienced drivers drive more often in the automatic mode than in the control mode, compared to novice drivers, also in situations with familiar hazards, it is likely that a secondary task not related to the driving task will affect the hazard anticipation skills of novice drivers more than of experienced drivers. In a study conducted by Baumann et al. (2008) experienced drives drove in a simulator. The simulator drive comprised hazardous situations that were hardly predictable. One of the scenarios was a blocked road because of road constructions in a curve with dense vegetation on both sides of the road and no sign before the curve that warned for these road constructions. The simulator drive also comprised hazardous situations that were predictable (e.g. the same situation with road works in a blind curve, but now with a warning sign before the curve). Some participants drove without a secondary task, some participants drove while performing a monitoring task (reacting as soon as possible when a particular sound was heard) and some participants drove while performing a running memory task (mentioning the last 3 letters heard every time the participant heard a new letter in a stream of letters). Baumann et al. (2008) hypothesised that the Time To Collision (TTC) at the moment the participants first released the throttle after the road block became visible, would be significantly shorter in the situations that were also unpredictable for experienced drivers, as the SAS would be more active in the unpredictable hazardous situation than in the predictable hazardous situation. This hypothesises was confirmed. Baumann et al. (2008) also hypothesised that a secondary task would affect the TTC more in the unpredictable hazardous situations than in the predictable hazardous situations and that the running memory task would deteriorate task performance more than the monitoring task, as the former would charge working memory (in the SAS) more than the latter. This hypothesis was also confirmed. The results indicate that even experienced drives do not function entirely on the CS when confronted with familiar latent hazards.

McKenna & Crick (1997) have developed a hazard perception task in which participants watched video clips from the driver's perspective in which overt latent hazards materialized, but they developed not so far that they resulted in a crash. Participants had to press a button as soon as they had detected the first signs of a developing hazard. The dependent variables were reaction time latency (the time between the onset of a developing hazard marked by the computer and the moment the participant pressed the button) and missed hazards. Experienced drivers had significantly shorter reaction times and missed fewer hazards than novice drivers, but in combination with a simple secondary task (production of a random sequence of letters) the performance of both groups dropped significantly. There was no difference in secondary task performance between novice drivers and experienced drivers. In combination with the secondary task, the decline in performance on the hazard perception task was stronger for experienced drivers than for novice drivers and task performance on hazard perception got almost equally bad for both groups (McKenna & Farrand, 1999). The results of this study would imply that in contrast of what is assumed by the presented framework, that there is no difference in the functioning of the CS in experienced drivers and novice drivers with regard to hazard perception and that hazard perception is mainly a question of the SAS. However, Bailly, Bellet & Goupil (2003) found that the decline in task performance on their hazard perception task in combination with a demanding secondary task (mental arithmetic) was stronger for novice drivers than for experienced drivers (although the difference was not significant). Both, in the condition without a secondary task and in the condition with the secondary task, the performances of experienced drivers were significantly better than the performances of novice drivers. In the hazard perception task of Bailly et al. (2003) participants watched video clips from the driver's perspective. At the end of the clip, the screen turned black and the next moment the last shot of the clip reappeared on the screen (as a photograph). In this photograph of the last moment of the video clip, something relevant for road safety was altered (e.g. a traffic light that was visible in the distance at the last moment of the clip and no traffic light in the photograph of that last moment). Experienced drivers detected significantly more often alterations than novice drivers did, both in the single task condition and in the dual task condition. The results of the study of Bailly et al. (2003) could imply that that the activated schemata of experienced drivers were more elaborated and fine-tuned than the schemata of novice drivers.

No studies could be found about the role of motivation and emotion in hazard anticipation. These independent variables are difficult to manipulate in laboratory conditions (e.g. Mesken, 2006). The results of the studies presented in this section suggest that there is a CS active when anticipating latent hazards (Baumann et al., 2008; Bowyer et al., 2009; Calhoun et al., 2002; Callan et al., 2009; Fort et al., 2010; Horikawa et al., 2005; Mader et al., 2009; Spiers & Maguire, 2007). The reviewed literature also suggests that there is a SAS when anticipating unfamiliar latent hazards (Bailly et al., 2003; Baumann et al., 2008; Beeli et al., 2008; McKenna & Farrand, 1999). The role of the SAS in hazard anticipation is probably larger for experienced drivers than suggested in Section 3.8.1 (Bailly et al., 2003; McKenna & Farrand, 1999). This is to say that even for experienced drivers; familiar situations with latent hazards may require some conscious attention.

3.10. Assumptions about the acquisition of hazard anticipation skills

In the study of Shiffrin & Schneider (1977) that was already referred to in Section 3.4, about controlled and automatic processing of information in a visual search task, participants started to process information automatically only after mass practicing. Skills tend to improve in accordance with the power-law of learning (Newell & Rosenbloom, 1981). This means that when it takes for instance 100 trials to half the number of errors in task performance, it will take N times N-1 trials (i.e. 9900) to half the number of errors again. According to Anderson (1982) learners go through three stages while practising (see also Section 2.4.3). The first stage is the declarative stage. In this stage, learners commit to memory a set of facts relevant to the skill. For instance, when learning to shift gears they define explicitly to themselves what to do step by step. This can be: "The location of the first gear is up right. To get the car in the first gear, I first push with my foot on the clutch pedal and then move the stick with my hand in the position of the first gear. After that I slowly release the clutch and meanwhile slowly push on the accelerator with my other foot." This information is rehearsed and spoken aloud or in silence when the task is performed. In this stage, the SAS is predominantly active and the CS is predominantly inactive. In the second stage (the knowledge compilation stage) errors in the initial understanding are gradually detected and eliminated. In this stage, gear shifting gets smoother. The connections between the steps also become stronger and each step in the procedure no longer has to be recalled explicitly when performing the skill. The schema 'first gear' contains all the separate operations. However, attention still is required and the task cannot be executed error free in combination with another task (e.g. talking to a passenger). In this stage, both the SAS and the CS are active. In the third stage (the procedural stage) task performance is automatic and activation of the SAS is only necessary when the monitor signals that the situation is new, when decision making is required, in dealing with danger and when temptation has to be overcome (Shallice, 1988). The decline in crash rate after licensing with culminating experience and age that is presented in Figure 1.2. The power functions of the curves of the trend lines in Figure 1.2 would suggest that learning to drive (after licensing) is in accordance to the power-law of learning.

The implication of the studies and theories about skill acquisition is that expertise comes with a lot of practice. Latent hazards only rarely develop into acute hazards and of the acute hazards only a few will result in a crash. It would take years to become an expert in hazard anticipation, if hazard anticipation is acquired in the same way as for instance gear shifting. From an evolutionary point of view, it would be disadvantageous if it takes an enormous amount of practicing in order to learn from threatening situations. Could it be that we learn faster when situations have serious consequences than when situations have no serious consequences? Groeger (2000, p.128-131) describes an experiment in which drivers drove along a fixed route while physiological measures were taken (Skin Conductance Response (SCR) and heart rate). The drivers also had to report the danger and the difficulty at particular moments during their drive. There was a significant correlation between the arousal measured (SCR and heart rate) and the danger experienced by the drivers. A week after the drive the drivers were asked what they could remember of their test drive. The situations that were originally rated as dangerous were also the moments that were remembered a week later. The moments that had not induced arousal were not remembered. Of the situations that participants could recall, details such as the colour of the car that caused the hazard were not remembered, but the location of that car and the manoeuvre it made, were. Chapman & Groeger (2004) have described experiments where participants had to rate the risk while they watched video clips from the driver's perspective at moments when the driver in the video negotiated a junction. Directly after this session the participants had to recognize the situations they had rated in videos that were mixed with very similar looking situations they had not seen before. Although the authors did not find a simple overall relationship between subjective risk ratings and recognition sensitivity, they found enhanced recognition for the riskier situations, whereas recognition of the less dangerous situations was impaired. In an experiment conducted by Koustanaï et al. (2008), participants that drove in a simulator were confronted with predictable hazardous behaviour and almost unpredictable behaviour of other road users. When experienced drivers were confronted with unexpected behaviour of another road user and had a crash to their surprise, they had learned from this situation. This is to say, most of the times they could avoid a crash three drives of ten minutes later in a similar situation, but in an environment in which this behaviour of that other road user was more predictable. On the other hand, when experienced drivers were first confronted with dangerous behaviour of another road user that was predictable an most of the times the drivers could avoid a crash, these drivers behaved worse and had more crashes in similar situations three drives of ten minutes later in a similar situation that was somewhat less predictable.

In neurobiological studies it was found that release of glucocorticoids (stress hormones) when aroused, act on the hippocampus (component of the limbic system that plays an important role in the storage in long-term memory and the retrieval from long-term memory), the amygdala and the PFC in such a way that it promotes memory consolidation (e.g. McGaugh, 2000; McGaugh et al., 2002). There is however not a linear relationship between arousal and memory enhancement. Only moderate arousal enhances memory. Extreme low and high levels of arousal seem to impair memory consolidation (e.g. Richter-Levin & Akirav, 2000).

A theory that explains how we may learn from critical social situations[8] is the 'somatic-marker hypothesis' (Bechara et al., 1997; Damasio, 1994; Damasio et al., 1996). This theory proposes that in a complex and uncertain situation, our decision making process is partly guided by emotional signals from the viscera. As these emotions are body-related, Damasio (1994) called these emotional signals 'somatic markers'. The marker signals help us to reduce the problem space to a tractable size by marking response options with an emotional signal. People are born with a number of primary emotions. Through learning (classical conditioning), these primary emotions get connected to stimuli and patterns of stimuli. If in new situations, these patterns of stimuli reappear, the emotions felt the first time are very briefly relived (the somatic markers) and this gut feeling helps a person to take decisions. This can happen without awareness. The briefly re-activated past emotions help us to focus our attention to what is important in the situation and help us to take decisions, without the necessity to analyse all the possible options. Especially in traffic, decision-making has to be quick and thus somatic markers can be very helpful.

Damasio (1994) assumes that patients with lesions in the VMPFC do not develop somatic markers. Although these patients have normal scores on IQ-tests, they take irresponsible decisions repeatedly and are impulsive. According to Damasio et al. (1996) not only the VMPFC is involved in the process of somatic marking, but also the somatosensory cortices, the insula, the gyrus cinguli anterior and the basal ganglia. Empirical support for the somatic marker hypothesis is largely based on research with the Iowa Gambling Task (e.g. Bechara et al., 1994). In this task, participants have to select cards from the top of any of four decks of cards until they are told to stop. Before they begin, they receive a $2000 loan of play money. The aim is to maximize profit on the loan of play money. After the turning of each card, a participant receives money. Turning a card from decks A or B yields $100 and turning a card from the decks C or D yields $50. After having turned some cards, irrespective of the deck, the card that is turned is a penalty card. The density of penalty cards and the severity of the penalties vary per deck. On the long run, selection of cards from the decks with small profits (deck C and D) is more advantageous than the selection of cards from the high-paying decks (A and B). Patients with lesions in the VMPFC continue to draw cards from the high-paying decks, whereas participants without lesions in the VMPFC switch to the decks C or D after a while, even before they

[8] Hazardous traffic situation involving other road users can be considered as critical social situations.

explicitly know the heuristic of the game. Bechara et al. (1994) called this prolonged drawing of cards from the high yielding decks that are disadvantageous on the long run, 'myopia for the future'. To some extent, adolescents have 'myopia for the future' too. This is to say that controlled for developmental changes in working memory, capacity or inductive reasoning, adolescents keep on turning cards from the decks with high payments, but also with high penalties for a longer period of time than adults (e.g. Crone & van der Molen, 2004). This myopia for the future of adolescents can be explained by the discrepancy between the late maturation of the PFC and the early maturation of the limbic system in adolescents (Casey et al., 2008) (see Section 2.3.1).

The somatic marker hypothesis is not undisputed. Dunn, Dalgleish & Lawrence (2006) have presented an overview of the critical arguments and research results that undermine the claims of the somatic marker hypothesis. Most of the critical reviews refer to the Iowa Gambling Task. Bechara et al. (1997) found that healthy participants switched decks before they explicitly know why. However, Maia & McClelland (2004) found that healthy participants switched decks after they knew that the high-paying decks were disadvantageous. This implies that no gut feelings, evoked by somatic markers have to be involved in the switch in strategy. Moreover, patients with 'Pure Autonomic Failure' who are not able to send feedback to the viscera (and because of this in essence are not able to develop somatic markers), appeared to be able to switch decks as timely as healthy participants (Heims et al., 2004). Although Dunn et al. (2006) concluded that the somatic marker hypothesis needs revision, they did not reject the whole theory. According to them, the somatic marker hypothesis has been helpful in the identification of brain regions involved in decision-making, emotion and body-state representation, but the theory has fallen short in explaining how these entities exactly interact at the psychological level.

Hazard anticipation in driving is different from risk anticipation in the Iowa Gambling Task. If for instance an experienced driver recognizes the possibility of oncoming traffic that he or she cannot see because of the lorry (see Figure 3.9) and still quickly turns left, this driver deliberately takes the risk of getting involved in a crash. If on the other hand this driver slowly turns left while looking to the right in anticipation of possible oncoming traffic, she or he will reach her or his destination only a few seconds later. In other words, when deliberately taking risks in traffic one can lose a lot and gain a little. In the Iowa Gambling Task, on the other hand one can lose some and gain a lot. Callan et al. (2009) did not measure increased activity in the VMPFC, but in the gyrus cinguli anterior instead, when experienced drivers were about to turn left while their view on possible oncoming traffic was blocked by a lorry (see Section 3.8). They presumed that the VMPFC was not activated because in the hazard anticipation task for drivers, in contrast to the Iowa Gambling Task, reward is of little importance. This is consistent with the hypothesis of Rushworth et al. (2007) that the OFC and the VMPFC are involved in reward expectations and the gyrus cinguli anterior is involved cost-benefit assessments.

Improved memory consolidation with regard to (moderate) arousal evoking events (e.g. near misses in traffic) and the somatic marker hypothesis despite its limitations, would predict that drivers learn quickly from rare, but dangerous situations and that the somatic markers developed in this way help drivers to identify latent hazards. Also Fuller (2007b) assumed that somatic markers "…have an impact on the distribution of attention over the traffic scene ahead of the driver". In Chapter 6 is examined if the experience of a few dangerous traffic situations in a driving simulator helps to improve visual search for latent hazards in young novice drivers.

3.11. Conclusions

Hazard anticipation is the skill to detect and recognize latent hazardous situations and to predict how these situations can develop. It also is the ability to realize/feel the risk involved in a latent hazardous situation and the willingness to reduce these feelings of risk. With regard to other road users, latent hazards can be covert or overt. Covert latent hazards are possible other road users on collision course that are hidden from view. Overt latent hazards are visible other road users who due to the circumstances may start to act dangerously. Models on driver behaviour that are based on theories about information processing fall short to offer a theoretical framework for hazard anticipation as the motivational and emotional aspects in hazard anticipation are not explicitly addressed. On the other hand, motivational models on driver behaviour fall short because they do not describe how latent hazards are detected, recognized and predicted. The zero-risk model on driver behaviour (Näätänen & Summala, 1974) addresses both the information processing aspect of hazard anticipation and the emotional and motivational aspect of hazard anticipation. However, it remains unclear in this model how drivers switch from the automatic mode of driving to the controlled mode of driving and the model does not describe the processes that take place in the brain during hazard anticipation in both young novice drivers and older, more experienced drivers. In this chapter a cognitive-neuropsychological framework was presented that is based on Norman and

Shallice's model on willed and automatic control of behaviour (Norman & Shallice, 1986; Shallice, 1988) and that also contains elements of the zero-risk model. This framework was proposed by Brouwer & Schmidt (2002) and in this thesis it is used to describe the processes that take place during hazard anticipation in both young novice drivers and older, more experienced drivers. The basic assumptions are that schemata in young novice drivers are less elaborated than in older, more experienced drivers and that the involvement of the SAS is larger in young novice drivers than in older, more experienced drivers. Some evidence was found in the literature, but there are indications that the SAS remains active during hazard anticipation in older, more experienced drivers, at least in laboratory conditions. How young novice drivers differ in hazard anticipation from older, more experienced drivers and what the influences of both experience and maturation are on hazard anticipation is explored in Chapter 4.

The somatic marker hypothesis (Bechara et al., 1997; Damasio, 1994; Damasio et al., 1996) was introduced as a concept that can explain how novice drivers may quickly learn to anticipate latent hazards from past events that evoked arousal. If novice drivers can learn to anticipate latent hazard by experiencing crashes and/or near crashes in a driving simulator is explored in Chapter 6.

4. Hazard anticipation, age and experience

4.1. Introduction

4.1.1. Objectives of the study

The crash rate of young novice drivers is highest directly after licensing and declines rapidly in the first year of driving. It takes however years before the crash rate does not decrease any further (Maycock et al., 1991; McCartt et al., 2003; Sagberg, 1998; Vlakveld, 2005). About 60% of the reduction in crash rate of young novice drivers that start to drive around 18 years of age can be attributed to increasing driving experience and 40% can be attributed to age (i.e. maturation of the brain over time (nature) and socialization over time (nurture)) (Maycock et al., 1991; McCartt et al., 2009; Vlakveld, 2005) (see Section 1.2). These percentages are no more than rough estimates as all the mentioned studies were based on self-reported crashes and mileages and no random assignment was possible, as people are free to choose if they start their driving carrier early in life or late in life. The question is if improvement in hazard anticipation is an important determinant of the decline in crash rate after licensing. If so, is this improvement mainly the result of experience or maturation?

In Section 3.2 of Chapter 3, it was proposed that hazard anticipation has a cognitive component (the detection and recognition of latent hazards and the prediction how recognized latent hazards can develop into a real threat) and an emotional and motivational component (threat appraisal, risk acceptance and calibration). If improvement of hazard anticipation is likely to be one of the causes of the decline in crash rate after licensing, could it be that the cognitive component mainly improves with increasing experience and the emotional and motivational component mainly improves with age (i.e.

maturation)? The exploratory research presented in this chapter was not conducted to provide final answers on the mentioned questions, but to find some indications for answers.

The framework of Brouwer & Schmidt (2002) and the somatic marker hypothesis (Damasio, 1994) presented in Chapter 3 that were applied to describe the neuropsychological processes of hazard anticipation, illustrate that the cognitive aspect of hazard anticipation and the emotional and motivational aspect of hazard anticipation are intertwined. No latent hazards can be recognized if the proper schemata are not activated and very short relived feelings of fear, the somatic markers, help to activate the proper schemata. On the other hand, no risk assessment will take place in which feelings and emotions are involved when a latent hazard remains undetected. Although the cognitive aspect and the emotional and motivational aspect are interrelated, it is expected that:

- At the beginning of their driving carrier, drivers who start to drive late in life (older novice drivers) and drivers that start to drive young in life (young novice drivers), will not differ with regard to the cognitive aspect of hazard anticipation. This cognitive aspect of hazard anticipation will be less developed in both young novice drivers and older novice drivers than in older, more experienced drivers.

The rationale for this expectation is that the cognitive aspect of hazard anticipation (detection, recognition and prediction) is presumed to improve primarily with culminating driving experience.

Furthermore, it is expected that:

- At the beginning of their driving carrier, drivers who start to drive late in life (older novice drivers) and drivers that start to drive young in life (young novice drivers), will differ with regard to the emotional and motivational aspect of hazard anticipation.

The rationale for this expectation is that the emotional and motivational aspect of hazard anticipation predominantly matures with age.

Two of the four types of latent hazards that were distinguished in Section 3.2 involve interactions with (possible) other road users. These are the *covert latent hazards* and the *overt latent hazards*. In order to anticipate covert latent hazards, drivers have to imagine a possible other road user they cannot see (yet). In order to anticipate overt latent hazards, drivers have to be aware of the fact that visible other road users in the given circumstances could start acting dangerously. It is probably more difficult to imagine another road user who is not visible than to predict a dangerous action committed by a visible other road user. There are indeed indications that young novice drivers have more problems anticipating covert latent hazards than overt latent hazards (Borowsky, Oron-Gilad , & Parmet, 2009; Pradhan et al., 2005; Sagberg & Bjørnskau, 2006), but to date, the difference between covert latent hazards and overt latent hazards has not been systematically analysed. In this thesis, an explicit distinction is made between covert latent hazards and overt latent hazards. The third expectation is that:

- Novice drivers (both young novice drivers and older novice drivers) have more problems anticipating covert latent hazards than overt latent hazards.

The objective of the study presented in this chapter was to test the mentioned three hypotheses. In order to test the hypotheses among others, eye movements and the durations of eye fixations were recorded with an eye tracker. The (theoretical) relationship between hazard anticipation and eye movements is discussed in the Sections 4.1.5, 4.1.6 and 4.1.7 of this introduction. Before these sections on eye movements and hazard anticipation, the literature on the relationship between hazard anticipation and crash rate is reviewed in Section 4.1.2. In Section 4.1.3, a review of methods used to test hazard anticipation and the differences found with these methods between novice drivers and experienced drivers is presented. What the most suitable types of test are to test the hypotheses, is discussed in Section 4.1.4. In the last section of this introduction (Section 4.1.8), the test methods that were applied are mentioned and the detailed hypotheses are presented.

4.1.2. Scores on hazard perception tasks and crash rate

In several studies an association has been found between crash rate and performance on what is mostly called a hazard perception task (Congdon, 1999; Darby, Murray, & Raeside, 2009; McKenna & Horswill, 1999; Pelz & Krupat, 1974; Quimby et al., 1986; Wells et al., 2008). The better the scores on the hazard perception tests were, the lower the crash rate was. There are however exceptions. In the method that is used most often to measure hazard perception, participants watch video clips taken from a driver's perspective. Participants have to press a button as soon as they have detected a hazard. The time interval is measured between the time the first indication(s) of a developing overt hazard become(s) visible and the time the button is pressed. The scores are based on these response latencies and whether or not the button is pressed at all during a developing overt hazard, which never fully materializes (i.e. the video clips never end in a crash). The shorter the response times and the fewer the missed developing overt hazards, the higher the score is. As there are no visible cues to mark the precise onset of a covert latent hazards, this method is not suitable to measure response latencies of covert hazards. McKenna & Horswill (1999), Darby et al. (2009) and Wells et al. (2008) found an association between the scores on this task and crash rate, but Grayson et al. (2003) and Grayson & Sexton (2002) using the same type of test, did not. Moreover, using this type of hazard perception task, Sagberg & Bjørnskau (2006) found no improvement in response time latencies in the first nine months after licensing, whereas the crash rate of the participants decreased considerably in this period. It could be that whether or not a relationship is found between response latencies and crash rate depends on the types and complexity of the hazards that materialize in the video clips. Although Sagberg & Bjørnskau (2006) did not find an overall improvement in scores on their test with increasing driving experience, they found an improvement with increasing driving experience after licensing with regard to the more complex hazards in their test. The more complex situations they used were mixtures of covert hazards and covert hazards (e.g. a pedestrian that first was visible on the pavement and then disappears between parked cars when crossing the road as the driver approaches), or were what was named precursors of hazards in Section 3.2. Precursors of hazards are situations in which the still invisible hazard ahead has to be inferred from (warning) signs.

It could be that whether or not a relationship is found between results on a hazard perception tests and crash rate depends on the types and complexity of hazards that are used in the test. In test with latent hazards, it is presumably more likely to find a relationship between test scores and crash rate than in a rather easy hazard perception test with only imminent hazards.

4.1.3. Methods to test hazard perception and the difference in scores between novice drivers and experienced drivers

As already mentioned, the response latency task that is described in Section 4.1.2 is the most widespread method to measure hazard perception on a PC. This task was for the first time used by McKenna & Crick in 1991 (see for an overview of their studies: McKenna & Crick, 1997). They found that older, more experienced drivers had shorter response latencies and had more correct button presses than young novice drivers. Their method was in fact a simplification of the method used by Pelz & Krupat (1974) and by Watts & Quimby (1979). In these early studies, participants were not requested to press a button, but to move a lever. The riskier the situation got according to the participant, the more the lever had to be moved in a particular direction. The button press task has been replicated many times. Most researchers found, just as McKenna & Crick, that novice drivers had lower scores than experienced driver (e.g. McKenna, Horswill, & Alexander, 2006; Sexton, 2000; Wallis & Horswill, 2007), but other researchers could not find a difference between novice drivers and experienced drivers (Chapman & Underwood, 1998; Underwood, 2000). Sagberg and Bjørnskau (2006) when using this type of task, also found no overall difference in scores between young novice drivers and older, more experienced rivers. However in three situations with more complicated latent hazards in their videos, Sagberg & Bjørnskau (2006) found that older, more experienced drivers responded significantly faster after the first signs of a hazard had appeared on the screen than young novice drivers. In a more advanced version of this type of testing, participants do not press a button, but point and click at the location of the developing hazard on the screen with their mouse (Smith et al., 2009) or press with one of their fingers on a touch screen (Wetton et al., 2010). The advantage of this method is that it reduces ambiguity about why participants press the button. When participants only have to press a button, it remains unknown why they have pressed. It could be that they have detected the developing overt hazard, but it could also be because of something else. The particular location on the screen they have clicked provides information about why they have clicked. Smith et al. (2009) found that the response latencies of older, more experienced drivers were significantly shorter than the response latencies of young novice drivers and that this difference was more pronounced when both groups were sleepy. With the use of a touch screen, Wetton et al. (2010) also found that the response latencies of older, more experienced drivers were significantly shorter than the response latencies of young novice drivers.

Instead of a button press or pointing, it is also possible to stop a video at moments the first signs of a developing overt latent hazard become visible. The participant then is asked what could happen next. Jackson, Chapman, & Crundall (2009) using this method, found that older, more experienced drivers were significantly better in predicting what could happen next than young novice drivers. This was only the case when participants made their predictions after the video had stopped and the screen had turned black. When the last image of the stopped video remained visible as a photograph on the screen, there was no significant difference in correct predictions between older, more experienced drivers and novice drivers. It could be that when the last moment of the video remains visible (as a photograph on the screen), novice drivers get enough time to process information (i.e. to activate the SAS; see Section 3.8.3) in order to 'see' the possible threat. A somewhat different method, but also based on the theory of situational awareness (Endsley, 1995), was used by Bailly et al. (2003) (see also Section 3.8). In this method, participants also watched video clips from the driver's perspective. Now, at the end of the clip the screen turned black and a few seconds later the last image of the clip reappeared on the screen (as a photograph). In this photograph of the last moment of the video clip, something relevant for road safety was altered (e.g. a traffic light that was visible in the distance at the last moment of the clip and no traffic light in the photograph of that last moment). Experienced drivers detected 74.9% of the alterations and the young novice drivers detected 58.5% of the alterations. The difference between the groups was significant.

Again another method in which video clips with developing hazards were used, was applied by Borowsky et al. (2009). In this study, the researchers asked both experienced drivers and novice drivers to classify the video clips they had watched. The dominant sorting criterion for the novice drivers appeared to be the instigator of the hazard (e.g. a group of hazards instigated by bicyclists and a group of hazards instigated by cars), independent of the context in which the hazardous situation occurred. The dominant sorting criterion of experienced drivers on the other hand was the context (i.e. similarities between the situations in which the hazards occurred (e.g. intersections), independent of the road user that caused the hazard. With regard to the framework presented in Section 3.6 (Figure 3.6), these results indicate that novice drivers tend to categorize hazards on the basis of content aspects and experienced drivers tend to categorize hazards on the basis of context aspects.

Photographs of traffic situations have also been used to test if hazard perception skills differ between young novice drivers and older, more experienced drivers. Kelly et al. (2010) hypothesised that novice drivers and experienced drivers do not differ with regard to their ability to detect (possible) hazards (the cognitive aspect of hazard anticipation), but differ with regard to the risk felt in these traffic situations with (possible) hazards (the emotional aspect of hazard anticipation). This is to say, they hypothesised that novice drivers know the (potential) hazards but do not feel fear when they see these (potential) hazards. In order to test this hypothesis they asked participants to classify photographs taken from the driver's perspective as (1) safe, (2) potentially hazardous (containing latent hazards) and (3) hazardous (containing imminent hazards). Meanwhile their Skin Conductance Response (SCR) was recorded. Novice drivers and experienced drivers did not differ significantly in their ability to classify photographs as potentially hazardous and hazardous. However, experienced drivers classified significantly more often photographs as safe than novice drivers did. Only when photographs that belonged to the group with potentially hazardous situations (latent hazards that could develop into imminent hazards) were displayed on the monitor, the mean number of SCRs of experienced drivers was significantly higher than that of novice drivers. This result suggests that whereas both groups recognized latent hazards equally well on photographs, the experienced drivers more intensely felt the risk involved in these situations. This is in support of the hypothesis of Spear (2000) that adolescents require more intense stimuli to experience positive or negative feelings than adults (see the section on brain function during adolescence in Section 2.3.1). As Kelly et al. (2010) did not test a group of novice drivers that started to drive late in life, it is not possible to tell if the increased feelings risk of the experienced drivers when they watched photographs containing latent hazards, were due to the fact that they were more matured or because they had more driving experience.

Huestegge et al. (2010) also used photographs that were classified by experts as safe, potentially hazardous and hazardous. Each photograph was exposed for two seconds on the screen. Within this timeframe participants could indicate (by pressing a button or not) if they would have reduced speed in this situation or not if they were the driver. In the period a photograph was exposed on the screen, the gaze directions and fixations of the participant were recorded with the aid of eye tracking equipment. Studies in which eye tracking equipment is used, are separately discussed in Section 4.1.6. Here it is important to mention that novice drivers and experienced drivers did not differ with regard to the button presses they made. This means that there was no difference in tendency to reduce speed between novice drivers and experienced drivers with regard to the three different traffic situations presented on photographs (safe, potentially hazardous and hazardous). From the two mentioned studies of hazard perception test in which photographs were applied, can be concluded that experienced drivers and novice drivers may differ in their feelings of risk, but they do not appear to differ in their ability to recognize latent hazards on photographs.

De Craen (2010) developed a behavioural adaptation test in which use was made of static traffic scenes. The emphasis in her test was not on the cognitive aspect of hazard anticipation, but on the emotional and motivational aspect of hazard anticipation. The questions she was interested in were whether older, more experienced drivers calibrate better than young novice drivers and whether calibration skills improve with culminating experience. De Craen measured calibration skills by presenting participants pairs of photographs of almost identical traffic situations, taken from a driver's perspective. Participants had to respond what their speed would be in these situations. In one of the two photographs of the same road and road environment, a latent hazard was present (most of times this was an overt latent hazards) and in the other not. Speed adaption was considered as good in one pair of photographs when the reported speed was lower in the complex situation than in the simple situation. De Craen found that older, more experienced drivers calibrated better than young novice drivers, but that in the first two years after licensing calibration skills of young novice drivers did not improve over time. However, it could be that novice drivers did not improve on this task, not so much of lack of improvement in calibration skills, but because they were not able to detect and recognize the latent hazards in the photographs. If the problem of novice drivers is primarily a question of poor hazard detection (the first part of the definition of hazard anticipation) or primarily a question of poor calibration (the second part of the definition of hazard anticipation) is subject of the study presented in this chapter.

Finally, Wetton et al. (2010) used a completely different method applying static traffic scenes in order to measure differences in hazard perception between experienced drivers and novice drivers. In this study, a hazard perception task was developed that was based on the change detection flicker paradigm task (Rensink, O'Regan, & Clark, 1997). In this task, the display of two photographs of the same road situation but each with a different traffic situation was very rapidly continuously alternated on the screen. In one of the two photographs an imminent hazard was present and in the other not. Except for this imminent hazard the two photographs were identical. A display of a photograph lasted 480 ms. In between the display of the two photographs a blank grey screen was displayed for 320 ms.

Participants were requested to press with one of their fingers on the touch screen the location of the acute threat as soon as they had detected the immanent hazard. The reaction time was measured. The assumption was that the reaction times of experienced drivers would be shorter than the reaction times of novice drivers, as domain specific knowledge speeds up the reaction time in change detection flicker paradigm tasks. The results were in the opposite direction of the hypothesis. The reaction times of novice drivers were significantly shorter than the reaction times of experienced drivers. It could be that the hazards were so obvious (i.e. immanent) that it was equally easy to detect these hazards for young novice drivers and older, more experienced drivers. As young people have shorter reaction times in general, the young novice drivers had shorter reaction times on this task than older, more experienced drivers. It would be of interest to test if the reaction times are in the expected directions when instead of immanent hazards, latent hazards are used.

4.1.4. Suitable tasks for testing the hypotheses

In order to test the first and the third hypothesis, a hazard anticipation test is required that measures performance of which can be inferred if participants have detected and recognized overt latent hazards *and* covert latent hazards. Of all the discussed methods in Section 4.1.3, only the method applied by Jackson et al. (2009) in which participants had to predict what could happen next, is suitable to measure if participants have detected and recognized not only overt latent hazards but also covert latent hazards. When the video clip has stopped and the screen has turned black, participants can mention that for instance from behind the lorry that blocks the view a vehicle may emerge on collision course (covert latent hazard) and they can for instance also mention that a visible pedestrian on the pavement may suddenly cross the road in order to catch the bus (overt latent hazard). If the eye movements are measured before a video clip stops it is also possible to measure if participants have looked in the direction of covert latent hazards or overt latent hazards they have mentioned. Are there for instance differences between young novice drivers and older, more experienced novice drivers in anticipatory eye glances and verbal responses about what could happen next?

The task with photographs (safe, potentially hazardous and hazardous) that Kelly et al. (2010) and Huestegge et al. (2010) have applied, seems to be the most promising to measure the emotional aspect of hazard anticipation. Detection of (latent) hazards on photographs appeared to be relatively easy (no difference between young novice drivers and older, more experienced drivers) and young novice drivers and older more experienced drivers differed in skin conductance when exposed to photographs with latent hazards. Skin conductance response is commonly used as a measure for emotional arousal. The motivational aspect is not measured this way. This could be done by asking participants what they would do in the depicted traffic situations on the photographs. Would they for instance reduce speed in situations with latent hazards?

4.1.5. Eye movements, fixations and attention

When driving, drivers look at various elements in the traffic scene. The rapid movements the eyes make from one gaze direction to the other are called saccades. Normally two to three saccades are made per second. The time in between two saccades that the gaze is directed on one point in the scene is called a fixation. How long a fixation at a certain object or situation must be in order to identify it, is not exactly known and depends on the situation. Under normal conditions, the duration of a fixation represents the amount of time it takes to identify the object plus the time it takes to program the next saccade. In these normal conditions the minimum duration for fixations to identify a special aspect it is about 200 ms (e.g. Pollatsek & Rayner, 1982). A fixation duration of about 200 ms is according to Velichkovsky et al. (2002) also the minimum duration required for focal vision and the detection and recognition of hazards in traffic. According Velichkovsky et al. (2002), shorter fixations are pre-attentive and are in the realm of the ambient visual system that is involved in spatial orientation of the driver. Do the saccades and fixations of drivers tell us something about their skills to anticipate hazards? The 'eye-mind assumption' is attractive, but are there indications that there is a relationship between eye movements, attention and what people think? When participants that were situated in an fMRI scanner were asked to pay attention to a certain area in a scene without directing their eyes (fixating) to that area the same regional networks in the parietal, frontal and temporal lobes got activated as when participants were requested to fixate on that area (Corbetta et al., 1998). This is a strong indication that there is a relationship between attention and fixation. Note that this experiment also demonstrates that attention can be paid to a particular area in a scene before a fixation to this area is made. Irwin (2004) presents an overview of studies from which can be inferred that except for reflexes, attention precedes fixations. One obvious reason why persons scan the environment is that the area of high visual acuity in the centre which is called the fovea, is very small (Rayner & Pollatsek, 1992). At 5° angle from the centre, the visual acuity is already half of the visual acuity in the fovea. In order to recognize what objects in a scene precisely are, eye movements are necessary. Fixations are also necessary because the limited capacity of our cognitive systems do not allow us to process all information from the environment around a fixation even when visual acuity would not have been a problem. The maximum area around a fixation of which information can be processed is called the functional or useful field of view (e.g. Ball et al., 1988). However, to understand the gist of a total (traffic) scene (e.g.: 'I'm driving on a motorway.') one short fixation in the centre of about 200 ms is sufficient (Oliva & Torralba, 2006). Note that the distinction between the 'overall picture' and what is exactly going on in that picture resembles the distinction between context aspects (the overall picture) and content aspects (objects in the scene) made by Brouwer & Schmidt (2002) (see Section 3.6). In 1935 with the aid of rudimentary eye tracking equipment, Buswell already concluded that fixations in scenes are not random (cited in Henderson & Ferreira, 2004). Some regions in a scene receive more and longer fixations because of their visual salience such as colour, intensity, contrast, orientation, movement, and because of their cognitive salience. Cognitive salience means that persons have learned that an area is salient within a certain context, independent of the visual features of that area. A fixation made because of visual salience is called bottom-up selection (Itti & Koch, 2001; Parkhurst, Law, & Niebur, 2002) and a fixation made because of cognitive salience is called top-down selection (Henderson et al., 2007). Different brain circuits are probably active for gaze control when a fixation is top-down and a fixation is bottom-up (Hahn, Ross, & Stein, 2006). Most fixations are bottom-up, but some are top-down. Henderson & Ferreira (2004) assume that schemata and task knowledge play an important role in top-down selection. This is relevant for fixations in relation to covert latent hazards. If a driver fixates at an empty region, this cannot be because of bottom-up selection, as this area has no visual salience. The area however can have meaning to the driver because based on the selected dominant schema the driver expects that a yet invisible hazard could materialize in that region. Fixations on other road users in a traffic situation that could start to act dangerously (overt hazards), however do not necessarily indicate that the driver has recognized the overt latent hazard. A fixation on a visible other road user could also be the result of bottom-up selection. This is the case when attention is drawn to a particular road user in the scene because of its visual salience (size, movement, contrast, and so forth). A fixation on another road user can also be top-down independent of hazard anticipation. A driver may for instance be interested in how that other road user looks. In the experiment reported in this chapter, fixations of participants while watching video clips from the perspective of a driver were measured and participants were also requested to report latent hazards orally. If a participant fixates on an overt latent hazard and does not mention this overt latent hazard it could indicate that the fixation was the result of bottom-up selection or top-down selection not related to hazard anticipation. If on the other hand a participant fixates the overt latent hazard and also mentions the overt latent hazard, it is likely that the fixation is the result of top-down selection related to hazard anticipation. It is expected that:

- Young novice drivers and older novice drivers more often fixate overt latent hazards without having recognized and predicted the overt latent hazard than older, more experienced drivers do.

The distinction between bottom-up fixations and top-down fixations is not the same as the distinction between willed and automatic control of behaviour (Norman & Shallice, 1986) as was discussed in Chapter 3. For experienced drivers fixations on areas where nothing can be seen, but from where something could be expected (a top-down fixation), can be the result of contention scheduling without interference of the SAS. This is the case when a covert latent hazard is over learned and the driver based on the automatically selected schema within the CS, fixates in the direction from where she or he expects that something could happen. On the other hand, drivers may fixate on an object because of its visual salience (a bottom-up fixation) and after it is fixated feel that this object may interfere with her or his goals and switch on the SAS.

4.1.6. A neuro-cognitive model of attention and eye movements

Based mainly on neurobiological research with monkeys, Knudsen (2007) has developed a model about attentional processes and gaze control. With this model a connection could be made between the theory on eye movements (discussed in Section 4.1.5) and the framework of Brouwer & Schmidt (2002) that was used to describe the possible neuropsychological processes when drivers anticipate hazards (see Section 3.6). Knudsen's model is here briefly described from the perspective of a driver. In order to anticipate forthcoming hazards in complex traffic situations, a driver must select from the abundance of visual cues the information that is most relevant with regard to her or his goals (e.g. to overtake that particular car). Only relevant information is evaluated in working memory, where it can be analysed in detail and decisions and plans for actions can be made. The mechanisms of attention are responsible for selecting the information that gains access to working memory. Both bottom-up processes and top-down processes determine what is processed in working memory and the eye movements made. According to Knudsen four processes are fundamental to attention: (1) processing information in working memory, (2) sensitivity control, (3) competitive selection and (4) the filtering of salient stimuli. Sensitivity control is about the same as the activation and inhibition of schemata by the SAS. Competitive selection can be conceived as the selection of the dominant schema at any point in time in the framework of Brouwer & Schmidt (2002). The filtering of salient stimuli can considered as contention scheduling; the energizing of particular schemata based on information derived from perceived context aspects and content aspects. Figure 4.1 depicts the functional attention model of Knudsen (2007).

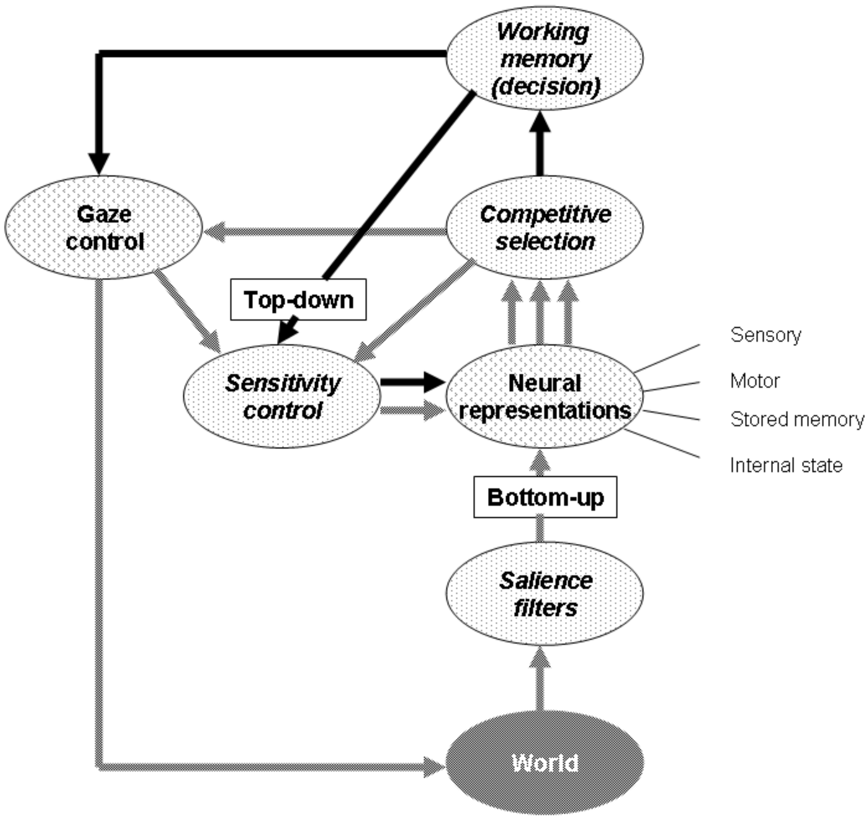

Figure 4.1. Knudsen's functional model of attention (adapted from Knudsen, 2007).

The four mentioned processes are the four ovals in Figure 4.1 that contain text in italic. The visual features of a traffic situation (affording the context aspects and the content aspects) are transformed by the nervous system in signals and are processed by salience filters. Objects and events are salient when they occur infrequently in time and space. This can be sudden sounds, a flash of light or something with a bright colour in a grey environment. Objects or events can also be instinctively salient (e.g. something with the shape of a snake) or can have become salient by learning. The well learned salient stimuli can be the content aspects and the context aspects of the road and traffic situations experienced drivers perceive and of which based on gut feeling, they immediately 'know' there is a latent hazard (see Section 3.8.1). This subconscious knowledge is stored in neural representations (schemata). Activation of neural representations (schemata) is not only the result of stimuli in the road and traffic situation, but also the result of knowledge stored in long term memory, feelings (internal state of the driver), the actions she or he can take (motor) and information from other senses than the eye (sensory). In terms of the theory presented in Chapter 3, the bottom-up process of salience filtering can be seen as an element of contention scheduling (the autonomous process of activation and inhibition of supporting and conflicting schemata) and the neural representations as the activated schemata at a particular moment in time. Note that bottom-up salience filtering in Knudsen's functional model of attention is not synonym with bottom-up fixations. A top-down fixation (e.g. when a driver looks in a direction where nothing can be seen, but something is expected) can be the result of bottom-up salience filtering for experienced drivers. The neural representations (or activated schemata) are not only determined by salience filtering, but also by sensitivity control. This is the process of the energizing of certain schemata of the group of schemata that already have been selected by the salience filters, comparable with what SAS does in Norman & Shallice's model on willed and automatic control of behaviour (1986). The black arrows in Figure 4.1 represent top-down attention and the grey arrows bottom-up attention. The third process in Knudsen's functional model of attention is 'competitive selection'. This means that signal strengths of activated neural representations (schemata) are compared. The weighing of the signal strengths of neural representations (schemata) leads to the selection of a dominant neural representation (dominant schema). Note that the dominant neural representation does not have to be processed in working memory in order to elicit an eye movement. If for instance in case of driving, the selected dominant schema is about a routine hazard (for an experienced driver), gaze control will be bottom-up. This is represented in Figure 4.1 by the gray arrow from 'competitive selection' to 'gaze control'. When information is not processed in working memory, the attentional processes remain in the realm of the contention scheduler. Also note that in the bottom-up process new schemata can be energized (sensitivity control) without gaze control (the gray arrow that goes straight from 'competitive selection' to 'sensitivity control'). This means that in cases of a developing 'routine hazard' a fixation at a certain object or in a certain direction is not always required for generating an evasive action. If the selected dominant neural representation (dominant schema) requires that information is processed in working memory, this is to say that in the framework of Brouwer & Schmidt (2002) the monitor has 'switched on' the SAS, an eye movement can be the result (e.g. looking in the direction were a covert latent hazard may materialize). This is represented in Figure 4.1 by the black arrow from 'working memory' to 'gaze control'. However, eye movements are not always necessary to reach a decision for an evasive action. The black arrow that goes straight from 'working memory 'to' sensitivity control' indicates this possibility. Figure 4.2 is the same as Figure 4.1, but now in the terminology of the concepts discussed in Chapter 3.

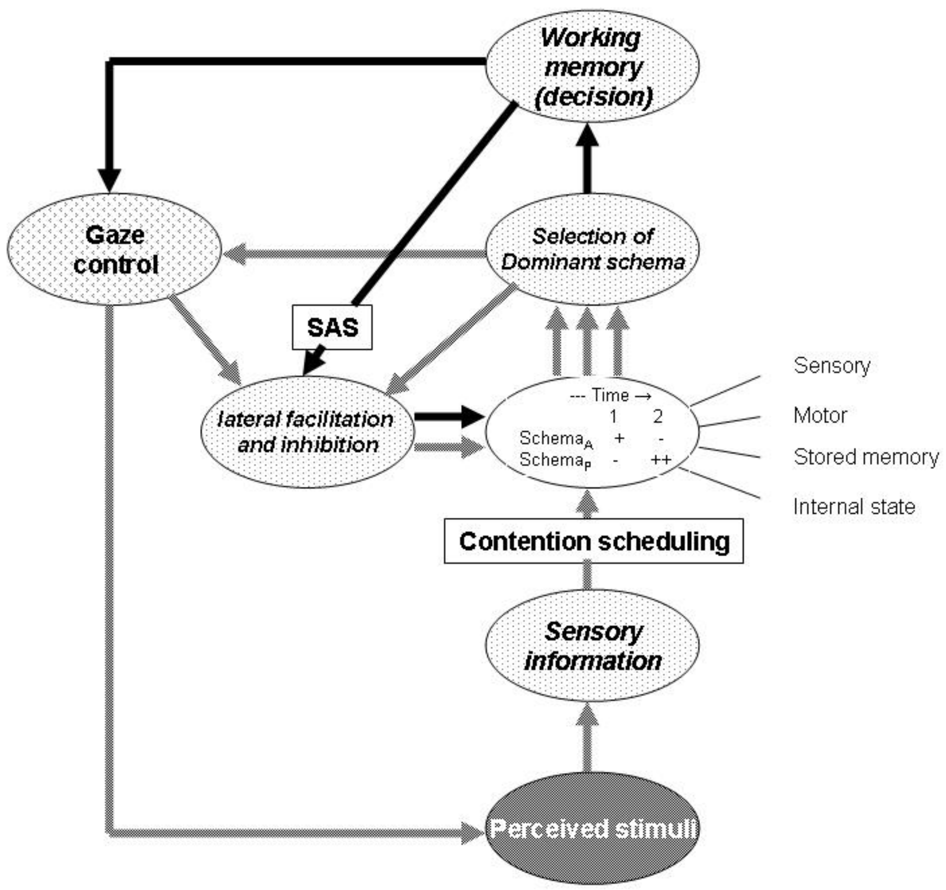

Figure 4.2. Knudsen's functional model of attention in which the terminology is used the framework of Brouwer & Schmidt (2002).

When 'translated' to the conceptual framework of Norman & Shallice (1986) and of Brouwer & Schmidt (2002), the functional model of attention (including gaze control) developed by Knudsen (2007) makes clear that attentional processes are both active within the CS and within the SAS. Gaze control can be both bottom-up (in the realm of the CS) of which the driver is not aware and can be top-down (in the realm of the SAS). Bottom-up gaze control can result in a bottom-up fixation, but also in a top-down fixation. An example of the former is a fixation on an object because this object is bright. Examples of the latter are fixations in directions of covert latent hazards that are routine situations for experienced drivers.

4.1.7. Differences in eye movements between novice drivers and experienced drivers

Eye movements and fixations of novice drivers and experienced drivers have been recorded with an eye tracker while participants in both groups drove in real traffic (Crundall & Underwood, 1998; Falkmer & Gregersen, 2005; Mourant & Rockwell, 1972; Underwood, Chapman, Brocklehurst, et al., 2003; Underwood & Crundall, 1998). They have also been recorded while participants in both groups drove in a simulator (Garay-Vega & Fisher, 2005; Konstantopoulos, Chapman, & Crundall, 2010; Miltenburg & Kuiken, 1990; Pradhan et al., 2005). Eye tracking equipment has been used while participants in both groups watched video clips taken from the driver's perspective (Borowsky, Shinar, & Oron-Gilad, 2010; Chapman et al., 2004; Chapman & Underwood, 1998; Crundall, Underwood, & Chapman, 2002; Underwood, Crundall, & Chapman, 2002) and while participants in both groups watched static traffic scenes (photographs) (Huestegge et al., 2010). The mentioned studies about eye movements while driving in real traffic were not about differences between novice drivers and experienced drivers in anticipatory eye glances in relation to latent hazards, but about scan patterns in general. The results of these studies are not conclusive. Mourant & Rockwell (1972) found that novice drivers looked less far ahead and less often in the rear-view mirror than experienced drivers. However, the fact that novice drivers tend to look in an area in front of the care that is closer to the car, could not be confirmed by Underwood & Crundall (1998) and Falkmer & Gregersen (2005). On the other hand, in all studies carried out in real traffic it was found that that young novice drivers scan less broadly side to side as older, more experienced drivers do. More over Crundall & Underwood (1998) found that novice drivers did not adapt their scan patterns as well to the complexity of the roadway as experienced drivers did. Whereas experienced drivers more often looked to the sides of the road in urban areas than on rural roads, novice drivers did not change their scan pattern when they drove on urban roads.

In contrast to real traffic, hazards can be staged in a driving simulator and drivers can experience a hazard that materializes, without being injured. This allows for studying anticipatory eye glances in predefined situations, containing specific latent hazards. In the mentioned simulator studies this was done by Garay-Vega & Fisher (2005) and by Pradhan et al. (2005). The study of Garay-Vega & Fisher (2005) was about 'foreshadowed' latent hazards. Imagine a driver who is driving on a rural road and in the distance there is a fork to the right that is hardly visible because of vegetation. Approaching traffic on that fork that will turn into the roadway of the driver cannot be seen until the very last moment because of this vegetation. This is an example of a covert latent hazard. Long before the driver has reached the fork, a car comes out of that fork and turns to the right onto the roadway of the driver. Does this car in the distance that turns into the roadway of the driver, hint the driver that she or he has to search for approaching traffic through the bushes when she or he is about to pass the fork? If this car in the distance foreshadows that more cars can be expected from the direction of the fork, this car has helped the driver to recognize a covert latent hazard. The two question Garay-Vega & Fisher (2005) posed, were: Do foreshadowed latent hazards help drivers to detect and recognize latent hazards? If so, who profits more from foreshadowed latent hazards: experienced drivers or novice drivers? The result of the study was that foreshadowing helped experience drivers to detect and recognize latent hazards, but that foreshadowing hardly helped novice drivers to detect and recognize latent hazards. In their simulator study Pradhan et al. (2005) found that 16- 17 year old drivers with less than six months driving experiences more often failed to show anticipatory eye glances in situations with mostly covert latent hazards (not foreshadowed) than 19-29 year old drivers with a couple of years of driving experience. They also found that on their turn 60-75 year old experienced drivers more often made anticipatory eye glances in situations with latent hazards than the 19-29 year old drivers did. A possible explanation not mentioned by the authors is that inexperienced novice drivers fail to show anticipatory eye glances in a simulator, not because they lack the skills to recognize these latent hazards, but because vehicle handling and mastering basic traffic situations cannot be executed at the procedural stage yet (Anderson, 1982) (see Section 3.9). If tasks cannot be executed at the procedural stage, the mental workload may be so high that no attentional capacity can be allocated to hazard anticipation. One of the aims of the research presented in this chapter is to investigate if novice drivers are also less good in hazard anticipation than experienced drivers are, when they do not have to drive.

Most of the studies on differences in eye movements between novice drivers and experienced drivers while watching videos taken from the driver's perspective have been carried out at the University of Nottingham (Chapman et al., 2004; Chapman & Underwood, 1998; Crundall et al., 2002; Underwood, Chapman, et al., 2002). These studies were not about anticipatory eye glances in situations with latent hazards, but about scanning patterns on different types of road and on fixations in situations with imminent hazards. A key finding of these studies was that also while watching videos, novice drivers did not adapt their scan patterns as much to the type of road (rural, suburban and urban) as experienced drivers did. A second key finding was that when there is an imminent hazard, novice drivers narrowed down there visual search for a longer period to the area where the imminent hazard was visible than older, more experienced drivers did. This is to say they kept staring in the direction of the detected hazard and forgot to look around for other information. From the first key finding can be concluded that lack of adaptation in visual search to the type of road and road environment is not caused by lack of attention that is available for visual search, but is caused by less developed mental models (schemata). From the second key finding can be concluded that novice drivers may miss important information that is necessary to avert the imminent hazard when this information is in the peripheral field of view. The only study found on hazard perception and differences between novice drivers and experienced drivers using video clips and eye tracker equipment, not carried out at the University of Nottingham, was a study by Borowsky et al. (2010). In this study, latent hazards in the video clips were mostly staged in real traffic. Except for one latent hazard, these latent hazards were overt hazards. There were no significant differences in eye movements between novice drivers and experienced drivers with regard to the overt latent hazards. One of the staged situations in a video clip was a lead vehicle that suddenly brakes at a T-intersection (road to the right) because a car approaches the T-intersection from the right and turns to the right just in front of the lead vehicle. From the driver's perspective in the video clip (the car behind the lead vehicle) the approaching car from the right cannot be clearly spotted because of parked vehicles. This situation is both an overt latent hazard (a lead vehicle that can brake) and a covert latent hazard (a possible car from the right that causes the lead vehicle to brake). In this, situation novice drivers tended to look only straight ahead to the lead vehicle whereas experienced drivers also looked to the right between the parked cars in order to catch a glimpse of a possible vehicle that was approaching from the right. It is too premature to conclude from eye movements in this one semi covert latent hazard that novice drivers are poorer in detecting and recognizing covert latent hazards than older, more experienced drivers even when they do not have to drive. Records of eye movements in more video clips with different covert latent hazards and overt latent hazards of both novice drivers and experienced drivers are required for a substantiated conclusion whether novice drivers have more difficulties in detecting covert latent hazards than overt latent hazards. This is one of the aims of the study presented in this chapter.

In the experiment conducted by Huestegge et al. (2010), novice drivers and experienced drivers watched snapshots of traffic situations taken from the driver's perspective while their eye movements were recorded. These snapshots were exposed on a screen for two seconds. Participants had to indicate as soon as possible after the snapshot became visible, if they would brake in this situation or not. If their decision was 'brake' they had to push a button, if they decided not to brake they needed to do nothing. Three experts in driving divided the snapshots into three categories: snapshots in which braking was urgent, snapshots in which there was a medium necessity to brake and snapshots with a low necessity to brake. There were no differences between experienced drivers and novice drivers with regard to the decision to brake or not to brake in all three categories, but when the response was 'brake', experienced drivers reacted faster than novice drivers did. With regard to eye movements, the researchers measured how long it took after the snapshot became visible before participants fixated for the first time in the area that contained the (overt) hazard. There was no difference between novice drivers and experienced drivers in latency of the first fixation on the hazard. There were also no differences in number of fixations and in fixation durations. However, the time between the first fixation on the hazard and the button press (when the response was 'brake') was shorter for experienced drivers than for novice drivers. This could indicate that in situations with imminent overt hazards (because braking is required to avert a collision) the time to detect these overt hazards does not differ between novice drivers and experienced drivers, but the time to select the action to brake after the imminent overt hazards was detected, is shorter for experienced drivers than for novice drivers. This could indicate that for novice drivers, intervention of the SAS in the contention scheduling is required and that experienced drivers can react directly on contention scheduling only (see the Sections 3.8.1, 3.8.2 and 3.8.3).

In the study presented in this chapter a similar task with snapshots was developed, but now with three response options: 'braking' in case of an imminent hazard, release throttle in case of a latent hazard (both covert latent and overt latent) and 'do nothing' in cases there were no plausible latent hazards. This task was used because in both the study of Kelly et al. (2010) and the study Huestegge et al. (2010), novice drivers and experienced drivers performed equally well in detecting and recognizing imminent hazards, latent hazards and no hazards in photographs of traffic situations taken from the driver's perspective. If there is no difference in detection and recognition if participants have the time to process information when they look at snapshots, could it be that they differ in the willingness to take risks in these situations?

4.1.8. Summary of the objectives and ideas about apparatus and materials

The objective of the study presented in this chapter is to gain insight in the improvement in hazard anticipation after licensing. It is assumed that hazard anticipation has a cognitive aspect (the detection and recognition of latent hazards and the prediction how recognized latent hazards can develop into real threats) and an emotional and motivational aspect (threat appraisal, risk acceptance and calibration). Both are interrelated, but it is hypothesised that the former aspect primarily improves with culminating driving experience and the latter aspect primarily improves with age.

Latent hazards involving other road users can be overt or covert. Overt latent hazards are visible other road users that may start to act dangerously in the given circumstances and covert latent hazards are possible other road users on collision course that are hidden from view. There are indications that novice drivers have more difficulties in anticipating covert latent hazards than overt latent hazards but to date, systematic research on this topic to is missing. This study is also intended to gain insight in possible differences in the anticipation of overt latent hazards and covert latent hazards by novice drivers and experienced drivers.

The idea is to develop two tasks: one with emphasis on the cognitive aspect of hazard anticipation and one with emphasis on the emotional and motivational aspect of hazard anticipation. Three groups carry out these two tasks: young novice drivers, older novice drivers and experienced drivers. In order to test the cognitive aspect, participants watch video clips taken from the perspective of a driver. Participants are requested to imagine that they are the driver of car in the video clips. The video clips contain both overt latent hazards and covert latent hazards that do not materialize. This is to say that in the video clips no visible other road user will start to act dangerously (overt hazards) and no other road user will suddenly appear on collision course from behind an object that blocks the view (covert hazards). After each short video clip and the screen has turned black, participants are asked what could likely have happened that did not happen and if it had happened would have been a real threat. When participants watch the video clips their eye movements are recorded with an eye tracker. In order to test the emotional and motivational aspect of hazard anticipation, participants watch photographs taken from the driver's perspective. There are three categories of photographs: safe situations (i.e. no imminent or latent hazard present), potentially hazardous situations (i.e. containing a latent hazard that can be a covert latent hazard or an overt latent hazard) and hazardous situations (i.e. contain an imminent hazard). Based on other hazard anticipation tasks in which photographs of traffic situations were used (Huestegge et al., 2010; Kelly et al., 2010), it is expected that novice drivers and experienced drivers will not differ in the skill to detect and recognize both imminent hazards and latent hazards on snapshots if they have the time to watch these snapshots. Whereas detection and recognition is supposed not to differ, it is expected that young novice drivers are willing to take more risks than older younger drivers in the depicted situations. Participants are asked what their action would be if they were the driver: do nothing (in case the situation is considered as safe), release the throttle (in case the situation is considered to contain a latent hazard), or brake (in case the situation is considered to contain an imminent hazard). Responses are risky when in case of a photograph with an imminent hazard, the response is 'release throttle' and in case of a photograph with a latent hazard, the response is 'do nothing'. The response is very risky when in case of a photograph with an imminent hazard the response is 'do nothing'. Responses are cautious when in case of a photograph of a safe situation, the response is 'release throttle' and in case of a photograph with a latent hazard, the response is 'brake'. The response is very cautious when in case of a photograph with a safe situation the response is 'brake'. While participants study the static traffic scenes, their eye movements are recorded.

The specific hypotheses are:

1. Young novice drivers and older novice drivers with almost no driving experience score equally low on a hazard anticipation task with the emphasis on the cognitive aspect of hazard anticipation (detection, recognition and prediction);

2. Older, more experienced drivers score significantly better than both young novice drivers and older novice drivers on a hazard anticipation task with the emphasis on the cognitive aspect of hazard anticipation;
3. Older novice drivers make less risky responses than young novice drivers do on a hazard anticipation task in which it is easy to detect the (latent) hazards and the emphasis is on the emotional and motivational aspect of hazard anticipation;
4. For both young novice drivers and older novice drivers it is more difficult to detect, recognize and to predict covert latent hazards than overt latent hazards;
5. For older, more experienced drivers it is equally difficult to detect, recognize and to predict covert latent hazards and overt latent hazards;
6. Young novice drivers and older novice drivers more often fixate overt latent hazards without having recognized and predicted the overt latent hazard than older, more experienced drivers do.

4.2. Method

4.2.1. Participants

Instead of novice drivers in their first month after licensing, learner drivers at driving schools were recruited. Only those learner drivers were recruited that were about to do the driving test. Learner drivers instead of novice drivers were chosen, because learner drivers could easily be recruited at driving schools as the tests were carried out at driving schools. The criteria for participation for young learner drivers were; 18 or 19 years of age (one has to be at least 18 years old to do the driving test in the Netherlands) and having passed the so called intermediate test. This intermediate test is an indication if learner drivers are about ready to do the driving test. The criteria for the older learner drivers were: at least 25 years of age and also having passed the intermediate test. Young learner drivers and older learner drivers were recruited from two different driving schools near The Hague. The criteria for the experienced drivers were: at least 10 years in possession of a driving licence (for car drivers) and an annual mileage of at least 15,000 km in the past year. The experienced drivers were recruited among office employees of the Dutch driving licence authority (CBR) and among parents of learner drivers at driving schools. The groups were:

- *Young learner drivers* (age range 18 to 19): n = 25; 52% male; average number of hours behind the wheel with an instructor = 24.3, *SD* = 6.9; mean age = 18.5, *SD* = 0.5;
- *Older learner drivers* (25 years of age and older): n = 19; 42% male; average number of hours behind the wheel with an instructor = 21.8, *SD* = 6.1; mean age = 31.9, *SD* = 6.2;
- *Experienced drivers* (at least 10 years in possession of driving licence and annual mileage ≥ 15,000 km): n = 31; 77% male; average annual mileage = 22,145 km, *SD* = 3,344 km; mean age = 47.7, *SD* = 10.0.

In some cases, the eye tracker data were too poor to be analysed, although all participants passed the calibration test of the eye tracking equipment. Of young learner drivers, the eye tracking data of six participants could not be analysed. Of the older learner drivers, the eye tracking data of four participants could not be analysed and of experienced drivers the eye tracking data of eleven participants could not be analysed. For the participants with good eye tracking records the groups were:

- *Young learner drivers* (age range 18 to 19): n = 19; 63% male; average number of hours behind the wheel with an instructor = 23.4, *SD* = 7.6; mean age = 18.6, *SD* = 0.6;
- *Older learner drivers* (25 years of age and older): n = 15; 53% male; average number of hours behind the wheel with an instructor = 23.1, *SD* = 6.3; mean age = 32.4, *SD* = 6.4
- *Experienced drivers* (at least 10 years in possession of driving licence and annual mileage ≥ 15,000 km): n = 20; 80% male; average annual mileage = 20,425 km, *SD* = 6,562 km; mean age = 46.7, *SD* = 8.1.

If the reported results in Section 4.3 did not include eye-tracking data, the first groups were used. If the analyses included eye-tracking data, the second groups were used. All participants had normal vision or vision corrected to normal with spectacles or contact lenses. The participants were naïve to the hypotheses. Participants were offered a stipend of € 30 upon completion of the test session that lasted about one hour.

4.2.2. Apparatus and Materials

The hazard detection and recognition task

To test the cognitive aspect of hazard anticipation, seven animated video clips were developed in total containing ten overt latent hazards and six covert latent hazards. None of the latent hazards in the video clips developed into imminent hazards. Detailed animation video clips were made because it was easier to stage situations and to fine-tune these situations on a computer than to shoot the situations in real traffic over and over again. All video clips were 'taken' from the driver's perspective and on the bottom of the screen the upper part of the steering wheel and the upper part of the dashboard were visible. Three experts of the Dutch driving licence authority (CBR) developed the scripts for the videos, after they were made acquainted with the concept of latent hazards and the difference between overt latent hazards and covert latent hazards. The first versions of these video clips were presented to five other experts of CBR who were not involved in the script development and the production of the animation videos. Based on their comments the video clips were improved and fine-tuned. See Appendix 1 for a description of the latent hazards and the screen captures of the critical moments. Each video clip lasted about 40 seconds and before a clip started, a plan view of the manoeuvre the car made was presented on the screen during 3 seconds. See for an example Figure 4.3.

Figure 4.3. An example of a plan view that preceded a video clip.

Before participants started the task they were told by the experimenter, they had to imagine they were the driver in the video clips and that directly after each video (and the screen had turned black) the following questions would be posed:

- What drew your attention in the video clip?

- Did you have moments that you thought: "Whew, I hope that this will not happen"? If so, what was it that you worried about?
- Were there moments that the developing situation could have ended in a crash? If so, describe this development?

Participants were also requested to talk aloud about things that drew their attention while they watched the videos. What participants said during the presentation of the video clips and the verbal responses on the questions after each video clip, were recorded. While participants watched the video clips, their gaze directions and fixations were recorded (see the subsection about eye tracking equipment in this section).

The risk assessment and action selection task

To test the emotional and motivational aspect of hazard anticipation, a task was developed in which participants were shown static traffic situations. The task consisted of twenty-five photographs that were presented on a computer screen. All photographs were taken from the driver's perspective. Part of the dashboard was visible at the bottom of each photograph. On this dashboard the current speed (in km/h) was indicated. In none of the photographs the presented speed exceeded the maximum speed limit. The presented speeds were not unrealistically low for the situation in general either (i.e. when the hazard was not considered). In the rear-view mirror in each photograph, participants could see what the road and traffic situation was from behind. For an example of a photograph, see Figure 4.4.

Figure 4.4. Example of a photograph from the risk assessment and action selection task.

Each photograph was exposed for 8 s. This is relatively long. In a pilot study where the response was self-paced, the mean response time was four seconds. The reason for this long exposure time was that the task was developed to measure risk taking tendencies in situations in which it was likely that the hazards were recognized. Even in a static traffic situation, it may take time to detect and recognize a hazard. Moreover, unlike driving in real traffic, from one moment to the other a participant is exposed to a traffic situation that is completely new for her or him. A participant may need time to 'read' this completely new traffic situation. Photographs have the disadvantage that they do not show how the traffic situation has developed. Speeds at which other road users travel are difficult to estimate in static traffic scenes. For this reason, only photographs were used of which the speed of other road users was considered not to be relevant for the assessment of the situation.

After a participant had watched a photograph and the screen had turned black, she or he had to respond orally if in the presented situation she or he: (1) would not have altered her or his speed (do nothing), (2) would have released the throttle, or (3) would have braked. The experimenter scored this response. While participants watched the photographs, their gaze directions and fixations were recorded.

Experts of CBR took the photographs. Before these experts took the pictures, they were informed about what hazard anticipation was, including the distinction between latent hazards and imminent hazards and the difference between overt latent hazards and covert latent hazards. The experts were instructed to take pictures of road and traffic situations with no hazards; with latent hazards (both covert latent hazards and overt latent hazards); and with imminent hazards. In combination with the depicted speeds, the correct response of the photographs with no hazards was considered to be 'do nothing', of photographs with latent hazards 'release throttle' and of photographs with imminent hazards 'brake'. In order to verify these responses, fifteen experts, not involved in the production of the photographs, were asked to do the task with fifty photographs. These experts were partly employees of CBR and partly experts from other organisations (e.g. driving instructors). Pictures were only included in the task if 80% of the experts provided the same response. Of the twenty-five photographs in the task, in nine items the correct response was 'brake', also in nine items the correct response was 'release throttle' and in seven items the correct response was 'do nothing'. An example of each category is presented in Appendix 2. The full set could not be reproduced, as the photographs are also used in the theory test of the Dutch driving test.

Visual perception test

The skill to detect a latent hazard in a visually complex environment could be related to the someone's visual perception abilities in general. With visual perception is not meant someone's visual acuity, but the ability to understand what is seen in a visually complex environment. It could be that persons do not recognize hazards in a visually complex environment not so much because they have no knowledge about the type hazard, but because they cannot detect it due to the visual complexity of the situation. In order to test if there is a correlation between the two previously described hazard anticipation tasks and visual perception, all participants performed a validated visual perception test. This test was the third edition of the Motor-free Visual Perception Test (MVPT-3) (Colarusso & Hammill, 2003). In combination with other tests the MVTP is used to assess fitness to drive in older drivers (i.e. drivers of sixty-five years of age and older). A significant correlation was found between on-road driving tests and MVPT scores (Mazer, Korner-Bitensky, & Sofer, 1998). Although MVPT-3 is composed of different sub-tests (spatial relationship, visual discrimination, figure-ground, visual closure and visual memory), one score is calculated. It took about 30 min to complete the test.

Questionnaire

All participants had to complete a short questionnaire with questions about demographics, their driving experience and the quality of their eyesight. For the learner drivers (both young and old), experience meant the number of hours behind the wheel when driving with a driving instructor. In contrast with many other countries, accompanied driving with for instance a parent in the learner phase (i.e. before having passed the driving test) was not possible in the Netherlands at the time the experiment was conducted. For the experienced drivers, experience meant the number of years in possession of the driving licence (more than 10) and the annual mileage in the past year (at least 15,000 km).

Eye tracking

The video clips and the photographs were displayed on a 17'' monitor (aspect ratio 4:3) with an integrated non-intrusive eye tracker and a data rate of 120 Hz. This eye tracker was a Tobii T120. The resolution was set on 1024 × 768 and both the video clips and the photos were presented full screen. The average distance from the eyes of the participants to the middle of the screen was approximately 60 cm, which provided them with a horizontal visual field of about 32°. See Figure 4.5 for an impression.

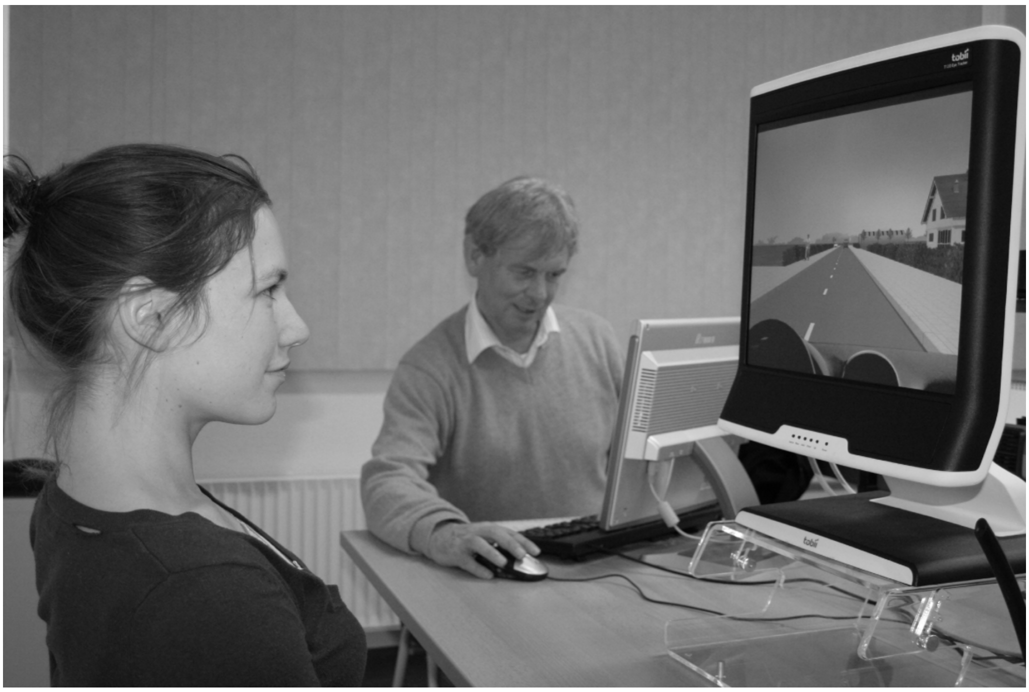

Figure 4.5. Test setup with eye tracker.

4.2.3. Procedure

On arrival, the experimenter explained to participants orally what the study in general was about (but not the hypotheses) and what they were going to do. Thereafter participants completed the questionnaire. The questionnaire also contained general information about the study. Participants then were seated in front of the monitor of the eye tracker and the eye tracker was calibrated to the eyes of the participant. This lasted no longer than one minute. Afterward, participants started either with the hazard detection and recognition task (the video clips) or the risk assessment and action selection task (the photographs). The order of these two tasks was counter balanced across participants. However, the order of the videos and the photographs within each task were fixed. With the software of the eye tracker no interim changes of the order within a task could be made. After these two tasks, participants did the visual perception test (the MVPT-3). This test was always completed at the end of the test session as this test did not require the use of an eye tracker. Finally, participants were paid for their participation. The total duration of a test session was approximately one hour.

4.2.4. Data processing and design

The hazard detection and recognition task
With the aid of two experts of CBR, for each latent hazard in the video clips the timeframe was established in which a fixation on the latent hazard of at least 200 ms (the minimum fixation duration supposed to be necessary to process information, see Section 4.1.4) was either not to soon or not too late for evasive actions, should the latent hazard have materialized. Thereafter, within these timeframes the area was defined the fixation or fixations had to be. In case of the overt latent hazard this area was the visible other road user that could start to act dangerously and in case of a covert latent hazard this was the area from where another road user on collision course could emerge. The coordinates and the size of these areas change while the video runs. As the eye tracker recorded the coordinates of fixations and the duration of fixations, but not the coordinates of the moving Areas Of Interest (AOIs) on the screen, the coordinates of the relevant areas had to be determined video frame by video frame. The data of the eye tracker were combined with the data of the coordinates of the areas. Of each area was established if a participant had a fixation of at least 200 ms on the latent hazard within the timeframe. If there was at least one correct fixation, the timestamp of the beginning of the first fixation, the duration of this fixation, the timestamp of the last fixation and the duration of this fixation, the total number of the

fixations on the area within the timeframe and the total duration of the fixations, were included in the database for analyses.

Independent of each other two experimenters listened to the sound recordings of the participants (what they said while they watched the video clips and their spoken answers to the questions directly after each video clip) and scored if participants had recognized the latent hazard or not. The two experimenters were blind to the participants' condition. The interrater reliability was substantial, $K = .77$ $p < .001$. In the few cases the experimenters differed, the experimenters listened to the recordings together and came to a consensus.

The risk assessment and action selection task

With the aid of two experts of CBR, the AOIs of each of the twenty-five photographs were determined. An area was considered to be an AOI when it provided information with regard to the decision to brake, release throttle or do nothing. These areas were the imminent hazards (if there were imminent hazards in a photograph) and the latent hazards if present (both covert latent and overt latent). An area in a photograph was an AOI of a covert latent hazard when it was the area from where possible road users on collision course could appear. The cause why this possible road user was invisible (e.g. a parked car) was not part of the AOI of a cover hazard. Two AOIs where the same on each photograph: the rear-view mirror and the speedometer. Included in the database were the number of fixations on AOIs and the total time of the fixation durations in the AOIs.

For each participant a total risk score was calculated. If a response on a photograph was correct, the score was 0. If the response was 'release throttle' and the correct response was 'brake' and if the response was 'do nothing' and the correct response was 'release throttle', the score was 1. If the response was 'do nothing' and the correct response was 'brake', the score was 2. If the response was 'brake' and the correct response was 'release throttle' and if the response was 'release throttle' and the correct response was 'do nothing', the score was -1. If the response was 'brake' and the correct response was 'do nothing', the score was -2. For each participant the scores on the twenty-five items then were totalled. A final score > 0 meant that action selection was too risky and a final score < 0 meant action selection was too cautious compared to the scores of the forum of fifteen experts.

Design and analysis

The independent variables were group (young learner drivers, older learner drivers and the experienced drivers), type of task (hazard detection and recognition task, risk assessment and action selection task, and the MVPT-3) and the type of latent hazard (overt hazards and covert latent hazards). The dependent measures were:

- The anticipatory eye glances and the mentioned latent hazards in the hazard detection and recognition task;
- The number of fixations in the AOIs and the total time of all fixation durations in the AOIs and the total risk score of the risk assessment and action selection task, and
- The score on the visual perception test (MVPT-3).

Before using parametric statistical test, checks were made if the criteria for normal distribution and homogeneity of variance were met. No situations were encountered in which these assumptions were violated. T-tests for independent samples were used to compare two means. Univariate analysis of variance was used to compare more than two means. Univariate analysis of variance is denoted in the text as 'ANOVA'. For the measurement of the detection of latent hazards in video clips two different methods were used: anticipatory eye glances and the mentioning of the latent hazards. In order to test if the profile style of the two methods was the same, univariate analysis of variance for repeated measures was applied. This is denoted as 'repeated measures ANOVA' in the text. When repeated measures ANOVA were applied the data was additionally checked if the assumption of sphericity was met. To analyse what the combined effect on the groups was of two different dependent variables (e.g. the scores on the hazard detection and recognition task and the scores on the risk assessment and action selection), multivariate analysis of variance was applied. This is denoted in the text as 'MANOVA'. For MANOVA the Phillai's Trace criterion was used. Each time MANOVA was applied, this test was succeeded with a discriminant function analysis in order to interpret the results of the MANOVA. In case of categorical data the chi-square test was used. The chi-square test is denoted as 'χ^2'. Pearson's correlation coefficients between for instance the scores on the hazard perception and recognition task and the risk assessment and action selection task were also calculated. No other types of correlation coefficients were used. The Pearson's correlation coefficient is denoted as 'r'. Differences were considered statistically significant when $p < .05$. In cases several variables were combined into one variable, the internal consistency reliability (Cronbach's α) was considered with $\alpha > .65$ as acceptable. In order to test if fixations on particular areas predicted the scores on the risk assessment and action selection task, multiple regression was applied.

Besides significance of the results, the effect size (Partial èta squared, η_P^2) was considered with $\eta_P^2 = .01$ as a small, $\eta_P^2 = .06$ as a medium, and $\eta_P^2 = .14$ as a large effect size (Cohen, 1988). To indicate the effect size of the results of χ^2 tests the value of Cramer's V is presented.

4.3. Results

4.3.1. The hazard detection and recognition task

Anticipatory eye glances

If participants fixated a latent hazard[9], there were no significant differences between the three groups (young learner drivers, older learner drivers and experienced drivers) in the moment of the first fixation, the duration of the first fixation, the number of fixations on the latent hazard, the total time of the fixation durations, the moment of the last fixation and the duration of the last fixation. However, there were differences between the groups whether a latent hazard was fixated at all (at least one fixation of 200 ms or more) or was not fixated. Table 4.1 contains the percentages of participants in a group that had at least one anticipatory fixation in the areas of each covert latent hazard and each overt latent hazard within the timeframes of each latent hazard. See for a description of the latent hazards Appendix 1. C1 means covert latent hazard 1 in Appendix 1 and O1 means overt latent hazard in Appendix 1. To test if the scores for each area differed significantly between the three groups, the χ^2 test was applied. For three covert latent hazards and eight overt latent hazards the assumptions for the χ^2 test were not met.

[9] A fixation was valid when it lasted at least 200 ms and was in the (moving) area of a latent covert hazard (all together six areas) or a at a (moving) latent overt hazard (all together ten areas) within the particular timeframe of that latent hazard.

Table 4.1. Percentage of the participants in a group with at least one anticipatory fixation within the timeframe on each of the covert latent hazards and each of the overt latent hazards.

No	*Young learner drivers*	*Older learner drivers*	*Expe-rienced drivers*	X^2	*p*	*Cramer's V*
C1	37%	67%	80%	7.91	.019*	.38
C2	84%	87%	100%	-	-	-
C3	90%	93%	100%	-	-	-
C4	79%	67%	85%	-	-	-
C5	11%	20%	65%	14.67	.001**	.52
C6	26%	53%	90%	16.30	.000***	.55
O1	58%	87%	75%	3.58	.17	.26
O2	84%	80%	100%	-	-	-
O3	79%	87%	100%	-	-	-
O4	68%	80%	90%	-	-	-
O5	100%	100%	100%	-	-	-
O6	90%	87%	95%	-	-	-
O7	95%	80%	80%	-	-	-
O8	84%	67%	85%	-	-	-
O9	100%	100%	100%	-	-	-
O10	74%	60%	70%	0.76	.68	.12

**p* < .05, ***p* < .01, ****p* <.001

In all six situations with covert latent hazards, experienced drivers had the highest percentage of anticipatory eye glances. Of the six covert latent hazards, three (C2, C3 and C4) were apparently relatively easy to detect and recognize, as the percentages were high in all three groups. Except for one covert latent hazard (C4), the percentages of the older novice drivers were higher than the percentages of the young novice drivers. Participants in all three groups more often fixated overt latent hazards than covert latent hazards. Note that in contrast to a fixation on a covert latent hazard a fixation on an overt latent hazard, not necessarily implies that the overt latent hazard is recognized and that the participants expects that this other road user may start to act dangerously. It is very likely that fixations in areas without visual saliencies (the directions where nothing special can be seen (yet) in case of a covert latent hazard) are top-down and related to hazard perception (see Section 4.1.5). However, fixations on other road users can also be top-down without having anything to do with hazard perception and can be elicited bottom-up.

One variable was made of the six covert latent hazards and one variable was made of the ten overt latent hazards. This was done by totalling all the fixated covert latent hazards and totalling all the fixated overt latent hazards. Cronbach's alpha of the composed variable on fixated covert latent hazards was not acceptable (α = .56) and the Cronbach's alpha of the composed variable on fixated overt latent hazards was not acceptable either (α = .44). Despite these low internal consistencies, one scale was made because of the exploratory character of the study and in order to compare the fixations at hazards with the mentioned hazards. Figure 4.6 shows the mean percentages of fixations on covert latent hazards and fixations on overt latent hazards per group.

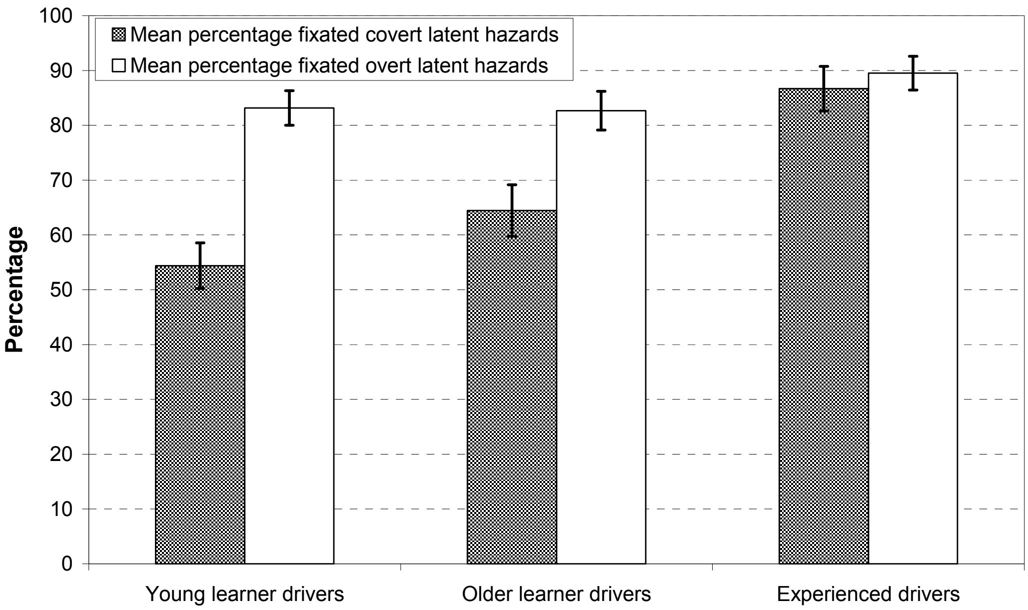

Figure 4.6. Mean percentage of fixated covert latent hazards and mean percentage of fixated overt latent hazards per group. Error bars indicate +/- 1 standard error.

On average, young novice drivers made at least one fixation in the direction of a covert latent hazards within the timeframe of that latent hazards in 54.4% (*SE* = 4.2) of the six situations with covert hazards. This percentage was 64.4 (*SE* = 4.7) for older novice drivers and 86.7 (*SE* = 4.1) for experienced drivers. ANOVA demonstrated significant differences between the three groups with a large effect size, $F_{(2,51)} = 16.07$, $p < .001$, $\eta^2_p = .39$. Post hoc Bonferroni tests showed that young learner drivers differed significantly from experienced drivers ($p < .001$) and older learner drivers differed significantly from experienced drivers ($p < .01$), but young learner drivers did not differ from older learner drivers ($p = .35$). With regard to covert latent hazards, these results are in support of hypotheses 1 and 2 in Section 4.1.8

that cognitive aspects of hazard anticipation improve with increasing experience and not with age.

On average, a young novice drivers had at least one fixation within the timeframes at an overt latent hazards in 83.2% (*SE* = 3.1) of the ten situations with overt latent hazards. This percentage was 82.7 (*SE* = 3.5) for older novice drivers and 89.5 (*SE* = 3.1) for experienced drivers. ANOVA revealed that there were no significant differences between the three groups, $F_{(2,51)} = 1.44$, $p = .25$. These results are not in support of hypotheses 1 and 2 in Section 4.1.8. This could be caused by the fact that a fixation on an overt latent hazard not necessarily implies that this hazard has been recognized.

Young learner drivers fixated relatively less on covert latent hazards than on overt latent hazards, t (18) = 7.33, $p < .001$. This was also true for older learner drivers, $t(14) = 3.21$, $p < .01$. Experienced drivers however did not differ significantly between fixations on overt latent hazards and covert latent hazards, $t(19) = 0.84$, $p = .41$. These results are in support of hypotheses 4 and 5 in Section 4.1.8 that inexperienced drivers (both young and somewhat older), but not experienced drivers, have more problems with detecting and recognizing covert latent hazards than overt latent hazards.

Mentioned covert and overt latent hazards

Table 4.2 contains the percentages of participants in a group that mentioned the covert latent hazard or the overt latent hazard.

Table 4.2. Percentage of the participants in a group that mentioned the overt or covert latent hazard.

No	*Young learner drivers*	*Older learner drivers*	*Expe-rienced drivers*	X^2	*p*	*Cramer's V*
C1	32%	42%	58%	3.90	.14	.23
C2	48%	53%	68%	2.43	.30	.18
C3	88%	74%	90%	-	-	-
C4	8%	11%	45%	13.01	.001**	.42
C5	4%	16%	36%	8.86	.012*	.34
C6	12%	26%	77%	26.99	.000***	.60
O1	40%	42%	61%	3.04	.22	.20
O2	4%	5%	16%	-	-	-
O3	24%	37%	71%	13.25	.001**	.42
O4	84%	89%	90%	-	-	-
O5	48%	32%	84%	15.04	.001**	.45
O6	32%	42%	58%	3.90	.14	.23
O7	88%	74%	90%	-	-	-
O8	40%	32%	71%	9.02	.01*	.35
O9	72%	95%	97%	-	-	-
O10	24%	26%	61%	10.00	.007**	.37

**p* < .05, ***p* < .01, ****p* <.001

The percentages mentioned latent hazards were the highest for experienced drivers in every situation (both covert latent hazards and overt latent hazards). In five of the six situations with covert latent hazards, the percentage mentioned latent hazards by older novice drivers was higher than the percentage mentioned by young learner drivers. In eight of the ten situations with overt latent hazards, the percentage mentioned by older novice drivers was higher than the percentage mentioned by young novice drivers. Just as with the anticipatory eye glances, one variable was made of the six covert latent hazards and one variable was made of the ten overt latent hazards, despite the weak internal consistencies of both scales. Cronbach's alpha of the composed variable on mentioned covert latent hazards was not acceptable (α = .55) and the Cronbach's alpha of the composed variable on mentioned overt latent hazards was not acceptable either (α = .60). Figure 4.7 shows the mean percentages covert latent hazards and overt latent hazards mentioned per group.

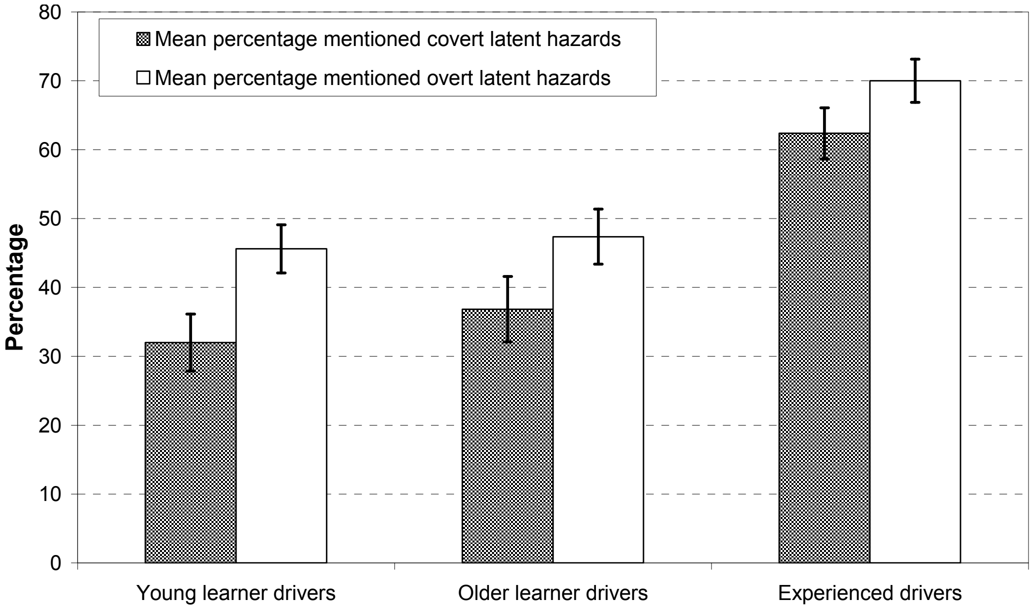

Figure 4.7. Mean percentage of mentioned covert latent hazards and mean percentage of mentioned overt latent hazards per group. Error bars indicate +/- 1 standard error.

On average, young novice drivers mentioned 32.0% (*SE* = 4.1) of the covert latent hazards. This percentage was 36.8 (*SE* = 4.7) for older novice drivers and 62.4 (*SE* = 3.7) for experienced drivers. ANOVA demonstrated significant differences between the three groups and a large effect size with regard to the mentioned covert latent hazard, $F_{(2,72)} = 17.28$, $p < .001$, $\eta^2_P = .32$. Post hoc Bonferroni tests showed that young learner drivers differed significantly from experienced drivers ($p < .001$) and older learner drivers differed significantly from experienced drivers ($p < .001$), but young learner drivers did not differ from older learner drivers ($p = 1.0$). These results with regard to covert latent hazards are in support of hypotheses 1 and 2 in Section 4.1.8 that cognitive aspects of hazard anticipation improve with increasing experience and not with age.

On average young novice drivers mentioned 45.6% (*SE* = 3.5) of the overt latent hazards. This percentage was 47.4. (*SE* = 4.0) for older novice drivers and 70.0 (*SE* = 3.1) for experienced drivers. ANOVA demonstrated significant differences between the three groups and a large effect size with regard to the mentioned overt latent hazard, $F_{(2,72)} = 16.69$, p < .001, $\eta^2_P = .32$. Post hoc Bonferroni tests showed that young learner drivers differed significantly from experienced drivers (p < .001) and older learner drivers differed significantly from experienced drivers (p < .001), but young learner drivers did not differ from older learner drivers (p = 1.0). These results with regard to overt latent hazards are also in support of hypotheses 1 and 2 in Section 4.1.8 that cognitive aspects of hazard anticipation improve with increasing experience and not with age. As mentioned before, the groups did not differ in the percentages of fixated overt latent hazards. However, they did differ significantly in percentages of mentioned overt latent hazards. As already indicated, a fixated overt latent not necessarily implies that this latent hazard is recognized. In contrast, a mentioned overt latent hazard is always recognized. This could explain the different results between the groups in fixated overt latent hazards and mentioned overt latent hazards.

In each group, the percentage of the mentioned overt latent hazards was higher than the percentage of the mentioned covert latent hazards. For young novice drivers and older novice drivers this difference was significant, respectively: t (24) = 4.53, $p < .001$, and t (18) = 2.04, $p < .05$. The difference between mentioned covert latent hazards and mentioned overt latent hazards was not significant for experienced drivers, t (30) = 1.83, $p = .08$. These results are in support of hypothesis 4 and 5 in Section 4.1.8 that inexperienced drivers have more problems with detecting and recognizing covert latent hazards than overt latent hazards, but that for experienced drivers there is no difference.

Fixated latent hazards and mentioned latent hazards

Table 4.3 shows the relationship between fixations (at least one fixation of at least 200 ms on the designated area within the timeframe of each latent hazard) and mentioned latent hazards.

Table 4.3. Percentages of latent hazards that were fixated and mentioned, fixated but not mentioned, not fixated but mentioned, and not fixated and not mentioned per group.

	Fixated / Mentioned				X^2	*p*
	yes/yes	*yes/no*	*no/yes*	*no/no*		
Covert latent hazards						
Overall	37.0%	30.2%	5.7%	27.1%		
Young learner drivers	27.2%	27.2%	7.0%	38.6%		
Older learner drivers	27.8%	36.7%	6.6%	28.9%	40.41	.000***
Experienced drivers	57.5%	29.2%	3.3%	10.0%		
Overt latent hazards						
Overall	49.7%	35.4%	5.1%	9.8%		
Young learner drivers	42.6%	40.5%	5.3%	11.6%		
Older learner drivers	43.3%	39.3%	5.3%	12.0%	26.13	.000***
Experienced drivers	65.0%	24.5%	5.0%	5.5%		

****p* <.001

Participants can fixate a latent hazard and mention the latent hazard. They can fixate a latent hazard and not mention this latent hazard. They can mention the latent hazard and not fixate that latent hazard and they can neither fixate the latent hazard nor mention the latent hazard. The results indicate that the three groups differed significantly with regard to these possibilities on both covert latent hazards and overt latent hazards. Experienced drivers more often fixated latent hazards (both covert latent hazards and overt latent hazards) and mentioned them too compared to both young learner drivers and older learner drivers. The differences between fixated covert latent hazards an mentioned covert latent hazards and the differences between fixated overt latent hazards and mentioned overt latent hazards between young learner drivers and older learner drivers were not significant, respectively: $\chi^2(3) = 2.84$, $p = .42$, and $\chi^2(3) = 0.05$, $p = .99$.

Note that for both overt latent hazards and covert latent hazards the percentages in the category fixation 'yes' and mentioning of the latent hazard 'no' were relatively high. The percentages in this category were in particularly high for young learner drivers and older learner drivers in situations with overt latent hazards. This means that both young novice drivers and older novice drivers relatively often looked at other road users that could start to act dangerously, but did not consider these other road users as potentially dangerous enough to mention them. It could be that fixations on other road users were more often the result of bottom-up processes and top-down processes not related to hazard detection than top-down processes related to hazard perception for both young learner drivers and older learner drivers than for experienced drivers. This is in support of hypothesis 6 in Section 4.1.8 that novice drivers (both young and older) more often fixate overt latent hazards without having recognized and predicted the overt latent hazard than experienced drivers do (see for a discussion about this topic the next sub-section). Note also that in around 5% of the cases the latent hazard, was mentioned but not fixated. According to Knudsen's functional attention model (2007), fixations on a latent hazard are not always necessary to recognize a latent hazard. The possibility of recognizing a latent hazard without explicitly having fixated it is represented in Figure 4.1 of Section 4.1.6 by the black arrow that goes straight from working memory to sensitivity control. It could also be that when asked to think about what had happened in the video clip after they have watched it, participants may realize there was a latent hazard they did not detect (i.e. did not fixate) and recognized while they watched the video clip.

There was a significant relationship between the number of fixated covert latent hazards and the number of mentioned covert latent hazard, $r = .44$, $p < .01$. The relationships were almost the same for novice learner drivers, older learner drivers and experienced drivers. There was also a significant relationship between the number of fixated overt latent hazards and the mentioned overt latent hazards, $r = .42$, $p < .01$. This relationship was stronger for young learner drivers ($r = .48$) than for older learner drivers ($r = .24$) and experienced drivers ($r = .20$). The relatively high percentages of the category 'fixated, but not mentioned' in Table 4.3 probably explains that the correlations between fixated latent hazards and mentioned latent hazards were not higher.

When the results presented in Table 4.1 (percentages fixated latent hazards) are compared with the results presented in Table 4.2 (percentages mentioned latent hazards), it turns out that young learner drivers and older learner drivers in all situations (both covert and overt) more often fixated latent hazards than mentioned latent hazards. For experienced drivers in none of the situations with covert latent hazards the percentage mentioned covert latent hazards was higher than the percentage fixated overt latent hazards, but in two out of the ten situations with overt latent hazard the percentage mentioned overt latent hazards was slightly higher than the percentage fixated hazards. In the situations C4, O2, O5, O7 and O10 (see for a description of these situations Appendix 1), the percentages mentioned latent hazards were substantially lower than the percentages fixated latent hazards, especially for young learner drivers and older learner drivers. Figure 4.8 shows the difference between the fixated covert latent hazards and the mentioned covert latent hazards per group.

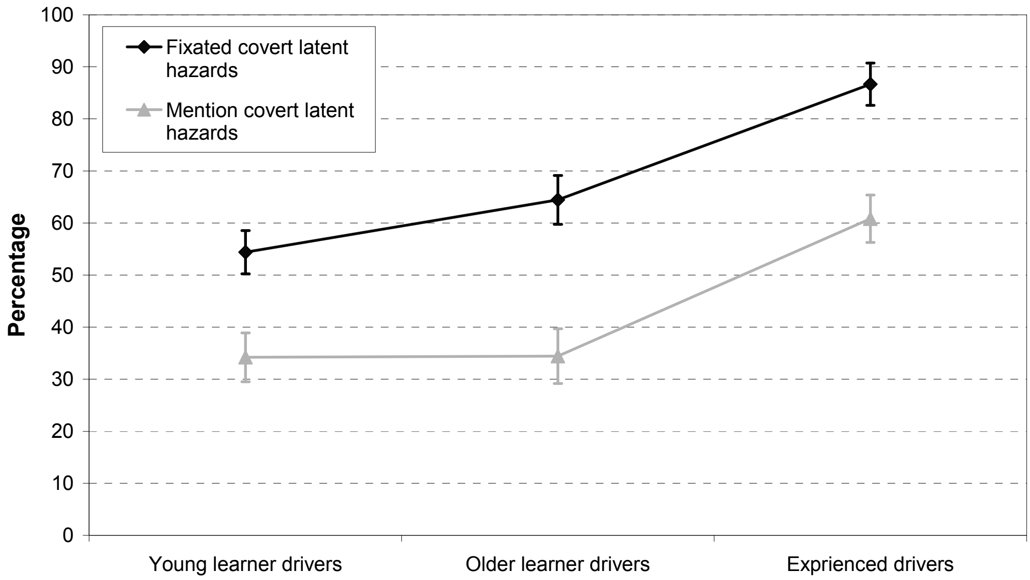

Figure 4.8. Mean percentages fixated and mentioned covert latent hazards per group. Error bars indicate +/- 1 standard error.

For the three groups, the percentage mentioned covert latent hazards was lower than the percentage fixated covert latent hazards and the difference in percentages fixated and mentioned covert latent hazard was more or less constant in the three groups. Repeated measures ANOVA showed that there was indeed parallelism in the two methods of measurement (fixated covert latent hazards and mentioned covert latent hazards) across the groups, $F_{(2,51)} = 0.67$, $p = .52$. This indicates that there probably is a structural difference between fixated covert latent hazards and mentioned covert latent hazards and that mentioned covert latent hazards can be as good an indicator of one's capability to recognize and predict covert latent hazards than recorded fixations by an eye tracker.

Figure 4.9 shows the difference between the fixated overt latent hazards and the mentioned overt latent hazards per group.

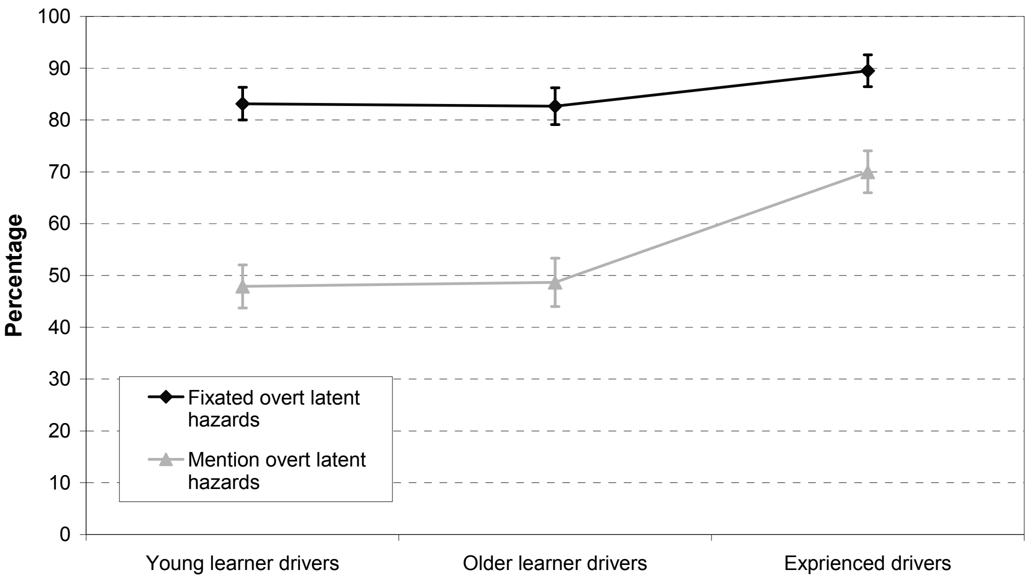

Figure 4.9. Mean percentages fixated mentioned overt latent hazards per group. Error bars indicate +/- 1 standard error.

For the three groups, the percentage mentioned overt latent hazards was lower than the percentage fixated overt latent hazards, but the difference between the two was considerably smaller for experienced drivers than for novice drivers (both young and older). Repeated measures ANOVA showed that there was a significant interaction effect with a large effect size, $F_{(2,51)}$ = 4.11, p < .05, η^2_P = .14. This indicates that fixations on overt latent hazards measure something different from what is measured by the mentioning of overt latent hazards. Probably mentioning overt latent hazards is a better indicator of one's capability to recognize and predict overt latent hazards than fixations on overt latent hazards. Again, it could be that for inexperienced drivers fixations on other road users were more often the result of bottom-up processes and top-down processes not related to hazard perception than for experienced drivers (see for a discussion the next sub-section). The results depicted in Figure 4.7 are in support of hypothesis 6 in Section 4.1.8 that for novice drivers, fixations on overt latent hazards more often are due to gaze control not related to hazard perception than for experienced drivers.

Discussion about fixated latent hazards and mentioned latent hazards

Fixations on overt latent hazards can be the result of different mechanisms. Firstly as was noted before, in situations with overt latent hazards a fixation on another road user is possible without having any expectations that this other road user may start to act dangerously. Secondly, a fixation can be the result of a bottom-up process, but *after* having 'seen' that other road user more or less accidentally, a driver may realize that this other road may start acting dangerously in the given circumstances. This is to say that a bottom-up fixation or a top-down fixation not related to hazard perception has led to the activation of the proper schema for noticing the overt latent hazard. Thirdly, a fixation on another road user can be purely the result of a top-down process related to hazard anticipation. A saccade then is made in the direction of the other road user with the intention to fixate (keep an eye on) this other road user because, based the activated dominant schema, it is expected that in situations like this, particular road users may show dangerous behaviour. These top-down fixations can be automatic when it is a routine overt latent hazard and can be controlled when it is a discovered new type of overt latent hazard.

In the first situation, participants will not mention the overt latent hazard because for them there was no overt latent hazard. In the second and third situation, participants may mention the hazard only when this overt hazard was a serious possible threat for them. In none of the video clips the latent hazards developed into an imminent hazard that required immediate action to avert a crash. When the risk assessment by the participants was low and the overt latent hazard did not materialize, it is likely that the overt latent hazard was immediately forgotten and therefore not mentioned, especially when the latent hazards were 'routine hazards' that did not require involvement of the SAS (see Section 3.8 and Section 4.1.6). This could explain why the percentages mentioned overt latent hazards were also lower than the percentages fixated overt latent hazards for the group of experienced drivers.

In contrast to fixations on overt latent hazards, fixations on covert latent hazards are very likely only top-down and related to hazard anticipation, as there has to be a reason why drivers look in directions where at the particular nothing special can be seen. One can argue that fixated covert hazards that are not mentioned, are more often automated top-down fixations. If this is the case, fixations are made based on the dominant schema that was selected within the CS, without involvement of the SAS (the gray arrow from 'Competitive selection' to 'Gaze control' in Figure 4.1). As these more or less automatic fixations require no decisions based on the processing of information in working memory, they are presumably easily forgotten when the latent hazard does not manifest itself. One can also argue that top-down fixations on covert hazards are mostly not made automatically and require involvement of the SAS. When this is the case, fixated covert latent may be forgotten and not mentioned because the covert latent hazard did not materialize and the risk was assessed as relatively low. If the former hypothesis would be true, the discrepancy between fixated covert latent hazards and mentioned covert latent hazards has to be larger for experienced drivers than for both young learner drivers and older learner drivers, as experienced drivers are supposed to have more automated gaze control. This hypothesis is not supported as the difference between fixated covert hazards and mentioned covert hazards was about the same for learner drivers and for experienced drivers, t (38.8) = 0.28, p = .79. If the latter hypothesis would be true, the discrepancy between fixated covert latent hazards and mentioned covert latent hazards has to be larger for young learner drivers than for older learner drivers, as young learner drivers presumably more often underestimate risks and/or overestimate their skills than older learner drivers. This hypothesis is also not supported as the difference between fixated covert hazards and mentioned covert hazards was not significantly larger for young learner drivers than for older learner drivers, t (32) = -1.14, p = .26. It could be that both hypothesised mechanisms were active and that they neutralized each other effect.

A scale for the hazard detection and recognition task

None of the four variables (fixations on covert latent hazards, fixations on latent hazards, mentioned covert latent hazards and mentioned overt latent hazard) were sufficient internally consistent to be a scale. As it is not exactly clear what the underlying concept of the scales are, scores on the scales cannot be compared with the scores on other tasks (in this case the risk assessment and action selection task) and tests (in this case the visual perception test MVPT-3). When the scores on all the six mentioned covert latent hazards and all the ten overt latent hazards were combined into one variable with the name 'mentioned latent hazard', a variable arose with an acceptable Cronbach's alpha (α = .71). On average young learner driver mentioned 37.7% (SE = 3.1) of the latent hazards. This percentage was 41.4 (SE = 3.5) for older learner drivers and 66.1 (SE = 2.8) for experienced drivers. ANOVA showed that the differences between the groups of mentioned latent hazard were significantly different with a large effect size, $F_{(2,72)}$ = 27.81, p < .001, η_p^2 = .44. Post hoc Bonferroni tests showed that on this variable of mentioned latent hazards, young learner drivers differed significantly from experienced drivers ($p < .001$) and older learner drivers differed significantly from experienced drivers ($p < .001$) but young learner drivers did not differ from older learner drivers ($p = 1.0$). There was a significant relationship between the number of fixated latent hazards and the number of mentioned latent hazard, $r = .52$, $p < .001$. The Cronbach's alpha of the combined scores of fixations on latent hazards was not acceptable ($\alpha = .62$). When in the remainder of this chapter scores on the hazard detection and recognition task are compared with other task and test, only the scores of mentioned latent hazards are considered.

Gender

The sample size of each group was too small to disaggregate by gender. As in the results presented so far, no significant differences were found between young learner drivers and older learner drivers, these two groups were combined in order to create a sample of learner drivers that was large enough to disaggregate. On average female learner drivers mentioned 36.5% ($SE = 3.0$) of the latent hazards and male learner drivers mentioned on average 40.4% ($SE = 3.4$) of the latent hazards. The difference between female learner drivers and male learner drivers was not significant, $t\ (50) = 0.87$, $p = .39$.

4.3.2. The risk assessment and action selection task

Risk score

For every participant, based on their response ('brake', 'release throttle' and 'do nothing') on each of the twenty-five photographs, one final risk score was calculated. This was done in accordance with the procedure described in Section 4.2.4. The Cronbach's alpha was acceptable ($\alpha = .68$). Figure 4.10 presents the boxplot of the results. The solid horizontal lines in the boxes indicate the median, the boxes themselves are the interquartile range, and the whiskers indicate the minimum and maximum values. The mean score is not indicated, but is an imaginary horizontal line through the centre of a box. A final score above zero is too risky and a final score lower than zero is too cautious.

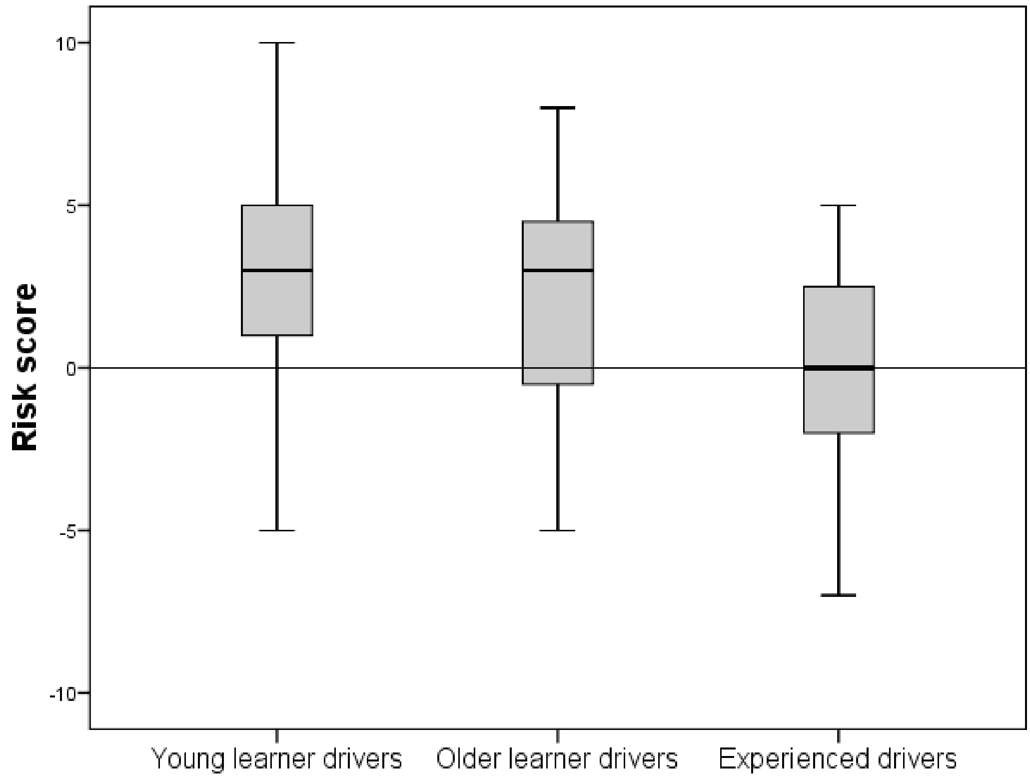

Figure 4.10. Scores on risk assessment and action selection task per group.

The mean scores of young novice drivers, older novice drivers and experienced drivers were respectively; M = 2.61 (SE = 0.76), M = 1.79 (SE = 0.84) and M = 1.00 (SE = 0.65). ANOVA demonstrated that the average scores differed significantly over the three groups with a medium effect size, $F_{(2,71)}$ = 3.63, p < .05, η^2_p = .09. Post hoc Bonferroni tests showed that only young learner drivers differed significantly from experienced drivers (p < .05), but older learner drivers did not differ significantly from experienced drivers (p = .29) and young learner drivers did not differ significantly from older learner drivers (p = 1.0). A t-test for independent samples was conducted, ignoring the existence of the group of experienced drivers. The difference between young novice drivers and older novice drivers was also not significant when this test was conducted, t(40) = 0.69, p = .51. If hypotheses 3 in Section 4.1.8 would be true and the risk assessment and action selection task would really measure the emotional and motivational aspect of hazard anticipation, older learner drivers should have had significantly lower scores on this task than young learner drivers. This is not the case and therefore the results are not in support of hypothesis 3.

Gaze directions and fixation durations while watching the photographs
Before a participant decided what action to take ('brake', 'release throttle', 'do nothing') in the depicted traffic situation if he or she would have been the driver, the participant watched this photograph for eight seconds while her or his eye movements were recorded. Included in the database for analysis were the number of fixations and the total fixation duration on areas of interests (AOIs) containing immanent overt hazards, AOIs containing overt latent hazards and covert latent hazard, the rear-view mirror and the speedometer (see Section 4.2.4).

On average the number of fixation on AOIs containing covert latent hazards were: M = 38.7 (SE = 3.3) for young novice drivers, M = 40.1 (SE = 3.5) for older novice drivers and M = 54.3 (SE = 2.8) for experienced drivers. ANOVA showed that these differences were significant with a large effect size, $F_{(2,56)} = 8.28$, $p < .01$, $\eta^2_P = .23$. Post hoc Bonferroni tests showed that the number of fixations on AOIs containing covert latent differed significantly between young learner drivers and experienced drivers ($p < .01$) and between older learner drivers and experienced drivers ($p < .01$), but not between young learner drivers and older learner drivers ($p = 1.0$). This is in support of hypotheses 1 and 2 that the cognitive aspects of hazard anticipation improves with increasing experience. Whereas the total number of fixations on AOIs containing covert latent hazards differed significantly, the total duration of the fixations on these AOIs did not, $F_{(2,56)} = 1.30$, $p = .28$.

On average the number of fixation on AOIs containing overt hazards (both immanent and latent) were: M = 73.2 (SE = 5.2) for young novice drivers, M = 77.6 (SE = 5.5) for older novice drivers and M = 88.6 (SE = 4.4) for experienced drivers. ANOVA showed that these differences were not significant, $F_{(2,56)} = 2.86$, $p = .07$. Also the total duration of the fixations on AOIs containing overt hazards did not differ between the groups, $F_{(2,56)} = 0.13$, $p = .88$.

ANOVA revealed that both the number of fixations on the rear-view mirror and the total duration of these fixations differed significantly across the groups with in both cases a large effect size. On average the number of fixations on all the rear-view mirrors in the twenty-five photographs was: M = 77.1 (SE = 8.2) for young novice drivers, M = 54.3 (SE = 8.7) for older novice drivers and M = 43.0 (SE = 7.0) for experienced drivers, $F_{(2,56)} = 5.06$, $p < .01$, $\eta^2_P = .15$. On average the total time of the fixations at the rear-view mirror in the twenty-five photographs was: M = 33299.9 ms (SE = 3538.4) for young novice drivers, M = 23341.7 ms (SE = 3753.0) for older novice drivers and M = 16413.32 ms (SE = 16413.32) for experienced drivers, $F_{(2,56)} = 6.62$, p < .01, η^2_P = .19. Post hoc Bonferroni tests showed that both with regard to the number of fixations and the total duration of the fixations in the rear-view mirror, only the differences between young learner drivers and experienced drivers were significant (p < .01). In none of the twenty-five photographs, a hazard was visible in the rear-view mirror. Experienced drivers possibly needed less time to conclude what the consequences were of what is visible in the rear-view mirror than young learner drivers did.

ANOVA showed that neither the number of fixations nor the total duration of the fixations on the speedometer differed between the groups. The results respectively were: $F_{(2,56)} = 1.06$, p = .35 and $F_{(2,56)} = 0.51$, p = .60.

Relationship between eye movements and risk score

A stepwise regression analysis was performed with the risk score as the dependent variable and as predictors: the number of fixations on covert latent hazards, total fixation duration on covert latent hazard, number of fixations on overt hazards, total duration of fixations on overt hazards, number of fixations in rear-view mirror, total duration of fixations in rear-view mirror, the number of fixations on the speedometer and the total duration of the fixations on the speedometer. Only the number of fixations on covert latent hazards was included in the model, $B = -0.07$, $SE\ B = 0.03$, standardized $\beta = -.29$, $p < .01$. The more fixations on covert latent hazards the lower the risk score was. The variation in the risk score the number of fixations on covert latent hazards accounted for was however modest, $R^2 = .08$.

Gender

The group of young learner drivers was combined with the group of older learner drivers in order to create a sample of learner drivers that was large enough to disaggregate by gender. On average female learner drivers had a risk score on the risk assessment and action selection task of 3.5 ($SE = 0.8$) and male novice drivers a score of 3.2 ($SE = 0.8$). The difference was not significant, $t\ (49) = 0.26$, $p = .80$. Based on the literature presented in Section 2.3.2 on biological gender differences and risk acceptance, one would expect that if the risk assessment and action selection task measures the emotional and motivational aspect of hazard anticipation, the risk scores are lower for females than for males. This was not the case and the results are an indication that the risk assessment and action selection task may not have measured what it was supposed to measure.

4.3.3. Relationship between the two tasks

There was a moderate but significant correlation between mentioned latent hazards on the hazard detection and recognition task and the risk scores on the risk assessment and action selection task, $r = -.37$, $p < .01$. MANOVA with mentioned latent hazards on the hazard detection and recognition task and risk scores on the risk assessment and action selection task as dependent variables, showed a significant difference between the groups with a large effect size. $F_{(4,140)} = 10.19$, $p < .001$, $\eta^2_P = .23$. The ANOVA of each of the two dependent variables separately was significant with a large effect size for 'mentioned latent hazards' and a medium effect size for 'risk score', respectively: $F_{(2,70)} = 27.57$, $p < .001$, $\eta^2_P = .44$ and $F_{(2,70)} = 3.63$, $p < .05$, $\eta^2_P = .09$. Apparently, the two tasks together measured an aspect of hazard anticipation that differed significantly between the groups and both the mentioned latent hazards and the risk score contributed to this aspect. The between-subjects SSCP matrix showed that the sums of squares for the SSCP error matrix were substantially larger than in the SSCP model matrix (16506 versus 13000 and 928 versus 96) and the cross-products in the SSCP error matrix and in the SSCP model matrix did not differ too much (-1103 versus -725). This indicates that most likely what both tasks measured in common was of more importance for the results of the MANOVA, than the supposed different aspects of hazard anticipation that were measured by the two tasks. To confirm this, a discriminant function analysis administered. This discriminant function analysis showed that of the two functions only one was significant and the relationship between the only significant discriminant function (function 1) and mentioned hazards was very strong ($r = .99$) and the relationship between the risk score and function 1 was moderate ($r = -.35$). Figure 4.11 shows a plot of the scores on the two functions of the discriminant function analysis of each participant and of the centroids of the three groups.

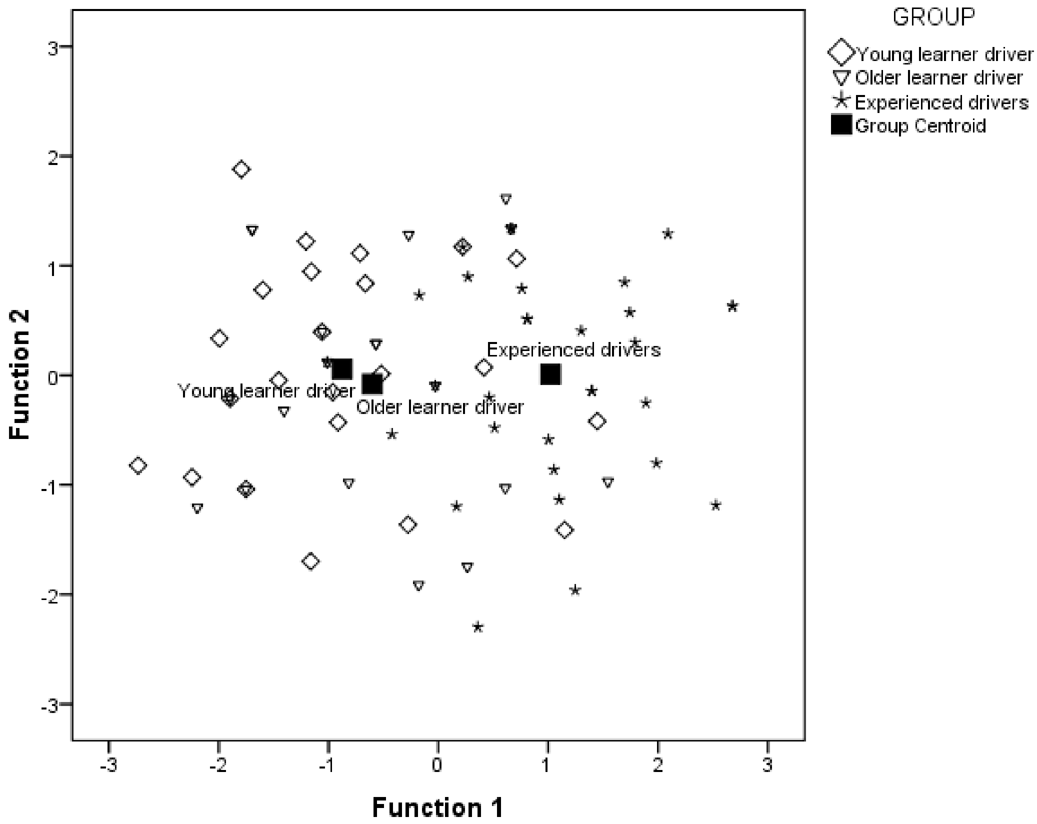

Figure 4.11. Plot of the scores on the two functions of the discriminant function analysis with group (young learner drivers, older learner drivers and experienced drivers) as grouping variable and the 'latent hazard mentioned' and the 'risk score' as the independents.

Figure 4.11 clearly shows that the latent variable 'function 1' discriminated experienced drivers from both young learner drivers and older learner drivers and that the latent variable 'function 2' had no effect. As function 1 correlated strongly with 'latent hazards mentioned' and correlated modestly with 'risk score', it is indeed questionable if the two tasks (the latent hazard detection and recognition task and the risk assessment and action selection task) measured distinct aspects of hazard anticipation. The hazard detection and recognition task seems to be the more influential of the two. The results indicate that the same aspect of hazard anticipation measured by the hazard detection and recognition task to a large extend was responsible for the differences between the groups on the risk assessment and action selection task. As the emotional and motivational aspect of hazard anticipation was not measured independently from what was measured by the hazard detection and recognition task, the results on the risk assessment and action selection task cannot be used to test hypothesis 3 of Section 4.1.8 that the emotional and motivational aspects of hazard anticipation improve with age.

4.3.4. Relationship between tasks and visual perception

On average the norm score on the MVPT-3 was M = 106.9 (SE = 3.3) for young novice drivers, M = 110.3 (SE = 3.6) for older novice drivers and M = 112.0 (SE = 2.8) for experienced rivers. The average norm score in the population per age group is 100. The differences between the groups were not significant, $F_{(2,68)} = 0.73$, $p = .49$. Table 4.4 shows the overall correlation and the correlations per group between the norm scores on the MVPT-3 and the mentioned latent hazards on the hazard detection and recognition task.

Table 4.4. Correlation between norm scores on the MVP-3 and the mentioned latent hazards on the hazard detection and recognition task.

GROUP	*Pearson's correlation coefficient r between norm scores MVPT-3 and mentioned latent hazards*	*p*
Overall	.35	<.01
Young learner drivers	.45	<.05
Older learner drivers	.19	ns
Experienced drivers	.17	ns

Overall there was a relatively small but significant relationship between the norm scores on the MVPT-3 and mentioned latent hazards. The group of young learner drivers contributed more to this overall correlation than the other two groups. There was no significant relationship between the norm scores on the MVPT-3 and the risk scores (r = -.08, p = .49). The results indicate that especially for young learner drivers the skill to detect and recognize latent hazards in a dynamic situation (the video clips) is partly influenced by someone's visual perception abilities as measured by the MVPT-3.

4.4. Discussion

Based on the theoretical framework presented in Chapter 5, it was assumed that hazard anticipation has a cognitive aspect (hazard detection, recognition and prediction) and an emotional and motivational aspect (threat appraisal and risk assessment). The principal hypothesis was that the cognitive aspect mainly improves with experience and that the emotional and motivational aspect mainly improves with age (i.e. maturation of predominantly the PFC). In order to test this hypothesis, two hazard anticipation tasks were developed: a hazard detection and recognition task presumed to measure in particularly the cognitive aspect of hazard anticipation and a risk assessment and action selection task presumed to measure in particularly the emotional and motivational aspect of hazard anticipation. Three groups made the two tasks: young learner drivers that started to take driving lessons as soon as the age limit was reached; older learner drivers that started to take driving lessons when they were 25 years of age or older; and experienced drivers.

Young learner drivers and older learner drivers showed significantly less anticipatory eye glances in situations with covert latent hazards than experienced drivers and there was no significant difference between young learner drivers and older learner drivers. This result is in support of the hypothesis that the cognitive aspect of hazard anticipation improves with experience as far as covert latent hazards concerned. Indications that novice drivers have problems detecting and recognizing covert latent hazards in studies using video clips and eye tracker equipment, were found before (Borowsky et al., 2010; Underwood, Chapman, et al., 2002). However, as in these studies no comparison was made between novice drivers that start to drive late in life and novice drivers that start to drive early in life, these studies did not provide indications whether poor detection and recognition of covert latent hazards is mainly a matter of lack of experience or mainly a matter of age. Pradhan et al. (2005) also found that novice drivers made fewer anticipatory eye glances than experienced drivers in situations with latent hazards of which most of the latent hazards were covert latent hazards. However, in this study participants drove in a simulator. It could be argued that novice drivers make less anticipatory eye glances while driving because the execution of the driving task (manoeuvring, shifting gear, the mastering of basic traffic situations) is not yet performed at the procedural stage (Anderson, 1982). Because of this, more mental capacity is needed for driving itself and therefore less mental capacity can be allocated to the anticipation of possible hazards. Underwood, Chapman et al. (2002) found that novice drivers did not adapt their visual scanning patterns as well as experienced drivers did to the type of road (rural roads versus urban roads) even when they watched videos and did not have to drive. In the study presented in this chapter, learner drivers made less anticipatory eye glances than experienced drivers while they did not have to drive. Both the study of

Underwood, Chapman et al. (2002) and the present study are in support of the hypothesis that lack of hazard anticipation is not caused by limited mental resources remaining for hazard anticipation, but because of poor schemata.

The strong indication found in the present study that the failure to detect and recognize latent hazards, is caused by lack of experience, implies that that the cognitive aspect of hazard anticipation is trainable. Although the cognitive aspect of hazard anticipation is in principle supposed to be trainable, a certain predisposition for detecting and recognizing latent hazards cannot be ignored. There was indeed a relatively weak but significant relationship between the scores on a visual perception test (MVPT-3) and the number of mentioned latent hazards on the hazard detection and recognition task, especially for young learner drivers.

Experienced drivers had a significantly lower risk score on the risk assessment and action selection task than young learner drivers, but older learner drivers did not have a significantly lower risk score than younger learner drivers. When assumed that the risk assessment and action selection task measures predominantly the emotional and motivational aspect of hazard anticipation, these results do not support the hypothesis that the emotional and motivational aspect of hazard anticipation improves when the brain matures. With hindsight, it is questionable if the risk assessment and action selection task measured the emotional and motivational aspect of hazard anticipation. There was a moderate but significant relationship between mentioned latent hazards on the hazard detection and recognition task and the risk assessment and action selection task. This is an indication that risk assessment and action selection task did not measure something that was completely different from what the hazard detection and recognition task measured. Moreover, detailed examination of the results of a multivariate analysis and a discriminant function analysis revealed that both tasks largely measured the same underlying concept and that this concept was measured better by the hazard detection and recognition task than by the risk assessment and action selection task. The emotional aspect of hazard anticipation was measured indirectly by asking participants what to do in situations of which was assumed that hazard detection was easy. Probably the detections of in particularly latent hazards in the photographs was not so easy after all. It would have been better if the emotional aspect was measured directly. Kelly et al. (2010) have measured skin conductance response (SCR) in a task that was similar to the risk assessment and action selection task. This is to say, they measured SCR while participants watched photographs with no hazards, with latent hazards and with imminent hazards. They found that while participants watched photographs with latent hazards the percentage of SCRs was significantly higher for experienced drivers than for novice drivers. It would be interesting to test if young learner drivers and older learner drivers differ in SCRs. Measuring SCRs is a possibility, but it is likely that it will remain difficult to measure the emotional and motivational aspect of hazard anticipation in laboratory conditions. The risks are never real and intentions can be very different in laboratory conditions from driving in real traffic. In real traffic novice drivers can drive with for instance their friends as passengers and in real traffic they know that that they are not observed by experimenters.

In the introduction of this chapter, the neuropsychological framework on hazard anticipation presented in Chapter 4, was connected with neuro-biological model on attention developed by Knudsen (2007). The reason was that gaze control is an integrated part of this model on attention and in the experiments presented in this chapter eye movements were used to measure hazard anticipation. Fixations on overt latent hazards can be the result of bottom-up processes, top-down processes not related to hazard anticipation and top-down processes related to hazard anticipation. Fixations on covert latent hazards are presumably only top-down and related to hazard anticipation if they are not accidental. In case of top-down fixations, either on overt latent hazards or on covert latent hazards, fixations can be controlled (i.e. the SAS is involved), or automatic (i.e. based on contention scheduling only). Top-down fixations are automatic when a driver encounters situations that contain 'routine' latent hazards. When a fixation is bottom-up or top-down not related to hazard anticipation, a participant will not mention the latent hazard. It was expected that the proportion fixated, but not mentioned overt latent hazards would be larger for inexperienced drivers (young learner drivers and older learner drivers) than for experienced drivers (hypothesis 6 in Section 4.1.8). The results support this hypothesis. Inexperienced drivers (both young and older) more often fixated overt latent hazards without mentioning them than older, more experienced drivers did. A practical consequence of this result is that in contrast to fixations on covert latent hazards, someone's ability to detect and recognize overt latent hazards cannot be tested with eye tracking equipment only.

Finally, it was hypothesised that in contrast to experienced drivers, inexperienced drivers (young learner drivers and older learner drivers) have more difficulties to detect and recognize covert latent hazards than to detect and recognize overt latent hazards. The detection and recognition of a covert latent hazard requires the selection of a dominant schema that can predict the hazard on context aspects only. The possibility of an invisible other road user on collision course is something the driver has to infer from other visual cues (e.g. 'there can be something behind this lorry that blocks my view'). On the other hand, in case of overt latent hazards content aspects are visible. To put it differently: It is probably more difficult to expect things to happen without direct visible cues than to expect actions from others who are visible. As fixations on overt latent hazards not necessarily indicate that an overt latent hazard was recognized, only differences in mentioned overt latent and covert latent hazards in each group can provide information in support or not in support of the hypothesis. For both young learner drivers and older learner drivers the percentage of mentioned covert latent hazards was significantly lower than the percentage of mentioned overt latent hazards, but the difference in percentages mentioned overt latent hazards and mentioned covert latent hazards was not significant for experienced drivers. These results are in support of the hypothesis.

Interestingly, the hazard detection and recognition task could be developed into a diagnostic tool for (learner) drivers to test their cognitive aspect of hazard anticipation, without the use of an eye tracker. The scale of mentioned latent hazards (overt and covert latent hazards combined) had an acceptable internal reliability, there was a large difference between experienced drivers and inexperienced driver and the relationship between fixated covert latent hazards and mention covert latent hazards was substantial. Jackson et al. (2009) used a slightly different task. In this task video clips were paused when overt latent hazards just became visible, but had not (yet) developed into an imminent threat. The screen turned black and participants had to tell what could happen next. Jackson et al. (2009) also found that experienced drivers mentioned significantly more potential hazards than inexperienced drivers. In the present study, participants watched short video clips in which overt latent hazards and covert latent hazards did not materialize. Directly after each clip participants were asked what could have happened that did not happen. Participants could also mention what drew their attention while they watched the video clip. An advantage of the method used in the present study is that participants are not triggered by what they have seen immediately before the video clip stopped. It could be that when the video stops after the first signs of the development of an overt latent hazard, this hazard was not recognized just before the video halted and the screen turned black. The very fact that the video stopped at that particular moment may help the participant realize that there could have been a hazard (McGowan & Banbury, 2004), even when the screen has turned black. A disadvantage of asking participants what could have happened that did not happen at the end of a video clip, the method applied in the present study, is that participants may have forgotten the latent hazard, even when a video clip lasts no longer than 40 s.

A limitation of the study presented in this chapter is that the samples of young novice drivers and older novice drivers may be biased. Age may be not the only difference between the two groups. It is practically impossible to assign participants randomly to a group by telling one participant you do the driving test now and to the other participant you do the driving test over seven years. There may be motives for the choice to start driving early in life or to start driving late in live that affect hazard anticipation.

5. Testing hazard anticipation, an exploratory study

5.1. Introduction

The aim of the research presented in this chapter was to examine if practical versions of the tasks presented in Chapter 4 (the hazard detection and recognition task and the risk assessment and action selection task) can be developed into tests that in principle are suitable for incorporation in the theory test of the driving test. Two studies are presented in this chapter. The aim of these two studies was to explore the validity of variants of the tasks applied in Chapter 4, with response methods that allow for mass testing. In this exploratory phase, it was not the intention to produce readymade tests that meet all the psychometric criteria. The research presented in this chapter was conducted before the research presented in the former chapter of this thesis.

With the hazard detection and recognition task presented in Chapter 4, it is not feasible to test hazard anticipation skills in the theory part of the driving test because eye trackers are expensive and data analysis is time consuming. Moreover, not everyone's eyes can be calibrated. The results of Chapter 4 however indicate that eye tracking equipment is not always an absolute prerequisite to reveal information about one’s skill/ability to detect and recognize latent hazards. It turned out that mentioning what could have happened that did not happen directly after each video clip, also was a good indicator of one's ability/skill to detect and recognize latent hazards. However, answers on open questions are also not a feasible response method for the theory part of the driving test. The answers have to be interpreted and the analysis of spoken answers requires time. Spoken answers to questions are probably also not a reliable response method unless tested on interrater reliability. In this chapter, therefore a variant of the hazard detection and recognition task is explored in which participants have to click with their mouse on overt latent hazards and covert latent hazards. This is to say that looking at someone who could start acting dangerously and looking in a particular direction from where a road user on collision course may appear, is replaced by pointing and clicking with a mouse at someone and pointing and clicking in a direction from where a road user may appear.

In contrast to the hazard detection and recognition task, the risk assessment and action selection task applied in Chapter 4, is a task with a response method that is suitable for incorporation in the theory test if all the psychometric criteria are met. The only difference between the type of task in Chapter 4 and the type of task presented in this chapter, is that participants had to respond within the time the photograph was exposed on the screen and not after the exposure of a photograph.

Although for both tasks in Chapter 4 the difference between learner drivers and experienced drivers was statistically significant, the hazard detection and recognition task was considerably better in discriminating learner drivers from experienced drivers than the risk assessment and action selection task. The results presented in Chapter 4 further indicated that the two tasks probably do not measure different aspects of hazard anticipation (the cognitive aspect and the emotional and motivational aspect), but rather one. Largely, this aspect appeared to be the cognitive aspect of hazard anticipation. Because of these results, more neutral names are used in this chapter for the practical version of the hazard detection and recognition task and the practical version of risk assessment and action selection task. In this chapter, the practical variant of the hazard detection and recognition task is named the *video task* and the practical variant of the risk assessment and action selection task is named the *photo task.*

An important criterion for a test is its concurrent validity. An indication for the concurrent validity of the tasks would be if participants with a high crash rate have lower scores on both the video task and the photo task than participants with a low crash rates. In the experiments presented in Chapter 4, it is demonstrated that on both tasks learner drivers had significantly lower scores than experienced drivers. This fact is an indication for the convergent validity of the two tasks, as in general experienced drivers have a lower crash rate than novice drivers. The question is whether the practical versions of the two tasks also have convergent validity. In this chapter, concurrent validity is examined by means of self-reported crashes. The hypotheses are:

- The video task and the photo task have concurrent validity. If these tasks have concurrent validity this would imply that controlled for exposure, crash free novice drivers have higher scores on both task than novice drivers that have reported a crash;
- The video task with mouse clicks and the photo task have convergent validity. If the two tasks have convergent validity this would imply that the more experienced drivers are the higher their scores on both the video task and the photo task will be.

As the version of the video task with the mouse clicks failed to discriminate between learner drivers, novice drivers and experienced drivers (i.e. there was no convergent validity), an improved version of the video task was developed. The hypothesis research question in this second study was:

- The improver video task has convergent validity, implying that professional drivers have higher scores on this improved video task than learner drivers.

Research that is necessary to test the first hypothesis of the first study (on concurrent validity) could not be conducted in the second study, as no crash data were available of the participants in study 2.

5.2. Study 1

5.2.1. Method

The video task

Just as in Chapter 4, animated video clips were developed that contained at least one latent hazard. Also just as in Chapter 4, a distinction was made between covert latent hazards and overt latent hazards. Figure 5.1 shows two screen captures of a developing traffic situation. Both the driver and the lorry are turning left. The left screen capture is of an earlier moment in time than the right screen capture. Is the participant aware of the fact that the lorry blocks her or his view and that another car or motorcycle may suddenly appear at the position where the cross is put in the right picture? This is the same situation as depicted in Figure 3.9, but now from the perspective of the driver.

Figure 5.1. Example of a covert latent hazard.

Figure 5.2 shows a typical example of an overt hazard. As in the screen capture the pedestrian is already running, this is not an example of an overt latent hazard, but of an overt hazard. Is a participant (before the moment of the screen capture and the pedestrian was still walking) aware of the fact that a pedestrian could start running and suddenly cross the road because this pedestrian might want to catch the approaching bus that stops in the opposing lane at the bus stop?

Figure 5.2. Example of an overt hazard.

In cooperation with five driving examiners, twelve scenarios were developed, each containing at least one covert latent hazard or one overt latent hazard they could remember that candidates failed to detect and recognize during test drives. Based on these scenarios, twelve detailed animation clips were made, each lasting about thirty-five seconds. All videos were 'taken' from the driver's perspective. Animation was used because it is easier to stage scenes in animation videos than in real life videos. In none of the clips the hazards materialized. This means that no car suddenly emerged from behind an object that blocked the view and no other road users performed risky actions.

An interactive pointing system (with a computer mouse) was applied. At certain moments in each clip, the clip was paused for 5 s. These short pauses with a frozen traffic situation on the screen were necessary to allow participants to make mouse clicks. During these pauses participants could click on covert latent hazards and on overt latent hazards. They also could click on small rectangles located at the left and right side of the screen. With a mouse click on the right rectangle participants could indicate that they would have looked to the right in search of a hazard if this would have been possible. With a mouse click on the left rectangle participants could indicate the same for hazards to the left. In each pause only the first three clicks, including the clicks on the rectangles were recorded. To ensure that participants concentrated on the task and did not randomly click as many times as possible, participants were told that clicks on irrelevant spots would lower their score. Not all pauses contained three latent hazards and in some pauses, there were no latent hazards at all. A disadvantage of pauses is that participants can reorient themselves (McGowan & Banbury, 2004). This is to say, the very fact that a video clip pauses, could be a cue for participants to start searching for latent hazards they had not noticed while the video was still running. The pause itself, in contrast to driving in the real world, also facilitates participants with time to search for these possible latent hazards. This was another reason to instruct participants in advance that false clicks would lower their score and to keep the pauses short (5 s).

Just as in the hazard detection and recognition task of Chapter 4, before the start of each video clip a plan view was presented of the manoeuvre the car would make in the video clip. The number of pauses per video clip differed and ranged between three and six per clip. When a pause started, a count-down timer was visible on the bottom of the screen, indicating the time left for pointing and clicking. On spots where a click was made a green cross appeared. However, after three clicks in a pause no more crosses appeared when a click was made. In contrast to video clips used in Chapter 4, no part of a dashboard and a steering wheel was visible. See for an example of a pause Figure 5.3.

Figure 5.3. Screen capture of a pause in the video task. In this video, the driver turns left. A click on a rectangle to the left or to the right meant that participants wanted to look either left or right in this situation if possible. The dark bar underneath the picture is the countdown timer.

The coordinates of the clicks were automatically captured in a database. For scoring, so called 'hot spots' were defined. A click within the area of a hot spot resulted in a score. Clicks in the hot spots that contained the covert latent hazard and/or the overt latent hazards were rewarded with four points. Clicks in hot spots that provide relevant information about the developing situation (e.g. a traffic sign that tells the driver that she or he is approaching a dangerous intersection) were scored with one point. Clicks in hot spots that were completely irrelevant (e.g. a sign with no relevant information for the driver) were scored -1. The hotspots were defined in close cooperation with three experienced driving examiners. Subsequently, the complete test and the scoring system were reviewed by six driving examiners who were not involved the development of the video task. Based on their remarks, hotspots were revised.

The photo task

Three experts on theory testing of CBR made Forty-four photo items. This was done the same way as described in Section 4.2.2 of Chapter 4. The photographs were taken earlier in time and were different from the photographs that were applied in the experiment presented in Chapter 4. Just as in Chapter 4, pictures were taken with imminent hazards, latent hazards and no hazards. In combination with the indicated speed, the correct response was supposed to be 'brake' in case of an imminent hazard, 'release throttle' in case of a latent hazard and 'do nothing' in case of no hazard. The procedure to select photographs for the task was different. In Chapter 4, photographs were included if independent from each other 80% or more of a forum consisting of fifteen experts had the same response. This time in a pilot study thirty-two driving examiners completed the task with the forty-four photographs and a group of twenty learner drivers completed this task. Only those photographs were included of which 80% or more of the driving examiners had the same response and less than 80% of the learner drivers made this response. It appeared that most of the photographs with 'do nothing' as a correct response, caused no problems for the group of learner drivers. These items were scored correctly by almost all learner drivers of the pilot study and therefore showed no variation in response. It was difficult to make photographs of which the correct response was 'do nothing' that were sufficiently complex to elicit another response than 'do nothing' in the group of learner drivers. Of the forty-four photographs only eighteen were included in the task. The correct response of nine items was 'brake', of seven items the correct response was 'release throttle' and of two items the correct response was 'do nothing'. Each photograph was presented on a computer screen for a maximum duration of 8 s. During the time a photograph was exposed on the monitor of a computer, participants had to press either key 1 for 'brake', key 2 for 'release throttle' or key 3 for 'do nothing' on the keyboard. At the bottom of the screen, a countdown timer bar was visible. As soon as a key stroke was made or the time limit was reached, the photograph disappeared from the screen and the staring screen of the next item appeared. This new item could be started by pressing the space bar. The participants were free to choose the moment when to respond within the timeframe of eight seconds a photograph was exposed on the screen. In the response method applied in Chapter 4 participants only could answer after the photograph had been exposed for eight seconds and the screen had turned black.

5.2.2. Participants

Both tasks were completed by three groups. The groups were:

- *Learner drivers* on the day that they successfully passed the driving test (n=30; 47% male; mean age = 20; SD = 2.6).
- *Novice drivers* that all had held their driving licence for eighteen months (n=76; 50% male; mean age = 21.6; SD = 1.8).
- *Experienced drivers* that had held their driving licence for more than 10 years (n=34; 53% male; mean age = 41.8; SD = 5.7).

Participants of the first group (the learner drivers) were recruited at test centres of CBR. After candidates have heard they passed the driving test, they have to wait at the examination centre for the official documents. During this time, they were asked to do the tasks. None of the candidates refused.

For the group of novice drivers a sample from another study (De Craen, 2010) was used. This was a longitudinal study about the effects of driving experience on 'calibration' in young novice drivers (see Section 3.3.2 and Section 4.1.3). In this study, participants kept a diary (on internet) about their driving experience from the moment they successfully had passed the driving test. Participants for the mentioned study of De Craen were also recruited at test centres of CBR. Of the participants that were asked to participate in that longitudinal study, 8% refused. None of participants in the sample of the longitudinal study (thus the ones that partook in that study) refused to partake in the present study. When the participants completed the tasks of the present study, they all held their driving licence for eighteen months. Of the seventy-six participants in this group, thirteen had reported at least one minor crash in traffic (reported crashes on for instance parking areas were excluded) on their internet diary during the past eighteen months. Every four months during three consecutive weeks the novice drivers also had to report how many days per week they had made use of a car as a driver.

For the group of experienced drivers, the sample of the aforementioned longitudinal study was used too. For this longitudinal study, addresses of experienced drivers were randomly selected from the database of the Dutch Vehicle Technology and Information Centre (RDW). None of the experienced drivers in this sample refused to partake in the present study.

5.2.3. Procedure

Participants were seated approximately 60 cm from a 15'' LCD-screen (aspect ratio 4:3). The diagonal of the photographs in the photo task was 30 cm and the diagonal of the animation video clips was 26.5 cm. This provided participants with a horizontal visual field of approximately 23° for the photo task and of approximately 20° for the video task. Before each task, written information was provided on the screen about the aim of the task and the response method. Before the actual task started, participants could practice with three photographs in case of the photo task and two video clips in case of the video task. On average, instruction and familiarisation took no longer than two minutes for the photo task and four minutes for the video task. The tasks were administered counterbalanced. It took about 25 min to complete the two tasks, including instruction and familiarisation. Participants received no financial reward for participation.

5.2.4. Data analysis

A between-groups design was applied. Before testing on significant differences between groups ($p < .05$), the assumptions for parametric testing were checked. In all cases the criterion of normal distribution were met, but in some cases the criterion with regard to homogeneity of variance was not met. In cases the equality of variances was violated, a t-test for independent samples was applied not assuming equality of variance. Univariate analyses of variance (ANOVA) or univariate analyses of covariance (ANCOVA) were applied where more than two groups were compared. When more than two groups were compared, the Bonferroni post hoc tests were applied to check for significant differences between two groups within the three groups. Pearson's correlation coefficients (denoted as r) were calculated to express the relationship between the scores on the photo task and the video task. Multivariate analyses (MANOVA) and discriminant function analysis were also applied to examine the relationship of the scores on both tasks. Besides significance of results, the effect size (Partial èta squared, η^2_P) was considered with $\eta^2_P = .01$ as a small, $\eta^2_P = .06$ as a medium, and $\eta^2_P = .14$ as a large effect size (Cohen, 1988). Prior to the statistical analysis the internal consistency reliability (Cronbach's α) was considered with $\alpha > .65$ as acceptable.

5.2.5. Scores on the video task

In total, participants could click on forty-three areas that were rewarded with scores. The internal reliability of the responses of all the participants of the three groups was acceptable (α = .84). Figure 5.4 presents the boxplot of the percentage of the maximum scores per group of clicks that were correct.

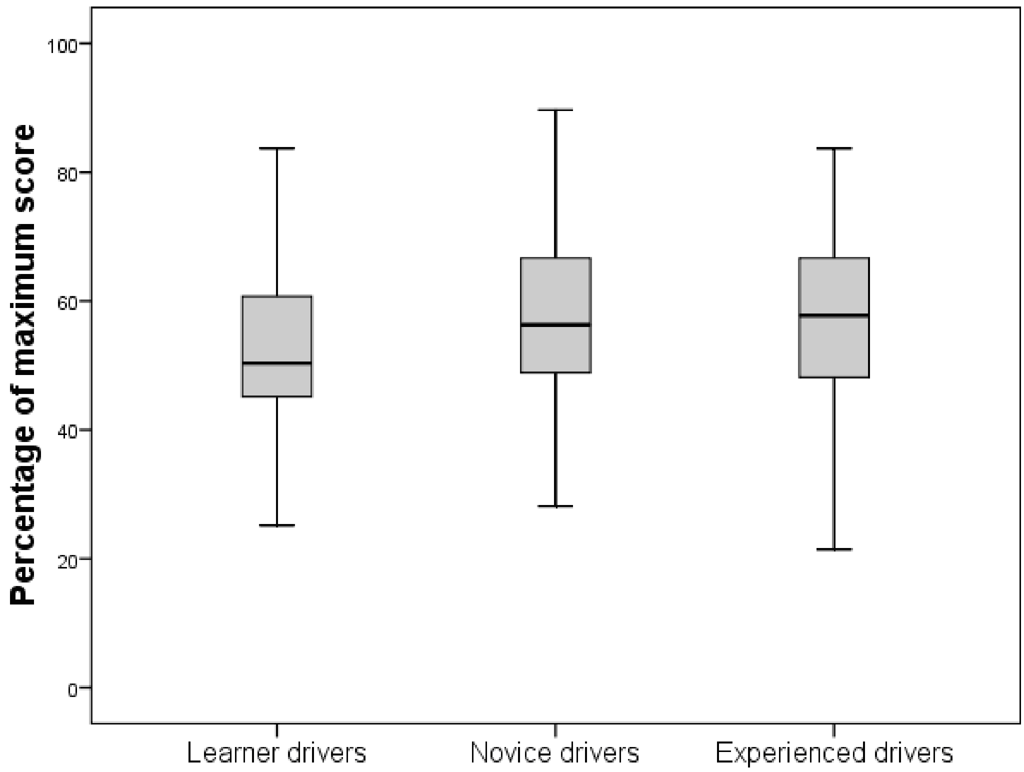

Figure 5.4. Percentages of clicks that were correct of learner drivers, novice drivers and experienced drivers.

The mean percentages correct clicks were: M = 51.5 (SE = 3.0) for learner drivers, M = 54.7 (SE = 1.9) for novice drivers and M =55.4 (SE = 2.9) for experienced drivers. ANOVA revealed that there was no significant difference between the groups, $F_{(2,137)} = 0.53$, p = .59. In all three groups, male drivers did not differ significantly from female drivers.

In the group of novice drivers the mean percentage correct clicks of the crash free drivers was M = 57.3 (SE = 1.8). For the drivers with at least one self-reported crash this mean percentage was M = 42.7 (SE = 7.9). A t-test for independent samples where equal variances is not assumed, showed that this difference was marginally significant, t (13.2) = 1.78, p = .098.

5.2.6. Overt and covert latent hazards

A distinction was made between clicks on overt latent hazards and clicks on covert latent hazards. In total, there were thirty-two overt latent hazards and eleven covert latent hazards. The mean percentages correct clicks on overt latent hazards were: *M* = 30.0 (*SE* = 3.4) for learner drivers, *M* = 37.9 (*SE* = 2.2) for novice drivers and *M* = 34.7 (*SE* = 3.2) for experienced drivers. ANOVA showed there was no significant difference between the groups with regard to clicks on overt latent hazards, $F_{(2,137)} = 1.91$, $p = .15$. In the group of novice drivers, male novice drivers clicked on 42.4% of the overt latent hazards and female novice drivers on 32.2% of the overt latent hazards. This difference was significant and had a small effect size, $t\ (72) = 2.16$, $p < .05$, $\eta^2_p = .056$. In the other two groups, male drivers did not differ significantly from female drivers with regard to clicks on overt latent hazards. No significant differences were found with regard to clicks on overt latent hazards between the crash free novice drivers and the novice drivers that had reported at least one crash, $t\ (74) = 1.05$, $p = .30$.

The mean percentages correct clicks on covert latent hazards were: *M* = 48.9 (*SE* = 3.7) for learner drivers, *M* = 47.6 (*SE* = 2.4) for novice drivers and *M* = 43.6 (*SE* = 3.5) for experienced drivers. ANOVA showed there was no significant difference between the groups with regard to covert latent hazards, $F_{(2,137)} = 0.62$, $p = .54$. In all three groups, male drivers did not differ significantly from female drivers with regard to covert latent hazards. No significant differences were found with regard to clicks on covert latent hazards between the crash free novice drivers and the novice drivers that had reported at least one crash, $t\ (74) = 0.28$, $p = .78$

5.2.7. Scores on the photo task

Analysis of the final scores

The internal reliability of the scores on the eighteen photographs of the photo task was acceptable, $\alpha = .68$. Figure 5.5 shows the boxplot of the results.

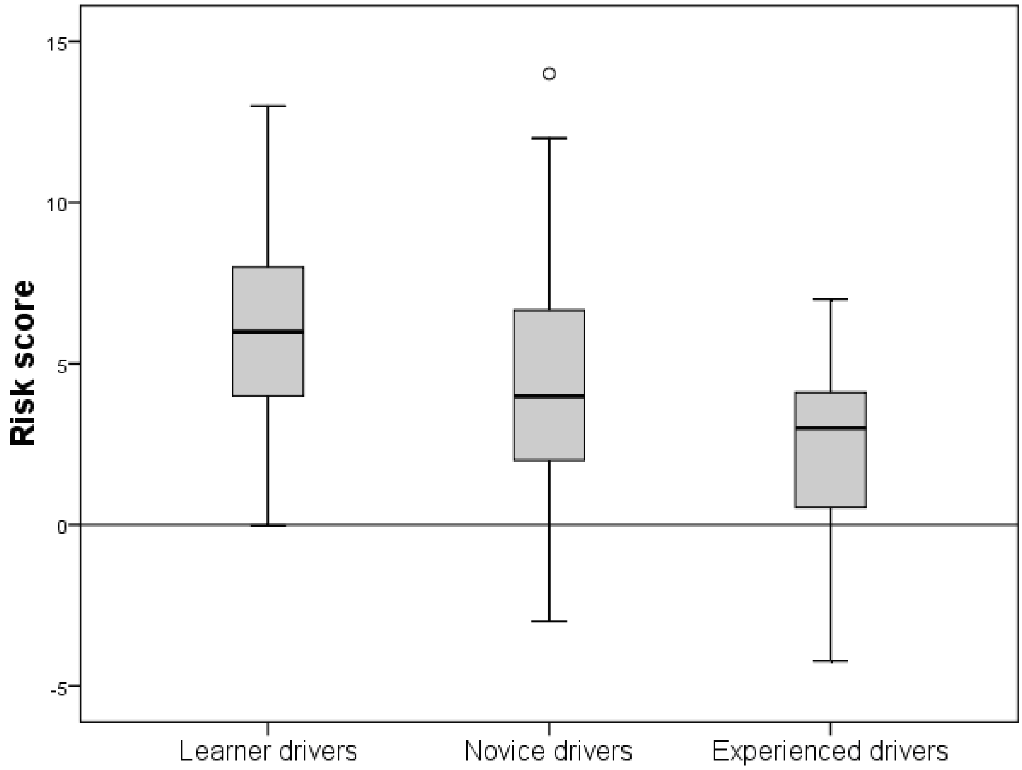

Figure 5.5. Risk scores on the photo task. Scores above zero reflect the tendency to opt for riskier actions than the reference group of driver examiners and scores lower than zero reflect the tendency to opt for more cautious actions than the reference group of driving examiners.

The mean risk score was M = 6.0 (SE = 0.6) for learner drivers, M = 4.1 (SE = 0.4) for novice drivers and M = 2.8 (SE = 0.6) for experienced drivers. ANOVA showed there was a significant effect of group with a medium effect size, $F_{(2,137)} = 6.0$; $p < .01$, $\eta^2_P = .08$. Post hoc Bonferroni tests showed that the decrease in average risk score was significant between learner drivers and novice drivers ($p < .05$) and between learner drivers and experienced drivers ($p < .01$), but not between novice drivers and experienced drivers ($p = .20$). Note that on average the experienced drivers had a higher risk score than the group of driving examiners that assessed and selected the photos as their risk score would have been M = 0. The mean score for all male drivers was M = 3.3 (SE = 0.4) and for all female drivers the mean score was M = 5.0 (SE = 0.4). This difference was significant and the effect size was small, t (138) = -2.48, $p < .01$., $\eta^2_P = .055$. The difference between male and female drivers was not significant for the learner drivers and marginally significant for the novice drivers, respectively; t (28) = -.23, p = .82, and t (74) = -1.95, p = .06. The difference between experienced male and experienced female drivers was significant with women having the higher risk scores, t (32) = -3.22, $p < .01$.

The effect size was small, $\eta_p^2 = .05$. The fact that there was no significant decrease in risk scores between novice drivers and experienced drivers thus presumably is caused by the relative high risk scores of the experienced female drivers.

Of the group of novice drivers, thirteen had reported at least one (minor) crash in traffic since the day they had passed the driving test and sixty-three had not reported a crash. The mean risk score of the crash drivers was $M = 6.0$ ($SE = .9$) and the mean risk score of the crash free drivers was $M = 3.7$. The difference was significant and had a medium effect size, t (74) = -2.18, $p < .05$, $\eta_p^2 = .06$. To control for possible differences in exposure, the average number of days per week of driving was used as a covariate. Also with this covariate, the difference between crash drivers and crash free drivers remained statistically significant, $F_{(1, 73)} = 4.00$; $p < .05$. The effect size was small, $\eta_p^2 = .05$.

5.2.8. Differences between the tasks

There was a weak but significant relationship between the number of clicks on latent hazards in the video task and the risk score on the photo task, $r = -.18$, $p < .05$. MANOVA with clicks on latent hazards in the video task and risk scores on the photo task as dependent variables indicated a significant difference between the groups with a small effect size, $F_{(4,274)} = 3.45$, $p < .01$, $\eta_p^2 = .04$. As already mentioned, there was no difference between the three groups on the video task ($F_{(2,137)} = 0.53$, $p = .59$) (see Section 5.2.5) and there was a significant difference between the groups on the photo task ($F_{(2, 137)} = 6.0$; $p < .01$, $\eta_p^2 = .08$) (see Section 5.2.7). This indicates that the contribution to the variance of MANOVA was larger for the photo task than for the video task. A discriminant function analysis showed that of the two underlying functions, only one was significant. The standardized canonical discriminant function coefficient was high for the relationship between this function and the risk scores on the photo task, $r = .98$. And the standardized canonical discriminant function coefficient was low for the relationship between the number of correct clicks on the video task, $r = -.10$. This implies that the weak relationship between the two tasks was caused by one underlying construct that was measured by both tasks and that the contribution of the scores on the photo task to this construct was large and the contribution of the scores on the video task was negligible.

5.2.9. Discussion

The objective of the study was to explore whether versions of the hazard detection and recognition task of Chapter 4 and the risk assessment and action selection task of Chapter 4 with response methods suitable for mass testing, would show: (1) substantial lower scores on both tasks for novice drivers than for experienced drivers, and (2) substantially higher scores for crash free novice drivers than for novice drivers with self-reported (minor) crashes. The photo task in this study did not differ much from the risk assessment and selection task that was applied in Chapter 4. In contrast to the risk assessment and action selection task of Chapter 4, participants had to respond within the maximum eight seconds a photograph was exposed on the screen and not after eight seconds when the screen had turned black. A second difference was a countdown timer bar that was visible at the bottom of the screen. The video task, however, differed genuinely from the task applied in Chapter 4. In the hazard detection and recognition task of Chapter 4, two response methods were used: recorded fixations on overt latent and covert latent hazards and mentioned latent hazards. In the video tasks pointing with a mouse and clicking replaced the eye fixations. As much more time is required to point and click than for a saccade, it was necessary to freeze the screen during five seconds a view times per clip to allow for pointing and clicking. In order to prevent possible negative effects from the interruptions (the pauses), such as the possibility that the pause would trigger the presence of a latent hazard not noticed while the video was running, pauses were also inserted not containing a latent hazards and participants were told that incorrect clicks would lower their score.

The difference between learner drivers and experienced drivers on the photo task with the learner drivers having the highest risk scores was of the same magnitude as in the very similar risk assessment and action selection task in Chapter 4. The average risk score of novice drivers with eighteen months driving experience was in between the average risk scores of the learner drivers and the experienced drivers. The average risk score of novice drivers was significantly lower than the average risk score of the learner drivers, but not significantly higher than the average risk score of the experienced drivers. This could indicate that what is measured by the photo task, and based on the results of Chapter 4 this presumably is more hazard detection and hazard recognition than risk assessment, improves rapidly after licensing. This is in line with the rapid decline in crash rate in the first period after licensing (see Section 1.2). On the very similar risk assessment and action selection task of Chapter 4, older learner drivers did not have a significantly lower risk scores than younger learner drivers. This suggests that what is measured by the photo task improves with experience and not with age. This fact and the fact that on average female drivers had higher risk scores than male drivers are indication that the photo task did not measure the emotional and motivational aspect of hazard anticipation. As the tendency to take risks in traffic among male drivers (especially among young male drivers) is greater than among young female drivers (e.g. Laapotti, Keskinen, & Rajalin, 2003) (see also Section 2.3.2), risk scores should have been lower for males than for females, should the photo task have measured the emotional and motivational aspect of hazard anticipation. The scores on the photo task for learner drivers, novice drivers and experienced drivers support the hypothesis that the photo task has convergent validity.

Controlled for exposure (expressed in number of car trips per week) crash free novice drivers had a lower risk score on the photo task than novice drivers that had reported a crash. This supports the hypothesis that the photo task has concurrent validity. The photo task might be a low cost alternative for the most commonly used hazard perception task in which participants must push button or to point with their finger on the screen as soon as they have detected a developing hazard while watching video clips from the driver's perspective (e.g. Grayson & Sexton, 2002; Horswill et al., 2008; McKenna & Crick, 1997; Sagberg & Bjørnskau, 2006; Sexton, 2000; Wetton et al., 2010). As a possible test the photo task however also has weaknesses. The ability to discriminate between learner drivers and experienced drivers was poor in comparison to the version of the video task in which participants had to mention the latent hazards in Chapter 4. Although the internal consistency of the photo task was just acceptable to study differences between groups, it is too low to test individual candidates. The relatively low internal consistency of the photo task possibly results from differences in difficulty of the individual test items. Some items were easy and some items were difficult. Especially photographs with 'do nothing' as correct response appeared to be too easy to answer.

The video task, the variant of the hazard detection and recognition task with mouse clicks as respond method, failed to discriminate between the groups. These results do not support the hypothesis that the video task has convergent validity. This is surprising as the variants of this task applied in Chapter 4 (mentioned latent hazards as response method and fixations on covert latent hazards as response method) revealed considerable differences between learner drivers and experienced drivers. There are several possible causes for this failure: (1) the task with the mouse clicks was too complex, (2) the response method was disadvantageous for the group of older more, experienced drivers, and (3) the interruptions (the pauses for clicking) enabled the participants to discover latent hazards they had not noticed before (McGowan & Banbury, 2004). These possible causes are elaborated below:

1. **Complexity**
   Participants could not only click on areas on the screen, but could also indicate if they preferred to look to the left or to the right in order to search for possible hazards. This is rather complex and not a natural action in this context. Test instruction and familiarisation (with two animation videos) was limited to four minutes and it is questionable if all participants were equally well prepared to complete the task. The animated video clips were made before the video clips that were used in Chapter 4. Some of the latent hazards in the old video clips used in the present study were rather ambiguous as the pauses were not always at the right moment. The animated video clips were produced with a software application that at that moment in time could not adequately model car behaviour. Because of this, vehicles in the traffic scene not always moved naturally. There was no dashboard visible at the bottom of the screen. This could have made some participants believe they were not the driver, but the driver of the lead vehicle in the video clip as sometimes is the case in computer games. The computer monitor was rather small (15") and the video clips were not presented full screen. This all could have made it more difficult to detect latent hazards.

2. **Disadvantageous for older participants**
   There were no computer illiterates in the groups. For the group of novice drivers and experienced drivers in the present study use was made of samples from another study (De Craen, 2010). Only participants were recruited for that study that frequently used the internet. Regular use of a computer however does not imply that all participants played computer games. It could be that pointing and clicking for regular computer gamers was performed at the procedural stage of skill acquisition and for participants not familiar with computer games at the declarative stage of skill acquisition (see Section 3.10). As computer games are in particularly popular among young people, it could be that the older, more experienced had a disadvantage.

3. **Effect of interruptions**
   The interruptions necessary to allow for time to point and click, could have triggered participants to search for latent hazards they had not noticed while the clip was still running. Speculative clicking was however discouraged. In the introduction of the task on the screen participants were informed that not all pauses contained latent hazards and that wrong clicks would lower their score. Despite this countermeasure, the pauses may have been advantageous for participants that were poor in hazard detection and recognition because the pauses not only could have triggered the possibility of a latent hazard, but also offered the time to search for that possible hazard.

With regard to the hypothesis of concurrent validity of the video task: novice drivers that had reported at least one crash had lower scores on the video task than crash free novice drivers, but the difference was only marginally significant. This implies that there is no clear support for the hypothesis that the video task has concurrent validity.

5.3. Study 2

5.3.1. Method

The improved video task
A new video task was developed in order to meet a number of shortcomings of the first video task. Thirteen new animation clips were made of which two video clips were for familiarisation. The new clips had a higher resolution and could be presented full screen. Seven of these video clips were the same as the video clips of the hazard detection and recognition task in Chapter 4. A brief description of the latent hazards in these seven video clips and a screen capture can be found in Appendix 1. A brief description of the additional latent hazards in the four other video clips not used in the hazard detection and recognition task of Chapter 4, but used in this improved version of the video task can be found in Appendix 3. This is to say that all the overt latent hazards and all the covert latent hazards mentioned in both Appendix 1 and Appendix 3 were included in the improved video task. At the bottom of the video clip, the upper part of a dashboard and the upper part of a steering wheel was shown. Based on the experiences with the first video test, the latent hazards were made more pronounced and less ambiguous. The vehicles in the new clips drove in a more realistic manner and the pedestrians walked in a more naturalistic way as the software for the

production of the animation clips had been updated with a plug-in to simulate vehicle and pedestrian behaviour. Participants no longer could click on rectangles to the left and the right to indicate that they would have looked left or right for possible hazards. The maximum number of clicks per pause was reduced to two and the length of a pause was reduced to three seconds. This was done to reduce the opportunity to search for latent hazards not already detected while the video clip was running. Also the number of pauses was reduced. Each video clip now contained three pauses.

Instead of written information on the screen, a video clip was made to introduce the task. In this video clip, participants could hear and see how the task had to be performed. Also the difference between overt latent hazards and covert latent hazards was visualised. In contrast to the first version of the video task, participants received feedback about where to click after they had made clicks in the first of the two trial videos for familiarization.

The scoring was simplified too. Only clicks on the predefined latent hazards counted (both covert latent hazards and overt latent hazards) and one correct click was one point. As there were almost three times as many overt latent hazards than covert latent hazards, for the calculation of the overall score, the score on covert latent hazards received as much weight as the score on overt latent hazards. As in the previous version, irrelevant clicks reduced the final score with one point.

5.3.2. Participants

In order to maximize the possibility of a significant difference, learner drivers were not compared with experienced drivers, but with professional drivers. All participants were recruited on the spot at the test centre of CBR in the city of Eindhoven. After candidates heard they had passed the test and had to wait for documents, they and their driving instructors that were also present, were asked to do the task. Between sessions, examiners were asked to participate in the test as well. Thus, the group of professional drivers consisted of professional driving instructors and driving examiners. The number of participants that refused was not registered. The groups were:

- *Leaner drivers* on the day they successfully passed the driving test: *n* = 37; mean age: 21.1; *SD* = 4.9; 40.5% male;
- *Professional drivers* (driving instructors and driving examiners): *n* = 39; mean age: 46.2; *SD* = 12.1; 74.4% male.

5.3.3. Procedure

Participants were seated approximately 60 cm from a 17" LCD-screen (aspect ratio 4:3). The resolution was 1024 × 768. The videos were presented full screen. This provided participants with a horizontal field of about 32°. Before participants started, they watched the instruction video and they practiced with two trial video clips. The instruction phase took on average five minutes. The videos were presented in a fixed order as the computer software did not allow for changes of the order. The time to complete the task was on average twenty-five minutes. After the task was completed participants filled in a short questionnaire with questions about demographics, their driving experience and their computer experience, including experience with computer games. Participants received no financial reward for their participation.

5.3.4. Data analysis and design

A between-groups design was applied. Before the actual testing on significance of differences between groups ($p < .05$), the sample was tested on the assumptions for parametric testing (normal distribution and homogeneity of variance). These assumptions were met. Prior to the statistical analysis, the internal consistency reliability (Cronbach's α) was considered. The t-test for independent samples was applied to test for significant differences between the groups. To test whether experience of computer games and age had an effect on the scores, univariate analysis of covariance (ANCOVA) was applied. Besides significance of results, the effect size (Partial èta squared, η^2_P) was considered with $\eta^2_P = .01$ as a small, $\eta^2_P = .06$ as a medium, and $\eta^2_P = .14$ as a large effect size (Cohen, 1988).

The videos used in Study 2 were partly the same as the videos used in the study reported in Chapter 4. For one video clip with a covert latent hazard, a comparison was made between the recorded fixations of learner drivers (both young learner drivers and older learner drivers) and experienced drivers in Chapter 4 and the position of the mouse clicks made by learner drivers and professional drivers in Study 2. This video clip is covert latent hazard 6 in Appendix 1. The participant driver is turning left and can only see possible oncoming traffic in the lane to the right of the lorry at the very last moment. A video clip with a covert latent hazard was chosen because a significant difference was found in Chapter 4 between learner drivers and experienced drivers in fixations on areas where nothing can be seen, but from where a covert latent hazard may emerge, with experienced drivers having significantly more often at least one anticipatory eye glance than learner drivers. The mentioned video clip of which the plan view is depicted in Figure 3.9 was chosen because the moment the video clip paused in order to allow for mouse clicks, was relatively late. It is about the last opportunity to take timely action (brake) to avert a crash should the covert latent hazard materialize. If a participant expects the hazard, it is likely that the participant will look in the direction from where the covert latent hazard may show up at this moment in time. Chi-square analysis (in this case the Fisher's exact test) was used to test if there were significant differences ($p < .05$) in fixations and clicks between learner drivers and experienced drivers or professional drivers.

5.3.5. Results

The internal consistency of the items was acceptable (α = .70). The maximum possible score was indexed at 10. Figure 5.6 shows the boxplot of the results.

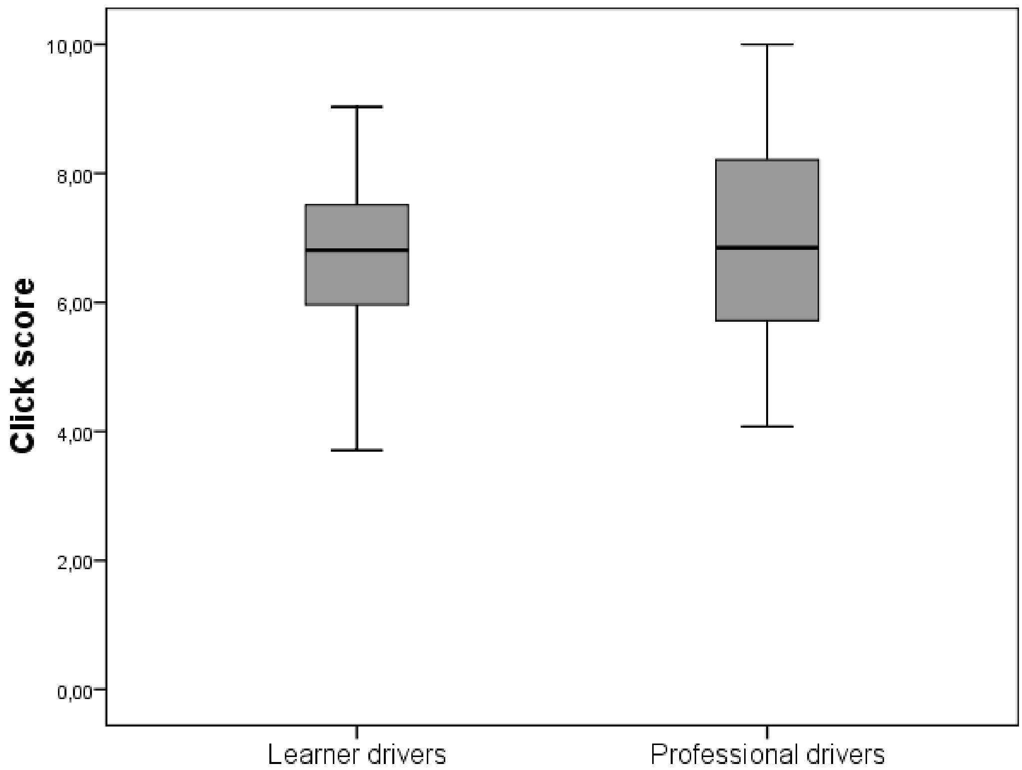

Figure 5.6. Scores of the clicks on the improved photo task of learner drivers and professional drivers. The maximum possible score was 10.

The mean click score was $M = 7.7$ ($SE = 0.2$) for learner drivers and $M = 8.0$ ($SE = 0.2$) for professional drivers. The difference in scores was not significant, $t\ (74) = 1.00$, $p = .32$. On average the score for learner drivers on overt latent hazards was $M = 9.6$ ($SE = 0.3$) and for professional drivers was $M = 9.1$ ($SE = 0.2$). This is in the opposite direction of what was expected. The difference was however not significant, $t\ (74) = -1.13$, $p = .26$. The mean click score on covert latent hazards was $M = 5.6$ ($SE = 0.3$) for learner drivers and $M = 6.4$ ($SE = 0.4$) for professional drivers. This difference was not significant, $t\ (74) = 1.66$, $p = .10$.

ANCOVA with the extent to which participants had experience with computer games as covariate and the overall click score as dependent variable, showed that the difference between the groups was significant with a small effect size and the professional drivers having the highest average score, $F_{(1,73)} = 4.00$; $p < .05$, $\eta^2_P = .05$. ANCOVA with age as covariate and the overall click score as dependent variable, showed that the difference between the groups was marginally significant, $F_{(1,73)} = 3.64$; $p = .07$. The group of learner drivers was split into a group with much experience with computer games and a group with little to no experience with computer games. The group of much experience with computer games was composed of the learner drivers that had responded to play a computer game every day and that had responded to play a computer game two to three times a week. The group with less to no experience was composed of the learner drivers that had responded: one time per week, a few times in a year and never. Fifteen learner drivers had much experience with computer games and twenty-two learner drivers had little experience with computer games. On average the overall click score for learner with much experience with computer games was $M = 7.2$ ($SE = 0.2$) and for learner drivers with little experience with computer games was $M = 6.1$ ($SE = 0.3$). This difference was significant with a large effect size, $t\ (35) = 2.40$, $p < .05$, $\eta^2_P = .14$. Female learner drivers had a significantly lower overall click score [$M = 6.2$, $SE = 0.3$] than male learner drivers [$M = 7.1$, $SE = 0.3$] (the effect size was medium), $t\ (35) = 2.07$, $p < .05$, $\eta^2_P = .11$. Of the female learner drivers, 23% had much experience with computer games and of the male learner drivers 67% had much experience with computer games.

Of all the participants with good eye tracking recordings in the study of Chapter 4 the coordinates of their fixations were captured in the film frame of the video clip described as 'covert latent hazard 6' in Appendix 1 that was the same film frame the video clip paused in Study 2. Picture A in Figure 5.7 shows the scatter plot of the fixations of both young learner drivers and older learner drivers (n = 42) and picture C shows the scatter plot of fixations of experienced drivers in this film frame (n = 27). Picture B shows the scatter plot of the mouse clicks made by the learner drivers of Study 2 during the pause (n = 33) and picture D shows the scatter plot of the mouse clicks made by the professional drivers of Study 2 during the pause (n = 42).

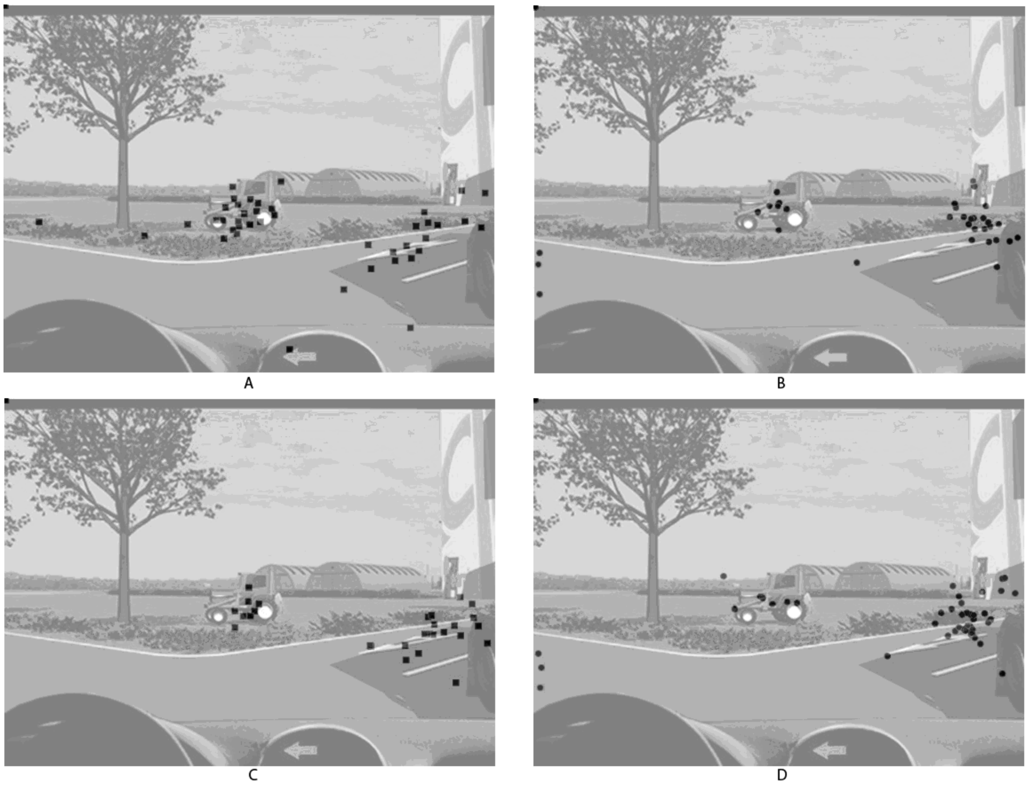

Figure 5.7. Scatter plots of the fixations of learner drivers of the study in Chapter 4 (A), the mouse clicks of learner drivers of Study 2 (B), the fixations of experienced drivers of the study in Chapter 4 (C) and the mouse clicks of professional drivers of Study 2.

Of all the fixations of the learner drivers in the study from Chapter 4 (picture A), 28.6% could be considered as anticipatory eye glances. This are the fixations in the lane to the right of the lorry further down the lane than the point of the lane arrow and the fixations on the bank of that lane, but not the fixations on the lorry itself. Of the mouse clicks made by the learner drivers of Study 2 (picture B), 51.5% could be considered as 'anticipatory eye glances'. The difference between the fixations and the clicks of learner drivers was significant, Fisher's Exact Test: $p < .05$. Learner drivers fixated notably more on the moving tractor in the video clip that is not a hazard, than they clicked on that tractor during a pause. This could have been caused by bottom-up gaze control (the tractor moved) or by top-down gaze control not related to hazard anticipation (a tractor is an interesting object).

Of all the fixations of the experienced drivers from the study in Chapter 4 (picture C), 59.3% could be considered as anticipatory eye glances. Of all the mouse clicks made by professional drivers of Study 2 (picture D), 59.5% could be considered as 'anticipatory eye glances'. The difference between the fixations of experienced drivers and the mouse clicks of professional drivers was not significant, Fisher's Exact Test: $p = 1$.

There was a significant difference between the fixations of the learner drivers of the study in Chapter 4 (picture A) (28.6% of all the fixations were anticipatory eye glances) and the fixations of the experienced drivers of the study in Chapter 4 (picture C) (59.3% of all the fixations were anticipatory eye glances), Fisher's Exact Test: $p < .05$. There was however no significant difference between the anticipatory mouse clicks of the learner drivers in Study 2 (picture B) (51.5% correct) and the anticipatory mouse clicks of professional drivers in Study 2 (picture D) (59.5% correct), Fisher's Exact Test: $p = .64$. These results imply that with regard to this covert latent hazard, mouse clicks are not a good substitute for anticipatory eye glances.

5.3.6. Discussion

The original video task was improved in many ways. Firstly, the animated video clips themselves were improved. The hazards were made less ambiguous, other road users moved in a more natural way, there was a dashboard and a steering wheel visible at the bottom of the screen, the resolution was higher, and the videos were presented full screen on a larger monitor. Secondly, a video clip was made to introduce the task and participants received feedback while practising in preparation for the task. Thirdly, the number of pauses was reduced, the length of a pause was reduced and the number of possible clicks per pause was reduced from three to two seconds. Fourthly, the task was made less complex as participants no longer could indicate that they wanted to search to the left or the right for possible hazards. Despite these improvements, the task failed to discriminate between learner drivers and professional drivers. Seven of the eleven video clips were the same as the video clips used for the hazard detection and recognition task of Chapter 4. In contrast to the improved video task the hazard detection and recognition task showed significant differences with a large effect size between experienced drivers and learner drivers in mentioned latent hazards and fixated covert latent hazards. The conclusion can only be that mouse clicks made on latent hazards during pauses in which the video holds, are not a good response method to test hazard detection and recognition.

The results indicate that experience in computer gaming may have confounded possible differences in hazard detection and recognition between the two groups. Participants with much experience in computer gaming had higher scores than participants with no experience or a little experience in computer gaming. Middle-aged persons and women in general have less experience in computer gaming than young males.

Apart from the effect of experience with computer games, there is the effect of the interruptions (the pauses) itself (McGowan & Banbury, 2004). The pauses may have triggered participants that there are latent hazards they had not yet detected while the video was running (although they were told that false clicks would lower their score and that there were pauses with no latent hazards). The pauses themselves also offered them extra time to search for hazards. This may have been to the advantage of the group of learner drivers, as it is assumed that the detection and recognition of latent hazards requires more involvement of the SAS for inexperienced drivers and involvement of the SAS is time consuming (see the Sections 3.6, 3.7 and 3.8). Jackson et al. (2009) found that experienced driver mentioned more hazards than novice drivers when a video clip had stopped and the screen had turned black, but not when the video clip had stopped and the last shot remained visible as a still picture on the screen.

For future research an alternative response method could be the response method that was used by Wetton et al. (2010) in which participants had to point on a touch screen at hazards without having the video paused. For Wetton et al. (2010) hazards were possible conflicts with other road users "in which the camera car would collide with another road user (including moving or stationary vehicles, cyclists, and pedestrians) unless the driver took action, such as braking or steering." This definition includes overt hazards, but excludes covert hazards. It would be interesting to apply the response method of Wetton et al. (2010) for the developed animated video clips of the present study in which latent hazards can also be covert latent hazards.

6. Simulator-based hazard anticipation training[10]

6.1. Introduction

In this chapter, the development of a short training intervention in hazard anticipation on a simple driver simulator is described and evaluated. This simulator-based training program is a variant of the PC-based Risk Awareness and Perception Training (RAPT) programs that were developed by the researchers of the Human Performance Laboratory at the University of Massachusetts, Amherst (Fisher, Pollatsek, & Pradhan, 2006; Pollatsek et al., 2006; Pradhan et al., 2009) and was named SimRAPT. In SimRAPT the same latent hazard scenarios were used as in the various versions of RAPT, but the didactical principles and training method were different from those used in RAPT. The training method used in SimRAPT was based on what is described in Section 3.10 about how drivers probably learn to anticipate hazards in real traffic. In this section, based on the somatic marker hypothesis (Bechara et al., 1997; Damasio, 1994; Damasio et al., 1996) and the framework of Brouwer & Schmidt (2002), it is argued that moderate feelings of risk, experienced during near misses in real traffic, may have promoted the development of schemata that enable the quick detection and recognition of latent hazards in similar situations in the future. These feelings of risk during near misses may also have contributed to the development of somatic markers that allow for swift actions once a latent hazard is detected.

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[10] This chapter is based on the following article: Vlakveld, W. P., Romoser M. R. E., Mehranian , H., Diete F., Pollatsek, A. & Fisher D. L. (2011). *Does the experience of crashes and near crashes in a simulator-based training program enhance novice drivers' visual search for latent hazards?* This article is accepted for publication in the Transportation Research Record (TRR), journal of the Transportation Research Board (TRB). The research presented in this chapter was conducted at the Human Performance Laboratory of the University of Massachusetts (UMASS) Amherst.

The effects on hazard anticipation of the exposure to risks in a driving simulator have hardly been studied and insofar it has been studied, the results are inconclusive. Triggs & Regan (1998) found no statistically reliable evidence to suggest that exposing novice drivers to near miss situations in a driving simulator made them any more cautious when subsequently driving in potentially risky situations similar to the near miss situation, although some data supported a trend in this direction. In contrast, Ivancic & Hesketh (2000) found that when drivers were exposed to situations that elicited errors during a simulator drive resulting in a crash or near crash, these drivers drove slower and had significantly fewer crashes in a simulator drive with similar situations than drivers who had not been confronted with the effects of their errors during a training drive. Koustanaï et al. (2008) found that experienced drivers learned from exposure to dangers in a driving simulator that were difficult to predict, but not from exposure to dangers that were easy to predict, but they used only overt latent hazards in their experiment. One of the objectives of this study is to gain insight the conditions that are required to make exposure to risk during simulator training effective.

Two elements are important when evaluating training programs: transfer and retention. Transfer of training is measured by the degree to which trainees apply in the actual world what they have learned during training. There is near transfer when trainees apply what they have learned in situations that may look different but contain latent hazards conceptually identical to the training situations. There is far transfer when trainees apply what they have learned in situations that conceptually differ from the trained latent hazards. Retention is poor when trainees show increased performance just after the training, but fall back to the level of performance from before the training soon afterwards. Retention is not investigated in this study.

In this introduction, before describing SimRAPT in Section 6.1.4, a review is presented of existing training programs in hazard anticipation. A distinction is made between standalone PC-based training programs with which novice drivers can practice at home (Section 6.1.1), experimental training programs in which no simulator was used (Section 6.1.2) and simulator-based training programs (Section 6.1.3).

6.1.1. PC-based training programs for self-study

Two PC-based training programs that among other learning objectives were intended to improve the hazard anticipation skills of young novice drivers have been evaluated in a transfer tests on an advanced simulator (Fisher et al., 2002; Regan, Triggs, & Godley, 2000). This was 'Driver Zed' developed by the Foundation for Traffic Safety (AAA) in the United States and 'Drive Smart' developed at the Monash University Accident Research Centre in Australia. Driver Zed consists of various modules. In the training module 'scan', video clips taken from the driver's perspective are presented on the screen. When the video stops questions are asked about what had happened so far in the video. In the module 'spot' videos (also from the driver's perspective) are paused and participants have to click with their mouse on overt latent hazards on the frozen video frame (e.g. a child playing with a ball on the pavement). In the module 'act' the videos pause just as in 'spot' and questions are asked about what the driver best can do in this situation. Finally, in the module 'drive' trainees have to decide when action is required and what the action should be. The modules in Drive Smart are called 'scan', 'keep ahead' and 'play safe' (skaps). In Drive Smart videos from the driver's perspective are used in the same way as in Driver Zed. In contrast to Driver Zed, Drive Smart also pays attention to calibration, the ability to prioritize attention and time-sharing.

Two weeks after having completed Driver Zed, participants drove more cautiously in a simulator and anticipated latent hazards better (i.e. they reduced speed in situations with latent hazards) than untrained drivers (Fisher et al., 2002). One week after having completed Drive Smart, the treatment group and a control group drove in a simulator. This simulator drive contained sixteen near transfer hazardous situations and sixteen far transfer hazardous situations. In seven out of the sixteen near transfer situations the treatment group anticipated the hazards significantly better than the control group. Differences between the groups were considered as significant when $p < .10$. In none of the sixteen near transfer situations the control group anticipated the hazards significantly better than the treatment group. In eight out of the sixteen far transfer situations the treatment group anticipated the hazards significantly better than the control group. In none of the sixteen far transfer situations the control group anticipated the hazards better than the treatment group. Four weeks later the two groups drove the same test simulator drive again. The results were the same (Regan et al., 2000).

Both, in Driver Zed and in Drive Smart no distinction is made between overt latent hazards and covert latent hazards. In Driver Zed none of the hazards in the video clips is a covert latent hazard and in Drive Smart some are covert hazards. Despite the fact that there are no clear covert hazards in the training scenarios of Driver Zed, Fisher et al. (2002) found that participants that had completed Driver Zed, braked more often in situations with covert latent hazards during the transfer drive on a simulator than participants in the control group did.

6.1.2. Studies on hazard anticipation training

McKenna & Crick (1997) developed a training program on hazard perception. This program of four hours was spread out over a period of three weeks. The training consisted of a classroom session, group video watching and one-to-one tutoring with video clips. In a second experiment it was found that only the one-to-one tutoring with video clips was effective. In these sessions, a participant and a driving instructor watched together videos from the driver's perspective. The driving instructor froze the videos at moments that hazards started to develop and then encouraged the participant to generate predictions about the development of possible hazards. To measure the effect of the training, the reaction latency test was used (see Section 4.1.3). Trained novice drivers had significantly shorter reaction times than untrained novice drivers and the reaction times of the trained novice drivers were about the same as the reaction times of the experienced drivers. In a more recent experiment, participants were only asked to generate verbal commentaries as they viewed the videos and had to listen to the commentary of experts while they watched the videos (McKenna et al., 2006). This simple training using commentary only, also resulted in shorter reaction times. The fact that participants had attended the training course did not make them more confident of their driving skills and no behavioural adaptation resulting in more risk taking was found. This is remarkable as short driver training programs in special skills such as skid training seem to have this adverse effect (see for a meta analysis: Elvik et al., 2009, pp. 781-785). This is to say that crash rate increases after the training. Gregersen (1996) presumed that short training programs in special skills increases self-confidence and self-efficacy although the special skills are not fully mastered. This false believe in superiority because of the training subsequently results in more risk taking.

The method of verbal commentary while watching videos from the driver's perspective was also used in a training program to improve the hazard perception skill of novice drivers that was developed by Isler, Starkey, & Williamson (2009). The test used in this study to measure the effect, differed from the reaction time test that was developed by McKenna & Crick (1997). While watching the videos from the driver's perspective, participants had to perform a secondary task. This secondary task was a tracking task that was projected in the centre of the screen. In contrast to driving in real traffic, drives do not have to allocate part of their cognitive resources to vehicle control (steering, braking, gear shifting, et cetera) when they watch a video. The idea of the secondary task was to compensate for the fact that in real traffic drives cannot allocate all their cognitive resources to hazard anticipation. When participants detected the onset of a developing hazard, they not only had to press a button (here it was a mouse click) but also had to identify the hazard. After the training the mean number of correctly detected hazards was significantly higher than that of a control group.

Commentary as a didactical method may improve reaction times in general, but does it also help to improve the hazard perception skills of novice driver with rather poor learning abilities? When learners comment on what they see, they receive no feedback and get no instruction. If a developing hazard is missed and therefore not mentioned, the participant will not learn. Another limitation may be the response method of the test. Participants must respond as soon as they detect the first visible signs of a developing hazard. As the signs have to be visible before one can react, the hazards can only be overt latent hazards, or covert latent hazards that have become visible. When for instance a child crosses the street from between parked cars, the first visible sign in the video is the first part of the body that emerges from between the parked cars. Someone who expects children to cross the road (i.e. expects this covert latent hazard) may press sooner than someone who does not expect this to happen. A driver may expect (not yet visible) children to cross the road in the context of the road and traffic situation (e.g. this is a residential area with many children). This participant will look between the gaps of parked cars. A participant that does not expect children to cross the road may only look straight ahead and therefore will press the button later. However, the training could also have resulted in a general sensitivity for unexpected events. In the studies mentioned, only one monitor was used. Therefore, the onset of developing hazards never was far from the centre of view. It could be that trained participants have shorter response latencies, not because of improved schemata and therefore better expectancies, but because of an enhanced sensitivity for unexpected events. This is to say that because of the training, they have gotten extremely vigilant and because of this, they react faster when they see the first signs of a developing hazard. If an eye tracker was used in the aforementioned studies, this alternative explanation could have been tested.

The question whether hazard perception training has an effected on gaze directions and eye fixations was investigated by Chapman, Underwood, &

Roberts (2002). In their training of about one hour, also videos from the driver's perspective were used. The training had five phases:

1. Producing commentary while watching videos and pressing a button as soon as a hazard was detected;
2. (a) Producing commentary while watching videos running at half speed on which areas of interest and specific hazards were marked with colours;
   (b) Watching the same type of videos but now with the commentary of experts;
3. (a) Predicting what could happen next in videos that were paused;
   (b) Watching videos and listening to experts who said what could happen next;
4. The same as the second phase, but now with videos on normal speed, and
5. The same as phase one, but with new videos.

Directly after the training the trained group showed a wider spread of search along the horizontal axis when driving in real traffic, but this effect was no longer observable three to six months after the training. Directly after the training the search along the horizontal axis was also wider while watching videos at moments when hazards developed. In contrast with driving in real traffic, the spread along the horizontal axis while watching videos was still wider three to six months later. The fixation durations at the spot of the developing hazard (i.e. staring at the threat only and not searching for other relevant information) while watching the videos, were only shorter directly after the training, but not three to six months later. Chapman et al. (2002) analysed the effect of training on visual search in general, but they did not analyse the effect of their training on the anticipation of particular hazards and the visual search for these particular hazards. Chapman et al. (2002) made also no distinction between overt latent hazards and covert latent hazards.

The presented evaluation studies indicate that trainees can learn to anticipate hazards. However, in the discussed training programs so far, no distinction was made between imminent hazards and latent hazards. If the detection of latent hazards was trained it was mostly about the detection of overt latent hazards. PC-based training programs for young novice drivers to improve the skills to detect and recognize latent hazards and in particular covert latent hazards have been developed at the Human Performance Laboratory of the University of Massachusetts (Fisher et al., 2006; Pollatsek et al., 2006; Pradhan et al., 2009). These PC-based training programs, as already mentioned are called, Risk Awareness and Perception Training (RAPT). RAPT is currently in its third version. RAPT-1 presents the participant with a plan view of various hazardous scenarios. Participants have to identify areas of the scenario that might contain a possible hazard. These are mostly covert latent hazards. Plan views are used to allow participants to process more deeply the reason that a particular scenario contained a latent hazard. This is to say that with the aid of plan views a learner can grasp the underlying principal of a hazard more profoundly than when photographs from the driver's perspective are used. When the general principles of the causes are understood far transfer will improve (Reeves & Weisberg, 1994). RAPT-2, in addition to the plan views, also includes a photograph of the scenario from the driver's perspective. This is done to aid the visualization process and to emphasize that the scenarios can occur in real life. In RAPT-3 sequences of photographs taken from the driver's perspective of a developing traffic situation that contains a latent hazard are presented on the screen. Each photograph is exposed for 3 s. The hazard never materializes in the sequence of photographs. These sequences of photographs of developing traffic situations are presented to participants as a pre-test and a post-test. Participants are requested to click with their mouse on areas of each photograph to which they would pay particular attention because of a possible latent hazard. In the training part between the pre-test and the post-test, different sequences of photographs are used. After each sequence of photographs, a plan view of the area where the latent hazard could materialize is presented. On the basis of the plan view, the particular latent hazard that could develop in the scenario is identified. After this instruction with the aid of a plan view, the same sequence of photographs is presented that was presented before the instruction section with the plan view. Learners can only starts with the next scenario (a new set of photographs of a developing traffic situation) if the mouse clicks are on areas that allow learners to detect hazards in this sequence of photographs. If this is not the case, the sequence of photographs is repeated up to three more times.

The different versions of RAPT were evaluated in test drives in a simulator and in drives in cars in real traffic. During these test drives (both in a simulator and in a real car) the eye movements of participants were recorded with the aid of an eye tracker. Trained young novice drivers made significantly more eye glances that allowed for early detection of latent hazards than untrained novice drivers. This was true in both near transfer scenarios and far transfers scenarios, although the effect size was smaller in the far transfer scenarios. The improvement in anticipatory eye glances was about the same for RAPT-1, RAPT-2 and RAPT-3 (Fisher et al., 2006; Pollatsek et al., 2006; Pradhan et al., 2009).

6.1.3. Existing simulator-based hazard perception training programs

Unlike PC-based hazard perception training programs, simulator-based programs offer trainees the possibility to experience the consequences of not having predicted, detected and recognized a potential hazard in time without the risk of physical injury. Moreover, exposure to these risky traffic situations can be accelerated in a simulator. A third advantage of simulator training compared to PC-based training is that also anticipatory actions can be trained (e.g. the reduction of speed after the detection of a latent hazard). A fourth advantage is that simulators often have a wide field of view. A wider field of view provides more environmental cues that are related to potential hazards and increases participants' opportunity to detect hazards (Shahar et al., 2010). A fifth advantage is that trainees actually drive. They must divide their limited cognitive resources between manoeuvring the vehicle, the interaction with regular traffic and the detection, recognition and prediction of latent hazards.

The first time the didactical advantage of a simulator of having the possibility of experiencing a crash without getting injured, was applied in Australia (Regan, Triggs, & Wallace, 1999; Triggs & Regan, 1998). In this training, during a simulator drive, novice drivers were first exposed to situations in which latent hazards materialized (the near miss situations). Later on during the same drive, they were exposed to similar situation in which the latent hazard did not materialize (the near transfer situations) and also to situations in which latent hazards did not materialize that were dissimilar from the near miss situations (far transfer). Prior to and after the simulator drive, participants were requested to rate the degree of risk associated with slides and videotaped sequences of situations in which it is known novice drivers have a high risk of collision, some of which were the same as the near miss situations. Based on the behaviour of the novice drivers in the near transfer situations and the far transfer situations (e.g. not reducing speed when latent hazards were encountered) and the before and after risk ratings, it was concluded that mere exposure to a near-miss event, at least in a simulator, was not sufficient to improve hazard anticipation, although the data supported a trend in this direction.

In contrast, Ivancic & Hesketh (2000), also in Australia, have developed a simulator-based training in which participants were exposed to critical situations that was effective. They developed a simulator-based-training program in which participants were exposed to manifest hazards. A group of drivers drove through the scenario in which errors were elicited and group of drivers drove though the scenario in which no errors were elicited. For the error-learning-group no additional feedback was provided about why the crashes could have happened and how a crash could have been prevented. They then evaluated both groups in the same simulator, but in a different scenario as the training scenario. This test scenario contained a couple of near transfer situations and one far transfer situation. The participants in the error-learning-group had significantly fewer crashes and drove slower in the near transfer situations. Participants in the error-learning-group did not have significantly fewer crashes in the far transfer situation, but drove significantly slower in this scenario. A limitation of this study is that most of the hazards were imminent hazards and none of the training scenarios contained covert latent hazards. Participants also were not typical young novice drivers anymore (mean age 23).

Another simulator-based training program for novice drivers was developed in the TRAINER project of the European Commission (TRAINER., 2002). This training program could run on a simulator with a narrow field of view (one monitor) or on a simulator with a wide field of view (three monitors). In contrast to the training developed by Ivancic & Hesketh (2000), the section on hazard perception in this training all were latent hazards. The scenarios in this section comprised of a deer that crossed the road, a parked car that pulled out, gap acceptance when negotiating an intersection, and driving in conditions with poor visibility and pedestrians that cross the road (darkness, rain). The aim of the training was to improve search strategies for possible hazards. If a crash occurred, participants had to drive through the same scenario again. It is not mentioned in the report whether additional feedback and instruction was provided in case of a crash. Falkmer & Gregersen (2003) have evaluated the effect of this training on an advanced simulator. Some of the test scenarios were near transfer situations (e.g., a moose that crossed the road instead of a deer) and others were far transfer situations (e.g., a crossing bus that did not give way instead of a car that pulls out). For each test scenario, different dependent variables were applied. All of them dealt with car performance such as speed, onset of braking, following distance, time to collision and lateral position. Visual search was not measured. The simulator training had a significant effect on only some of the dependent variables in two of the six test scenarios and only when the simulator had a wide field of view. There was not one significant effect when the training simulator had a narrow field of view. In the two test scenarios some effect was found were near transfer scenarios. A possible explanation for the rather poor results is the fact that the didactical opportunities that simulators offer were not fully utilized in this training program. In case of a crash participants only had to drive through the same scenario again.

A fourth simulator-based training program that among others was aimed to enhance the higher order skills of novice drivers such as hazard perception, situation awareness and decision making under time pressure, is the Driver Assessment and Training System (DATS) (Allen et al., 2003; Allen, Park, & Cook, 2008; Allen et al., 2007; Allen et al., 2002). In the part of this training program that addresses the mentioned higher order skills, students drive in scenarios that contain critical events. These events are situations in which various types of collisions are elicited, such as pedestrians that walked out or cars on a collision course at intersections. All hazards are imminent hazards. The other road users that create the critical situations are automatically triggered by the driving behaviour of the student. If for instance a student drives fast, the pedestrian that start to cross the road also walks fast. During each drive, performance indicators such as speed, time to collision, and traffic signal violations are automatically recorded. Only when the scoring meets a certain criterion the students can graduate to the next training scenario. If the criterion is not met, students have to drive through additional scenarios. The crash data (recorded by the police) of three large groups of students that did DATS during their initial driver training were compared over a two year period after licensing. The first group did DATS on a desktop simulator with one monitor (narrow field of view), the second group did DATS on a desktop simulator with three monitors (wide field of view) and the third group did DATS in a vehicle cab simulator with a wide field of view. The development over time of the cumulative crash rate of the single monitor group was about the same as that of a control group that did not do DATS. The cumulative crash rate of the group that did DATS on the 3 monitor desktop configuration was at all times somewhat lower than the cumulative crash rate of the single monitor group and the cumulative crash rate of the group that did DATS in the wide screen vehicle cab configuration was considerably lower at all times than that of the single monitor group. However, these results have to be interpreted with caution. There was no random assignment of the participants to the various groups. The participants in the one and three monitor desktop groups were high school students, whereas participants that did DATS in the vehicle cap simulator were recruited at local Department of Motor Vehicle offices when people apply for their learner's permits.

Finally, Wang, Zhang & Salvendy (2010) developed a simulator-based training program for novice drivers in which eight critical situations where embedded in the scenario; seven overt latent situations and only one covert latent hazard situation. After the training drive, each participant watched the video from the driver's point-of-view of his (only young male novice drivers participated in this study) own performance in the critical situation and then viewed a video in which an experienced driver averted the hazards. To assess training retention, an evaluation drive on the same simulator was arranged six weeks after the training. The scenario of the evaluation drive differed from the scenario in the training drive. Four of the situations in the evaluation drive were near transfer situations and four were far transfer situation. The dependent variables were the scores on a 5-point scale by two independent assessors that were blind with regard to the condition. A score of 1 meant involvement in a crash and a score of 5 meant good hazard anticipation. Scores were significantly better for the trained group than for untrained group in six out of the eight critical situations. This was the case for both near transfer situations and for far transfer situations, but the effect was greater in the near transfer situations than in the far transfer situations.

The results of the effect of simulator-based hazard anticipation training are not conclusive. The didactical methods ranged from mere one time exposure to immanent hazards (Regan et al., 1999; TRAINER., 2002) to a debriefing in which participants saw a video of their own performance and the performance of an expert (Wang et al., 2010). It seems that mere exposure to immanent hazards during a simulator drive is not sufficient. Participants have to be challenged to discover (by trial and error) why the critical event occurred and what they themselves can do to prevent it from happening the next time. It could be that Regan et al. (1999) did not find an effect whereas Ivancic & Hesketh (2000) did, because Ivancic & Hesketh (2000) made use of the principles of error learning. Errors are usually salient, unexpected events that can motivate further learning about a task. The negative feedback provided by errors that are transparent to the individual who commits them, creates an element of surprise that temporarily halts task performance while learners try to work out why the error occurred. This is thought to delay the automatization of a skill and to increase the duration under which the task is performed using controlled processing (Kulhavy, 1977). Ideally, a simulator-based hazard anticipation training is needed which is focused on latent hazards and in particularly covert latent hazards that combines error learning with verbal and visual instruction. Not one of the simulator-based training program that were discussed had all these characteristics.

6.1.4. Principles underlying SimRAPT and hypotheses

In Section 6.2.3 the developed simulator-based training is described in detail. In this section, the principles underlying SimRAPT are discussed. The intention was to develop a simulator-based training that is a condensed version of the 'natural' way drivers are supposed to learn to anticipate hazards in real traffic (see Section 3.10). This is to say that participants had to experience critical events. Although drivers may learn from critical situations in real traffic, they probably will learn nothing when drivers attribute the cause of the crash to the other road user involved in a crash. A didactical method had to be found in which the experience of critical situations made participants reflect on their own behaviour and to think about possible solutions and not in blaming others. In order to do this use was made of the principles of error learning. It was also important that some arousal was created in the training, but not too much as this could hamper learning from critical situations. Too much arousal caused by the experience of a crash does not enhance memory consolidation (Richter-Levin & Akirav, 2000) and could inflict driving fear instead. As participants know they are driving in a simulator, it is expected that experiencing a crash in a simulator will only result in moderate levels of arousal. The fact that moderate levels of arousal enhance memory does not necessarily imply that the relevant lessons are learned from risky events in order to cope with this type of situations in the future. Not only because of the possibility of attribution, but also because participants miss the overview why the critical event could occur, may hamper learning from crashes or near crashes. Especially novice drivers when experiencing hazardous traffic situations, narrow their attention down to the most threatening aspect in the traffic scene and do not store peripheral information in memory that is also relevant for the comprehension of the situation (Underwood, Chapman, Berger, et al., 2003). For this reasons, after having had a crash or a near crash during the simulator-based training program, instruction was provided based on a plan view of the situation and participants were challenged to reflect on their own behaviour and find ways to improve their visual search in order to prevent similar crashes or the near crashes in the future. Furthermore, the emphasis in the training was on covert latent hazards, as novice drivers in particularly have problems in detecting and recognizing these types of hazards (see Section 4.3). Scenarios for the training were based on those developed for RAPT (Fisher et al., 2006; Pollatsek et al., 2006; Pradhan et al., 2009).

The hypotheses were:

1. Trained novice drivers will more often search for latent hazards in near transfer situations than untrained novice drivers, in particular when the situation involves a covert latent hazard;
2. Trained novice drivers will more often search for latent hazards in far transfer situations than untrained novice drivers, in particular when the situation involves a covert latent hazard;
3. The effect size for the near transfer situations will be larger than for the far transfer situation, and
4. SimRAPT is more effective than RAPT-3.

6.2. Method

6.2.1. Participants

Novice drivers with at least one year experience in solo driving were recruited from the student population of the University of Massachusetts (UMASS) in Amherst and were randomly assigned to one of two cohorts:

- *SimRAPT group*: (*n*=18; 53% male; mean age = 19.4, *SD* = 0.7; mean number of months in possession of license = 28.4, *SD* = 13.0);
- *Control group* that were given placebo pen and paper training on traffic signs: (*n*=18; 47.1% male; mean age = 19.1; *SD* = 0.5; mean number of months in possession of license = 28.3, *SD* = 6.5).

All participants had normal vision or visions corrected to normal with contact lenses and were naïve to the hypotheses. Aspirant participants with spectacles were excluded as the eye tracking system consisted of a pair of goggles that could not be put over a pair of glasses. After completion of their session each participant in both the SimRAPT-group and the control group, was offered an inconvenience allowance of $ 50 for their time.

6.2.2. Materials and Apparatus

In this study, a training simulator and a test simulator were used. The SimRAPT training was delivered using the Driver Training Simulator (DTS – see Figure 6.1 a) of the Human Performance Laboratory of UMASS. The DTS cab consists of an automobile seat in front of a fixture holding a steering and pedal assembly. The cab sits in front of three 5' diagonal projection screens subtending approximately 135° of visual angle with the image refreshed at 30 Hz. The simulator runs on a Systems Technology Inc. simulation (STISIM) platform. The post-training evaluation (see Section 6.2.4) for both groups was performed on the lab's Advanced Driving Simulator (ADS – see Figure 6.1 b).

(a) (b)

Figure 6.1. Human Performance Lab simulators. (a) The Driver Training Simulator (DTS) and (b) the Advanced Driving Simulator (ADS).

The ADS consists of a full cab Saturn sedan positioned in front of three large projection screens each with a 11' diagonal, subtending approximately 135° of visual angle. The roadway is virtually projected on the screens and is refreshed at a rate of 30 Hz. The ADS operates off a simulator platform from Realtime Technologies Inc. (RTI). During the post-training evaluation drives on the ADS, participants wore an ASL Mobile-Eye eye tracking system. The Mobile-Eye consists of a pair of lightweight goggles complete with a scene camera and eye camera and allows for full mobility and freedom of movement for the participant. The output from the system includes video with a set of crosshairs (eye position) superimposed upon the scene recorded from a head-mounted scene camera.

In a pre-study questionnaire, participants provided demographic data and driving history information. They self-rated their driving skills and ability and they rated their driving style. In the post-study questionnaire, participants rated their driving skills again and they made prognoses of their future driving style.

6.2.3. Training intervention

SimRAPT began with a familiarization drive of about 5 min. After this drive the training session started. The training consisted of ten scenarios: seven hazard anticipation scenarios with common latent hazards and three scenarios without any high-priority hazards. Of the seven latent hazard scenarios, six were covert latent hazards and one was a precursor of a hazard (see Section 3.2). It took about 1 min to drive through a scenario. There were three versions of each hazard anticipation scenario:

1. *Hazard detection drive.* In this drive the possible hazards did not materialize;
2. *Error drive.* This drive was the same as the *hazard detection drive,* except that this time the hazard materialized aggressively;
3. *Improvement drive.* This drive was the same as the *error drive*, but with the latent hazard manifesting itself less aggressively.

Directly after a *hazard detection drive* the participant was asked: "Did you have a moment where you thought: "Whew, I hope that something will not happen? If so, what is it you worried about?" No feedback was provided, regardless the response. Thereafter participants drove the *error drive* of that scenario. Whether this drive ended up in a crash or in a near crash, in all cases after the *error drive* an instruction video was projected on the centre screen of the simulator. In this video a plan view of the scenario was presented in which the movements of road users and fields-of-view were animated. A voiceover explained what had happened, why it had happened and in what similar kind of scenarios this could have happened. The next phase in the instruction video was a clip that explained to participants the appropriate gaze directions in the present scenario. After this, the plan view reappeared on the screen and participants had to point with a laser pointer to where the hazard would be located before it became visible, the direction in which the participant should have looked in order to see the hazard as early as possible and at which point in time the participant should have slowed down in order to enlarge her or his safety margin. After the instruction video, participants drove the *improvement drive.* Hereafter the cycle started anew with the next hazard anticipation scenario. In order to discourage hyper-vigilance during the training, three scenarios were included in the training that did not contain any high-priority hazard. A summary of scenarios trained in SimRAPT can be found in Table 6.1.

Table 6.1. Description of the training scenarios with a latent hazard.

ID	*Type*	*Description*	*Hazard*
T1	Covert	Straight on at intersection. Line of bushes on the right obscures view on left sidewalk of the right hand road	Possible pedestrian or cyclist on sidewalk of right hand road that may cross the road of the driver
T2	Covert	Approaching an intersection and intention to drive straight through. Lorry in front in adjacent lane to the left is about to turn left. Lorry obscures view on opposing traffic that turns left	Possible opposing traffic that turns left
T3	Covert	Overtake a lorry that is parked at the far right side of the road. Just before the lorry is a cross-walk	Possible pedestrian that crosses the road just in front of the lorry
T4	Covert	Turn left at intersection. Opposing lorry waits to turn left. Lorry obscures view on lane right of the lorry	Possible oncoming traffic (to the right to the lorry) that drives straight on at intersection
T5	Covert	Straight on at intersection. A line of cars left to the driver waits to turn left. Just in front of the first car is a cross-walk. Line of cars obscure view on the left side of the cross-walk	Possible pedestrian on the cross-walk
T6	Precursor	Straight on. A curve and dense vegetation on both sides of the road. Just after the curve is an intersection. The driver has to stop and give way, but due to the vegetation the stop sign only gets visible just before the intersection. Before the curve is a warning sign for a stop sign ahead	A speed that is too high to stop at the intersection in time and a stop sign that is not noticed
T7	Covert	Straight on at intersection. The road to cross is a one-way street. Parked cars in the one way street obscure the view on possible traffic from the right	Possible traffic from the right

A screen capture of the centre screen of one of the SimRAPT scenarios can be found in Figure 6.2.

Figure 6.2. Example of the error drive of a SimRAPT scenario. The scenario is T4 in Table 6.1. Only the view on the centre screen is presented.

6.2.4. Transfer test

After the training session, participants completed an evaluation drive on the ADS to evaluate training transfer. The evaluation drive consisted of three drives of approximately ten minutes each on the ADS while participants wore the ASL Mobile Eye tracking system. In total nineteen potential hazardous situations were embedded in the scenarios of the three drives of which seven were near transfer situations and twelve were far transfer situations. None of the latent hazards in the evaluation drives actually materialized. The participant's fixations while navigating the scenario were used as an indication of whether or not the participants successfully anticipated the latent hazard. An overview of the critical situations is presented in Table 6.2.

Table 6.2. Critical situations embedded in the scenarios of the test drives.

No	*Type**	*Transfer*	*Description*	*Hazard*	*Critical visual search*
A	O	Far	Straight through at T-intersection. Line of cars waiting in lane left of the driver.	A driver in the line of cars may pull out to the right into the driver's lane	At least 3 glances to the line of cars when passing
B	C	Near	Straight through at intersection. Bushes on the right obscure view on left sidewalk of the right hand road.	Hidden pedestrian on sidewalk of right hand road that may cross the road of the driver	Glance to the far right at the sidewalk and a second glance in same direction after starting moving again
C	C	Near	Turn left at intersection. Opposing lorry waits to turn left. Lorry obscures view on lane to the right of the lorry	Hidden oncoming traffic (in lane to the right of the lorry)	Glance at right side of lorry just before turning and a second glance in this direction when turning
D	P/C	Far	Straight through. A hidden driveway to the left. Sign warns for a hidden driveway.	A car that may pull out from the driveway	Glance to the right after the warning sign
E	C	Far	Overtake a bus at bus stop. Before the bus is a cross-walk	Hidden pedestrian that may cross the road just in front of the bus	Glance towards the left edge of bus while passing
F	C	Near	Cross a one way street. Objects obscure the view into the one way street.	Traffic from the right	Glance to the right into the one way street before crossing the street
G	P	Far	Traffic light turns green when driver approaches	Traffic from left or right that run the red light (just turned red)	Glances to left and right before crossing the intersection
H	C	Far	Turn right at T-intersection. Vegetation obscures view to the left	Possible traffic from left	Glance to the far left after a glance to the right
I	P/C	Far	Straight through at intersection. Driver has priority at intersection.	Possible traffic from left or right not obeying rules of the road	Glances left and right before crossing the intersection
J	C	Far	Footpath to school crosses the road. Bushes obscure footpath on the left side.	Possible pedestrians (children) that cross the road	Glance to the left before crossing the footpath

* C = Covert latent Hazard   O = overt latent Hazard   P = Precursors of Hazards

Table 6.2. (continued) critical situations embedded in the scenarios of the test drives.

No	*Type[*]*	*Transfer*	*Description*	*Hazard*	*Critical visual search*
K	P/C	Far	Straight through. Fork from the left that is obscured by trees. A sign warns for fork ahead.	Possible traffic merging from the left	Glance to the left before passing the fork
L	C	Near	Overtake a parked lorry. Just before the lorry is a cross-walk	Pedestrian that crosses the road in front of the lorry	Glance beyond left edge of lorry when passing the lorry
M	P/C	Far	Straight through. Fork from the right that is obscured by trees. A sign warns for fork ahead.	Possible merging traffic from the right that is obscured by the bushes	Glance to the right before passing the fork
N	P	Near	Straight through. A 4-way intersection after a blind curve. Stop sign is partly hidden by trees. Before the curve is a warning sign for a stop sign ahead	A speed that is too high to stop at the intersection in time and a stop sign that is not noticed	Glance at the warning sign 'stop sign ahead' and at least 2 glances to the right in search for intersection and stop sign
O	O	Far	Straight on along a line of parked cars to the right	A car may pull out into the path of the driver	At least 3 glances at the line of parked cars to the right
P	O/C	Far	Straight through. Pedestrian walks on a driveway towards the road. The pedestrian disappears behind bushes	The temporarily hidden pedestrian may cross the road	Glance to the left (searching for pedestrian) before passing the driveway
Q	C	Near	Straight through at T-intersection. Line of cars to the left of the driver obscure view on cross-walk.	Possible pedestrian on the cross-walk	Glance to the left, beyond the right edge of the car in front while passing
R	C	Near	Approaching an inter-section. Intention to drive straight through. Lorry in front in the left adjacent lane. Lorry obscures view on op-posing traffic turning left	Opposing traffic that turns left	Glance to the far left, beyond the right edge of the lorry when passing
S	C	Far	Turn left into a driveway. Driveway is just before a blind curve (because of trees) to the right.	Possible oncoming traffic	Glances on the opposing lane as far as possible in the distance before and when turning

* C = Covert latent Hazard   O = overt latent Hazard   P = Precursors of Hazards

6.2.5. Procedure

Participants were first provided informed consent forms to sign and were given basic instructions about what they were going to do in the study. Afterwards, participants filled out the questionnaires. Participants then were taken to the appropriate locations to complete their training. The length of training ranged from forty minutes to approximately one hour. After training, participants received a short break and then drove the evaluation simulation on the ADS. First they did a familiarization drive and after this the three test drives as described. The order in which the three drives were presented was counterbalanced across participants to mitigate learning effects. Finally, participants filled out the post-test questionnaire and were paid for their participation.

6.2.6. Design and data analysis

The study employed a between subjects design, comparing the scores on the evaluation drive of the SimRAPT group with a control group. The dependent variable was the number of correctly anticipated latent hazards in the test drives. A latent hazard was assessed as correctly anticipated when two experimenters that were blind to the participant's condition, independent of each other scored the gaze directions as such that they allowed for timely detection of the hazard in case the hazard should have materialized. Note that when more than one glance was required, the scenario was scored as correctly anticipated only if all necessary glances were made. Timely detection meant enough time for evasive actions to avert a crash. For each latent hazard a critical *launch zone* was determined on the roadway upstream of the potential hazard. The participant had to direct her or his eyes to the *target area* (the area in which the hazard could materialize) within the launch zone in order to score the latent hazard as anticipated. A brief description of these critical target areas for each latent hazard and the scanning criteria can be found in the sixth column of Table 6.2. As an example of how a target area was defined, consider the situation in which a bus is parked on the near side of a crosswalk (E in Table 6.2). Glances that were positioned anywhere between the front left hand edge of the bus and the crosswalk were counted as anticipatory. In cases that the experimenters differed, the experimenters came to consensus after having watched the video of the particular situation again together. In 2% of all the recordings of the situations it was not logically possible to decide whether participants had recognized the latent hazard or not (e.g. because the participant missed the situation due to a wrong turn during the drive). All of the participants could be given a score in at least sixteen of the nineteen situations. In the few cases when a score could not be assigned, the average score across all scenarios was used. The samples were too small to disaggregate by gender.

In cases where the assumptions for parametric testing were met a parametric test was used to test significant differences in scores between the two groups ($p < .05$). In cases where the assumptions for parametric testing were not met, a non-parametric equivalent test was used ($p < .05$). Besides significance of the results, the effect size was considered. As most of the times the assumptions for parametric testing were not met, instead of partial èta squared (η^2_p), the Pearson's correlation coefficient (r) was considered as effect size, with $r = .10$ as small (explaining 1% of the total variance), $r = .30$ as medium (explaining 9% of the total variance) and $r = .50$ as large (explaining 25% of the total variance) (Cohen, 1988). Prior to the statistical analyses the internal consistency reliability (Cronbach's α) of the scale composed from the nineteen latent hazards in the test drives was considered with $\alpha > .65$ as acceptable.

6.3. Results

6.3.1. Near transfer situations, far transfer situations and overall scores

The final hazard anticipation score on the three test drives was internally consistent ($\alpha = .83$). This implies that the nineteen potential hazardous situations in the three drives of the transfer test in the ADS measured one concept. Column 2 and Column 3 of Table 6.3 displays the percentage of the situations per group in which the anticipatory gaze directions in the launch zone that were correct. The distribution of the scores of some of the groups was significantly non-normal. Therefore, the Mann-Whitney test was applied instead of the t-test for independent samples.

Table 6.3. Correct anticipatory gaze directions in situations that contain latent hazards.

	SimRAPT	*Control*	*Mann-Whitney's U*	*Significance*	*Effect size r*
Near transfer	83.61%	56.91%	63	$p < .01$	- .53
Far transfer	70.95%	53.49%	88	$p < .05$	- .39
All	75.60%	54.73%	74	$p < .01$	- .47

Compared to the control group, the SimRAPT group anticipated latent hazards significantly more often in the near transfer situations, the far transfer situations and in all the situations together. The effect size was large in the near transfer situations and was medium in the far transfer situations and in all the situations together. These results indicate that SimRAPT improved the visual search for latent hazards of novice drivers and that the improvement was larger for near transfer situations than for far transfer situations, although the improvement in far transfer situations still was significant.

The near transfer situations for the SIMRAPT group were the situations B, C, F, L, N, Q and R of Table 6.2. If the correctly anticipated near transfer situations (i.e. the visual search of the participant met the criteria formulated in column 7 of Table 6.2) are scored as 1 and the incorrectly anticipated situations as 0, the mean score of the sum of the near transfer situations was 5.86 for the SimRAPT group and was 3.97 for the control group. The standard deviation in the near transfer situations was .23 for the SimRAPT group and .43 for the control group. The difference in standard deviations between the SimRAPT group and the control group was significant with a medium effect size, t (34) = -2.93, p < .01, r = .45. The relatively high scores and the relatively low dispersion of the SimRAPT group compared to the scores and dispersion of the control group, could indicate that learners who before the training are relatively poor in hazard anticipation and learners who before the training are already relatively good in hazard anticipation, rise to more or less the same level of hazard anticipation skills with regard to near transfer situations. The difference in standard deviations between the SimRAPT group and the control group was not significant for the far transfer situations, t (34) = -0.81, p = .43. This could indicate that far transfer situations still are difficult to detect and recognize for learners with a low entrance level, after they have completed SimRAPT.

Six of the seven near transfer situations contained covert latent hazards. The difference between the SimRAPT group and the control group for covert latent hazards in the near transfer situations was highly significant with a large effect size, U = 48.0, p <.001, r = -.61. Eight of the twelve far transfer situations contained covert latent hazards or precursor/covert latent hazards. The difference between the SimRAPT group and the control group in far transfer covert latent hazard scenarios was significant with a medium effect size, U = 80.0, p <.01, r = -.44. These results indicate that SimRAPT in particular can improve the skills of young novice drivers to anticipate covert latent hazards. This is not very surprising as the training scenarios were mostly scenarios that contained situations with covert hazards (see Table 6.1).

6.3.2. Results per potential hazardous scenario in the test drives

Table 6.4 contains the percentage of anticipatory gazes initiated in the launch zone that were in the direction of the latent hazard in each of the nineteen different potentially hazardous situations of the test drives (Table 6.2). The resulting odds ratios are also reported for each scenario. For instance, an odds ratio of 6.25 indicates that it was 6.25 times more likely that a participant who had completed SimRAPT had anticipatory gaze directions in this situation than a participant who had completed the placebo training. To test if the scores differed significantly between the SimRAPT group and the control group, the χ^2 test was used. For five situations the assumptions for the χ^2 test were not met.

Table 6.4. Percentage correct anticipatory gaze directions per situation between the SimRAPT group and the control group.

No	*Transfer*	*SimRAPT*	*Control*	X^2	*p*	*Odds ratio OR*
A	Far	61.1%	50.0%	0.45	.74	1.57
B	Near	88.9%	41.2%	8.83	.005**	11.43
C	Near	83.3%	44.4%	5.90	.035*	6.25
D	Far	61.1%	16.7%	7.48	.015*	7.86
E	Far	94.4%	61.1%	-	-	10.82
F	Near	77.8%	50.0%	3.01	.16	3.50
G	Far	77.8%	61.1%	1.18	.47	2.23
H	Far	77.8%	83.3%	-	-	0.70
I	Far	77.8%	66.7%	0.55	.71	1.75
J	Far	77.8%	50.0%	3.01	.16	3.50
K	Far	83.3%	44.4%	5.90	.035*	6.25
L	Near	94.4%	70.6%	-	-	7.08
M	Far	47.1%	50.0%	0.03	1.00	0.89
N	Near	66.7%	77.8%	0.55	.71	0.57
O	Far	66.7%	44.4%	1.80	.315	2.50
P	Far	76.5%	72.2%	-	-	1.25
Q	Near	88.9%	72.2%	-	-	3.08
R	Near	88.2%	41.2%	8.24	.010*	10.71
S	Far	55.6%	41.2%	0.72	.505	1.79

**p* < .05, ***p* < .01

In three of the five near transfer situations in which the assumptions for the χ^2 test were met, the difference between the scores of the SimRAPT group and the control group was significant and in the expected direction. In the other two near transfer situations in which a χ^2 could be applied, the difference in percentages between the SimRAPT group and the control group was small but also in the expected direction. In one near transfer situation (situation L) in which the χ^2 test could not be applied, the difference between the two groups was in the expected direction and substantial, *OR* = 7.08. In the other situation (situation N) which could not be tested, the difference was small and in the opposite direction. This latter situation (a blind curve with an intersection just after the curve and a warning sign 'stop sign ahead' before the curve) was the only precursor of hazard scenario in the training. Hazard anticipation in this scenario not only means adequate visual search (gazes to the right side of the road in search of the expected stop sign), but also speed adaptation (driving into a blind curve). In this study, the dependent variable was gaze direction and not speed adaptation. Further analysis that includes speed adaptation is required.

In two of the twelve far transfer situations the difference between the scores of the SimRAPT group and the control group was significant and in the expected direction. In one far transfer situations (E) the difference between the two groups was also substantial (*OR* = 10.8) and in the expected direction, but the assumption of the χ^2 test was not met. In seven far transfer situations the difference was in the expected direction but small and in two far transfer situations the difference was very small but in the opposite direction. The situations in the opposite direction were situation H (right turn at T-intersection) and situation M (Right merging fork). In situation H, the scores of both groups were relatively high and in situation M, both groups scored relatively low. It could be that H was a too easy test item to discriminate between the groups. Why the difference between the groups in situation M is in the unexpected direction, is not clear. In the very similar far transfer situation K (Merging fork from the left), the scores of the SimRAPT group were significantly better than the scores of the control group.

6.3.3. Questionnaires

Before and after the training (the simulator-based training for the SimRAPT group and the placebo pencil and paper training for the control group) and testing, participants were requested to rate their driving skills and abilities compared to drivers of the same age on a 5-point Likert scale (1 = much worse and 5 is much better). After the training and testing, participants in the SimRAPT-group still overestimated their skills (*M* = 3.88, *SD* = 0.72), but the overestimation was slightly less than before the training (*M* = 4.00, *SD* = 0.66).

For the control group the opposite was the case: before the placebo training the mean was 3.88 (*SD* = 0.93) and after the placebo training and testing the mean was 4.00 (*SD* = 0.69). However, repeated measures ANOVA showed that the small decrease in overestimation of the SimRAPT-group and the small increase in over estimation of the control group was not significant, $F_{(1,28)} = 0.45$, $p = .25$. Although the overestimation of skills and abilities was not significantly lower after the training because of SimRAPT, the intention to drive more conservative in the future, was. After the (placebo) training and the testing, participant were requested to indicate what they thought their future driving style would be on a 5-point Likert scale (1 = very conservative and 5 = very aggressive). The SimRAPT-group rated their future driving style significantly as more conservative than the control group with a medium effect size, $U = 88.5$, $p < .05$, $r = -.38$.

6.3.4. Comparison between SimRAPT and RAPT-3

Eighteen young novice drivers (56% male, mean age = 18.9, *SD* = 0.6; mean number of months in possession of licence = 21.8, *SD* = 10.3) that had completed the PC-based risk awareness and hazard anticipation training RAPT-3 (see Section 6.1.2 for a description of RAPT-3), also did the transfer test on the ADS. The training scenarios used in RAPT-3 partly differed from the training scenarios used in SimRAPT. Three of nineteen situations in the scenarios of the three test drives with latent hazards were near transfer situations for both the SimRAPT group and the RAPT-3 group and seven of nineteen situations with latent hazards were far transfer situations for both the SimRAPT group and the RAPT-3 group. The ten situations (the three near transfer situations together with the seven far transfer situations) the SimRAPT group and the RAPT-3 group had in common, constituted an acceptable scale ($\alpha = .68$). Figure 6.3 shows the boxplot of the percentage correctly anticipated latent hazards in these ten common situations for the SimRAPT group, the RAPT-3 group and the control group.

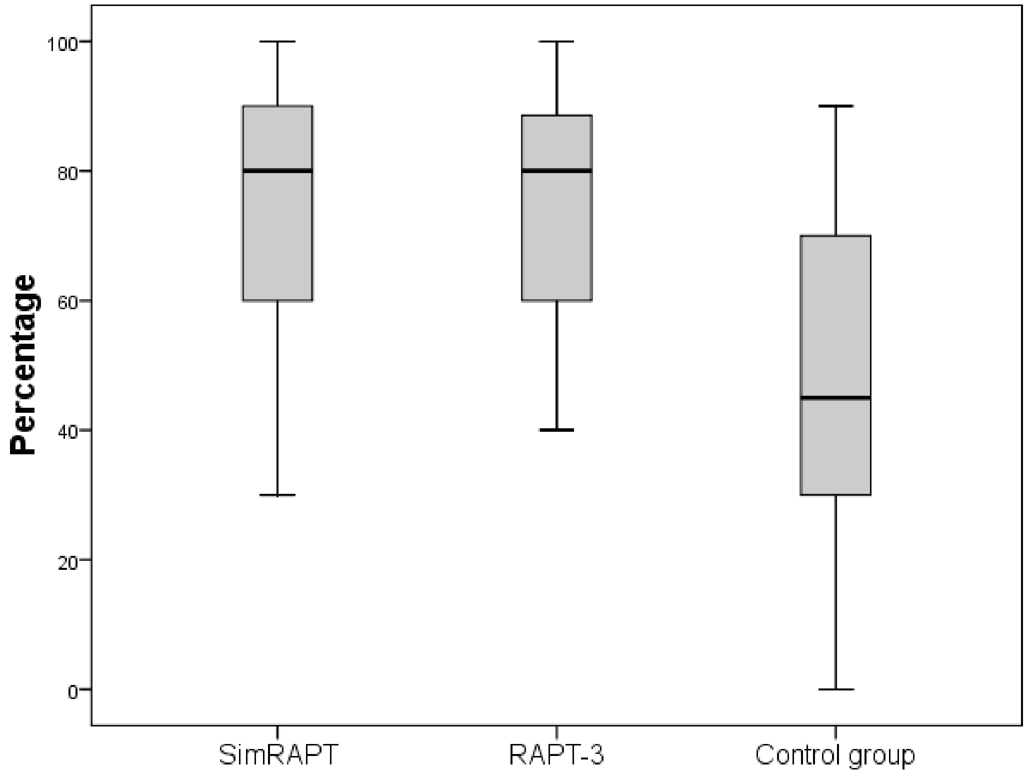

Figure 6.3. Percentage correctly anticipated latent hazards in the ten situations the SimRAPT group and the RAPT-3 had in common as a near transfer situation or as a far transfer situation.

The mean percentage of correctly anticipated latent hazards was M = 76.63 (SE = 4.85) for the SimRAPT group, M = 73.78 (SE = 4.85) for the RAPT-3 group and M = 50.83 (SE = 4.85) for the control group. As the scores of the SimRAPT group were not normally distributed [D (18) = 0.23, $p < .05$], the Kruskal-Wallis test was applied: H (2) = 12.70, $p < .01$. This result indicates that the three groups differed significantly. A Bonferroni correction when three groups are involved in the analysis, turns a significance level of $p < .05$ into a significance level of $p < .0167$. Applying a Bonferroni correction, a Mann-Whitney test shows that the mean percentage correctly anticipated latent hazard was significantly higher for the SimRAPT group than for the control group and the effect size was large, U = 65.5, p = .002, r = -.72. The mean percentage correctly anticipated latent hazards was also significantly higher for the RAPT-3 group than for the control group and the effect size was large, U = 68.5, p = 0.002, r = -.70. However, the difference in percentages correctly anticipated latent hazards between the SimRAPT group and the RAPT-3 group was not significant, U = 136, p = .41.

The combined three near transfer situations had not enough internal consistency to form a scale (α = .50) and also the seven far transfer situations did not form an acceptable internally consistent scale (α = .61). Table 6.5 shows the percentages correctly anticipated hazards for each of the situations the SimRAPT group and the RAPT 3 group had in common.

Table 6.5. Percentage correct anticipatory gaze directions of the SimRAPT group and the RAPT-3 group in situations both groups had in common.

No	Transfer	Type*	SimRAPT	RAPT-3	X^2	p	Odds ratio OR
B	Near	C	88.9%	94.4%	-	-	0.47
C	Near	C	83.3%	76.5%	-	-	1.54
L	Near	C	94.4%	94.4%	-	-	1.00
D	Far	P/C	61.1%	55.6%	0.11	.74	1.23
E	Far	C	94.4%	72.2%	-	-	6.54
G	Far	P	77.8%	58.8%	1.46	.23	2.54
I	Far	P/C	77.8%	76.5%	-	-	1.07
J	Far	C	77.8%	47.1%	3.53	.09	3.94
M	Far	P/C	47.1%	82.4%	4.64	.07	0.19
O	Far	O	66.7%	77.8%	0.55	.71	0.57

* C = Covert latent Hazard   O = overt latent Hazard   P = Precursors of Hazards

The differences in percentages correctly anticipated latent hazards in each of the ten situations between the SimRAPT group and the RAPT-3 group were in almost all situations very small. In situations E and J, the SimRAPT group performed substantially, but not significantly better that the RAPT-3 group and in situation M the RAPT-3 group performed substantially, but not significantly better than the SimRAPT group. It can be concluded that as far as SimRAPT and RAPT-3 could be compared, RAPT-3 was about equally effective in enhancing visual search for latent hazards as SimRAPT.

6.4. Discussion

Failing to look in the right direction or at the right objects at the right time and to correctly process the significance of the information in the driving environment, leads to crashes (Dingus et al., 2006; Klauer et al., 2006). Visual search for potential hazards is more poorly developed in young novice drivers than in older, more experienced drivers (Crundall & Underwood, 1998; Falkmer & Gregersen, 2005; Pradhan et al., 2005). A simulator-based training program for young novice drivers (SimRAPT) of approximately one hour was developed to improve visual search for latent hazards. The scenarios used in SimRAPT came from the scenarios developed for RAPT (Fisher et al., 2006; Pollatsek et al., 2006; Pradhan et al., 2009). SimRAPT was based on the principles of active learning from errors (Ivancic & Hesketh, 2000), inducement of arousal to promote memory consolidation (McGaugh et al., 2002), and instruction aimed at the promotion of far transfer (Brown, 1990). In order to promote self-reflection after a crash or a near crash and to minimize the tendency to attribute the cause of the crash to the other road users involved in the situation, participants first had to predict the latent hazard during a drive in which the latent hazard did not manifest itself.

SimRAPT had clear influences on the visual search patterns of young novice drivers in quasi (near and far) transfer scenarios. The term 'quasi' is used here because the effect of the training was not tested in real world traffic, but in an advanced driving simulator with a considerably better fidelity of the representation of reality than the low-cost training simulator. With respect to the first hypothesis, the group that received SimRAPT had 46.92% (26.70 percentage points) more proper gaze directions in these near transfer scenarios than the control group. This difference was significant and the effect size was large. With respect to the second hypothesis, the group that received SimRAPT had 32.64% (17.46 percentage points) more gazes in the correct direction than the control group in far transfer scenarios. This difference was significant with a medium effect size. Groeger & Banks (2007) argued that there is little theoretical foundation and empirical evidence that traditional basic driver training (formal instruction by a certified driver trainer aimed at acquiring the skills to pass the driving test) can effectuate far transfer. The applied learner centered method in SimRAPT and the use of plan views in order to grasp the abstract principle behind very different looking situations, may in contrast to traditional driver training have promoted far transfer, although the effect size was smaller for the far transfer situations than for near transfer situations. The fact that the effect size was smaller in the far transfer situations is in support of hypothesis three. As expected, because of the emphasis on covert latent hazards in the training, performance after training was better in the covert latent hazard situations only than in all the latent hazard situations taken together. This is in support of hypothesis one and two. Similar effects with regard to near transfer and far transfer were found in the simulator-based training programs that were developed by Ivancic & Hesketh (2000) and by Wang et al. (2010), but the former training program was mostly about imminent hazards and the latter training program was mostly on overt latent hazards and did not apply error training. In SimRAPT, the simulator based error training of Ivancic & Hesketh (2000) and the hazard handling performance training of Wang et al. (2010), participants were not merely exposed to risks. In the simulator training of the European project TRAINER (2002) and in the Australian simulator training of Regan et al. (1999) they were. The former were effective and the latter not. It could be that if trainees are only exposed to immanent hazards in a simulator, they do not learn. It could be that when only exposed to hazards, trainees may not receive sufficient feedback and information to comprehend what caused the (near) crash. Moreover, when merely exposed to danger they can easily attribute the cause of the (near) crash to the circumstances and/or the other road users involved in the (near) crash.

It is of interest to know whether simulator-based training programs have value over PC based training programs. Effective PC based training programs for enhancement of visual search have been developed (Chapman et al., 2002; Fisher et al., 2006; Isler et al., 2009; Pollatsek et al., 2006; Pradhan et al., 2009). In this case a direct comparison could be made between the PC based versions of RAPT-3 and SimRAPT. Eighteen novice drivers of about the same age and with the same driving experience as the participants of the SimRAPT group, did RAPT-3 and directly after completion of RAPT-3, did the same quasi transfer test on the advanced simulator as the participants of the SimRAPT group did. The RAPT-3 group performed equally well on the quasi transfer test as the SimRAPT group. The conclusion is that when tested directly after the training, SimRAPT had no value over the PC-based training program RAPT-3 and consequently the fourth hypothesis that SimRAPT is more effective than RAPT-3 is rejected.

There are four additional questions to address. First, short training programs for novice drivers to enhance their skills (i.e., skid training) tend to have an adverse effect on their crash rate because novice drivers tend to overestimate their abilities after training (Elvik et al., 2009). Did SimRAPT inadvertently stimulate novice drivers' confidence in their own abilities that could result in more risk taking? Compared to drivers of the same age group, participants in the SimRAPT group rated their abilities slightly lower after the training than before the training, whereas the control group rated their abilities slightly higher after their placebo training. Although these changes in self-assessment were not significant, participants in the SimRAPT group intended to drive in a significantly more conservative manner in the future than the control group intended to drive. Because in error training participants are confronted with their own limitations, an increase in confidence is not very likely. This was also found in other studies about hazard anticipation training (Ivancic & Hesketh, 2000; McKenna et al., 2006).

Second, it is of interest to ask whether SimRAPT would be as effective with novice drivers at 16 years of age as it is with participants in this study who have held their license for approximately 2 years. In fact, there are indications from the reduction in variability observed in the trained drivers that, especially for the near transfer scenarios, SimRAPT seems to bring drivers who do relatively poor and drivers who do relatively well to the same level of hazard anticipation skills. This implies that SimRAPT could also be an effective training at a moment earlier in one's driving career than two years after full licensing. This is important because the highest crash rate is directly after licensing (see Section 1.2).

Third, it is of interest to ask whether one can expect the effects of training to last for an extended period of time (retention). A real limitation of the present study is that participants were tested directly after the training. Thus, the effects on long term retention are not known. Because the experience of crashes or near crashes during the simulator training is presumed to create arousal and moderate levels of arousal enhance memory (McGaugh et al., 2002), it could be that retention of skills is better for SimRAPT than for RAPT-3 as in RAPT-3 no deliberate actions were taken to enhance memory consolidation. Whether SimRAPT has a more lasting effect than RAPT-3 remains to be tested.

Fourth, it is of interest to ask whether the learning which occurs with SimRAPT and generalizes to the advanced simulator would actually be found in the real world and, additionally, whether there would be a corresponding reduction in crash rates. What the effect of SimRAPT is for driving behavior in the real world, is not known. This has been studied for RAPT-3 and significant positive effects of RAPT-3 on driving in the real world could be demonstrated (Pradhan et al., 2009). No studies of the effect of simulator-based error training on visual search for latent hazards on crash rates have been conducted. Clearly more research is required.

7. Discussion and conclusions

7.1. Hazard anticipation and driving

This thesis is on hazard anticipation of young novice drivers. Hazard anticipation is defined as:

> *The detection and recognition of road and traffic situations that could increase the possibilities of a crash, including the prediction of how these situations can develop into acute threats. The feelings of risk that are evoked by these predictions and the execution of actions that will reduce the feelings of risk and will ensure a safety margin that is large enough to avert a crash should the latent hazard materialize. Hazard anticipation can range from 'automatic' to 'controlled'.*

Although in the definition hazard anticipation is decomposed into various processes, it is assumed to be one holistic process that especially experienced drivers perform on the procedural stage without or with little conscious awareness. This implies that for experienced drivers most of the times hazard anticipation is automatic. The subject of this thesis is not hazard anticipation, but hazard anticipation of young novice drivers. The objective of this thesis is to investigate how well young novice drivers anticipate latent hazards and what influences culminating driving experience and maturation of in particular the brain have on hazard anticipation. Besides this theoretical objective, there are two applied objectives. These objectives are: (1) to explore ways to test hazard anticipation that are suitable for mass testing (e.g. in the theory test of the driving test) and (2) to investigate the possibility to train hazard anticipation in a driving simulator environment.

In this thesis, hazard anticipation is conceived as a precondition to perform adequately on what Michon (1985) has defined as the tactical level of the driving task. On the tactical level, drivers choose their speed and headway in changing traffic situations. They more or less automatically take certain risks when dealing with traffic situations (e.g. 'Shall I overtake that slow driving car in front of me?' or 'Is the gap wide enough to turn left?').

Both of what is usually called hazard perception and the over representation of young novice drivers in crashes, are not new topics in traffic psychology. In the past decades a vast amount of studies have been devoted to the novice driver problem and poor hazard perception has often been mentioned as one of the causes of the high crash rate of young novice drivers. Indeed, more than once an association has been found between poor performance on a hazard perception task by mostly young novice drivers and crash involvement (Congdon, 1999; Darby et al., 2009; McKenna & Horswill, 1999; Pelz & Krupat, 1974; Quimby et al., 1986; Wells et al., 2008). To date however, poor hazard anticipation has been viewed either as a cognitive problem (i.e. not having the skill to detect, to recognize and to predict hazards) or as motivational problem in terms of poor risk assessment, poor self-assessment and the acceptance of high levels of risks. In this thesis, an attempt is made to bridge the two different views. In order to do this the phenomenon of hazard anticipation has been approached from a cognitive-neuropsychological perspective. The key concept in this approach is mental representation or schema. While driving schemata unfold in interaction with external stimuli (i.e. what the driver perceives) and internal stimuli (i.e. what the driver feels), the selected dominant schemata enable the driver to find valid cues in the road and traffic situation and to anticipate forthcoming events. Activation and inhibition of schemata and action selection most of the times happen automatically, especially when the driver is an experienced driver. Sometimes selection of schemata is controlled. To explain in more detail how drivers anticipate hazards the framework of Brouwer & Schmidt (2002) is applied. This framework was originally developed to provide insight in the multiple causation of sometimes aberrant (driving) behaviours dependent on underlying (brain) disorders and differences in expertise. The framework describes the hypothetical sub-processes that are involved in action selection by drivers and the interaction between these sub-processes. Errors or omissions in action selection by drivers with mild Alzheimer's disease could for example be the result of slow information processing of content information and limited working memory capacity. On the other hand in patients with mild frontotemporal dementia poor monitoring of the risks involved in road and traffic situations and impaired inhibition of unsafe behaviour could be the cause of unsafe acts. The framework of Brouwer & Schmidt (2002) is based on Norman and Shallice's model on willed and automatic control of behaviour (Norman & Shallice, 1986) and incorporates some elements of the zero-risk model on driver behaviour developed by Näätänen & Summala (1974). In contrast to Norman & Shallice, Brouwer & Schmidt make way for emotional and motivational processes in their framework and attention is not only manifest in the intervention of the Supervisory Attentional System (SAS) into the Contention Scheduler (CS), but also in processes of the CS itself. Brouwer & Schmidt (2002) also assume that action selection in complex cognitive tasks always is a mixture of automatic and controlled processing. The framework has been leading for the research on differences in hazard anticipation between young novice drivers, older novice drivers and experienced drivers that is presented in Chapter 4. The framework has also been used for the development of the simulator-based hazard perception training that is presented in Chapter 6. In the sections below, the key results of Chapter 2 to Chapter 6 are discussed. The last two sections of this thesis are about the practical implications of this thesis and possible future directions of research.

7.2. Young novice drivers

Young novice drivers are overrepresented in car crashes. The young novice driver problem is a worldwide phenomenon and in the past decades, a plethora of causes has been reported. The fact is that the 'young driver problem' is not simply one, but rather a variety of multifaceted problems, for which there is no single solution. In Chapter 2 the causes are presented that are mentioned in the literature that may relate to hazard anticipation. These causes are presented on basis of a taxonomy that was developed for this purpose. With regard to the underlying causes that may affect hazard anticipation in this taxonomy, a distinction is made between: biological causes, social and cultural causes, acute impairments and exposure.

7.2.1. Biological aspects

Our understanding of behaviour, and the brain based systems on which it relies, has developed considerably in the past twenty years. Because of new brain imaging techniques such as Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET), we now know that the brain is not fully matured before the age of 25, at least in males. Maturation is especially late in some areas of the Pre Frontal Cortex (PFC) such as the DorsoLateral

Prefrontal Cortex (DLPFC) and the Orbito Frontal Cortex (OFC). It is not so much the late maturation of these areas in itself, but rather the late maturation of these areas in combination with the earlier maturation of other brain areas, including the sub-cortical areas related to motivation and emotion such as the amygdala and the nucleus accumbens. The slowly maturing prefrontal systems are supposed to have an inhibitory function on emotional and motivational systems. It is thought that because of this imbalance young people are relatively speaking: impulsive, have an inclination towards sensation seeking, prefer immediate rewards, have a greater sensitivity to peer influences and find it difficult to plan ahead. Adolescents however, do not seem to be less rational than adults are when reflecting on their own capabilities. This is to say, both young drivers and middle-aged drivers tend to overestimate their own driving capabilities. Young drivers also do not underestimate known risks when they have the time to reflect on these risks. When asked for, they will tell that drinking and driving is dangerous. The problem is that although they know the risks (when asked for), at least some of them still will take the risks.

Although both young female drivers and young male drivers are overrepresented in crashes, the young driver problem is predominantly a young male driver problem. The pace at which the volume of gray matter declines (until well into the third decade of life) and the volume of white matter increases (during the second decade of life), differs between young females and young males. Decrease in gray matter makes information processing more effective and increase in white matter makes information processing faster. Because of these differences in pace, young females mature earlier than young males. Not only the brain matures at a different pace in young females and in young males, also the hormonal regulation starts to differ considerably between boys and girls when they get into puberty. The effect of the different pace in brain development and differences in hormonal regulation affecting the cortical and sub-cortical areas, could explain the greater self-control over emotional behaviour and a lower tendency for sensation seeking in young females than in young males.

7.2.2. Social and cultural aspects of being young

The social and cultural aspects of being young cannot be isolated from the biological aspects of being young. It is both 'nature' and 'nurture' and the interaction between the two. Motives for driving and having a car can be different for young drivers compared to middle-aged drivers and may differ across lifestyle groups. For many young drivers a car is not only a means of transport to travel from A to B without the inconveniences of public transport. It can also be status, a means to impress friends, a means to test the limits of one's skills and a symbol of freedom. Crash rates of young drivers are higher than average in groups that prefer a lifestyle in which driving and cars are important and/or there is a preference for leisure time activities with low structure and high impulsivity such as partying.

Driving with passengers can have a negative and a positive effect on the crash rate of young novice drivers. Especially for very young novice drivers (both male and female), driving with a male passenger of about the same age increases the crash rate. However, driving with a middle-aged passenger (e.g. a parent) decreases the crash rate of young novice drivers considerably.

There are indications that the socioeconomic status of the family of young novice drivers may have some effect on the crash rate as well. Most studies show that young novice drivers of families with a low socioeconomic status have a higher crash rate than young novice drivers of parents with a high socioeconomic status. The results may however be confounded by the fact that young novice drivers of a low socioeconomic status will normally drive in older cars that offer less protection.

7.2.3. Acute impairments

As any driver, a young novice driver may temporarily be less capable to anticipate hazards in traffic when she or he is under the influence of psychoactive substances (e.g. alcohol and/or illicit drugs). Other transient factors that hamper hazard anticipation are tiredness or drowsiness, distraction or inattention and emotions. There are indications that alcohol and fatigue affect young novice drivers more than older, more experienced drivers. The temptation to use particular types of electronic equipment while driving (MP3 players, CD-players, smart phones) is stronger for young drivers than for middle-aged drivers. Young novice drivers also more often drive with passengers that might distract them. Passengers of the same age implicitly or explicitly may also encourage young drivers to take risks. Emotions may have a more pronounced effect on young drivers than on middle-aged drivers, but so far, there is no clear evidence for this.

7.2.4. Exposure

Young novice drivers more often drive in circumstances that are more demanding and hazardous for all drivers. Except for the youngest group of novice drivers (18 and 19 years of age in the Netherlands), they have a tendency to drive too fast. Although the youngest group of novice drivers do not tend to speed constantly, they often do drive too fast for the circumstances (e.g. too fast in a curve). Young novice drivers also more often drive late at night and they more often drive with passengers that might distract them. Crash involvement is higher and the crashes are also more serious because young novice drivers more often drive in older cars with less active and passive safety features.

7.3. Age, experience and hazard anticipation

Hazard anticipation has a cognitive aspect and an emotional and motivational aspect. The cognitive aspect is the detection and recognition of latent hazards, including the prediction of how the latent hazard can develop into imminent hazards. The emotional aspect is the feeling of risk associated with these predictions and the motivational aspect is the willingness to take actions in order to reduce those feelings of risk. These are actions to keep a safety margin large enough to avert a collision should the latent hazard materialize. The anticipatory actions could be: 'keeping an eye' on someone who may start to act dangerously (in case of overt latent hazards), looking in a particular direction from where a road user could emerge on collision course (in case of covert latent hazards), reduction of speed and if possible change of lateral position in the lane. Based on the framework of Brouwer & Schmidt (2002) it is assumed that the cognitive, the emotional and motivational aspects are interrelated. As experience culminates, schemata get more elaborated. Because of these elaborated schemata, known latent hazards are 'seen' immediately and experienced drivers anticipate these hazards most often automatically, without (much) conscious awareness. It could be that 'somatic markers' (Damasio, 1994) help to select the proper dominant schema. Somatic markers are emotional signals from the viscera that have developed from emotions felt in previous situations in which a similar latent hazard had developed into an imminent hazard almost resulting in a crash. When drivers do not detect and recognize a latent hazard automatically on the basis of the selected dominant schema, it is assumed that what is the monitor in the framework of Brouwer & Schmidt (2002), 'senses' some feeling of loss of control. This is to say that the driver may experience something that makes her or him feel that something could intervene with her or his goals. According to Shallice (1988) this happens in novel situations, when the situation is such that deliberate choices have to be made, when temptation has to be overcome or when there is a sense of danger without exactly knowing what. The monitor inhibits the CS and then activates the SAS. The problem is processed in working memory. The result of this is an intervention in the automatic activation and inhibition of schemata in the CS. Because of this intervention, a different dominant schema is selected and based of this schema hopefully the latent hazard is detected and recognized.

It was hypothesised that older novice drivers (persons that start to drive after the age of 24) will sooner switch on SAS in unknown situations than young novice drivers (people that start to drive as soon as they have reached the age limit, 18 years of age in the Netherlands) because of the more matured brain of older novice drivers. It was also hypothesised that both young novice drivers and older novice drivers would be equally bad in the automatic detection and recognition of latent hazards as both groups lack experience. In order to test this hypothesis, two PC-based tasks were developed: the hazard detection and recognition task and the risk assessment and action selection task. The hazard detection and recognition task consisted of seven animated video clips, 'taken' from the driver's perspective and each lasting approximately forty seconds. These video clips contained overt latent hazards and covert latent hazards that did not materialize. See for an overview of these latent hazards Appendix 1. Participants in three different groups watched these videos as if they were the driver in the video clip. This was a group of young learner drivers (18 or 19 years of age) that were almost ready to do the driving test, a group of older learner drivers (25 years of age or older) that also were almost ready to do the driving test and a group of experienced drivers. While participants watched the videos, their gaze directions and fixations were recorded. Immediately after each video, participants were asked what could have happened that could have increased the likelihood of a crash. The risk assessment and action selection task consisted of twenty-five photographs. Each photograph was exposed for eight seconds on the screen of a monitor. These photographs were taken from a driver's perspective. A part of the photographs contained imminent hazards (i.e. visible other road users that would collide with the driver (of the photograph) if no one would change speed and/or course). A part of the photographs contained latent hazards (both covert latent hazards and overt latent hazards) and a part of the photographs contained no hazards at all. In all photographs the speed on the speed-o-meter was presented. After participants had watched a photograph (during eight seconds) and the screen had turned black, participants had to respond if they would have (1) braked in this situation (in case of an imminent hazard), (2) released the throttle in this situation (in case of a latent hazard), or (3) would have continued with the same speed (in case of no imminent or latent hazard). While participants watched the photographs on a monitor, their gaze directions and fixations were recorded. It was assumed that the responses on this photo test would measure the inclination to take risks as research with similar sets of photographs had indicated that there is no difference between novice drivers and experienced drivers in the ability to categorize photographs with imminent hazards, latent hazards and no hazards (Huestegge et al., 2010; Kelly et al., 2010). It was hypothesised that on the hazard detection and recognition task both young learner drivers and older learner drivers would score equally worse and that experienced drivers would score significantly better. This was expected because both groups of learner drivers lack the experience that is needed to elaborate the schemata. It was also hypothesised that the group of older learner drivers would have a significantly lower risk score on the risk assessment and action selection task than young learner drivers. This was expected because due to a more matured PFC the inclination to take risk would be lower for older learner drivers than for younger learner drivers.

On the hazard detection and recognition task, experienced drivers fixated covert latent hazards significantly more often than young learner drivers and older learner drivers. There was no significant difference in fixated covert latent hazards between young learner drivers and older learner drivers. Exactly the same pattern was visible in the mentioned covert latent hazards. However in all three groups on average around 30% less covert latent hazards were mentioned than fixated. Almost all the participants in all three groups fixated all the overt latent hazards and there was no significant difference between the groups in fixated overt latent hazards. In contrast, experienced drivers mentioned significantly more often overt latent hazards than both young learner drivers and older learner drivers. There was no significant difference in mentioned overt latent hazards between young learner drivers and older learner drivers. From the difference in fixated overt latent hazards and mentioned overt latent hazards can be inferred that counting fixations on overt latent hazards is probably not a valid method to measure someone's skill to recognize overt latent hazards. Apparently, inexperienced drivers (both young learner drivers and older learner drivers) fixate more often on overt latent hazards without knowing that they are latent hazards. It could be that for inexperienced drivers a greater proportion of the fixations on overt latent hazards were the result of bottom-up processes and top-down processes not related to hazard anticipation than for experienced drivers.

The results with regard to fixations on covert latent hazards and mentioned covert and overt latent hazards are in support with the hypothesis that lack of experience and not age causes the rather poor performance in hazard detection and recognition of young novice drivers. To say it simply, novice drivers (both young and old) do not always know where to look or what to expect (based on not yet fully elaborated schemata) because they lack experience. It could be argued that inexperienced drivers are bad in hazard perception because driving itself (steering, adjusting speed, shifting gear) still requires so much mental workload as vehicle control has not yet become automated, that no or too little mental capacity can be allocated to hazard perception. The results on the hazard detection and recognition task however show that inexperienced drivers also have poor hazard perception skills without having to drive.

In contrast to what was expected, older learner drivers did not have a significantly lower risk score on the risk assessment and action selection task than young learner drivers. This means that no evidence was found in support of the second part of the principal hypothesis that the emotional and motivational aspect of hazard anticipation improves with age. Rejection of this second part of the principle hypothesis on the basis of the results would however be inappropriate without further research. The statistical analyses revealed that it is questionable if the risk assessment and action selection task (the photo task) indeed measured the emotional and motivational aspect of hazard anticipation. The results of the statistical analyses indicated that the two tasks measured more or less the same and that what was measured (most probably hazard detection and recognition), was measured better by the hazard detection and recognition task (the video task) than by the risk assessment and action selection task (the photo task).

7.4. Possibilities of testing hazard anticipation

Especially the hazard detection and recognition task is not suitable for mass testing. Eye tracking equipment is expensive and analysis of eye tracking data is too cumbersome to be used in for example the theory test of the driving test. Moreover, because people wear particular spectacles or their eyes have a particular colour, eye tracking equipment sometimes fails to record fixations and saccades. The response method of mentioned latent hazards without the use of an eye tracker is more suitable, but for mass testing, answers on open questions are not very practical either. A variant of the hazard detection task was developed in which participants instead of fixating on overt latent and covert latent hazards, could point and click with their mouse on overt latent hazards and covert latent hazards. As pointing and clicking with a mouse takes time, the video clips were paused a couple of times per clip during five seconds to allow for pointing and clicking. In order to discourage multiple clicking on spots that participants not actually had recognised as latent hazards, participants were told that not all pauses contained latent hazards, that only three clicks per pause were recorded and that false clicks would lower their score.

In contrast to the hazard detection and recognition task, the risk assessment and action selection task is suitable for mass testing. The only thing that was changed with respect to the task discussed in the previous section was that the task was made self-paced. Participants had to press a key on the keyboard of the computer within the eight seconds a photograph was presented on the monitor. The three options were brake, release throttle or keep the speed as it is. A soon as a participant had pressed one of the three keys the screen appeared that enabled participants to start with the next item.

As the results presented in Section 7.3 indicate that both tasks probably did not measure two distinct aspects of hazard anticipation, the hazard detection and recognition task was named more neutrally the 'video task' and the risk assessment and action selection task was named more neutrally the 'photo task'. Different video clips and different photographs were used than those used in the experiments with the eye tracker, which were discussed in Section 7.3. The research on variants of both tasks that are suitable for mass testing discussed in this section, was carried out at an earlier moment in time than the experiments with the eye tracker. Three groups made the two tasks: learner drivers on the day they had passed the driving test, novice drivers that hold their driving licence for eighteen months and experienced drivers.

With regard to the video task, there were no significant differences between the three groups in clicks on latent hazards (both on covert latent hazards and on overt latent hazards). This is remarkable because there was a significant difference with a large effect size in mentioned latent hazards between learner and experienced drivers in the hazard detection and recognition task discussed in Section 7.3. There was also no significant difference between novice drivers that had reported at least one crash and crash free novice drivers. Three possible explanations were considered why the variant with mouse clicks in pauses failed to discriminate between novice and learner drivers on one hand and experienced drivers on the other. Firstly, it could be that the variant with the mouse clicks was too complicated and that participants were not well enough prepared to do the task. Secondly, it could be that clicking with a mouse on areas on a screen was more complicated for the group experienced drivers than for the learner drivers and novice drivers. The experienced drivers were considerably older than both other groups. It is likely that on average older persons have less experience with computer games and it could be that the more experience a person has with computer games the easier it is to point and click with a mouse. Thirdly, the pauses that were necessary to allow for sufficient time to point and click could have enabled learner drivers and novice drivers to detect latent hazards they had not yet detected while the video still was running. The very fact that the video clip paused could have triggered participants that there could be latent hazards and the pause itself offered the time to detect and recognize these possible latent hazards.

With regard to the photo task, there was a significant difference between learner drivers and novice drivers and between learner drivers and experienced drivers with the learner drivers having the highest risk scores. There was no significant difference in risk scores between novice drivers and experienced drivers. The magnitude of the difference between learner drivers and experienced drivers was relatively small and was about the same as between learner drivers and experienced drivers in the risk assessment and action selection task, discussed in Section 7.3. In the photo task, a different set of photos was used than in the risk assessment and action selection task. Controlled for exposure (defined as number times use was made of a car per week), novice drivers that had reported at least one crash had a significantly higher risk score than crash free novice drivers. Both the lower risk scores for the crash free novice drivers and the higher risk scores for learner drivers compared to the risk scores of experienced drivers are indications that the photo task has validity. The fact that the risk scores of novice drivers were significantly lower than the risk scores of learner drivers, but not significantly higher than the risk scores of experienced drivers, could indicate that the aspect of hazard anticipation measured by the photo tasks improves rapidly in the first months after licensing.

As the video task was unable to discriminate between learner drivers and novice drivers on the one hand and experienced drivers on the other and this failure could have been caused by the poor quality of the video task, an improved video task was developed. In this video task, the latent hazards were less ambiguous, the quality of the videos was better and the videos were presented on a larger screen. The task was also simplified and an introduction video clip was made to prepare participants for the tasks. Two groups completed this improved version of the video task: learner drivers on the day they had passed the driving test and professional drivers (driving instructors and driving examiners). On this improved video task, again the average score of the group of learner drivers was not significantly lower than the average score of in this case of even a group of professional drivers. Self-reported experience with computer games had an effect on the scores. Whereas there was no significant difference in the scores between learner drivers and professional drivers, this difference got significant when the scores were controlled for experience with computer games. As the improved video task also failed to discriminate between learner drivers and in this case even professional drivers, the conclusion has to be that mouse clicks on latent hazards during pauses in video clips are not a good response method to test hazard detection and recognition. Possible explanations for this failure are the confounding effect of experience with computer games and the confounding effect of the interruptions (the pauses).

7.5. Simulator-based hazard anticipation training

From the experiments discussed in Section 7.3 can be concluded that both young novice drivers and older novice drivers fail to detect and recognize latent hazards, because they do not know what to expect and accordingly do not know where to look and that this deficiency is probably caused by lack of experience. As poor hazard detection and recognition is presumably caused by lack of experience, hazard detection and recognition is a skill that in principle must be trainable. It is assumed that for the detection and recognition of latent hazards elaborated schemata are required and that for the quick and proper selection of the dominant schema in a particular road and traffic situation, 'somatic markers' (Damasio, 1994) may help. When situations resemble situations that have elicited emotions (e.g. fear) in the past a tiny bit of this emotion, the somatic marker, is relived and this helps to select the proper dominant schema without (much) conscious awareness. If this is so, drivers have learned to detect and recognize latent hazards because they have experienced near misses in which the latent hazard materialized and they have felt emotions. In a simulator, drivers can experience crashes without the negative physical consequence of a crash. However, mere exposure to risky situations in a simulator probably is not enough to develop hazard anticipation skills. Therefore, participants were challenged to detect hazards and to improve themselves the way this is done in error training (Ivancic & Hesketh, 2000). Use was also made of plan views to promote far transfer. It was hypothesised that a simulator-based training in which crashes or near crashes were elicited in combination with instruction, would result in better scanning for latent hazards in situations that were similar to the training scenarios, but different in appearance. These were the near transfer situations. It was also hypothesised that the training would result in better scanning for latent hazards in situations that were in concept different from the training scenarios, except for a general principle. These were the far transfer situations. As trainees were confronted with the consequences of their errors, it was finally hypothesised that the training would not promote overconfidence.

For the training, a low cost fixed-base simulator was used with wide-angle projected display. The training lasted about one hour. In this hour, trainees drove through short scenarios of about one minute each that contained latent hazard. Most of these latent hazards were covert latent hazards. There were three versions of each scenario. First, they drove the scenario in which the latent hazard did not materialize. After this short drive, trainees were asked what could have happened that did not happen. Hereafter, irrespective of their answer they drove the so-called error drive. This error drive was the same drive as the first drive, but now with the latent hazard materializing aggressively. If the latent hazard was not detected and recognized, this drive ended in a crash or a near miss. After this, a plan view of the traffic situation appeared on the centre screen of the simulator. Trainees had to explain to themselves on the basis of this plan view why the near miss or crash had happened and what they could have done to avert the crash or near miss. Trainees also received instruction about how to anticipate the latent hazard. A plan view was used in order to promote far transfer. Finally, trainees drove the scenario for the third time. In this third version the latent hazard also materialized, but less aggressively than in the error drive. This third drive was intended to offer trainees the opportunity to practice what they had learned. After this third drive, the cycle started all over again with a different latent hazard in a different scenario. In order to test the hypotheses the skill to detect and recognize latent hazards of eighteen trained and eighteen untrained young novice drivers that were around 19 years of age and had around two years driving experience, was evaluated on an advanced driving simulator. Participants drove through three scenarios that all together contained seven situations with latent hazards that did not materialize that were the same as the latent hazards in the training, but that were different in appearance. These were the near transfer situations. The participants also encountered twelve situations with latent hazards that did not materialize that were conceptually different from the latent hazards in the training. These were the far transfer situations. The eye movements of both groups were measured. The trained group made anticipatory gaze directions in 84% of the near transfer latent hazard situations and the untrained group made correct gaze directions in 57% of these situations. The trained group made anticipatory gaze directions in 71% of the far transfer latent hazard situations and the untrained group made anticipatory gaze directions in 53% of these situations. The differences between the groups in both the near transfer situations and the far transfer situations were significant, but the effect size was smaller in the far transfer situations than in the near transfer situations. However, as far as the effect of the simulator-based training program could be directly compared with a PC-based training program that used the same latent hazards for training, the simulator-based training was not better than the PC-based training. Self-rating of driver confidence was lower (but not significantly) after the training for the trained group than before the training. And after the training the trained group had the intention to drive significantly more conservative in the future than the untrained group.

A limitation of the study is that participants were tested on an advanced simulator and not while driving in real traffic. Another limitation is that retention was not tested as the participants were tested within one hour after the training.

7.6. Key results

Assumed is that hazard anticipation has two aspects: a cognitive aspect and an emotional and motivational aspect. If this is the case, could it be that for young novice drivers the cognitive aspect (the detection and recognition of latent hazards and the prediction how these latent hazards can develop into acute threats) mainly improves with increasing experience and the other aspect (the feeling of risk, the acceptance of low levels of risk and the willingness to drive safely) mainly improves with age (maturation of the brain)? The results of the study presented in Chapter 4 clearly supports the assumption that the cognitive aspect of hazard anticipation improves with increasing experience. In contrast, no support could be found that the emotional and motivational aspect of hazard anticipation improves with age. However, it is too early to reject the latter assumption, as this emotional and motivational aspect of hazard anticipation was probably not operationalized properly by the risk assessment and action selection task used in Chapter 4. The study presented in Chapter 4 yielded three other important conclusions. These conclusions are: (1) mentioned latent hazards during and after the presentation of video clips containing latent hazards, are an adequate method to test hazard detection and recognition, (2) fixations on overt latent hazards are not a good indicator of the ability of young novice drivers to detect and recognize overt latent hazards, and (3) fixations on covert latent hazards are a good indicator of someone's ability to detect and recognize covert latent hazards.

The study presented in Chapter 5 was on practical methods to measure various aspects of hazard anticipation that are suitable for mass testing. The results show that on the developed photo task, learner drivers (tested on the day they had passed the driving test) responded riskier with regard to speed adaptation than both novice drivers with 18 months driving experience and experienced drivers did. In addition, novice drivers who had reported a crash had riskier responses than crash free novice drivers. These are indications that the photo task has validity. On the developed video task with pauses in which participants could click on latent hazards however, only a marginally significant difference between crash free novice drivers and novice drivers that had reported a crash was found. Moreover, on this video task, no significant difference was found in detected and recognized latent hazards between learner drivers on the day they passed the driving test and professional drivers. The conclusion is that in principle the photo task is a good method to test hazard perception and the video task with mouse clicks on latent hazards during pauses in the clips, is not. The results of Chapter 4 however indicate, that a video task (but not with pauses and mouse clicks) has more potential to discriminate between good and bad drivers in hazard anticipation than the photo task.

The results the study presented in Chapter 6 show that it is possible to train visual search for latent hazards in a training program of approximately one hour on a simple simulator. According to Elvik (2010), the young novice driver problem is almost impossible to solve as "the high risk of young drivers is probably attributable to a powerful mixture of biological factors (hormones and brain development), overoptimistic self-assessments and being in a phase of life in which becoming independent, testing limits and rebelling against adult values is important." This all may be true but there is hope. Lack of hazard anticipation skills is one of the causes why novice drivers have such a high crash rate (Congdon, 1999; Curry et al., 2011; McKenna & Horswill, 1999; McKnight & McKnight, 2003; Wells et al., 2008). The results of the studies presented in this thesis indicate that poor hazard anticipation is partly caused by the fact that novice drivers do not know what to expect and therefore do not know where to look. The results in this thesis also indicate that this shortcoming can be overcome by training, without stimulating the tendency to take more risks, which often is the case after completion of a short training program in which skills are trained.

7.7. Practical implications

This thesis is not the first study about what is mostly called hazard perception and young novice drivers. There are more studies in which a test was developed that could discriminate between the hazard perception skills of novice drivers and experienced drivers. Also in some studies, an association has been found between scores on hazard perception tests and crash liability. Successful training programs in hazard perception have also been developed before. To date however, hazard anticipation and the young novice driver problem have not been approached from a broad cognitive-neuropsychological perspective. This approach has resulted in a new and practical method to measure hazard anticipation. This is the photo task. The photo task could discriminate between novice drivers that had reported at least one (minor) crash in traffic and crash free novice drivers. The photo task could also discriminate between learner drivers and experienced drivers. As this task does not require moving images, it is a task that is easy to apply and can easily be incorporated in for example a theory of a driving test. This has in fact already happened. From March 1 2009 on, a version of the photo task presented in this thesis is incorporated in the theory test of the Dutch driving test for licence category B (private cars). This photo task has however weaknesses. The power to discriminate between learner drivers and experienced drivers was much bigger for the (in this thesis called) hazard detection and recognition task. In this task participants had to mention the covert latent and overt latent hazards that did not materialize in animated video clips. Answers on open questions are however not very suitable for mass testing and a practical version of this task with mouse clicks as response method failed to discriminate between learner drivers and experienced drivers. Besides the relatively small effect size of the difference between learner drivers and experienced drivers on the photo task, the internal consistency of the test items was rather low. This is probably due to the differences in difficulty between the test items.

Based on (1) the previously developed PC-based Risk Assessment and Hazard Perception Training programs (RAPT) at the Human Performance Laboratory of the University of Massachusetts in Amherst (Fisher et al., 2006; Pollatsek et al., 2006; Pradhan et al., 2009), (2) the framework on executive functioning and willed and automatic control of action with an emphasis on the functioning of mental representations (schemata) that was developed by Brouwer & Schmidt (2002) and (3) the somatic marker hypothesis of Damasio (1994), a simulator-based hazard anticipation training was developed. In order to avoid attribution of an experienced crash or near crash to the other road users involved in the situation and to promote far transfer, participants were also challenged to detect hazards, to comprehend the mechanisms behind the development of a hazard with the aid of plan views and to improve themselves. This training program of approximately one hour, in which a low cost fixed-base simulator was used, improved visual search for latent hazards of young novice drivers in both near and far transfer situations significantly. The developed simulator-based training program can become part of initial driver training programs or part of an advanced course for novice drivers.

7.8. Further research

In this thesis, it is hypothesised that hazard anticipation has an emotional and motivational aspect and that there is a difference with regard to this aspect between young drivers and middle-aged drivers. This aspect could not be demonstrated. It is likely that this aspect could not be demonstrated because it was not adequately operationalized in the risk assessment and action selection task (i.e. the photo task). It could be that something of this aspect would have been measured if Skin Conductance Response (SCR) had been used. Another possibility to measure this aspect is to show participants the video clips that contain the latent hazards while they are situated in an apparatus for functional Magnetic Resonance Imaging (fMRI). If there is greater activity in for example the amygdala when approaching a latent hazard, this would be an indication of emotional arousal.

The video clips with latent hazards that do not materialize have a high potential to measure differences in hazard detection and recognition skills between novice drivers and experienced drivers, as the differences between the two groups on this task both with regard to fixations on covert latent hazards and mentioned latent hazards were large. This potential disappeared when mouse clicks in pauses were used as response method. It could be worthwhile to try out response methods that are suitable for mass testing in which there are no interruptions in the video clips and in which the response method is not advantageous for persons with experience in computer gaming.

The simulator-based hazard anticipation training had a positive effect on visual search for latent hazards. Whether this effect retains over a longer period was not investigated, as the participants were tested within an hour after the training. Because the experience of crashes or near crashes during the simulator training is presumed to create arousal and moderate levels of arousal enhance memory (e.g. McGaugh, 2000), retention of the simulator-based training program maybe better than retention of PC-based training program on hazard anticipation that showed about similar improvements in visual search directly after the training. Whether the effects of simulator-based hazard anticipation training indeed retain longer than the effects of a PC-based training program remains to be tested. It is also important to test if there is transfer of the training to driving in real traffic and that the ultimate goal is to test if the training results in a reduction of crash rate.

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Summary

Driving most of the times, is a self-paced task. Based on their expectations of how things will develop in the near future, drivers proactively influence the road and traffic situation. They do this by looking in particular directions from where possible hazards may materialize (the areas that contain latent hazards) and by adjusting their speed and if possible their lateral position. Young novice drivers are not very good in proactively controlling the road and traffic situation. This is one of the causes they are overrepresented in crashes. Firstly, this thesis aims to clarify why young novice drivers are not very good in hazard anticipation. Is this mainly because their predictions about how things will develop in the near future are not so good or mainly because they accept more risks than older drivers do, as they do not 'feel' the risks so easily and/or are not motivated to accept only low levels of risk? Secondly, this thesis aims to find a practical method to test the skill to detect and recognize latent hazards, and a separate method to test the element of risk acceptance in hazard anticipation. Thirdly, this thesis aims to find an effective method to train hazard anticipation.

Chapter 2 is a literature review of studies about the causes of the high crash rate of young novice drivers. The emphasis in this review is on studies concerning determinants that indirectly influence hazard anticipation. The young novice driver problem is not a new problem and in the past decades, hundreds of studies have been conducted to find out what the underlying causes for the overrepresentation of young novice drivers in car crashes are. In the literature, two main components are distinguished that are strongly interrelated. These two components are lack of experience and immaturity. Each component in itself consists of many different determinants. For a coherent presentation of the findings, a taxonomy of determinants was

developed. In this taxonomy four categories are distinguished that indirectly influence hazard anticipation at mainly the tactical control level of the driving task (Michon, 1979). These categories are: (1) biological aspects, (2) social and cultural aspects, (3) transient factors that reduce the driving capabilities, and (4) exposure to risks.

The biological aspects are age (immaturity of the brain), gender, personality and physical and mental constitution. Because of new brain imaging techniques we now know that maturation of especially some areas of the prefrontal cortex is late in life and full maturation is not reached before the age of 25, especially for males. It is not so much the late maturation of these areas in itself, but rather the late maturation of these areas in combination with the earlier maturation of other brain areas, including the sub-cortical areas related to motivation and emotion such as the amygdala and the nucleus accumbens. The slowly maturing prefrontal systems are supposed to have an inhibitory function on emotional and motivational systems. It is thought that because of this imbalance young people are relatively speaking: impulsive, have an inclination towards sensation seeking, prefer immediate rewards, are sensitive about what their peers think of them and find it difficult to plan ahead. Adolescents however, do not seem to be less rational than adults are when reflecting on their own capabilities. This is to say, both young drivers and middle-aged drivers tend to overestimate their own driving capabilities. Young drivers also do not underestimate known risks when they have the time to reflect on these risks. When asked for, they will tell that drinking and driving is dangerous. The problem is that although they know the risks (when asked for), at least some of them still will take the risks. In the Netherlands, the crash rate of young female drivers is much lower than the crash rate of young male drivers. There are some structural differences between the male and female brain, but these differences are rather small. Brain development is somewhat faster in female adolescents than in male adolescents, especially during the first years of adolescence (before the age they are allowed to drive). The fact that girls are more risk averse than boys as a driver, probably is mainly due to differences in secretion of hormones and neurotransmitters in response to stressors. This is regulated by the HPA axis and the function of this axis depends largely on sex hormones (testosterone and oestrogen). The crash rate of all young novice drivers is not equally high. Especially young novice drivers that score high on sensation seeking have a high crash rate. Sensation seeking probably is influenced by the rate of dopamine to serotonin that increases throughout adolescence. Two mental disorders with a rather high prevalence during adolescence are different types of autism and Attention

Deficit Hyperactivity Disorder (ADHD). The effect of autism on hazard anticipation in traffic has hardly been studied. In one study it was found that adolescents with some kind of autism have difficulties to predict what possible dangerous actions visible other humans in the traffic scene could take. Young drivers diagnosed with ADHD have a substantial higher crash risk than young drivers that have no ADHD. This is probably caused by the fact that individuals with ADHD are more often inattentive, adhere less to the rules of the road, show reduced inhibition and are more easily distracted.

The reviewed social and culture aspect are lifestyle, peer group influences, education (including driver training) and social and cultural background. The already mentioned biological aspect of being young cannot be isolated from the social and cultural aspect of being young. For young people driving is not only a fast and convenient way of travelling. Driving and having a car also means status, you can impress your friends with your car and your 'sporty' driving style, you can test your skills and a car is also a symbol for freedom. Young people who like driving and cars and/or prefer leisure time activities with low structure and high impulsivity such as partying, have a higher crash rate than average. Driving with passengers can have a negative and a positive effect on the crash rate of young novice drivers. Especially for very young novice drivers (both male and female), driving with a male passenger of about the same age increases the crash rate. However, driving with a middle-aged passenger (e.g. a parent) decreases the crash rate of young novice drivers considerably. The effect of the general level of education on crash rate is probably low and traditional formal driver training in preparation for the driving test does not lower the crash rate. There are indications that the socioeconomic status of the family of young novice drivers may have some effect on the crash rate. Most studies show that young novice drivers of families with a low socioeconomic status have a higher crash rate than young novice drivers of parents with a high socioeconomic status. The results may however be confounded by the fact that young novice drivers of a low socioeconomic background will normally drive in older cars that offer less protection.

The reviewed transient factors that reduce driving capabilities are alcohol and illicit drugs, fatigue, distraction and inattention, and emotions. Alcohol affects the driving capabilities of young drivers somewhat more than it affects the driving capabilities of middle-aged drivers and there are indications that in the Netherlands the prevalence of drug driving is relatively high among drivers of 18 to 24 years of age. Young drivers are more involved in fatigue related crashes than middle-aged drivers are. There are indications that the prevalence of crashes in which inattention and/or distraction was a contributing factor, is higher in young drivers than in older, more experienced drivers. If young drivers are more involved in crashes than middle-aged drivers due to strong emotions (e.g. anger), is not clear.

Young novice drivers are also overrepresented in crashes because they chose to drive in circumstances that are more demanding for all drivers. Except for the youngest group of novice drivers (18 and 19 years of age in the Netherlands), young novice drivers tend to drive too fast. Although the youngest novice drivers speed less often than older novice drivers do, they do drive too fast for the circumstances (e.g. driving too fast in a curve). Young novice drivers more often also drive late at night and they more often drive with passengers that might distract them. Crash involvement is higher and the crashes are more severe because young novice drivers more often drive in older cars with less active and passive safety features.

Chapter 3 provides the theoretical background for the empirical studies in this thesis. Hazard anticipation is described as including processes related to:

- Detection and recognition of potential dangerous road and traffic situations;
- Prediction about how these latent hazards may develop into acute threats;
- Feelings of risk that are evoked by these predictions;
- Selection and execution of actions that will reduce these feelings of risks and will ensure a safety margin that is large enough to avert a crash should the latent hazard materialize.

Hazard anticipation has a cognitive aspect (detection recognition and prediction) and hazard anticipation has an emotional and motivational aspect (feelings of risk and the willingness to reduce these feelings of risk). Various types of latent hazards are distinguished. The two types that are investigated in this thesis are covert latent hazards and overt latent hazards. Covert latent hazards are possible other road users on collision course that are hidden from view. A for the driver possible but yet invisible child that may cross the road from between parked cars is an example of a covert latent hazard. Overt latent hazards are visible other road users that due to the evolving circumstances may start to act dangerously. A pedestrian that may suddenly cross the road in order to catch his bus, is an example of an overt latent hazard. The processes involved in hazard anticipation can be executed automatically without much conscious awareness and these processes can be executed in a controlled manner. To illustrate how this may function the framework of Brouwer & Schmidt (2002) was applied. The key concept in this framework is mental representation or schema. While driving, schemata unfold in interaction with external stimuli (i.e. what the driver perceives) and internal stimuli (i.e. what the driver feels). The selected overarching dominant schema at any point in time, enable the driver to find relevant information in the road and traffic situation and to anticipate forthcoming events. Activation and inhibition of schemata and action selection most of the times happen automatically, especially when the driver is an experienced driver. Sometimes selection of schemata is controlled. The framework describes the hypothetical sub-processes that are involved in action selection by drivers and the interaction between these sub-processes. The framework of Brouwer & Schmidt (2002) is based on Norman & Shallice's model on willed and automatic control of behaviour (1986) and incorporates some elements of the zero-risk model on driver behaviour developed by Näätänen & Summala (1974). In contrast to Norman & Shallice, Brouwer & Schmidt make way for emotional and motivational processes in their framework and attention is not only manifest in controlled hazard anticipation but also in automatic hazard anticipation. Brouwer & Schmidt (2002) also assume that action selection in complex cognitive tasks always is a mixture of automatic and controlled processing. It is hypothesised that 'somatic markers' (Damasio, 1994) help to select the proper dominant schema. Somatic markers are little emotional signals from the viscera that have been developed from emotions felt in previous situations in which a similar latent hazard has materialized. These somatic markers may help to speed-up schema selection and decision-making. It is assumed that the schemata of young novice drivers are less elaborated and that they do not have all the somatic markers that are necessary to recognize latent hazards and to respond swiftly once a latent hazard is recognized.

With regard to the cognitive aspect and the emotional and motivational aspect of hazard anticipation, it was hypothesised that the cognitive aspect mainly improves with experience and the emotional aspect mainly improves with age (maturation of the brain). In order to test this, two tasks were developed: a hazard detection and recognition task and a risk assessment and action selection task. Chapter 4 describes the development of the two tasks, the method how the hypothesis was tested and the results of the tests. The hazard detection and recognition task consisted of seven animated video clips, 'taken' from the driver's perspective and each lasting approximately forty seconds. These video clips contained overt latent hazards and covert latent hazards that did not materialize. While participants watched these videos, their gaze directions and fixations were recorded. Immediately after each video, participants were asked what could have happened (that did not happen) that would have increased the likelihood of a crash. It was assumed that this task primarily tested the ability to detect and recognize latent hazards. The risk assessment and action selection task consisted of twenty-five photographs. Each photograph was exposed for eight seconds on the screen of a monitor. These photographs were taken from a driver's perspective. A part of the photographs contained imminent hazards (i.e. visible other road users that would collide with the driver (of the photograph) if no one would change speed and/or course). A part of the photographs contained latent hazards (both covert latent hazards and overt latent hazards) and a part of the photographs contained no hazards at all. After participants had watched a photograph (during eight seconds) and the screen had turned black, participants had to respond if they would have (1) braked in this situation (in case of an imminent hazard), (2) released the throttle in this situation (in case of a latent hazard), or (3) would have continued with the same speed (in case of no imminent or latent hazard). While participants watched the photographs on a monitor, their gaze directions and fixations were recorded. It was assumed that the responses on this task would primarily indicate the inclination to take risks as research with similar sets of photographs had shown that there is no difference between novice drivers and experienced drivers in the ability to categorize photographs with imminent hazards, latent hazards and no hazards (Huestegge et al., 2010; Kelly et al., 2010). Participants in three different groups did both tasks. This was a group of young learner drivers (18 or 19 years of age) that were almost ready to do the driving test, a group of older learner drivers (25 years of age or older) that also were almost ready to do the driving test and a group of experienced drivers. On the hazard detection and recognition task, experienced drivers fixated covert latent hazards significantly more often than young learner drivers did and older learner drivers did. There was no significant difference in fixated covert latent hazards between young learner drivers and older learner drivers. Exactly the same pattern was visible in the mentioned covert latent hazards. However in all three groups, on average around 30% less covert latent hazards were mentioned than fixated. Almost all the participants in all three groups fixated all the overt latent hazards and there was no significant difference between the groups in fixated overt latent hazards. In contrast, experienced drivers mentioned significantly more often overt latent hazards than both young learner drivers did and older learner drivers did. There was no significant difference in mentioned overt latent hazards between young learner drivers and older learner drivers. From the difference in fixated overt latent hazards and mentioned overt latent hazards can be inferred that fixations overt latent hazards not necessarily imply that these hazards are recognized. In contrast to what was expected, older learner drivers did not have a significantly lower risk score on the risk assessment and action selection task than young learner drivers, but experienced drivers had a lower risk score on this task than young learner drivers. Statistical analysis revealed that the risk assessment and action selection task probably did not measure risk acceptance, but rather the same aspect of hazard perception that was measured by the hazard detection and recognition task, only not as good. The results indicate that the cognitive aspect of hazard anticipation most probably improve with experience. No evidence was found that the emotional and motivational aspect of hazard anticipation improves with age. However, the hypothesis that the emotional and motivational aspect of hazard anticipation predominantly improves with age cannot be rejected based on the results of this study, as this aspect of hazard anticipation most probably was not operationalized properly by the risk assessment and action selection task.

Chapter 5 is on testing of hazard anticipation. In Chapter 4 hazard detection and recognition was measured using recorded eye fixations and recorded answers on open questions. This method is not suitable for mass testing. A variant of the hazard detection task was developed in which participants instead of fixating on overt latent and covert latent hazards in video clips, could point and click with their mouse on overt latent hazards and covert latent hazards. A different set of video clips was used than the video clips that were used in Chapter 4. As pointing and clicking with a mouse takes much more time than a saccade, the video clips were paused a couple of times per clip during five seconds to allow for pointing and clicking. The hazard assessment and action selection task was also slightly adapted. A different set of photographs was used and the task was made self-paced. Instead of responding orally after a photograph had been exposed for eight seconds and the screen had turned black, participants now could press on three keys (a key for 'brake', a key for 'release throttle' and a key for 'keep speed as it is') during the eight seconds the photograph was exposed on the screen. As the results of Chapter 4 indicated that the hazard detection and recognition task and the risk assessment and action selection task did not measure two distinct aspects of hazard anticipation, the hazard detection and recognition task was named more neutrally the 'video task' and the risk assessment and action selection task was named more neutrally the 'photo task'. Three groups made the two tasks: learner drivers on the day they had passed the driving test, novice drivers that hold their driving licence for eighteen months and experienced drivers. With regard to the video task, there were no significant differences between the three groups in clicks on latent hazards (both on covert latent hazards and on overt latent hazards). This is remarkable because there was a significant difference with a large effect size in mentioned latent hazards between learner and experienced drivers in the hazard detection and recognition task of Chapter 4. There was no significant difference on the video task between novice drivers that had reported at least one crash and crash free novice drivers either.

With regard to the photo task, there was a significant difference between learner drivers and novice drivers and between learner drivers and experienced drivers with the learner drivers having the highest risk scores. There was no significant difference in risk scores between novice drivers and experienced drivers. The magnitude of the difference between learner drivers and experienced drivers was relatively small and was about the same as between learner drivers and experienced drivers in the risk assessment and action selection task of Chapter 4. Controlled for exposure (defined as number times use was made of a car per week) novice drivers that had reported at least one crash had significantly higher risk score than crash free novice drivers. Both the lower risk scores for the crash free novice drivers and the higher risk scores for learner drivers compared to the risk scores of experienced drivers are indications that the photo task has criterion validity.

The fact that the video task failed to discriminate between learner drivers and novice drivers on one hand and experienced drivers on the other hand could and also failed to discriminate between novice drivers who had reported a crash and crash free novice drivers, could have had various causes. Firstly, the animated video clips were far from perfect, the task was rather complex and participants could hardly familiarize. Secondly, it could be that clicking with a mouse was more of an effort for older drivers than for young drivers, as older drivers in general are not familiar with computer games. Thirdly, the pauses that were necessary to allow for sufficient time to point and click could have enabled learner drivers and novice drivers to detect latent hazards they had not yet detected while the video was running. The very fact that the video clip paused could have triggered participants that there could be latent hazards and the pause itself offered the time to detect and recognize these possible latent hazards. A new video task was developed. In this video task the latent hazards were less ambiguous, the quality of the videos was better and the videos were presented on a larger screen. The task was simplified and an introduction video clip was made to prepare participants for the tasks. There were less pauses and the length of a pause was shorter (three seconds). It was made more explicit that not all pauses contained latent hazards and that irrelevant clicks would lower their score. Two groups completed this improved version of the video task: learner drivers on the day they had passed the driving test and professional drivers (driving instructors and driving examiners). On this improved video task, again the average score of the group of learner drivers was not significantly lower than the average score of in this case of even a group of professional drivers. Self-reported experience with computer games had an effect on the scores. Whereas there was no significant difference in the scores between learner drivers and professional drivers, this difference got significant when the scores were controlled for experience with computer games. As the improved video task also failed to discriminate between learner drivers and in this case even professional drivers, the conclusion has to be that mouse clicks on latent hazards during pauses in video clips are not a good response method to test hazard detection and recognition. Possible explanations for this failure are the confounding effect of experience with computer games and the confounding effect of the interruptions (the pauses).

The research presented in Chapter 4 suggests that novice drivers inadequately search for possible hazards that are hidden from view due to lack of experience. Can simulator training accelerate exposure to road and traffic situations in such a way that hazard anticipation skills develop faster? Chapter 6 describes the development and evaluation of a simulator-based training program in hazard anticipation. Based on the somatic marker hypothesis (Damasio, 1994) and the theory on hazard anticipation presented in Chapter 3, it was assumed that elicited crashes in a driving simulator would result in better scanning for latent hazards. However, trainees may not learn enough from mere exposure to dangerous traffic situations in a driving simulator. There is a chance that they will attribute the cause of the crash or near miss to the other road users involved in the situation and they may not grasp why the situation could occur and what they could have done about it from happening. In order to minimise this, use was made of the principles of error learning (Ivancic & Hesketh, 2000). In error learning trainees are stimulated to think about why they have made an error and what they can do the next time to prevent it from happening, should a similar situation occur. For the training, a low cost fixed-base simulator was used with wide-angle projected display. The training lasted about one hour. In this hour trainees drove through short scenarios of about one minute each that mostly contained a latent hazard. Most of the times this was a covert latent hazard. There were three versions of each scenario. First, they drove the scenario in which as in the video clips the latent hazard did not materialize. After this short drive, trainees were asked what could have happened that did not happen. Hereafter, irrespective of their answer they drove the so-called error drive. This error drive was the same drive as the first drive, but now with the latent hazard materializing aggressively. If the latent hazard was not detected and recognized, this drive ended in a crash or a near miss. After this, a plan view of the traffic situation appeared on the centre screen of the simulator. Trainees had to explain to themselves on the basis of this plan view why the near miss or crash had happened and what they could have done to avert the crash or near miss. Trainees also received instruction about how to scan and anticipate the latent hazard. Finally, trainees drove the scenario for the third time. In this third version, the latent hazard also materialized, but less aggressively than in the error drive. This third drive was intended to offer trainees the opportunity to practice what they had learned. After this third drive, the cycle started all over again with a different latent hazard in a different scenario.

In order to test if the training had improved visual search for latent hazards, eighteen trained and eighteen untrained young novice drivers that were around 19 years of age and had around two years driving experience, were evaluated on an advanced driving simulator. Participants drove through three scenarios that all together contained seven situations with latent hazards that did not materialize that were the same as the latent hazards in the training, but that were different in appearance. These were the near transfer situations. The three drives contained twelve situations with latent hazards that did not materialize that were conceptually different from the latent hazards in the training. These were the far transfer situations. The eye movements of participants were recorded while they drove. The trained group showed anticipatory gaze directions in 84% of the near transfer latent hazard situations and the untrained group showed correct gaze directions in 57% of these situations. The trained group showed anticipatory gaze directions in 71% of the far transfer latent hazard situations and the untrained group showed anticipatory gaze directions in 53% of these situations. The differences between the groups in both the near transfer situations and the far transfer situations were significant, but the effect size was smaller in the far transfer situations. However, as far as the effect of the simulator-based training program could be compared with a PC-based training program that used the same latent hazards for training, the simulator-based training was not better than the PC-based training. Self-rating of driver confidence was not higher after the training for the trained group than before the training and after the training, the trained group had the intention to drive more conservatively in the future than the untrained group.

A limitation of the study is that participants were tested on an advanced simulator and not while driving in real traffic. Another limitation is that retention was not tested as the participants were tested within one hour after the training.

Finally, in Chapter 7 as in this summary but more extensively, the results of the literature review on the young novice driver problem, the developed theory on hazard anticipation and the empirical studies are summarized. In Chapter 7, the practical implications and possibilities for further research are also discussed. Based on the research conducted for this thesis, a hazard anticipation test was included in the theory test of the Dutch driving test for licence category B (private cars) on March 1, 2009. This test is very similar to the risk assessment and action selection task presented in Chapter 4 and the photo task presented in Chapter 5. Although the results indicated that the photo task had criterion validity, it had some psychometric weaknesses. The internal consistency of the items was rather low and the ability to discriminate between learner drivers and experienced drivers was rather poor compared to the hazard detection and recognition task with oral responses on open questions as response method. However, oral response on open questions are not suitable for mass testing. One of the possibilities for further research is finding a response method for the hazard detection and recognition task that is suitable for mass testing.

The research conducted for this thesis has also resulted in an effective simulator-based hazard anticipation training, although it is not yet known if improvement in visual search for latent hazards endures. If it endures, is a possibility for further research. The developed simulator-based hazard anticipation training could be implemented in basic driver training in order to prepare trainees for the hazard anticipation test in the driving test.

In Chapter 3, it was hypothesised that hazard anticipation has an emotional and motivational aspect and that this aspect mainly improves with age. This could not be demonstrated. It could be that this aspect can demonstrated if physiological arousal is measured (Skin Conductance Response, heart rate variability, et cetera) or even better, if brain scanning techniques such as fMRI are applied. This could be done in possible further research.

Samenvatting

Automobilisten kunnen voor een groot deel zelf bepalen hoe zwaar en/of gevaarlijk hun rijtaak is. Op basis van hoe zij verwachten dat de verkeersituatie zich zou kunnen ontwikkelen, verrichten zij meestal automatisch handelingen die van invloed zijn op hoe de weg- en verkeerssituatie zich daadwerkelijk ontwikkelt. Die handelingen kunnen onder andere zijn: het kijken in richtingen vanwaar een gevaar zou kunnen opdoemen en het matigen van de snelheid om daarmee de veiligheidsmarge groot genoeg te houden om een ongeval te vermijden, zou het verwachte gevaar werkelijkheid worden. Jonge beginnende automobilisten zijn niet goed in het proactief controleren van weg- en verkeerssituatie en dit is één van de oorzaken waardoor zij oververtegenwoordigd zijn bij ongevallen in het verkeer. Het proefschrift heeft in de eerste plaats tot doel inzicht te verwerven in waarom jonge beginnende automobilisten minder goed in staat zijn om op mogelijke gevaren te anticiperen in het verkeer. Kunnen zij dat niet zo goed omdat ze niet weten te voorspellen wat er zou kunnen gebeuren? Of zijn ze minder goed in staat om op mogelijke gevaren te anticiperen omdat ze veel risico accepteren, de risico's niet zo voelen en niet erg gemotiveerd zijn om veilig te rijden? In de tweede plaats heeft dit proefschrift tot doel om praktische methoden te ontwikkelen voor het meten van verschillende aspecten van gevaaranticipatie. In de derde plaats heeft dit proefschrift tot doel om een effectieve methode te ontwikkelen om gevaaranticipatie te trainen.

Hoofdstuk 2 is de weerslag van een literatuuronderzoek naar de determinanten van het hoge ongevalsrisico van jonge beginnende automobilisten. De nadruk in dit literatuuronderzoek ligt op de achterliggende factoren die van invloed zijn op gevaaranticipatie in het verkeer. Het probleem van de jonge beginnende bestuurder is niet nieuw en in de afgelopen decennia zijn wereldwijd honderden onderzoeken uitgevoerd om de oorzaken van dit probleem in kaart te brengen. Daarbij zijn twee hoofdcategorieën van oorzaken te onderscheiden die onderling sterk met elkaar zijn verweven. Deze twee hoofdcategorieën zijn: gebrek aan ervaring en onvolwassenheid (onder andere doordat het brein nog niet volgroeid is). Elk van deze twee overkoepelende determinanten bestaat weer uit vele onderliggende determinanten. Om de determinanten op een coherente manier te presenteren is een taxonomie ontwikkeld. Deze taxonomie bestaat uit vier categorieën die indirect van invloed zijn op het anticiperen van gevaren op het tactische niveau van de verkeerstaak (Michon, 1979). Deze categorieën zijn: (1) biologische aspecten, (2) sociale en culturele aspecten, (3) factoren van tijdelijke aard die van invloed zijn op de rijgeschiktheid, en (4) blootstelling aan gevaar. Elke categorie bestaat weer uit vier determinanten.

De biologische aspecten zijn leeftijd (ontwikkeling van lichaam en geest), geslacht, persoonlijkheid en lichamelijke en geestelijke constitutie. Door magnetische resonantie imaging (MRI) kan de ontwikkeling van de anatomische structuur van het brein van levende personen gevolgd worden in de tijd. Door functionele beeldtechnieken zoals fMRI en positron emissie tomografie (PET) kunnen fysiologische activiteiten van het brein zichtbaar gemaakt worden. Uit onderzoeken met deze nieuwe technieken is gebleken dat enkele gebieden van de prefrontale schors pas rond het vijfentwintigste levensjaar volledig volgroeid zijn. Vooral bij jonge mannen is de rijping van de hersenen traag. Het gaat niet zozeer om de late rijping van deze hersengebieden op zich, maar om de late rijping van deze gebieden in combinatie met de al aan het begin van de pubertijd gevoelig geworden subcorticale gebieden die betrekking hebben op de regulering van emoties en motivatie, zoals de amygdala en de nucleus accubens. Gebieden in de prefrontale schors remmen de primaire impulsen op gevaar of het verlangen naar directe behoeftebevrediging vanuit de subcorticale delen enigszins af. Door het min of meer uit fase zijn van gebieden in de prefrontale schors en enkele subcorticale gebieden zijn jongeren en jongvolwassenen naar verhouding impulsief, hebben ze een hang naar avontuur en opwindende zaken (sensation seeking), vinden ze directe behoeftebevrediging belangrijk, zijn ze extra gevoelig voor wat hun vrienden van ze vinden en hebben ze moeite met het plannen van zaken (Casey et al., 2008). Anderzijds zijn adolescenten niet minder rationeel dan volwassenen wanneer ze de tijd hebben om te kunnen nadenken over hun eigen capaciteiten (Reyna & Farley, 2006). Het probleem is bijvoorbeeld niet zozeer dat jonge automobilisten het rijden onder invloed niet gevaarlijk vinden, maar dat enkelen, hoewel ze weten dat het gevaarlijk is, het toch doen.

In Nederland is het aantal ernstige ongevallen van jonge vrouwelijke automobilisten veel lager dan dat van jonge mannelijke automobilisten. Er zijn enkele verschillen in de ontwikkeling van het brein tussen mannen en vrouwen. Deze verschillen zijn echter relatief klein. Het belangrijkste verschil is dat de ontwikkeling van het brein bij jonge vrouwen sneller gaat dan bij jonge mannen, vooral in de eerste jaren van de adolescentiefase (nog voor de leeftijd waarop men mag autorijden). Het feit dat wat oudere meisjes over het algemeen wat meer risicomijdend zijn dan wat oudere jongens, wordt vermoedelijk grotendeels veroorzaakt door verschillen in de hormoonhuishouding en de rol van hormonen en neurotransmitters (in het bijzonder dopamine) in reactie op stressoren. De reactie op stressoren wordt geregeld door de zogenoemde hypothalamisch-hypofisair (pituitairy)-adernale (HPA) as en het functioneren van deze as hangt voor een groot deel af van geslachtshormonen (testosteron en oestrogeen).

Sommige jonge automobilisten hebben een hoger ongevalsrisico dan andere jonge automobilisten. Vooral jonge automobilisten die hoog scoren op spanningsbehoefte (de sensation seeking-schaal) hebben een hoog ongevalsrisico. De behoefte aan spanning hangt vermoedelijk af van de verhouding tussen dopamine en serotonine in het brein. Twee mentale stoornissen met een tamelijk hoge prevalentie in de adolescentiefase zijn de aandachtstekort-hyperactiviteits-stoornis ADHD en verschillende gradaties van autisme. Het effect van autisme op rijgeschiktheid is nauwelijks onderzocht. In één onderzoek is aangetoond dat adolescenten met een vorm van autisme, meer moeite hebben om te voorspellen wat mensen in het verkeer kunnen gaan doen (bijvoorbeeld voetgangers) dan wat auto's (waarin je geen bestuurder kunt zien zitten) kunnen gaan doen. Naar de rijgeschiktheid van mensen met de diagnose ADHD is wel veel onderzoek gedaan. Jonge bestuurders met ADHD hebben een aanzienlijk hoger ongevalsrisico dan jonge bestuurders zonder ADHD. Dit wordt vermoedelijk veroorzaakt doordat mensen met ADHD meer moeite hebben om zich langdurig te concentreren op de rijtaak, minder geneigd zijn zich strikt aan de verkeersregels te houden, vaker zijn afgeleid en minder goed impulsen kunnen onderdrukken.

De sociale en culturele aspecten waarvan de literatuur is onderzocht, waren: leefstijl, invloed van leeftijdsgenoten, educatie (inclusief rijonderricht) en de sociaal-culturele achtergrond. De sociale en culturele aspecten van jongeren kunnen niet gescheiden worden van de biologische aspecten. Voor veel jongeren en jonge volwassenen is autorijden niet alleen een manier om je vlot en comfortabel van A naar B te verplaatsen. Autobezit betekent ook status en een auto betekent ook vrijheid. Je kunt je vaardigheden ermee beproeven en met een 'sportieve rijstijl' kun je indruk maken op je vrienden. Jonge beginnende bestuurders die veel om auto's geven en veel van autorijden houden en/of jongeren die veel van uitgaan houden, hebben een hoger ongevalsrisico dan gemiddeld. Wanneer jonge beginnende bestuurders met passagiers rijden, kan dat zowel een positief als een negatief effect hebben. Jonge mannen als passagier leiden bij zowel jonge vrouwelijke bestuurders als jonge mannelijke bestuurders tot een hoger ongevalsrisico. Wanneer het echter om een passagier van middelbare leeftijd gaat, dan daalt het ongevalsrisico aanzienlijk. Het effect van het algemeen opleidingsniveau op het ongevalsrisico is vermoedelijk klein en uit internationaal onderzoek blijkt dat traditionele rijlessen ten behoeve van het rijexamen, niet leiden tot een lager ongevalsrisico na het rijexamen dan wanneer men bijvoorbeeld alleen maar informeel rijles heeft gehad van de ouders. Er zijn internationaal aanwijzingen gevonden dat jonge beginnende bestuurders van gezinnen uit lagere inkomensklassen een iets hoger ongevalsrisico hebben dan jonge beginnende bestuurders van gezinnen uit hoge inkomensklassen. Dit tamelijk kleine verschil kan mede zijn ontstaan, doordat jonge beginnende bestuurders van gezinnen met een laag inkomen in oudere en minder degelijke auto's rijden.

De literatuur die onderzocht is over de factoren die tijdelijk de rijgeschikt doen verminderen, zijn alcohol en drugs, vermoeidheid, gebrek aan aandacht en afleiding en, als laatste, de invloed van emoties op het rijden. Alcohol heeft een desastreuzer effect op de rijgeschiktheid van jonge beginnende bestuurders dan op oudere, meer ervaren bestuurders. Rijden onder invloed van drugs komt relatief veel voor bij bestuurders van 18 tot en met 24 jaar. Jonge beginnende bestuurders zijn relatief vaak betrokken bij ongevallen waarbij vermoeidheid een rol heeft gespeeld. Er zijn ook aanwijzingen dat jonge beginnende bestuurders relatief vaak bij ongevallen betrokken zijn waarbij afleiding een rol heeft gespeeld. Of jonge beginnende bestuurders vaker bij een ongeval betrokken zijn, omdat hun stemmingen mogelijk heviger zijn en snel kunnen veranderen, is niet duidelijk.

Jonge beginnende bestuurders zijn vaker bij ongevallen betrokken, mede doordat ze relatief vaak in omstandigheden rijden die voor alle bestuurders gevaarlijk zijn. Behalve voor de jongste groep in de eerste periode na het behalen van het rijbewijs (de 18- en 19-jarigen), ligt de zelfgerapporteerde gemiddelde snelheid hoger dan bij iedere andere leeftijdscategorie. Hoewel de jongste groep de maximumsnelheid iets minder ver zegt te overschrijden dan de wat oudere beginners, zijn er aanwijzingen dat jonge beginners vaak wel te hard rijden voor de omstandigheden, bijvoorbeeld met een te hoge snelheid door een bocht rijden. Jonge bestuurders rijden naar verhouding vaker in het donker en ze rijden vaker met leeftijdsgenoten als passagier. De betrokkenheid bij ongevallen met een ernstige afloop wordt ten slotte mede veroorzaakt doordat jonge bestuurders relatief vaak in oude auto's rijden met minder actieve en passieve veiligheidsvoorzieningen dan gemiddeld.

Hoofdstuk 3 vormt de theoretische basis voor de onderzoeken die in de daaropvolgende hoofdstukken worden gepresenteerd. Aangenomen wordt dat gevaaranticipatie de volgende processen omvat:

- Detecteren en herkennen van potentieel gevaarlijke weg- en verkeerssituaties;
- Voorspellen hoe deze latente gevaren zich zouden kunnen ontwikkelen tot directe bedreigingen;
- Voelen van de risico's die worden opgeroepen door die voorspellingen;
- Selecteren en uitvoeren van handelingen om de gevoelens van gevaar te verminderen en ervoor zorgen dat de veiligheidsmarge groot genoeg wordt om een botsing te voorkomen, mocht het latente gevaar zich tot een acuut gevaar ontwikkelen.

Gevaaranticipatie heeft een cognitief aspect (detectie, herkenning en voorspelling) en een emotioneel en motivationeel aspect (het gevoel van gevaar en de motivatie om zo te handelen dat die gevoelens van gevaar worden teruggedrongen). Verschillende typen van latente gevaren worden onderscheiden. De twee typen die centraal staan in dit proefschrift zijn zichtbare latente gevaren en onzichtbare latente gevaren. Zichtbare latente gevaren zijn zichtbare andere verkeersdeelnemers die zich (nog) niet onveilig gedragen, maar gelet op de omstandigheden zich wel eens zo zouden kunnen gaan gedragen dat ze op botskoers komen. Een voetganger op het trottoir die ziet dat zijn bus aan de andere kant van de straat stopt en weleens de straat over zou kunnen rennen om nog net zijn bus te halen, is een voorbeeld van een zichtbaar latent gevaar. Onzichtbare latente gevaren zijn mogelijke andere verkeersdeelnemers op botskoers die niet te zien zijn, omdat het zicht erop ontnomen wordt. Wanneer een bestuurder in een kinderrijke omgeving door een straat rijdt met aan weerszijde geparkeerde auto's, kan deze bestuurder zich realiseren dat een kind dat niet te zien is, tussen de geparkeerde auto's door de straat zou kunnen oversteken. Dit is een voorbeeld van een onzichtbaar latent gevaar. Afdeksituaties zijn ook voorbeelden van onzichtbare latente gevaren.

Belangrijk is dat zowel bij zichtbare latente gevaren als onzichtbare latente gevaren, het anticiperen op die gevaren automatisch kan verlopen, zonder dat men zich daar van bewust is en gecontroleerd en bewust kan verlopen. Dat het anticiperen op latente gevaren zowel automatisch als gecontroleerd kan verlopen, is duidelijk gemaakt aan de hand van een raamwerk dat ontwikkeld is door Brouwer & Schmidt (2002). In dit raamwerk staan mentale representaties of schemata centraal. Wanneer men rijdt, ontvouwen zich schemata in interactie met externe stimuli (dat wat de bestuurder ziet) en interne stimuli (dat wat de bestuurder voelt). Het dominante overkoepelende schema dat op een bepaald moment in de tijd is geactiveerd, stelt de bestuurder in staat relevante informatie uit de weg- en verkeerssituatie te selecteren en op toekomstige gebeurtenissen te anticiperen. Het activeren en deactiveren van schemata verloopt met name voor ervaren bestuurders meestal automatisch. Soms, wanneer het voor de bestuurder moeilijker en/of complexer wordt, verloopt het activeren en deactiveren van schemata echter gecontroleerd. Hoe dat precies zou kunnen verlopen, maakt het raamwerk van Brouwer & Schmidt duidelijk.

Het raamwerk van Brouwer & Schmidt is gebaseerd op het model van Norman & Shallice (1986) over gewilde en automatische controle van gedrag en bevat elementen uit het 'zero-risk' model over rijgedrag dat ontwikkeld is door Näätänen & Summala (1974). In tegenstelling tot Norman & Shallice bieden Brouwer & Schmidt ruimte aan emotionele en motivationele processen die de al dan niet geautomatiseerde gedragskeuze beïnvloeden en speelt aandacht niet alleen een rol bij de gecontroleerde processen, maar ook bij de automatische processen. Ten slotte menen Brouwer & Schmidt, in tegenstelling tot Norman & Shallice, dat aan handelingen een mix van automatisch en gecontroleerd processen ten grondslag ligt en dat het gedrag soms meer in de richting van automatisch en soms meer in de richting van gecontroleerd gaat.

In Hoofdstuk 3 wordt voorts verondersteld dat de 'hypothese van het somatische stempel' (the somatic marker hypothesis) van Damasio (1994) een rol zou kunnen spelen bij de selectie van het dominante schema. Somatische stempels zijn korte lichamelijk prikkels (bijvoorbeeld even zweten) die ook wel secundaire emoties genoemd worden. Het gaat in feite om het zeer kort herbeleven van de gevoelens die men had bij een gelijksoortige gebeurtenis in het verleden, waarin het latente gevaar manifest is geworden. Deze somatische stempels zouden het proces van de selectie van het dominante schema kunnen versnellen en daarmee ook de snelheid waarmee het latente gevaar 'gezien' wordt en beslissingen worden genomen. In Hoofdstuk 3 wordt aangenomen dat jonge beginnende bestuurders minder uitgewerkte schemata hebben en nog niet over de somatische stempels beschikken die nodig zijn om latente gevaren snel te herkennen en om snel handelingen te verrichten nadat het latente gevaar is herkend.

Het experiment waarvan in Hoofdstuk 4 verslag wordt gedaan, had primair ten doel om de hypothese te toetsen dat het cognitieve aspect van gevaar-anticipatie bij jonge beginnende bestuurders voornamelijk beter wordt met het opdoen van rijervaring en het emotionele en motivationele aspect van gevaaranticipatie voornamelijk beter wordt met het oplopen van de leeftijd (de ontwikkeling van de hersenen). Om deze hypothese te toetsen zijn twee taken ontwikkeld: een taak in het detecteren en herkennen van gevaren en een taak in risicoperceptie en keuze van handelingen om het risico te doen afnemen.

De taak in het detecteren en herkennen van gevaren bestond uit zeven videoanimaties die 'opgenomen' waren vanuit het perspectief van de bestuurder en die elk ongeveer veertig seconden duurden. In deze films zaten zowel zichtbare latente gevaren als onzichtbare latente gevaren die niet manifest werden. Van proefpersonen die naar deze films keken en zich moesten inbeelden dat zij de bestuurder waren, werden met behulp van een 'eyetracker' de oogbewegingen en de fixaties geregistreerd. Direct na afloop van iedere film werd aan de proefpersonen gevraagd wat er had kunnen gebeuren (maar dus niet gebeurd is), waardoor er een grote kans op een ongeval zou zijn ontstaan. Aangenomen werd dat met deze taak primair het kunnen detecteren en herkennen van latente gevaren werd gemeten. De taak in risicoperceptie en keuze van handeling bestond uit vijfentwintig foto's die genomen waren vanuit het perspectief van de bestuurder. Elke foto was gedurende acht seconden zichtbaar op het beeldscherm. Op een deel van deze foto's was een acuut gevaar zichtbaar. Meestal was dit een verkeers-deelnemer waarmee men binnen korte tijd zou botsen zou alles zo doorgaan. Een ander deel van de foto's bevatte een latent gevaar (zowel zichtbaar als onzichtbaar) en op weer een ander deel was noch een direct gevaar noch een latent gevaar te zien. Nadat een foto van het scherm verdwenen was, werd aan proefpersonen gevraagd wat zij in die situatie zouden hebben gedaan. Men kon kiezen uit: remmen (bij een acuut gevaar), gas los laten (bij een latent gevaar) en niets aan de snelheid veranderen (bij geen gevaar). Ook tijdens deze taak werden van iedere proefpersoon de oogbewegingen en fixaties vastgelegd. Aangenomen werd dat bij deze taak voornamelijk risicoperceptie en het al dan niet voorzichtig handelen werd gemeten, omdat uit ander onderzoek gebleken was dat bij het herkennen van acute of latente gevaren op foto's, er geen verschillen waren tussen beginnende bestuurders en ervaren bestuurders (Huestegge et al., 2010; Kelly et al., 2010). Drie groepen hebben de twee taken gemaakt: jonge rijschoolleerlingen aan het eind van hun rijopleiding die 18 of 19 jaar oud waren, oudere rijschoolleerlingen aan het eind van hun rijopleiding die 25 jaar of ouder waren en ervaren bestuurders met meer dan 10 jaar rijervaring en die meer dan 15.000 km per jaar reden. Bij de detectie en herkenningstaak keken ervaren bestuurders significant vaker in de richting van waaruit onzichtbare gevaren manifest konden worden dan zowel de jonge rijschoolleerlingen als de oudere rijschoolleerlingen. Zichtbare latente gevaren werden door alle drie de groepen bijna altijd gefixeerd en er was geen significant verschil in fixaties op de zichtbare latente gevaren tussen de drie groepen. De ervaren bestuurders noemden (na afloop van iedere film) eveneens significant meer verborgen gevaren dan de twee andere groepen. In tegenstelling tot fixaties op zichtbare latente gevaren, waren er wel significante verschillen in genoemde zichtbare latente gevaren. De ervaren bestuurders noemden significant vaker zichtbare latente gevaren dan de twee groepen van rijschoolleerlingen. Tussen de jonge en de oudere rijschoolleerlingen was geen significant verschil in genoemde zichtbare latente gevaren. Uit dit resultaat kan afgeleid worden dat rijschoolleerlingen weliswaar kijken naar zichtbare latente gevaren, maar niet noodzakelijkerwijs weten dat het latente gevaren zijn.

In tegenstelling tot wat werd verwacht, was de risicoscore op de taak in risicoperceptie en keuze van handeling niet significant lager voor de oudere rijschoolleerlingen dan voor de jonge rijschoolleerlingen. De ervaren bestuurders hadden wel een significant lagere risicoscore dan de jonge rijschoolleerlingen. Statistische analyses doen vermoeden dat de taak in risicoperceptie en keuze van handeling taak (de fototaak) niet heeft gemeten wat deze taak verondersteld werd te meten en ongeveer hetzelfde mat als de detectie- en herkenningstaak (de filmtaak), maar dan slechter. De resultaten ondersteunen de hypothese dat het cognitieve aspect van gevaaranticipatie beter wordt met het opdoen van rijervaring. Geen ondersteuning kon gevonden worden voor de aanname dat het emotionele en motivationele aspect voornamelijk beter wordt met het vorderen van de leeftijd (de rijping van het brein). Het is echter voorbarig om op basis van de resultaten dit deel van de hypothese te verwerpen, daar risicoperceptie en risicoacceptatie waarschijnlijk niet goed geoperationaliseerd zijn met de ontwikkelde fototaak.

Hoofdstuk 5 gaat over onderzoek naar praktische manieren om gevaaranticipatie te testen. In Hoofdstuk 4 werd het vermogen gemeten om latente gevaren te detecteren en te herkennen met behulp van een eyetracker en antwoorden op open vragen. Eyetrackers zijn niet praktisch in gebruik en kunnen niet ingezet worden bij bijvoorbeeld de theorietest van het rijexamen. Open vragen zijn ook niet geschikt wanneer grote groepen getest moeten worden en de resultaten direct na afloop van het examen bekend moeten zijn. Om deze redenen is een variant van de filmtaak uit Hoofdstuk 4 ontwikkeld, waarbij het kijken in een bepaalde richting en het kijken naar een bepaald object, vervangen is in het wijzen en klikken met een muis in een bepaalde richting of op een bepaald object. Omdat wijzen en klikken met een muis veel meer tijd in beslag neemt dan een saccade (oogsprong), werd het videobeeld een aantal malen per video gedurende vijf seconden bevroren, om de proefpersoon in staat te stellen gedetecteerde en herkende latente gevaren aan te klikken. De taak in risicoperceptie en keuze van handeling van Hoofdstuk 5 was min of meer gelijk aan die van Hoofdstuk 4, behalve dat andere foto's zijn gebruikt en proefpersonen binnen de acht seconden dat de foto in beeld was moesten antwoorden (door een toets in te drukken) en niet nadat de foto gedurende acht seconden vertoond was en van het scherm was verdwenen. Daar de resultaten van het experiment in Hoofdstuk 4 erop duidden dat de taak in risicoperceptie en keuze van handeling met foto's ongeveer hetzelfde meet als de gevaardetectie- en -herkenningstaak met video's, maar dan slechter, is ervoor gekozen om in Hoofdstuk 5 de neutrale termen 'filmtaak' en 'fototaak' te gebruiken. Drie groepen van proefpersonen hebben de filmtaak en de fototaak gemaakt: rijschoolleerlingen op de dag dat ze waren geslaagd voor hun rijexamen, beginnende bestuurders die achttien maanden in het bezit waren van hun rijbewijs en ervaren bestuurders met meer dan tien jaar rijervaring.

Op de filmtaak waren er geen verschillen tussen de drie groepen in het aantal aangeklikte zichtbare en onzichtbare latente gevaren. Bij de onzichtbare latente gevaren van de videotaak in Hoofdstuk 4 was er juist wel een significant verschil met een robuuste effectgrootte ($\eta^2_P \geq .14$) tussen het aantal fixaties in de richting van onzichtbare latente gevaren van ervaren bestuurders en van beginners en was er een significant verschil met een robuuste effectgrootte ($\eta^2_P \geq .14$) tussen ervaren bestuurders en beginners in het aantal genoemde latente gevaren (zowel zichtbare latente gevaren als onzichtbare latente gevaren). Er was ook geen significant verschil in score op de filmtaak tussen beginnende bestuurders die een ongeval hadden gerapporteerd en die geen ongeval hadden gerapporteerd.

Bij de fototaak in Hoofdstuk 5 hadden de rijschoolleerlingen die net hun rijopleiding hadden afgerond, een significant hogere risicoscore dan de ervaren bestuurders. Rijschoolleerlingen die net hun rijopleiding hadden afgerond, hadden ook een significant hogere risicoscore dan de beginnende bestuurders, maar beginnende bestuurders hadden geen significant hogere risicoscore dan ervaren bestuurders. Gecontroleerd voor expositie (het aantal autoritten per week), hadden beginners die een ongeval hadden gerapporteerd een hogere risicoscore op de fototaak dan beginners die geen ongeval hadden gerapporteerd. Zowel de lagere risicoscore voor de beginnende bestuurders die geen ongeval hadden gerapporteerd als de lagere risicoscore van ervaren bestuurders ten opzichte van de rijschoolleerlingen, zijn aanwijzingen dat de fototaak criteriumvaliditeit heeft.

Het feit dat de filmtaak niet in staat was te discrimineren tussen rijschoolleerlingen en beginnende bestuurders aan de ene kant en ervaren bestuurders aan de andere kant en ook niet in staat was te discrimineren tussen beginners die een ongeval hadden gerapporteerd en beginners die geen ongeval hadden gerapporteerd, kan verschillende oorzaken hebben gehad. Ten eerste waren de gebruikte filmpjes niet perfect, was de taak nogal complex en hadden proefpersonen te weinig mogelijkheden zich de taak goed eigen te maken. Ten tweede zou het kunnen dat het aanwijzen en klikken met een muis gemakkelijker is voor jonge proefpersonen dan voor oudere proefpersonen, daar jongeren over het algemeen meer ervaring hebben met computergames dan mensen van middelbare leeftijd. Ten derde zou het feit dat een film op een bepaald moment pauzeerde, proefpersonen op het idee hebben kunnen brengen dat er mogelijk een latent gevaar was dat ze nog niet eerder hadden ontdekt en verschafte de pauze zelf hun tijd om dat latente gevaar te vinden. Om aan een aantal van de beperkingen tegemoet te komen, is een nieuwe videotaak met nieuwe films ontwikkeld. De latente gevaren in de nieuwe films waren duidelijker, de kwaliteit en de resolutie van de films waren beter, de taak was eenvoudiger en proefpersonen konden zich beter inwerken op de taak. Er waren minder pauzes per film en de duur van een pauze was korter (drie seconden). Aan proefpersonen werd nog duidelijker dan bij de eerste versie van de videotaak verteld dat klikken op plekken waar geen latent gevaar was, hun score zou verminderen en dat niet in alle pauzes latente gevaren voorkwamen. Ook op deze verbeterde filmtaak was er geen significant verschil tussen rijschoolleerlingen op de dag dat ze geslaagd waren voor hun rijexamen en in dit geval zelfs professionele ervaren bestuurders (rijinstructeurs en rijexaminatoren) in het aantal aangeklikte latente gevaren. Verklaard kon worden dat het feit dat ook deze filmtaak niet kon discrimineren, verband hield met het gebrek aan ervaring in het spelen van computergames bij de oudere proefpersonen. Waarschijnlijk heeft ook het feit dat pauzes om te klikken noodzakelijk bleven, er aan bijgedragen dat in tegenstelling tot in de experimenten in Hoofdstuk 4, geen verschil tussen beginners en ervaren bestuurders gevonden kon worden.

De resultaten van het onderzoek dat gepresenteerd is in Hoofdstuk 4 duiden erop dat met name onzichtbare latente gevaren niet herkend worden vanwege gebrek aan rijervaring. Zou door training in een rijsimulator het opdoen van die ervaring versneld kunnen worden? In Hoofdstuk 6 wordt de ontwikkeling en evaluatie van een training in het anticiperen van latente gevaren gepresenteerd. Gebaseerd op de hypothese van het somatische stempel (Damasio, 1994) (zie de samenvatting van Hoofdstuk 3) werd aangenomen dat het meemaken in een rijsimulator van uitgelokte ongevallen of bijna-ongevallen doordat latente gevaren manifest worden, het detecteren en herkennen van latente gevaren bij beginnende bestuurders zou verbeteren. Om echter tegen te gaan dat cursisten de oorzaak van het ontstaan van het ongeval zouden toeschrijven aan de onoplettendheid of gevaarlijk gedrag van de ander en zo niet meer zouden hoeven nadenken over hoe zij in de toekomst een dergelijke situatie zouden kunnen vermijden, werd tevens gebruikgemaakt van de principes van 'het leren van je fouten' (Ivancic & Hesketh, 2000). Het leren van je fouten (error learning) houdt in dat leerlingen gestimuleerd worden na te denken over hoe het heeft kunnen gebeuren en wat zij zelf zouden kunnen doen om de fout in de toekomst te voorkomen.

Voor de training werd een eenvoudige rijsimulator gebruikt zonder bewegingsplatform, maar die wel 135° beeld bood. De training duurde ongeveer een uur. In dat uur reden cursisten door korte scenario's van ieder ongeveer één minuut. Elk scenario had drie versies: een versie waarin het latente gevaar (meestal was dit een onzichtbaar latent gevaar) niet manifest werd, een versie waarin het latente gevaar zeer plotseling manifest werd en een versie waarin het latente gevaar iets minder snel manifest werd. Eerst reden proefpersonen door het scenario waarin het latente gevaar niet manifest werd. Onmiddellijk daarna werd hen gevraagd wat er had kunnen gebeuren (maar dus niet gebeurd is). Of ze nu het latente gevaar hadden herkend of niet (meestal was dat niet zo), reden ze daarna de versie waarin het latente gevaar op agressieve wijze manifest werd. Wanneer het latente gevaar niet was herkend, eindigde deze rit in een ongeval of bijna-ongeval. Hierna verscheen er op het middelste scherm van de simulator een bovenaanzicht van de verkeerssituatie. Proefpersonen moesten aan zichzelf uitleggen wat er gebeurd was en wat zij zouden hebben kunnen doen om het (bijna) ongeval te voorkomen. Ook kregen de proefpersonen instructie over kijkgedrag in de betreffende situatie en wat ze zouden hebben kunnen doen om hun veiligheidsmarge te vergroten in deze situatie en in gelijksoortige situaties. Ten slotte reden de proefpersonen door de derde variant waarin het latente gevaar op iets minder agressieve wijze manifest werd. Deze rit was bedoeld om het geleerde in praktijk te brengen. Na de derde variant gereden te hebben begon de cyclus opnieuw met een nieuw scenario waarin sprake was van een ander latent gevaar.

Om te testen of door de training het kijkgedrag, en daarmee het detecteren en herkennen van latente gevaren, verbeterd was reden achttien proefpersonen die de training doorlopen hadden en achttien proefpersonen die een training hadden doorlopen in de betekenis van verkeersborden (de placebotraining) drie ritten van ongeveer tien minuten in een geavanceerde rijsimulator. Alle proefpersonen waren ongeveer 19 jaar oud en hadden twee jaar rijervaring. Daar dit onderzoek in Amerika is uitgevoerd, konden 19-jarigen twee jaar rijervaring hebben. In de langere ritten van de geavanceerde simulator kwamen in totaal zeven latente gevaren voor die conceptueel hetzelfde waren als de latente gevaren uit de training, maar er anders uitzagen. Dit waren de 'nabije transfer situaties'. Er kwamen in de ritten twaalf latente gevaren voor die conceptueel verschilden van de latente gevaren die getraind waren. Dit waren de 'verre transfer situaties'. Terwijl de proefpersonen in de simulator reden werden hun oogbewegingen geregistreerd met behulp van een eyetracker. In de nabije transfer situaties maakten in 84% procent van de gevallen de experimentele groep oogbewegingen waaruit bleek dat ze het latente gevaar gedetecteerd en herkend hadden. Voor de controlegroep was dit 57%. In de verre transfer situaties maakte 71% van de experimentele groep de juiste anticiperende oogbewegingen en voor de controle groep was dit 53%. Zowel in de 'nabije transfer'-situaties als de 'verre transfer'-situaties was het verschil tussen beide groepen significant. Voorts bleek dat de training niet had geleid tot risicocompensatie. Er is ook een vergelijking gemaakt tussen een training in gevaaranticipatie waarbij geen simulator, maar een pc werd gebruikt en de onderhavige training op de eenvoudige rijsimulator. Voor zover een directe vergelijking mogelijk was, was de simulatortraining niet effectiever dan de training op een pc. Een beperking van het onderzoek is dat alleen nagegaan is wat de transfer van de training was tijdens ritten op een geavanceerde rijsimulator en niet tijdens ritten in het werkelijke verkeer. Een tweede beperking was dat geen onderzoek is gedaan naar retentie, daar de proefpersonen binnen een uur na de training de testritten maakten.

In Hoofdstuk 7 zijn net als in deze samenvatting de belangrijkste resultaten op een rijtje gezet, maar dan wat uitgebreider. Ook wordt in Hoofdstuk 7 ingegaan op hoe de resultaten in de praktijk gebruikt kunnen worden. Het onderzoek heeft al tot één praktische implicatie geleid. Op basis van de in dit proefschrift vermelde resultaten is op 1 maart 2009 een onderdeel gevaarherkenning opgenomen in het theorie-examen voor het rijbewijs B (personenauto's). Dit onderdeel is afgeleid uit de taak in risicoperceptie en keuze van handeling van Hoofdstuk 4 en de fototoets van Hoofdstuk 5. Hoewel uit de resultaten is gebleken dat de fototaak criterium validiteit had, is deze taak psychometrisch gezien niet ideaal. De interne consistentie was aan de lage kant en de spreiding in scores was ondanks het significante verschil op groepsniveau, bij zowel de rijexamenleerlingen als de ervaren bestuurders tamelijk groot. In dat licht bezien biedt de taak in gevaardetectie en gevaarherkenning met films van Hoofdstuk 4 betere perspectieven om als toets in het theorie-examen te worden opgenomen. De bij deze taak gebruikte responsmethoden (oogbewegingen en mondelinge antwoorden op open vragen) zijn echter niet geschikt voor gebruik in het theorie-examen. Gebleken is dat muisklikken in plaats van de registratie van oogbewegingen geen goed alternatief was. Onderzoek naar een responsmethode bij een filmtaak die geschikt is voor gebruik in bijvoorbeeld het theorie-examen, zou dus een vervolgonderzoek kunnen zijn.

Uit het onderzoek vermeld in dit proefschrift, is ook gebleken dat gevaaranticipatie getraind kan worden in een eenvoudige rijsimulator. Of de verbetering in deze vaardigheid ook beklijft, is echter nog niet onderzocht. Als uit vervolgonderzoek zou blijken dat de verbetering in gevaaranticipatie daadwerkelijk beklijft, zou deze training onderdeel kunnen gaan vormen van de rijopleiding.

In Hoofdstuk 3 werd verondersteld dat gevaaranticipatie een emotionele en motivationele component heeft. Deze component kon niet worden aangetoond. Mogelijk had deze component wel kunnen worden aangetoond indien fysiologische verschijnselen die verband houden met emotie, zoals hartslagvariabiliteit en/of huidspanning, waren gemeten. In plaats van fysiologische maten zou de filmtaak ook afgenomen kunnen worden terwijl proefpersonen liggen in een apparaat voor hersenscans (fMRI). Ook dit is een mogelijkheid voor vervolgonderzoek.

About the author

Willem Vlakveld was born in Hilversum on May 17th in 1953. After obtaining his Atheneum diploma from the 'Rijksscholengemeenschap' in Breukelen he began his study of Pedagogy at Utrecht University. In 1988 he received his master's degree within the Division of Philosophical and Historical Pedagogy after a study on education and responsibility.

While still studying, he started his working carrier as a research assistant of the Nederlands Maritiem Instituut (Dutch Maritime Institute) in Rotterdam in 1979. After a merger, he continued this work as a researcher at MARIN (Maritime Research Institute Netherlands) in Wageningen. In 1991, he switched from research to politics and started to work as a policy maker for the Directorate-General of Shipping and Maritime Affairs of the Ministry of Transport, Public Works and Water Management. In 1997, he switched from the water to the road and started to work as a research advisor at the Transport Research Centre (Adviesdienst Verkeer en Vervoer) of the same Ministry. Here for the first time he became acquainted with road safety research. In 2002, he started his carrier at SWOV Institute for Road Safety Research and turned back to his roots as a researcher, but now in road safety. He has done studies on young novice drivers, road safety education and driver education, but he has also done studies on completely different subjects such as demerit point systems, the effect of impairments on driving capabilities, bicycle safety and road protection scores. The studies on young novice drivers triggered him to start this PhD study on hazard anticipation of young novice drivers.

Appendix 1 Latent hazards of the video clips in Chapter 4

Overt latent hazards

1.

When leaving the motorway and driving on the slip road, is the driver aware of the fact that a van in the outer left lane that just has overtaken a coach and that starts moving to the left, may also exit the motorway at the very last moment and cross the pathway of the driver? In the clip the van eventually just moves one lane to the right after having overtaken the coach and does not leave the motorway.

2.

When driving straight on, just before passing a fork to the right, an oncoming moped approaches the junction. Is the driver aware of the fact that the oncoming moped may turn left without signalling just in front of him? Young moped riders in the Netherlands are notorious for their risk taking behaviour. In the clip, the moped does not turn left.

3.

On a rather narrow road when driving straight on, a tractor in the oncoming lane approaches that drives slowly. Behind this tractor, a motorcycle approaches that drives fast. When everyone maintains his speed, the motorcycle will overtake the tractor just at the moment when the driver will pass that tractor. Is the driver aware of the fact that the three of them will meet at the same spot and the road is too narrow for this? In the clip the motorcyclist reduces his speed and stays behind the tractor.

4. 

On a rural road when driving straight on, a moped is riding before the car in the same direction as the driver, but slower. Before the moped is a cyclist. The speed of the cyclist is slower than the speed of the moped. An oncoming car is approaching. When the moped does not reduce his speed and overtakes the cyclist, all four will meet at the same spot. Is the driver aware that the road is too narrow for this? In the clip the moped reduces his speed at the very last moment and stays behind the cyclist.

5. 

On a rural road, a woman on a bicycle with a young child sitting at the back cycles from the farm house to the entrance of the driveway. The woman is only occasionally visible because of bushes. She is not looking in the direction from where the driver is approaching (at least not until the very last moment). Will she turn into the road without looking or will she look and stop on the driveway? In the clip the woman looks and stops at the very last moment.

6. 

When driving on a country road, a tractor in the distance on a courtyard of a farm starts to drive slowly in the direction of the entrance of the driveway. There are bushes that obscure the view on the entrance of the driveway. Will the tractor remain on the courtyard or will it turn into the road just at the moment when the driver passes the driveway? In the clip the tractor stops behind the bushes.

7. 

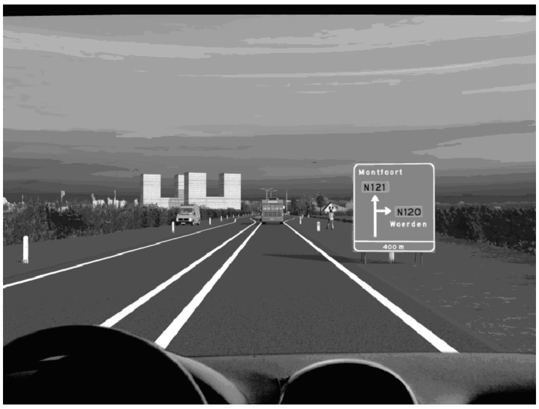
When driving on an urban road and approaching a zebra crossing, a woman with a shopping car crosses the road at the zebra crossing. She will reach the other side of the road in time and the driver does not have to reduce his speed for her. On the pavement on the side of the road where the woman has come from a child is playing. Is the driver aware of the fact that this child may belong to the woman and that it could start to run in the direction of his mother? In the clip the child remains on the pavement.

8. 

On an urban road ahead of the driver, a van is driving in the same direction. This van stops at the side of the road and the rear lights of this van start to flash. The driver in the clip is approaching this van and there is no oncoming traffic. Is the driver aware that these flashing rear lights are a warning signal and that the driver of the van may open the door and get out of the van just at the moment when the driver of the clip passes the van? In the clip the driver of the van partly opens the door and looks to the left (in the direction of the driver) in order to check if no traffic is approaching. The driver of the van remains seated in his van.

9. 

On an urban road the driver approaches an intersection. The driver is about to drive straight on at the intersection. There are no traffic lights. Just in front of the driver is a bus that is driving in the same direction. The bus turns left at the intersection. Two pedestrians walk on the pavement of the street on the left hand side of the driver. The turning bus obscures the view on the two pedestrians when they are close to the crossing. Will they stop or will they cross the street when the driver of the clip cannot see them? If they keep on walking in the same direction and cross the street, the driver of the clip may hit them. Is the driver aware that this may happen? In the clip the pedestrians stop.

10. 

When driving on a rural road, a road worker is walking on the shoulder of the right side of the road towards the direction of the road. What could be the van of this road worker is parked on the shoulder to the left. When the driver of the car in the clip is approaching this scene, the road worker disappears behind a signpost. Is the driver aware of the fact that the road worker may keep on walking in the same direction and may cross the road in order to get to his van? In the clip the road worker changes his direction and when still on the shoulder starts to walk parallel to the approaching driver.

Covert latent Hazards

1. 

On an urban but not crowded road, in the distance a van is driving in the same direction as the driver. This van stops before the entrance of a parking lot and signals that it intends to turn right into the parking lot. A low fence blocks the view on the parking lot, but the hoods of parked coaches are visible. The van that has stopped and that intends to turn right does not turn right. Is the driver aware of the possibility that the van does not turn right because a car is leaving the parking lot that he cannot see because the van that has stopped blocks his view? In the clip the driver passes the van that has stopped and no vehicle leaves the parking lot.

2.

When driving straight on, the driver passes a fork to the right. Containers on the pavement block the view on possible traffic from the right. Does the driver look to the right before passing the fork, despite he has right of way? In the clip no traffic comes from the right.

3.

On an urban road on one side is a shopping mall and on the other side is a parking lot. There is a zebra crossing from the pavement in front of the mall to the parking lot. The driver/ participant approaches the zebra crossing. Cars are also parked along the right side of the road (the side of the shopping mall). Pedestrians are visible on the pavement in front of the shopping mall, but possible pedestrians near to the zebra crossing are not visible because the parked cars along the side of the road block the view on these possible pedestrians. Is the driver aware that there may be pedestrians that will cross the road that he cannot see? In the clip the driver passes the zebra crossing and no pedestrians cross the road.

4.

A coach ahead of the driver turns left at a crossing and the driver/ participant drives straight on. The coach blocks the view on pedestrians to the left that the driver/participant has seen before the coach turned left. Does the driver due to the overt hazard to the left (the pedestrians on which the view is temporarily blocked) does not forget to look to the right for traffic that has right of way? In the clip no traffic comes from the right (and the pedestrians do not cross the road).

5. 

The driver drivers straight on at a t-junction. The view on traffic from the right is blocked by a lorry from the opposite direction has turned left and a coach in the lane to the right of the driver/participant that is about to turn right (after the lorry has passed. Does the driver look to the right before passing the road to the right, despite he has right of way? In the clip no traffic comes from the right.

6. 

The driver wants to turn left at an intersection, while an opposing lorry is waiting to make a left turn. The driver cannot see possible oncoming traffic in the lane to the right of the lorry because the lorry blocks the view. Does the driver look into the lane to the right of the lorry before taking a full turn to the left? In the clip no traffic approaches the crossing in the lane to the right of the lorry.

Appendix 2 Examples of items of the risk awareness and action selection task

Example of a photograph with an imminent hazard.

Boy between the parked cars to the left and a bal on the street

Correct response is *brake*

Example of a photograph with a latent hazard.

The driver cannot see possible traffic approaching from the left because of the hedge.

Correct response is *release throttle*

Example of a photograph with no high priority hazard.

The lorry wants to turn left, but this will be behind the driver.

Correct response is *do nothing*

Appendix 3 Additional latent hazards used in Study 2 of Chapter 5

Overt latent hazards

1.

A lorry to the left (behind the van) is turning to the right. As it is a long lorry (which is not visible because of the buildings) the lorry will whip to the left into the lane of the driver. In the clip the lorry stops before turning.

2.

The driver will continue straight, but the lead vehicle is turning to the right. The traffic light is green. It is also green for the pedestrian at the pavement. If this woman will cross the road, the lead vehicle has to brake suddenly and will block the intersection. In the clip the pedestrian turns right and does not cross the road.

3.

A bus has stopped at a bus stop. Has the participant driver noticed the passengers at the bus stop and has the participant driver also noticed the pedestrian to the left that is walking to the pedestrian crossing before the participant driver overtakes the bus?

4. 

A moped rider in front of the van approaches a spot where this moped rider has to cross the road in order to continue his trip on the bicycle path to the left. The two traffic signs indicate the fact that the moped rider has to move to the bicycle path. If the moped rider, without turning his head, suddenly crosses the road just before the van, the van has to brake hard. It is important that the driver keeps sufficient distance from the van.

5. 

The driver is passing a line of parked cars to the right. A moped is riding just in front of the driver. This moped rider is about to pass a sports car with a driver in it and the front wheels turned to the left. If this sports car pulls out, the moped rider has to brake and to swerve to the left. Has the participant driver noticed the sports car?

Covert latent Hazards

1. 

The driver is passing a bus at the bus stop. Is the driver aware of the fact that possible passengers, on which the bus blocks the view, may cross the road just in front of the bus?

Appendix 4 Glossary of abbreviations

Terms in *italics* are explained in the glossary on brain issues.

ACT-model Adaptive Control of Thought model. Theory on skill acquisition in three stages: 'the declarative stage', the 'knowledge compilation stage' and the 'procedural stage'.

AD Alzheimer's disease.

ADHD Attention Deficit Hyperactivity Disorder.

ADS Advanced Driving Simulator of the Human Performance Laboratory at the University of Massachusetts, Amherst.

AOI Area Of Interest.

ASD Autistic Spectrum Disorders.

BAC Blood Alcohol Concentration.

CBR In Dutch "Centraal Bureau Rijvaardigheidsbewijzen". This is the Dutch driving license authority. CBR is responsible for all driving tests and all (medical) fitness-to-drive tests.

CEN Central Executive Network. The CEN encompasses brain circuits that are active when processing information in working memory and during decission-making in the context of goal directed behaviour. The key brain areas of CEN are the *DLPFC* and the *parital cortex*.

CS Contention Scheduling or the Contention Scheduler. The decenteralised relatively automatic selection, activation and inhibition of low-level schemata in routine situations.

CSF *CerebroSpinal Fluid*

DATS Driver Assessment and Training System; simulator-based training program for learner drivers.

DLPFC *DorsoLateral Prefrontal Cortex.*

DMN Default Mode Network. The DMN comprises brain circuits that are involved in the integration of autobiographical, self-monitoring, and related socialcognitive functions. Key brain areas involved in the DMN are the *VMPFC* and the *posterior cingulate cortex*.

DRUID Driving under the Influence of Drugs, Alcohol and Medicines; European project to gain new insights to the degree of impairment caused by psychoactive drugs and their actual impact on road safety.

DTS Driver Training Simulator of the Human Performance Laboratory at the University of Massachusetts Amherst.

fMRI *functional Magnetic Resonance Imaging.*

FTD FrontoTemporal Dementia.

HPA-axis *Hypothalamic-Pituitary-Adrenal axis*.

MDMA ± 3,4-methylenedioxymethamphetamine; ecstacy.

MEG *MagnetoEncephaloGraphy*.

MOP Memory Organisation Packet; overarching schema or script.

MRI *Magnetic Resonance Imaging.*

MVTP Motor-free Visual Perception Test. This test measures visual cognition such as spatial relationship, visual discrimination, figure-ground, visual closure and visual memory.

OECD Organisation for Economic Co-operation and Development. This is an international economic organisation of 34 countries founded in 1961 to stimulate economic progress and world trade. It defines itself as a forum of countries committed to democracy and the market economy, providing a platform to compare policy experiences, seeking answers to common problems, identifying good practices, and co-ordinating domestic and international policies of its members.

OFC *Orbito Frontal Cortex*.

PBT Problem Behaviour Theory. PBT categorizes motives for reckless behaviour in three systems. The first system is the perceived environment system. This includes for instance peer group pressure. The second system is the personality system (i.e., feelings and perceptions about the self that promotes tolerance of deviance) and the third system is the behavioural system (other risky behaviour than the risky behaviour of study).

PDD-NOS Pervasive Developmental Disorder Not Other Specified, one of the autistic spectrum disorders.

PET *Positron Emission Tomography.*

PFC *Pre Frontal Cortex.*

PROV In Dutch "Periodiek Regionaal Onderzoek Verkeersveiligheid", in English "Periodical Regional Traffic Safety Survey". This a questionnaire research that is administered every two years about road user behaviour and opinions of road users in the Netherlands.

RAPT Risk Awareness and Perception Training; PC-based training programs developed by researchers of the Human Performance Laboratory at the University of Massachusetts Amherst. There are 3 different versions of RAPT.

RDW In Dutch "Rijksdienst voor Wegverkeer. In English "Dutch Vehicle Technology and Information Centre".

SAS Supervisory Attentional System; conscious interference in the more or less automatic process of contention scheduling in non-routine actions.

SCR Skin Conductance Response.

SES SocioEconomic Status.

SimRAPT Simulator-based Risk Awareness and Perception Training; simulator-based training program developed by researchers of the Human Performance Laboratory at the University of Massachusetts Amherst.

SN Salience Network. The SN encompasses brain circuits that are involved in saliance detection. An important area of the brain of this network is the *insula*.

TAS Thrill and Adventure Seeking, a subscale of the sensation seeking questionnaire.

tDCS *transcranial Direct Current Stimulation.*

THC Delta-9-tetra-hydrocannabinol; psychoactive component of cannabis.

TPQ Thee-dimensional Personality Questionnaire. A personality test with three scales: novelty seeking, harm avoidance and reward dependence.

TTC Time To Collision.

UMASS University of Massachusetts Amherst.

VMPFC *Ventromedial Prefrontal Cortex.*

Appendix 5 Glossary on brain issues

Amigdala	Almond-shaped groups of nuclei within the limbic system involved in the processing and memory of emotional reactions.
Basal ganglia	The basal ganglia play an important role in action selection, procedural learning and movement control. The basal ganglia function in close cooperation with the PFC (the executive functions). In cooperation with the PFC, the basal ganglia influence motivational processes (cooperation between basal ganglia and cingulate cortex), social reactions (cooperation between basal ganglia and the OFC) and planning (cooperation between basal ganglia and the DLPFC).
Caudate	The caudate nucleus is a nucleus located within the basal ganglia of the brains. It is involved in learning and memory processes. The caudate gets activated when individuals receive feedback.
Cerebellum	The cerebellum (Latin for *little brain*) is a region of the brain that plays an important role in motor control. It is also involved in some cognitive functions such as attention and language, and probably in some emotional functions such as regulating fear and pleasure responses.
Corpus callosum	Dense network of tissue connecting the right and left cerebral hemisphere of the brain.
CSF	CerebroSpinal Fluid. This is a watery fluid which flows in the ventricles (cavities) within the brain and around the surface of the brain and spinal cord.
Dendritic and axonal arborisation	See synaptic pruning.

DLPFC	DorsoLateral Prefrontal Cortex. This is about the last region of the brain to mature. It loses gray matter well into the third decade of life. The DLPFC is a region of the Pre Frontal Cortex (PFC) and is involved in impulse control, judgment, planning and decision making.
Dopamine	Dopamine is a neurotransmitter that influences activities such as movement, attention and learning. Parkinson's disease involves the degeneration of a particular group of neurons that produce dopamine.
fMRI	functional Magnetic Resonance Imaging. Like in MRI in fMRI powerful magnetic fields are used. The magnetic property of blood changes with the amount of oxygen in the blood. A fMRI scanner can visualise where in the brain is blood with more oxygen and where in the brain is blood with less oxygen. An area of the brain that is active has blood with more oxigen than an area of the brain that is inactive. When a person is situated in an apparatus for fMRI and performs a certain task without moving her or his head, the areas of the brain that are active during task performance become visible.
Glucocorticoid Secretion	Secretion of the stress hormones corticosterone, cortisol and cortisone. Glucocorticoids increase the availability of energy substrates which enables the organism to cope more effectively with stress. Through actions in the brain, glucocorticoids promote goal-directed behaviour and facilitate the formation of memories and thus shape behavioural and psychological reactions to similar stressors in the future.

Gonadotropin releasing hormone	Gonadotropin-releasing hormone or GnRH is considered a neurohormone. GnRH stimulates the synthesis and secretion of the gonadotropins that regulates normal growth, sexual development, and reproductive function. GnRH activity is very low during childhood, and is activated at puberty.
Gray matter	Gray matter is one of the two components of the central nervous system and is mainly made up of neuronal cell bodies. The other component is white matter. Decrease in gray matter is related to synaptic pruning or also named dendridic and axonal arborisation. Because of synaptic pruning the brain operates more effectively.
Gyrus cinguli Anterior	Frontal part of the gyrus cinguli. The gyrus cinguli is a structure of the limbic system. The gyrus cinguli anterior gets activated when some form of conflict is elicited such as in the Stroop task.
Gyrus cinguli Posterior	Gyrus cinguli posterior is the hind part of gyrus cinguli. The gyrus cinguli posterior has a memory related function and gets activated by emotional stimuli.
Hippocampus	A structure within the limbic system that plays an important role in the consolidation of information from short-term memory to long-term memory and spatial navigation.
HPA-axis	Hypothalamic-Pituitary-Adrenal axis. An important role of the HPA response to stressors is to restore the physiological balance to prevent overreaction of defence mechanisms to stress. How the HPA axis functions depends to a large extend on sex hormones (testosterone and oestrogens).

Hypothalamus	A structure within the limbic system involved in controlling many bodily functions (e.g. body temperature, hunger, thirst, fatigue, sleep, and circadian cycles).
Inferior frontal Gyrus	The inferior frontal gyrus plays a role in inhibition and risk aversion.
Insula	The insulae or the insular cortex. The insulae play a role in diverse functions usually linked to emotion or the regulation of the body's homeostasis. These functions include perception, motor control, self-awareness, cognitive functioning, and interpersonal experience. The insulae get activated when deviant stimuli embedded in a stream of continuous stimuli are signaled.
Insular cortex	See Insula.
Limbic system	With limbic systems a group of subcortical areas are denoted that among others play a role in experiencing negative emotions (the amygdala), feelings of anticipated pleasure (the nucleus accumbens), motivation (the gyrus cinguli anterior), long term memory storage (the hippocampus) and regulation of emotions not involving top-down control by the PFC (the hypothalamus). The gyrus cinguli is actually not considered to be a part of the limbic systems, but is closely related to the limbic systems.

MEG	MagnetoEncephaloGraphy (MEG) just as fMRI and PET, is a technique for mapping brain activity. In MEG the magnetic fields are recorded that are produced by electrical currents occurring naturally in the brain. In fact MEG is such a precise way electroencephalography (EEG) that active areas of the brain can be located. MEG has a higher temporal resolution than fMRI. A very short activity of a particular area of the brain can be detected by MEG that can not be detected by fMRI. MEG machines are very sensitive and magnetic fields other than those caused by brain activity can confound measurement.
Motor cortex	Band around the central fissure of the cortex that is involved in planning, control, and execution of movements in particularly of movements involving any kind of delayed response.
MRI	Magnetic Resonance Imaging. A MRI machine uses a powerful magnetic field to align the magnetization of atoms in the body. Some atoms recover sooner from a temporary change caused by a magnetic field than others. This difference is used to make among others brain structure visible. MRI scanning is non intrusive.
Myelination	Myelin is a fatty substance that coats the axons of some neurons. Myelination is the coating process. Neurons with myelinated axons communicate faster and more accurately.
Neuro-endocrine processes	The secretion of hormones in the brain, particularly in the pituitary gland, which is located at bottom of the hypothalamus.
Nucleus Accumbens	A collection of neurons within the striatum that play an important role in reward, pleasure, laughter, addiction, aggression, fear, and the placebo effect.

Occipital lobe	One of the four major regions of the cerebral cortex. The occipital lobe is chiefly involved in visual processing.
Oestrogens	Oestrogens are steroid hormones and are the the primary female sex hormones. While oestrogens are present in both men and women, they are usually present at significantly higher levels in women of reproductive age. They promote the development of female secondary sexual characteristics, such as breasts, and are also involved in the thickening of the endometrium and other aspects of regulating the menstrual cycle. Sudden oestrogen withdrawal, fluctuating oestrogen, and periods of sustained oestrogen low levels correlates with significant mood lowering.
OFC	Orbito Frontal Cortex. Area of the PFC. Persons with lesions in the OFC and/or VMPC have difficulties with empathy, control over emotions and the weighing of risks.
Parieto-occipital Cortices	Play a role in the accurately locating of visual objects.
Parital cortex	One of the four major regions of the cerebral cortex. The parital cortex or parital lobe is chiefly involved in somatosensory processing.
PET	Positron Emission Tomography. As fMRI, PET is a scanning method to make areas of the brain visible that are active during task performance. The method is however completely different. In PET use is made of the fact that active areas of the brain consume glucose (simple sugar). PET scans use a radioactively tagged form of glucose, which can be detected by a scanner.

PFC	Pre Frontal Cortex. The PFC consists of various sub-areas such as the DLPFC and the OFC and is essential for what are called the executive functions. Executive functions refer to the regulation of planning and social behaviour in situations when 'automatic' responses are inadequate such as when persons are planning tasks, weighing risks and other tasks related to decision making.
Serotonin	Serotonin is a neurotransmitter that appears to be related to the regulation of mood, as well as the regulation of arousal and sleep, appetite, and sensitivity to pain. Serotonin also has some influence on memory and learning processes.
Striatum	The striatum is a sub cortical region that functions as an intermediate between the PFC and the basal ganglia and plays a role in both planning of movements and in executive functions. In humans the striatum is activated by stimuli associated with reward, but also by aversive, novel, unexpected or intense stimuli, and cues associated with such events.
Synaptic pruning	Synaptic pruning is regulatory of neuro-structural re-assembly. The overall number of neurons and connections between neurons are reduced, leaving more efficient synaptic configurations in existence. Maturation presupposes synaptic pruning.
tDCS	transcranial Direct Current Stimulation, externally activation or inhibition by means of electrodes of particular brain areas.

Temporal lobe One of the four major regions of the cerebral cortex. The temporal lobe is chiefly involved in auditory processing. It is also important for the processing of semantics in both speech and vision. In relation with the hippocampus the temporal lobe plays a key role in the formation of long-term memory.

Testosterone Testosterone is a steroid hormone. It is the principal male sex hormone and an anabolic steroid. On average, an adult human male body produces about ten times more testosterone than an adult human female body, but females are more sensitive to the hormone. The relationship between testosterone and aggression in humans has been examined in many studies, but the results are not conclusive.

VMPFC Ventromedial Prefrontal Cortex. Area of the PFC close to the area of the OFC. Persons with lesions in the OFC and/or VMPC have difficulties with empathy, control over emotions and the weighing of risks.

White matter White matter is one of the two components of the central nervous system and consists mostly of myelinated axons. Neurons with myelinated axons communicate faster and more accurately. The other component of the central nervous system is gray matter.

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ISBN: 978-90-73946-09-5