Assisting the older driver

Intersection design and in-car devices to improve the safety of the older driver

Ragnhild Davidse

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General introduction

This doctoral thesis is concerned with the possibilities offered by road design and driver assistance systems to improve older adults' safe and independent mobility by compensating for their age-related functional limitations. The focus is on drivers of private cars aged 75 years and above. In this thesis, this group of drivers is called 'older drivers'. When referring to the mere age group, the interchangeable terms 'older adults' and 'older people' are used.

The specific attention for the age group of 75 years and above originates in the relatively high fatality rate for drivers of this age. An extensive analysis of the safety of older drivers is part of this thesis (*Chapter 1*). Among others, their safety is described in terms of involvement in crashes and resulting injuries. The term 'accidents' is deliberately not used in this thesis, as it suggests that the events had to do with bad luck and were thus not preventable (Davis & Pless, 2001). Most injuries and their precipitating events are, however, predictable and preventable. In fact, specific preventive measures are the main topic of this thesis. Therefore, the terms 'crash' and 'collision' will be used instead of the term 'accident'.

Age-related functional limitations play a central role in the search for measures that can extend the older adult's safe and independent mobility. Their influence on driving performance directs the selection of measures in this thesis. A functional limitation is not a clearly defined term in itself. However, it can be regarded as a synonym for the term "impairment" used by the WHO in its International Classification of Functioning, Disability and Health (known as ICF; WHO, 2001). Impairments refer to symptoms or characteristics that can be directly related to the "body level", that is, having a physiological or anatomical causation. They can consist of a defect, lack or loss of, or reduction in for example visual performance, information processing speed or attentional capacity. According to the ICF, impairments can lead to activity limitations and participation restrictions. Activity limitations are difficulties an individual may have in executing activities of daily life which are important for independent functioning, such as driving a car or having a telephone conversation (Brouwer, Van Zomeren, Berg, Bouma & De Haan, 2002; WHO, 2001). Participation restrictions are problems an individual may experience in involvement in life situations, such as going to the bridge club or maintaining a friendship (WHO, 2001). These participation restrictions indicate a loss or significant deficiency in a social role which is normal for a person's age and social position (Brouwer et al., 2002). Both activity limitations and participation restrictions can be resolved by assistive devices or personal assistance. While neither devices nor personal assistance eliminate the impairments, they may remove limitations on functioning in specific domains (WHO, 2001).

The influence of age-related functional limitations on driver safety can be reduced in several ways. First of all, drivers can compensate for their functional limitations by avoiding difficult driving circumstances such as driving during peak hours, darkness or bad weather conditions. Secondly, the driving task can be made easier by simplifying traffic situations, by personal assistance in the car, or by improving driver performance through education. Thirdly, increased crash rates as a result of functional limitations can be prevented by assessing persons' fitness to drive. If, from a safety point of view, driving is no longer justified, ex-drivers must be supported in swapping the car for other modes of transport. Although all of the abovementioned compensation strategies reduce the influence that functional limitations have on driver safety, not all of them resolve the activity limitations and participation restrictions to which functional limitations might lead. Some of them might even increase them by restricting driving. Measures that are specifically aimed at removing limitations and restrictions on a person's functioning as a driver, are those mentioned under the heading of making the driving task easier: simplifying traffic situations, providing personal assistance in the car, and education.

Whereas Withaar (2000) describes ways to improve selection and training procedures as means to compensate for functional limitations, the aim of this thesis is to determine the extent to which road design and in-car driver assistance systems can compensate for functional limitations that affect road safety. Three central research questions can be distinguished. The first question is a general one: how can the safety of older drivers be characterised, and which characteristics of older people may be of influence on their driving performance. The second question is which age-related functional limitations have the greatest influence on driving performance and road safety. The third question is what road design elements and driver assistance systems may compensate for these functional limitations.

In order to answer the first question, various aspects of older drivers are described: their current fatality and injury rates, the types of crashes they are involved in, and their general physical and mental state. The second question is answered by examining the strengths and weaknesses of older drivers, and the relationship between their weaknesses, the difficulties they encounter in traffic, and their relevance to the occurrence of crashes. To answer the third question, an inventory is made of adjustments to road design and driver assistance systems that may improve the safety of older drivers. In addition, two studies are presented that evaluate the effects of some of those adjustments and driver assistance systems. As the implementation of measures concerning road design, and the development of prototype assistance systems are very expensive, both types of 'assistive devices' are evaluated in a simulated environment using a fixed base driving simulator. Measures concerning road design are implemented by bringing variation into the design of the intersections which participants have to pass while driving the simulator car. A driver assistance system is simulated by oral messages that are sent depending on the situation participants' find themselves in, and on the way they behave in that particular situation.

Analogous to the research questions, this doctoral thesis can be divided into three main sections. Chapters 1 and 2 relate to the first question. In *Chapter 1*, the safety of older drivers is described based on crash and injury data for the Netherlands. Their current fatality and injury rates are discussed, as well as the underlying factors which determine the level of these rates. Furthermore, the crash types which prevail among older drivers are described. In *Chapter 2*, the physical and mental qualities of older adults are described, as well as the way in which they can influence driver performance. *Chapter 3* closes the first section of this thesis. In this chapter, factors are discussed that may influence future crash and injury rates for older drivers, as well as measures which can be taken to reduce these rates.

Chapter 4 addresses the second question. In this chapter, the physical and mental qualities of older adults are discussed from a theoretical perspective. The aim of this chapter is to identify the relative weaknesses of the older driver, as it is assumed that specific measures will be most capable of reducing the crash involvement of older drivers if they support these weaknesses of the driver. With this aim, the strengths and weaknesses of older drivers are deduced from the literature that originates from several theoretical perspectives on human functioning: Fuller's task-capability interface model, the human factors approach, cognitive psychology, and game theory. The result is a list of the relative weaknesses of the older driver and the difficulties that older drivers encounter in traffic as a result of these weaknesses. To be able to rate the relevance of these weaknesses to road safety, the weaknesses are compared with crash data. Those weaknesses that have a substantial influence on road safety, as indicated by the percentage of crashes that could have been avoided if the weakness would not have existed (or would have been compensated for by, for example, ADAS), are considered to indicate a need for support. The result is a shortlist of desired types of support.

In the third section (chapters 5 to 8), the focus is on road design and in-car driver assistance systems as devices which may offer the desired types of support. In the first two chapters of this section, chapters 5 and 6, the focus is on measures concerning road design. To find leads for road design elements that put the older driver to the test, *Chapter 5* starts with an analysis of the differences between intersections at which many and those at which few crashes occur involving older drivers. Following on that, adjustments to road design are discussed which take into account the limitations of older drivers, and which for that reason appear to offer the desired types of support mentioned in chapter 4. In *Chapter 6*, the results are described of a simulator study in which several types of intersection designs were compared on their effects on driver workload and driver behaviour.

In chapters 7 and 8, the focus is on driver assistance systems that may offer the desired types of support. In *Chapter 7*, specific types of in-car driver assistance systems are described that appear to offer the desired types of support. In addition, it is discussed which conditions assistance systems should meet to actually improve the safety of older drivers. Topics included are user acceptance, design requirements for the human-machine interface, and prevention of negative side-effects. In *Chapter 8*, the results are described of a simulator study in which one specific driver assistance system was tested for its effects on driver workload and driver behaviour.

Finally, in the last part of this thesis, the main findings are summarized and conclusions are drawn about the role that road design and in-car driver assistance systems can play in compensating for functional limitations.

1. Current state of the art: crashes and injuries[1]

In this chapter, it is argued that older drivers are not so much a risk to others, but that they are at risk themselves. Older drivers are frailer, which makes them vulnerable to personal injury in the event of a crash. As a result, older drivers particularly have a high fatality rate. Whereas the injury rate for drivers aged 75 and above is two times higher than the average for all ages, their fatality rate is more than five times higher. Therefore, to lower the fatality rate of older drivers, secondary safety measures are very important.
However, improvements in the field of primary safety are also needed. Older drivers appear to be over-represented in multi-vehicle crashes at intersections. These crashes particularly occur when the older driver has to turn left across a lane of traffic. Not only are older adults over-involved in such crashes, they are also significantly more frequently legally responsible for those crashes, often because they failed to yield.

1.1. Introduction

The safety of older drivers can be studied using several indicators: the total number of injury crashes older drivers are involved in, the number of fatal crashes older drivers are involved in, and the number of fatal and non-fatal injuries among older drivers. To compare the number of crashes and injuries among older drivers with those among other age groups, crash and injury numbers should be related to some indicator of exposure, such as the amount of kilometres travelled by the respective age groups. The resulting ratios are called ‘crash rate’ and ‘injury rate’. In case only fatal injuries are related to the number of kilometres travelled, the term ‘fatality rate’ is used. This chapter gives an overview of what these figures tell us about the safety of the older driver in the Netherlands: what are the numbers of fatal and non-fatal injury crashes among older drivers, how do they relate to the mobility of older drivers, what are the underlying factors which determine their crash and injury rates, and what crash types prevail among older drivers. To put these figures into perspective, comparisons are made between data for older drivers and those for younger drivers. Age groups of ten years are used, except for the upper and lower parts of the age distribution (younger than 30 years of age and 60 years of age and above). These other age groups are subdivided into smaller or larger age groups, dependent on common age classifications used in the literature. Since the figures are based on Dutch crash statistics, the youngest age group starts at

[1] This chapter was based on chapter 2 of SWOV report D-2000-5 (Davidse, 2000).

the age of 18, the age at which one is allowed to obtain a driving licence in the Netherlands.

An analysis of the safety of older drivers is not new. Various international studies are available on this topic (Aizenberg & McKenzie, 1997; Hakamies-Blomqvist, 1993, 1994a; Maycock, 1997; McGwin & Brown, 1999; OECD, 2001; Zhang, Fraser, Lindsay, Clarke, & Mao, 1998). However, the situation in the Netherlands has never been studied in detail before. Therefore, this chapter compares the results of an analysis of Dutch crash statistics with conclusions drawn in other studies on older driver safety. The analysis of Dutch data was carried out in 1999 (see Davidse, 2000). As a result, crash and injury statistics represent the situation in the period of 1994-1998. However, a less detailed analysis based on data for the period 2001-2005, which was also carried out by Davidse, shows that the overall picture has not changed since the late nineties of the last century (European Road Safety Observatory, 2006). The conclusions regarding crash involvement and injury rates of older adults are the same. Data on crashes[2] and injuries used in both analyses were obtained from the Dutch Ministry of Transport, Public Works and Water Management. Data on kilometres travelled, the number of driving licences per age group, and the number of inhabitants were obtained from Statistics Netherlands. Sources mentioned in the captions of tables and figures of this chapter relate to the raw data. Calculations were carried out by the author.

1.2. Injury rate: crash involvement and physical vulnerability

A comparison of the injury rates for different age groups (*Figure 1.1*) shows the well-known U-shape. Injury rates are high for the youngest group of drivers, after which they decline to a minimum for drivers aged 40-59. Then they increase again, to a maximum for those aged 75 and above. A comparison of the fatality rates shows the same U-shape (*Figure 1.2*). However, whereas drivers aged 18-24 have the highest injury rate, those aged 75 and above have the highest fatality rate.

The cause of this difference between young and older drivers may be found in the two aspects that underlie the injury rate of a group of road users: their crash involvement and vulnerability. The crash involvement of a group of

[2] Numbers of crashes refer to injury crashes only. Crashes with material damage only (MDO) are not included in the analyses discussed in this chapter.

road users indicates how often they are involved in crashes of a certain severity regardless of the severity of their own injuries. The vulnerability of a group of road users indicates what their average injury severity is when they collide with a particular force against another vehicle or obstacle.

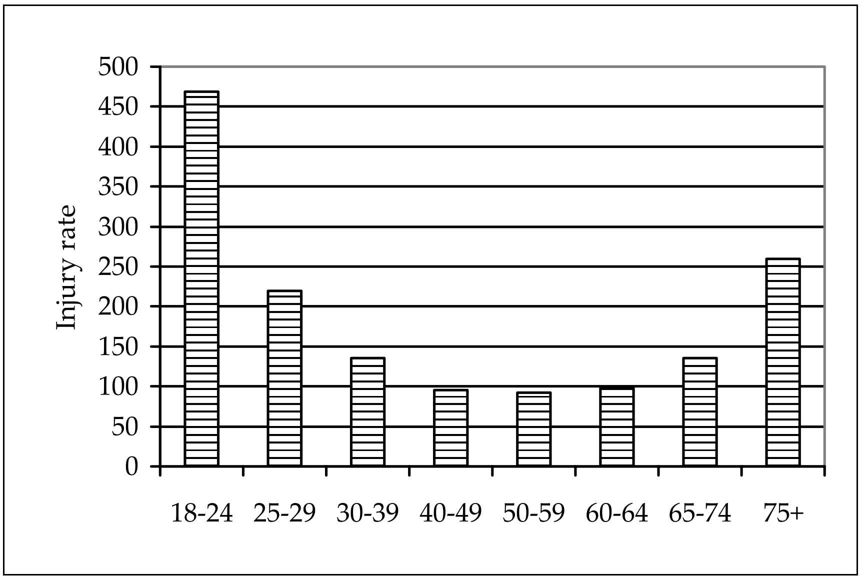

Figure 1.1. Injury rate per billion driver kilometres: number of injured drivers (fatal and non-fatal) per billion driver kilometres (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

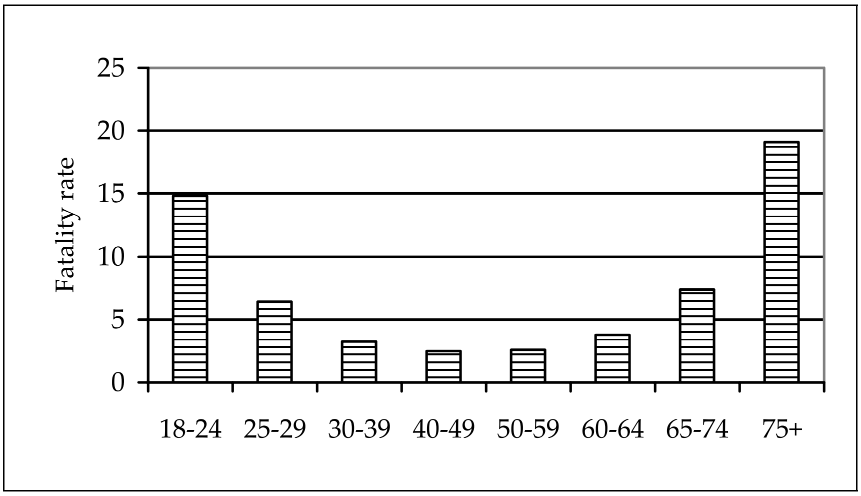

Figure 1.2. Fatality rate for drivers per age group; number of killed drivers per billion driver kilometres (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

1.2.1. Crash involvement

A comparison between the involvement in *injury crashes* per billion driver kilometres of drivers from different age groups (*Figure 1.3*) reveals a picture that very much resembles the one that was the result of the comparison between the *injury rates* for different age groups (*Figure 1.1*). Again, the youngest age group has the highest rate, followed by the oldest age group of those aged 75 and above, and the group of drivers aged 25-29. However, when comparing the involvement in *fatal crashes* per billion driver kilometres between drivers from different age groups (*Figure 1.4*), the result is different from the comparison between the *fatality rates* for drivers from different age groups (*Figure 1.2*). Whereas crash rates for fatal crashes are the highest for the youngest group of drivers, fatality rates are the highest for the oldest group of drivers. Therefore, it appears that the fatality rate for young drivers is influenced more by their *involvement* in fatal crashes than is the case for those aged 75 and above. Although older drivers are also more often involved in fatal crashes than drivers aged 40-59, their higher fatal crash rate cannot fully account for the level of their fatality rate. Other factors that could contribute to their high fatality rate are their physical vulnerability (see *Section 1.2.2*), their driving experience (see *Section 1.2.4*), the types of crashes they are involved in, and their driving behaviour (see *Section 1.3*).

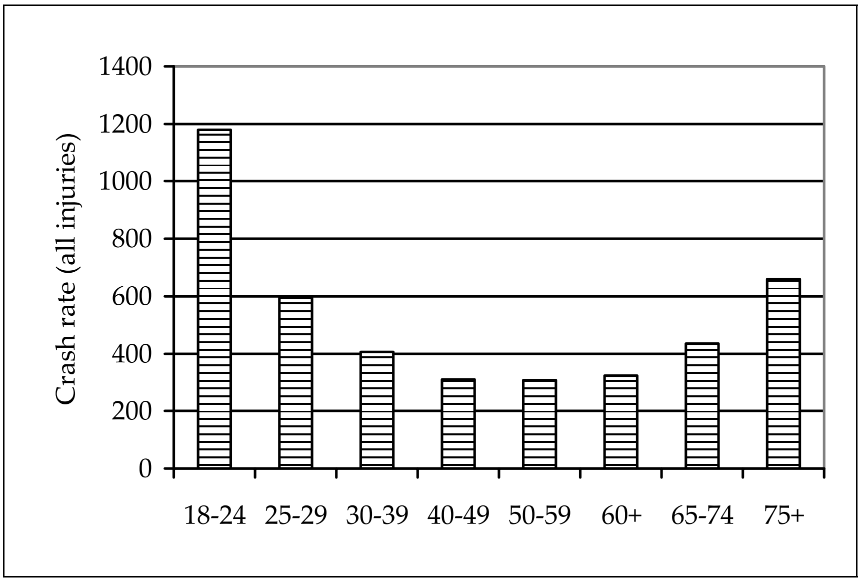

Figure 1.3. The involvement of drivers in injury crashes (fatal and non-fatal); number of drivers involved in injury or fatal crashes per billion driver kilometres of the age group concerned (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

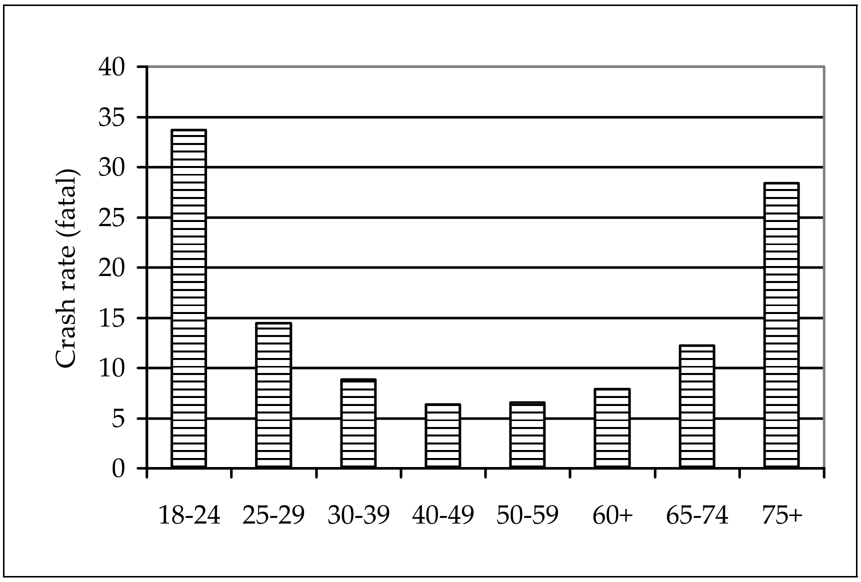

Figure 1.4. Crash rate; involvement of drivers in fatal crashes; number of drivers involved in crashes per billion driver kilometres of the age group concerned (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

1.2.2. Physical vulnerability

Various studies have pointed out that physical vulnerability increases as people age (Evans, 1988; Koornstra, 1998; Mackay, 1988; Wouters, 1989). Mackay (1988), for example, concluded that, when compared with the younger age groups, older car occupants are a) more seriously injured for a given crash exposure, b) hospitalised longer for a given initial injury, and c) exposed to more disabling injuries, especially to the head and lower limbs.

Describing physical vulnerability in a quantitative way introduces several problems. Wouters (1989), for example, used the number of fatalities per 100 injured persons to compare the vulnerability of drivers of different age groups. The disadvantage of using this so-called lethality to measure vulnerability, is that it measures more than that. It also covers the average impact of crashes, which is largely determined by driving speed and crash type. This would not be a problem if driving speeds and crash types were the same for all age groups. It is known, however, that younger drivers are more often involved in crashes involving high speeds and against rigid objects than older drivers do (see *Sections 1.3* and *1.5*). As a result, lethality may exaggerate the younger driver's vulnerability. As there is no better measure of vulnerability that is easy to calculate, lethality will nevertheless be used to compare the vulnerability of people of different ages. *Figure 1.5* shows that the indexed lethality (that of the 30-39 year olds is set at 1) begins to increase at 55 years old and, at 85, reaches a level that is four times higher than that for the 30-39 year olds. With an equal fatality rate for all age groups, this would mean that the older one gets, the more the fatality rate of a driver is dominated by the vulnerability factor, and the less it is influenced by crash involvement. Therefore, it is expected that the high fatality rate of older drivers is the result of a slightly larger involvement in fatal crashes and a much greater vulnerability, whereas the high fatality rate of young drivers is the result of a considerably larger involvement in fatal crashes and a slightly greater vulnerability. For this last conclusion, a reference should be made to the disrupting influence of crash type on lethality. The generally greater severity of crashes of young drivers may be completely responsible for their higher lethality. This means that the greater vulnerability of young drivers as shown in *Figure 1.5* may be the mere result of using lethality to measure vulnerability.

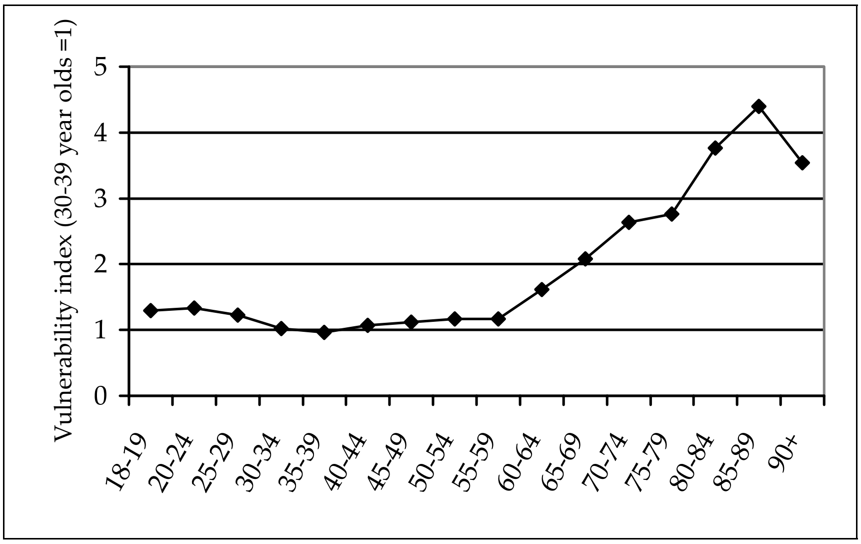

Figure 1.5. Vulnerability index: number of fatalities per 100 injured in the age group concerned (1996-1998). Source: Ministry of Transport, Public Works and Water Management.

The large share that the vulnerability factor has in the involvement of older drivers in fatal crashes was for Koornstra (1998) reason to believe that the road safety measures taken within the framework of sustainable safety can indeed lower the general crash rate, but that the fatality rate of older road users will always remain higher than average. Some comments can be given on this. First of all, it may be expected that certain vehicle measures will have a greater effect on the fatality rate of older drivers than on the average fatality rate. Vehicle measures such as Side Impact Protection systems do indeed intervene in the vulnerability factor (Mackay, 1988; Maycock, 1997). They are not so much aimed at a reduction in the number of crashes (also known as primary safety) as they are at limiting injury severity if a crash happens (secondary safety). Moreover, they are specifically aimed at reducing injuries in crashes that are over-represented among older drivers: side-collisions at intersections (see *Section 1.3*).

1.2.3. Crash responsibility

A second comment that can be given on Koornstra's remark has to do with the relative improvement (i.e., more so than for other age groups) that can be achieved in terms of primary safety; a reduction in the number of crashes. Various studies have shown that older drivers more often appear to be 'responsible' for the crashes they are involved in (Cooper, 1989; Verhaegen, Toebat & Delbeke, 1988). If that is the case, crash involvement of older drivers can be lowered to a level that is closer to the average driver by finding out what the causes of their crashes are, and by producing measures that prevent such crashes from happening. Suppose, for example, that crashes for which older drivers are responsible are predominantly caused by functional limitations that are more common in the older age group. Assistive devices may then be developed which may prevent these crashes, resulting in a reduction of the crash involvement of older drivers that is larger than the one obtained for younger drivers.

In order to estimate the relative responsibility of drivers of a certain age group for the crashes they were involved in, Cooper (1989) divided the share that drivers of that age group had in the total number of legally *responsible drivers* by the share that drivers of that age group had in the total number of *not-responsible drivers*. For the youngest age group (< 25 years old) he found a ratio of 1.5, for the age groups up to 65 years of age ratios were below 1 (around 0.80), whereas for the age groups of 65 and above ratios increased from 1.20 for the 66-70 year olds to 5.67 for the 86-90 year olds. Verhaegen, Toebat and Delbeke (1988) found slightly different ratios. They found lower ratios for the youngest age group (0.95) and higher for the age groups from 40 to 60 years old (1.00). These differences are possibly the result of different sample compositions. In Cooper's study, injury crashes as well as Material Damage Only (MDO) crashes were included, whereas Verhaegen, Toebat and Delbeke only included MDO crashes.

Based on Dutch crash statistics, similar estimates of the relative legal responsibility of drivers of different age groups were made (see *Appendix A* for assumptions made to derive crash responsibility). The data selection consisted of drivers involved in injury crashes between two cars. The results are shown in *Table 1.1*. The column that is titled 'Ratio R/I' shows the ratios for all injury crashes. These ratios are similar to those of Cooper (1989), with the exception of the ratio for the 60-64 years old. For this age group, the ratio for the Netherlands has already reached 1.00, whereas Cooper found 0.89. The three other 'Ratio' columns include ratios for injury crashes that resulted in fatalities, hospital admissions, or less severe injuries as maximum injury severity respectively. In general it can be said that for the 18-39 year olds, 60-64 year olds, and those aged 75 or above, crash responsibility is not related to crash severity. However, it appears that the 40-60 year olds are less often responsible for crashes that led to more severe injuries; the more severe the maximum injury severity of a crash is, the less often they are legally responsible for it. The 65-74 year olds, on the other hand, appear to be more often legally responsible the more severe the maximum injury severity is. Of course, vulnerability again plays a role here. In general, the older driver himself will be the one who is the most severely injured.

Age	All fatal and injury crashes			Fatal	Hospital	Less severely injured
	Responsible Number (%)	'Innocent' Number (%)	Ratio R/I	Ratio	Ratio	Ratio
18-24	8148 (21.2)	5968 (15.6)	1.37	1.40	1.28	1.39
25-29	6258 (16.3)	6354 (16.6)	0.98	0.98	1.00	0.98
30-39	8522 (22.2)	10114 (26.4)	0.84	0.82	0.83	0.85
40-49	5711 (14.9)	7265 (18.9)	0.79	0.62	0.76	0.80
50-59	4053 (10.6)	4780 (12.5)	0.85	0.64	0.79	0.87
60-64	1363 (3.6)	1353 (3.5)	1.01	1.00	1.06	0.99
65-74	2351 (6.1)	1586 (4.1)	1.48	2.06	1.53	1.45
75+	1512 (3.9)	505 (1.3)	2.99	2.84	3.40	2.84
Total	38388 (100)	38388 (100)	1.00	1.00	1.00	1.00

Table 1.1. Relative chance of being the legally responsible crash opponent in a fatal or injury crash, by age group and crash severity (1994-1998). Source: Ministry of Transport, Public Works and Water Management.

However, the most important conclusion that can be drawn from *Table 1.1* is that older drivers not only have a higher than average injury rate, but are also more often legally responsible for the crashes they are involved in. This offers possibilities for developing measures that prevent the crash types for which the older driver is legally responsible. It is expected that these measures will lead especially to a decrease in their crash involvement, and with it the fatality rate of the older driver, if the crashes they are involved in are the result of functional limitations instead of (wilful) risk-taking behaviour. In *Section 1.3*, it is examined whether there are indeed crash types that are over-represented among older drivers, and if so, how they can be characterized. The next section discusses another factor that may influence the older driver's fatality rate: annual mileage.

1.2.4. Role of annual mileage

Older drivers typically drive a shorter distance per trip and hence have lower accumulated driving distances per year. In general, drivers travelling more kilometres have reduced crash rates per kilometre compared to those driving fewer kilometres. Therefore, the low mileage of older drivers may exaggerate older driver risk per kilometre estimates (Janke, 1991). Several studies, using data from different countries, have tested this hypothesis (Fontaine, 2003; Hakamies-Blomqvist, Raitanen & O'Neill, 2002; Holte, 2005; Langford, Methorst & Hakamies-Blomqvist, 2006). They all found that when driver groups were matched for yearly mileage, age-related increases in crash rates per km disappeared. That is, older drivers with an average or high annual mileage have crash rates that are comparable to those of younger adult drivers with the same annual mileage. Only drivers with a low annual mileage have more crashes per million driver kilometres, but this goes for younger drivers as well as for older drivers.

Crash rates can also be biased by the type of roads typically travelled by older drivers. Many avoid driving on motorways (with interchanges), the safest types of roads, and tend to drive on streets with intersections, which are, by their very nature, less safe and have more crashes (Janke, 1991). Hence, older drivers' risk estimates based on injuries or fatalities per mile driven will be overestimated when compared to those of younger drivers with higher yearly mileage on safer roads (OECD, 2001).

1.3. Crash types of older drivers

The crash types that are over-represented among crashes for which older drivers are legally responsible can be identified by comparing the general ratio between the number of legally responsible and "innocent" drivers of an age group (see *Table 1.1*) with the same ratios for the various causes of crashes and the related intended movements. The cause and intended movement of the legally responsible driver are considered to give a description of the crash type. In this, the behavioural approach is emphasized; which behaviour of the responsible driver led to the crash. Had other crash specifications been used, such as frontal collision versus side collision or collision with an object, the available data would not have made it possible to include the legal responsibility of the driver into the comparison.

The causes and intended movements distinguished in the Dutch crash database are of great diversity. In order to maintain a clear view, the causes and intended movements were divided into categories (see *Table 1.2*). These categories were partly based on the crash types that are quoted in the literature on over-represented crash types among older drivers. Note, however, that the registration of crashes is done by the police. The available classification of crash causes is therefore predominantly based on legal grounds. Behaviours that are included in the category 'Behavioural mistakes' include 'speeding', 'overtaking', 'wrongly joining/exiting', 'tailgating', and 'wrong position on carriageway'.

In comparison with the general ratios of legally responsible and innocent drivers in the various age groups (i.e. those mentioned in the category 'All crashes'), the following crash types appear to be over-represented in the crashes that older drivers are considered legally responsible for:

- crashes at intersections,
- not yielding,
- fatigue/illness,
- turning left,
- turning round,
- joining/exiting through-traffic.

		Age group							
		18-24	25-29	30-39	40-49	50-59	60-64	65-74	75+
All crashes		1.37	0.98	0.84	0.79	0.85	1.00	1.48	2.99
Crashes at intersections		1.23	0.90	0.79	0.83	0.94	1.23	1.65	3.41
Cause	Ignoring traffic signs or lights	1.30	0.97	0.76	0.85	1.06	1.08	1.16	2.35
	Behavioural mistake	1.67	1.08	0.90	0.71	0.73	0.70	1.19	2.23
	Not yielding	1.01	0.81	0.77	0.90	1.05	1.47	2.00	4.24
	Alcohol/medication	1.24	1.11	1.31	0.76	1.00	0.50	0.67	1.00
	Fatigue/illness	1.73	1.02	0.58	0.63	0.78	1.79	2.65	5.67
	External causes (e.g., animals, flat tyre, weather conditions)	2.44	1.44	0.89	0.65	0.62	0.56	0.63	1.56
	No cause (not responsible)	1.29	1.40	0.94	0.87	0.69	0.91	0.89	1.09
Intended movement	Driving/stopping	1.47	1.05	0.87	0.76	0.78	0.92	1.35	2.58
	Turning right	1.09	0.83	0.86	0.96	1.33	1.41	1.24	1.33
	Turning left	1.01	0.75	0.73	0.91	1.20	1.56	2.25	7.07
	Changing lanes	1.76	1.09	0.91	0.62	0.75	0.70	0.85	1.05
	Turn (round)	1.03	0.75	0.77	0.91	1.15	1.54	2.26	8.25
	Join/exit through-traffic	1.47	1.00	0.70	0.92	0.70	1.50	2.71	3.50
	Join from/exit to a stop	1.14	1.03	0.73	1.04	0.68	1.00	2.33	2.50

Table 1.2. Ratios between the number of 'guilty' and 'innocent' drivers in various crash types between two cars, by age group (1994-1998). Source: Ministry of Transport, Public Works and Water Management.

In the literature, these crash types and manoeuvres are also mentioned frequently as being over-represented in crashes of older drivers (e.g., Aizenberg & McKenzie, 1997; Hakamies-Blomqvist, 1993, 1994a; McGwin & Brown, 1999; Zhang et al., 1998). Crashes for which older drivers are (relatively) less often responsible are crashes as a result of a behavioural mistake, alcohol, or external causes, and while changing lanes, or turning right. Mitchell and Suen (1997) and Garvey, Gates, and Pietrucha (1997) do mention changing lanes as a crash cause that is over-represented in crashes of older drivers. However, the crashes they referred to occurred while changing lanes to join or exit through-traffic on a motorway. These intended movements formed a separate category in *Table 1.2*, and were indeed noted as being over-represented in crashes for which older drivers were responsible.

Another crash cause that is mentioned in the literature, ignoring traffic signs and lights (e.g., Maycock, 1997; McGwin & Brown, 1999), is according to data from the Netherlands not a crash cause that is over-represented in crashes of older drivers. This may have to do with different regulations for the placement of signs and traffic lights.

1.4. Threat to other road users or not

Having established that older drivers are relatively often legally responsible for the crashes they are involved in (see *Section 1.2.3*), the question presents itself of whether older drivers are a threat to others. To answer this question, a comparison was made of the number of older drivers that were the crash opponent of a road user that got injured and the number of older road users that got injured as a result of a collision with a(nother) car. It turned out that older drivers are about twice as often injured as they cause injuries to others. For younger people, the ratio is closer to one as far as it concerns injuries to other drivers (see *Figure 1.6*; ratios below one in this figure indicate that people of that age group are more often being hurt than they themselves hurt other road users). As regards injuries to other types of road users (including car passengers), the ratios for younger drivers indicate that they more often cause injuries than that they get injured themselves.

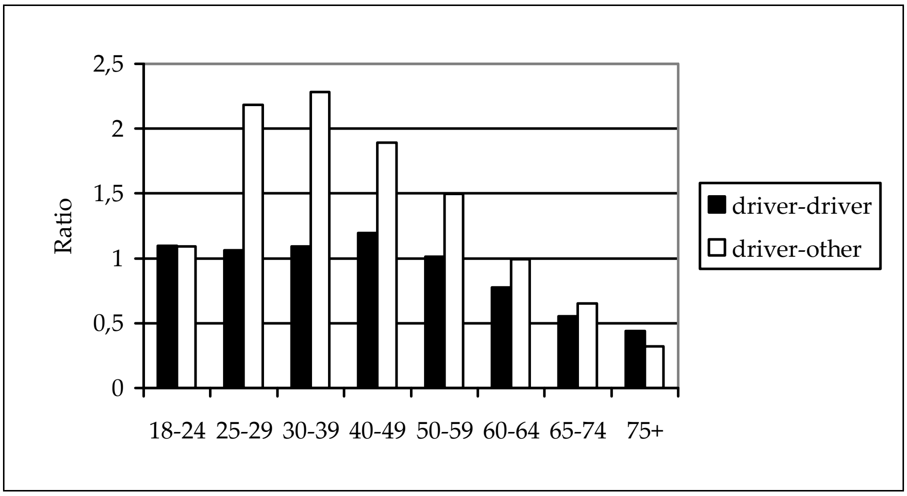

Figure 1.6. Ratio of being the driver versus being injured for crashes between cars and collisions between cars and other road users respectively. Number of drivers involved in crashes divided by the number of hospitalised or killed drivers or other road users in that same age group (1996-1998). Source: Ministry of Transport, Public Works and Water Management.

1.5. Differences between men and women

Apart from the differences between age groups, everything discussed up until now applied to all drivers, men and women. However, crash and injury rates may differ between male and female drivers. After all, it is known that the driving experience of older men and women is very different (see also *Chapter 3*), and it is assumed that more driving experience leads to lower crash rates (see, for example, Massie, Green & Campbell, 1997). By contrast, young male drivers have higher crash rates than young female drivers. Among other things, this has to do with their high risk acceptation (Moe & Jensen, 1993), overestimation of their driving skills (Moe, 1987) in combination with underestimation of the complexity of traffic situations (Brown & Copeman, 1975; Matthews & Moran, 1986), larger exposure to extra dangerous circumstances such as weekend nights (Forsyth, 1992; Van Kampen, 1989; Weissbrodt, 1989), and life style: trying out new things, wanting to impress and outdo each other, and conforming to the group norm (Twisk & Van der Vorst, 1994).

With regard to the older age groups, it seems that roles have been reversed. Various studies indicate a larger crash rate for older women, and a greater crash involvement of women in crash types that are characteristic for older drivers, such as crashes at intersections and crashes while turning left (Guerrier, Mannivannan & Nair, 1999; Hakamies-Blomqvist, 1994b; Kim, Li, Richardson & Nitz 1998; Massie, Green & Campbell, 1997). In this respect, Massie, Green and Campbell (1997) point at differences in injury severity. Women are more often involved in MDO (material damage only) and injury crashes, whereas men are more often involved in fatal crashes. Massie et al. moreover found that the greater crash involvement of women entirely disappeared when the crash rate (the number of crashes per motor vehicle kilometre) was corrected for the average annual kilometres travelled by the driver group concerned (see also *Section 1.2.4*). This confirms the assumed relation between driving experience and crash rate. If women had as much driving experience as men, the model of Massie et al. predicts that women would have lower crash rates than men.

Differences between male and female injury rates in the Netherlands are shown in *Figures 1.7* and *1.8*, for all injury severities and fatalities respectively.

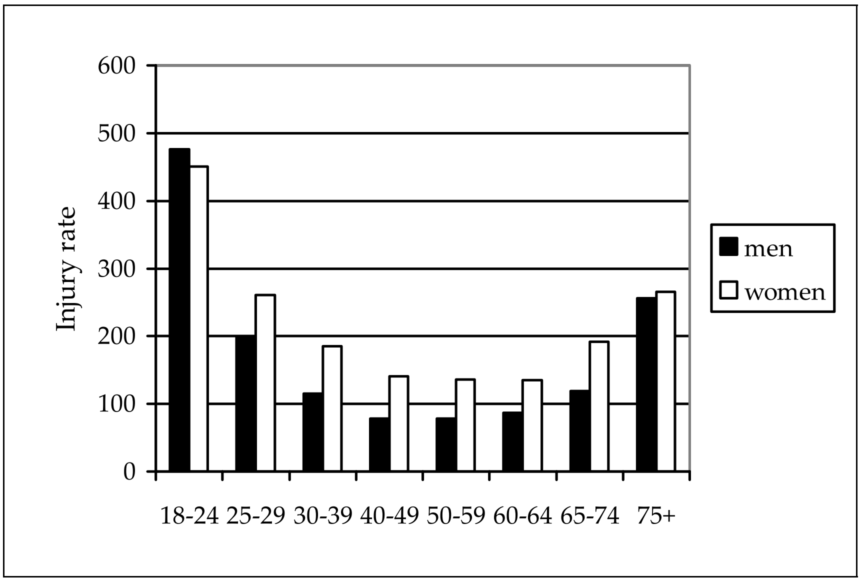

Figure 1.7. Comparison of the injury rates of male and female drivers by age group; number of injured or killed drivers per billion kilometres travelled by the age group concerned (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

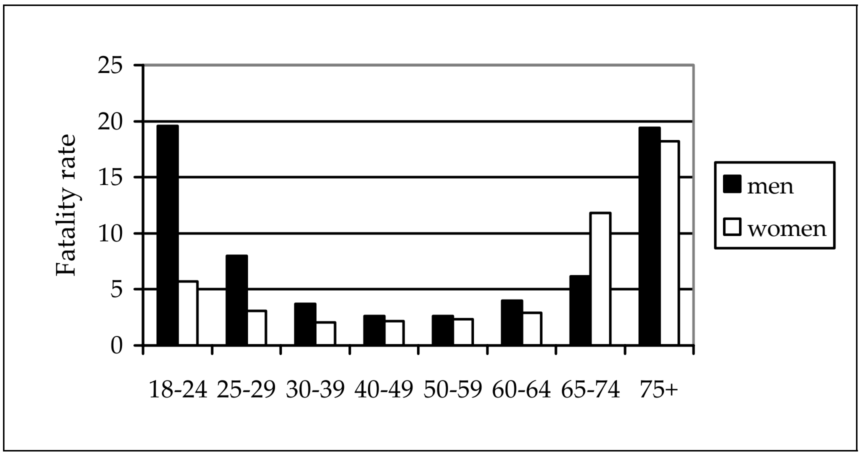

Figure 1.8. Comparison of the fatality rates of male and female drivers by age group; number of killed drivers per billion kilometres travelled by the age group concerned (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

The risk of being injured as a result of a road crash is, except for the youngest age group, larger for women than for men (*Figure 1.7*). The risk of being killed as a result of a road crash is larger for men (*Figure 1.8*). The only exception is the group of 65-74 year old women. The cause of this exception lies possibly in a different start of the ageing process for men and women, as a result of which women are more vulnerable at an earlier age. One can think, for example, of the process of osteoporosis that starts earlier in women than in men, and of which it is known that it leads to more severe injuries with the same collision force (Mackay, 1988).

A comparison of the injury and fatality rates for men and women (*Figures 1.7* and *1.8*) with the general rates as shown in *Figures 1.1* and *1.2*, shows that especially younger men are responsible for the high fatality rate of young drivers. The fatality rate of young men equals that of men and women of 75 years and older.

Figure 1.9 shows that the oldest men and women are much less involved in fatal crashes than young male drivers. This illustrates what was already mentioned in *Section 1.2.1*, namely that the high fatality rate of older drivers is largely the result of their greater vulnerability, whereas the high fatality rate of young men is mainly the result of the fact that they are more often involved in fatal crashes (see also Brouwer & Ponds, 1994; Evans, 1988, 1999).

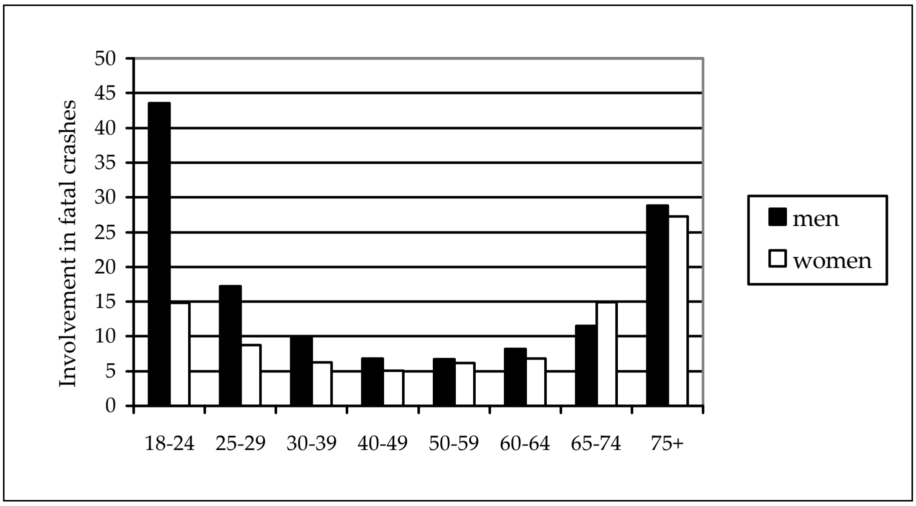

Figure 1.9. Comparison of the involvement of male and female drivers in fatal crashes; number of drivers involved in fatal crashes per billion driver kilometres travelled by the age group concerned (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

The role that vulnerability plays in the crash rates of older men and women can be derived from *Figure 1.10*.

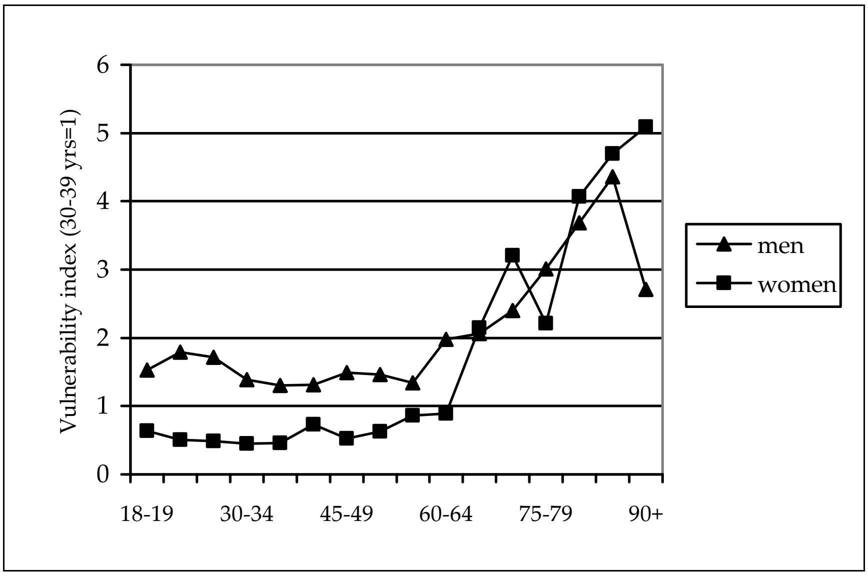

Figure 1.10. Vulnerability of male and female drivers; number of fatalities per 100 injured in the age group concerned. (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

Men appear to be more vulnerable until they have reached the age of 65. From that age on the vulnerability of men and women is more or less the same. However, using lethality data to compare the vulnerability of men and women again introduces the problem that was mentioned in *Section 1.2.2*. In general, men are more often involved in single vehicle crashes (see *Table 1.3*). The severity of these crashes is, in general, greater than average. As a result, lethality measures more than vulnerability; it also measures the severity of the crash types that are most common among the age group considered.

Crash type	Total		18-24		40-49		65+	
	Male	Female	Male	Female	Male	Female	Male	Female
Pedestrian	6.2%	6.1%	6.2%	5.2%	6.3%	6.9%	4.3%	4.8%
Single vehicle	19.8%	14.0%	31.8%	20.9%	15.0%	10.6%	12.7%	14.4%
Head-on collision	10.9%	10.6%	10.1%	10.6%	11.5%	11.8%	10.0%	10.7%
Side collision	47.4%	52.8%	40.5%	46.6%	48.8%	54.7%	57.9%	57.2%
Rear end collision	14.4%	15.3%	10.1%	15.6%	17.3%	15.3%	13.3%	11.5%
Other	1.3%	1.1%	1.4%	1.1%	1.2%	0.7%	1.8%	1.4%

Table 1.3. Drivers involved in severe crashes (fatalities and in-patients) by age group and sex, by crash type (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

Evans (1988; 1999) compared the vulnerability of men and women using the 'double pair comparison' method. This method has the advantage that differences in vulnerability are cleared of general differences between crashes of men and women, such as crash type and collision impact. These studies, in which FARS data were used (i.e., only fatal crashes), showed that women up to the age of 55 have a greater risk of dying than men. However, given the same crash type, there are no indications that older men and women (i.e., aged 56 and above) differ in vulnerability.

1.6. Comparison with other modes of transport

One of the reasons for carrying out research into the crash involvement of older drivers is to be able to take measures that can ensure that they can remain mobile for as long as possible using a safe mode of transport. Therefore, analyses of crash and injury rates are not complete without having looked at the injury rates for alternative modes of transport. These rates are needed to estimate what the consequences would be of, for example, trading in the car for a bicycle. *Table 1.4* shows the injury rates of older road users and a reference group for each mode of transport.

	Age group			
	40-49	60-64	65-74	75+
Car driver	24	33	51	116
Car passenger	23	33	46	69
Motorcycle	576	390	500	316
(Light) moped	1150	1701	2120	3673
Bicycle	114	207	354	832
Pedestrian	100	124	248	644
Public transport	0.76	0.87	1.23	2.23

Table 1.4. Injury rates per mode of transport for the older age groups and a 'reference group' of 40-49 year olds: number of fatalities and in-patients per billion kilometres travelled (1996-1998). Source: Ministry of Transport, Public Works and Water Management / Statistics Netherlands.

Although injury rates increase with age, car drivers appear to have the lowest rates of all independent transport modes. The rates for older cyclists and older pedestrians are 7 and 5.5 times higher. Therefore, it is justified to stay behind the wheel for as long as possible. Anyway, the relatively high fatality rate of older drivers should not be used to encourage the total group of older people to stop driving. A shift from the private car to the bicycle will unquestionably lead to an increase in the general injury rate for older people. Moreover, as older people have more difficulties walking (to the bus stop) and cycling, driving is often the only option for independent mobility. Several studies have found that over 90% of older drivers indicate that giving up driving would restrict their independence and mobility (Jansen et al., 2001; Rabbitt, Carmichael, Jones & Holland, 1996).

Driving cessation is not only likely to reduce mobility but also quality of life (Hakamies-Blomqvist, Sirén & Davidse, 2004; Harrison & Ragland, 2003). Driving cessation has been found to decrease the amount of out-of-home activities (Marottoli et al., 2000) and to be related to increased depression (Fonda, Wallace & Herzog, 2001; Marottoli et al., 1997; Ragland, Satariano & MacLeod, 2005). It has also been argued that giving up driving has negative impacts on older person's identity, feeling of independence, and dignity (Bonnel, 1999; Burkhardt, Berger & McGavock, 1996; Carp, 1988; Eisenhandler, 1990; Peel, Westermoreland & Steinberg, 2002). These negative feelings are related to having to give up something that had been a large part of their adult life, and was closely identified with their perceived roles in family and society.

1.7. Conclusions regarding current crash and injury rates

The analyses in this chapter showed that the injury rates and fatality rates of older drivers increase from the 65th and 60th year respectively. However, the most important increase in rates occurs only after the 75th year. The fatality rate of drivers aged 75 and above is the largest of all drivers. Their injury rate is the second highest, after those aged 18-24.

A comparison between male and female drivers showed that their oldest age groups have equally high fatality rates. Their rates are as high as the fatality rate for young male drivers, who have a much higher fatality rate than young female drivers. The difference between young male drivers and drivers aged 75 and above is that the high fatality rate of young men is mainly the result of a greater involvement in fatal crashes, whereas older drivers are more vulnerable. Therefore, to lower the fatality rate of older drivers, secondary safety measures are very important. However, primary safety measures are also needed, as older drivers appear to be relatively often legally responsible for the crashes they are involved in.

By examining the causes of these crashes, and by removing these causes by taking specific measures, the crash involvement of older drivers may be reduced. By doing so, the fatality rate of older drivers will also come closer to that of the 'average' driver. Crash statistics show that older drivers are more often responsible for crashes at intersections. The causes of these crashes are relatively often not yielding, fatigue or illness, and unsafe joining or exiting in through-traffic. To be able to prevent these crashes from happening, it is important to know which factors lead to the involvement of older drivers in these types of crashes. Possible sources of causal factors are the general characteristics of older drivers, the characteristics of intersections and the compatibility of these two sets of characteristics. These three sources form the main topics of the rest of this thesis. The next chapter deals with the first causal factor: the general characteristics of the older driver.

2. Physical and mental characteristics of the older driver[3]

This chapter discusses the age-related functional limitations, diseases and disorders that may affect the driving performance of older people. Only in the case of severe sensory, perceptual, and cognitive limitations does the relation between functional limitations and crash involvement become visible. Examples are eye disorders such as cataract, macular degeneration and glaucoma, and diseases like dementia, stroke, and diabetes. Less severe functional limitations can usually be compensated for by older drivers.

2.1. Introduction

Characteristics of older people that may be related to the difficulties older drivers encounter in traffic can be divided into three categories: age-related functional limitations, age-related disorders, and medication. This chapter briefly discusses each of these categories and describes their relevance to the driving task. No attempt is made to be complete. The aim is to present a general understanding rather than to give a comprehensive overview of all age-related functional limitations and disorders.

While reading this chapter, it should be kept in mind that individual differences in health, functions and activities are large in the older age group, probably even larger than in younger adults (Hardy, Satz, d'Elia & Uchiyama, 2007; Heron & Chown, 1967). This implies that there are large differences in the chronological age at which certain functional limitations manifest themselves, as well as in the pace at which the decline of functions continues. In addition, it should be kept in mind that the influence that functional limitations have on the mobility and safety of the driver is dependent on whether and how they are compensated. Are functional limitations taken into account in selecting and regulating activities, for example, by using assistive devices or by using compensation strategies such as avoiding peak hours? The latter topics will be discussed in the last section of this chapter.

[3] This chapter was based on chapter 4 of SWOV report D-2000-5 (Davidse, 2000) and on a text about Older drivers by Davidse which was written for the European Road Safety Observatory (ERSO, 2006).

2.2. Age-related functional limitations

The functional limitations which accompany ageing that are most relevant for driving are those that relate to vision and cognition. There are few indications that a decline in visual and cognitive functions as part of normal ageing has negative road safety consequences. Only in the case of moderate and severe visual and cognitive limitations resulting from age-related disorders does the relation between functional limitations and crash involvement become visible (Brouwer & Davidse, 2002; Brouwer, Rothengatter & Van Wolffelaar, 1988; Van Wolffelaar, Rothengatter & Brouwer, 1989). Examples are eye disorders such as cataract, macular degeneration and glaucoma, and diseases like dementia, stroke, and diabetes (see *Section 2.3*). The older the sample, of course, the more difficult it is to disentangle effects of ageing and pathology. With few exceptions, the probability of degenerative processes exponentially increases with age. Therefore, beyond a certain age, pathology is statistically normal. However, as Brouwer and Ponds (1994) conclude, "Whatever the nature of the impairments is, their final common effects are often quite similar: an increase in the time needed to prepare and execute a driving manoeuvre and a decreased ability to perform different actions in parallel" (p. 153).

2.2.1. Vision

Vision is the most important sense for the driving task. After all, most of the sensory input necessary to drive a car is visual. Visual functions generally taken into account in driver licensing are binocular visual acuity and visual field. Both functions decrease with ageing but the decrease is relatively small and scores generally remain well above the minimum licence requirements until high age unless there is ocular or neurological pathology. Declines in visual acuity, for example, typically occur in people with macular degeneration, whereas declines in visual field occur in people with glaucoma (increased eye pressure), diabetes and after stroke or other cerebral diseases (see *Section 2.3*). These diseases are found more often in the group of older drivers (Klein, 1991).

Functions that are more sensitive to ageing (i.e., deterioration begins earlier and accelerates faster with increasing age) are dynamic visual acuity, detection of movement, night-time visual acuity, sensitivity to glare, and contrast sensitivity (for a detailed description see Shinar & Schieber, 1991). Furthermore, higher order visual functions such as perceptual speed, field dependence, functional field of view and visual working memory are quite sensitive to ageing. Tests in these domains have been repeatedly found to correlate with poor on-road driving performance and crash involvement (see e.g., Ball et al., 2006; Hoffman, McDowd, Atchley & Dubinsky, 2005; Wood, 2002).

Dynamic visual acuity and detection of movement

Dynamic visual acuity is the ability to resolve details of a moving target. Its deterioration is probably attributable to the required oculomotor control (Shinar & Schieber, 1991). The oculomotor system is also involved in detection of movement. However, the decline in detection of movement with increasing age appears to be mainly the result of age-related changes to neural mechanisms. Obviously, the ability to detect movement is very important for safe driving, not only for being able to detect vehicles driving on an intersecting road and to estimate their speed, but also for being able to detect changes in the speed of vehicles in front, i.e., stopping, slowing down, speeding up, and reversing (Holland, 2001; Shinar & Schieber, 1991).

Night-time visual acuity and sensitivity to glare

Impaired night-time visual acuity is the result of two age-related changes that reduce the amount of light reaching the retina: reduced pupil size and yellowing of the lens (Olson, 1993). A consequence of reduced retinal illumination is that sources must be of higher intensity to be seen at night (e.g., Olson, 1993). Sensitivity to glare, which increases between the ages of 40 and 70, leads to a slower recovery from headlights and other reflecting sources (Fozard et al. (1977) cited in Aizenberg & McKenzie, 1997).

Contrast sensitivity

As far as contrast sensitivity is concerned, older adults have more difficulties detecting objects that are not outlined clearly or that do not stand out from their background. Its deterioration is probably attributable to changes in the eye itself as well as neural factors. Contrast sensitivity is – even more than visual acuity – necessary for the perception of (the information on) traffic signs. Besides this, contrast sensitivity is also believed to play a role in distance perception and the estimation of the speed of moving objects (Holland, 2001; Shinar & Schieber, 1991).

2.2.2. Cognitive functions

Age-related declines in sensory functions such as vision and hearing have an impact on the input the driver receives from other road users and from the road environment (e.g., traffic signs and signals, road markings). To select the appropriate information, interpret it and make decisions which must then be translated into an appropriate driving action, and to compensate for sensory limitations, various perceptual and cognitive functions come into play. Some of these functions show effects of ageing. Cognitive functions for which appreciable effects of ageing are described, are fluid intelligence, speed of processing, working memory, and executive functions like inhibition, flexibility and selective and divided attention (Brouwer & Ponds, 1994; Salthouse, 1982).

The speed at which information is processed, is important to making safe decisions as a driver. Fundamental to this aspect of the driving task is the time taken by a driver to respond to the demand placed upon him or her by the traffic environment (often referred to as 'perception-reaction' time). Research studies have generally found that reaction times to simple stimuli do not deteriorate dramatically with age (Olson & Sivak, 1986). Reaction times of older drivers only slow down when drivers have to make decisions in complex situations (Quimby & Watts, 1981).

2.2.3. Motor functions

Motor functions that decline as people age are joint flexibility, muscular strength, and manual dexterity. These age-related changes can influence the ability to get in and out of a car, operate the vehicle, and can influence injury and recovery (Sivak et al., 1995). An example of the influence of reduced joint flexibility is that reduced neck rotation can hinder the driver while checking for approaching traffic at intersections or before merging. This is especially detrimental to older drivers, since they rely on neck rotation to compensate for their restricted visual field. Decline in joint flexibility is not the same for all body parts. In a study by Kuhlman (1993), older adults had approximately 12% less cervical flexion, 32% less neck extension, 22% less lateral flexion and 25% less rotation than the younger control group (Sivak et al., 1995). Joint flexibility can be greatly influenced by degenerative diseases such as arthritis, which is experienced to some degree by approximately half the population over 75 (Adams & Collins, 1987; cited in Sivak et al. 1995).

Muscle strength declines from the age of 50. The strength of muscles can play a role in limiting injuries from small impact collisions, such as whiplash. Other age-related physical factors that can influence injury severity are brittleness of the bones and reduced elasticity of soft tissues (Sivak et al., 1995).

2.3. Age-related disorders

A number of age-related diseases and disorders are found to be related to crash proneness. These are: eye disorders, dementia, Parkinson's disease, stroke, cardiovascular diseases and diabetes (Becker, 2000; Brouwer & Davidse, 2002; Marottoli et al., 1994; Vaa, 2003). These diseases and disorders can occur at every age, but they are more common among older adults.

2.3.1. Eye disorders

The eye disorders cataract, macular degeneration, glaucoma and diabetic retinopathy are the leading causes of a significant decline in visual acuity and visual field while ageing (Klein, 1991). *Cataract* is characterized by a clouding of the eye lens and affects glare sensitivity, colour perception and night vision. Fortunately, it can be treated by replacing the lens with an artificial one. *Age-related macular degeneration* is a disorder of the central part of the retina and affects visual acuity and colour perception. This disorder, therefore, can lead to the inability to read road signs or to have a good view of distant road and traffic situations. *Glaucoma* affects the peripheral part of the retina as a result of damages caused by high intraocular pressure. This condition is painless and the patient is often unaware of the deficit in visual field, a deficit which interfere with the perception of cars or pedestrians approaching from the side (Klein, 1991). Persons with diabetes, a disease that affects between 10% and 20% of the older adults (Harris, Hadden, Knowler & Bennett, cited in Klein, 1991), are at higher risk of developing cataract, glaucoma and abnormalities that affect the retinal blood vessels (*diabetic retinopathy*). The latter often result in deficits in the peripheral visual field.

2.3.2. Dementia

Dementia is characterized by severe limitations in multiple cognitive functions (as a result of (degenerative) brain pathology. As a rule of thumb, the prevalence of dementia doubles every five year starting from 1.0% for those aged 65 to 32% for those aged 90-94 (Hofman et al., 1991). The most common dementing illness is Alzheimer's disease, accounting for approximately half of all dementia cases. Alzheimer's disease is a steadily progressing degenerative disorder and is characterized by severe memory limitations and at least one other severe cognitive limitation such as apraxia, agnosia, aphasia or a dysexecutive syndrome.

Dementia often includes an impaired awareness of one's own illness, as a result of which patients are often not capable of judging their own limitations and of adapting their behaviour accordingly (Kaszniak, Keyl & Albert, 1991). Thus, drivers with dementia are less likely to limit their exposure to high risk situations than drivers who have diminished visual and physical abilities but intact cognitive abilities (Staplin, Lococo, Stewart, & Decina, 1999). The mere diagnosis of dementia is not always enough to advise older adults to stop driving. According to an international consensus group on dementia and driving, drivers should be advised to stop driving when they are diagnosed with moderate or severe dementia. When continued driving is considered permissible, it is of great importance to ensure regular follow-up examinations (Lundberg, Johansson and Consensus Group, 1997). With regard to patients with mild dementia, Veen and Bruyns (1999) – in their article in the Dutch journal *Tijdschrift voor Gerontologie en Geriatrie* – advise to request a driving test to determine the patient's practical fitness to drive.

Vaa (2003) has calculated the relative risk of being involved in a crash due to dementia by means of a meta-analysis of 18 relevant studies. He found that drivers with dementia have a 45% higher crash rate than drivers without any medical condition.

2.3.3. Parkinson's disease

Parkinson's disease is a progressive, age-associated neurological syndrome that is primarily due to the insufficient formation and action of dopamine. Patients suffer from resting tremor, stiffness, the inability to initiate movements (akinesia), and impaired postural reflexes. In addition, Parkinson's disease is associated with depression and dementia at rates much higher than age-related norms. Estimates of the prevalence of dementia in patients with Parkinson's disease range from 30 to 80% (Kaszniak, 1986, cited in Holland, Handley & Feetam, 2003), whereas estimates of the frequency of dementia in the total group of people over 65 years of age vary from 5 to 15% (Hofman et al., 1991; Kaszniak, Keyl & Albert, 1991).

Both the movement and cognitive effects of Parkinson's disease have potentially important implications for the patient as a driver. In particular, laboratory and simulator studies have found impaired steering accuracy, reaction times and interpretation of traffic signals in patients who were in the early stages of Parkinson's disease (Madeley, Hulley, Wildgust et al., 1990, cited in Poser, 1993). A meta-analysis of 11 studies that examined the relative risk of being involved in a crash due to Parkinson's disease or another disease that affects the central nervous system (such as stroke) showed that drivers that have one of these diseases have a 35% higher crash rate than drivers without any medical condition (Vaa, 2003).

One particular area of concern relating to driving and Parkinson's disease is the occurrence of excessive sleepiness that is common in this disease. A study by Frucht (cited in Holland, Handley & Feetam, 2003) showed that excessive sleepiness was prevalent in 51% of the study participants. This sleepiness correlated with severity and duration of Parkinson's disease and with risk of falling asleep at the wheel. The use of anti-Parkinson (dopaminergic) drugs also seems to contribute to the excessive sleepiness (Fabbrini et al., 2002; cited in Holland, Handley & Feetam, 2003).

2.3.4. Stroke

A stroke, also known as cerebrovascular accident (CVA), is a neurological injury whereby the blood supply to a part of the brain is interrupted, either by a clot in the artery or by a burst of the artery. Strokes can occur at every age, but are more prevalent among older than among younger adults. The incidence of stroke is five times higher among people aged 75 and above than it is for people between 55 and 64 years of age (Kappelle & De Haan, 1998). Many stroke patients recover well enough to resume driving. Those who stop driving are generally older and/or have other sources of impairment or disability in addition to the effects of their stroke (Fisk, Owsley & Pulley, 1997).

Little research has been done into the effects of stroke on fitness to drive. In general, it is assumed that effects of a stroke on motor performance, such as paralysis, can be compensated for by vehicle adaptations and retraining. Other effects, such as apraxia (lack of ability to imagine, initiate or perform an intended action) and lateral neglect, have more severe consequences. In the case of lateral neglect, which means that the patient does not react to or look at things that are located on one side of the visual field (the side opposite to the affected hemisphere), people should be advised to stop driving (Brouwer & Davidse, 2002). A study in which driving of left and right-sided stroke victims and controls were compared, showed that the performance of those with right-sided brain-damage was consistently poorer than that of those with left-sided damage. The former more frequently failed the driving test, and particularly performed more poorly at intersections (Simms, 1992).

2.3.5. Cardiovascular diseases

Cardiovascular diseases include diseases such as angina pectoris (chest pain), cardiac arrhythmias, heart failure and hypertension (abnormally high blood pressure). Studies that have separated out these different conditions have indicated that only cardiac arrhythmias and angina pectoris increase crash risk (see e.g., Foley, Wallace & Eberhard, 1995; Gresset & Meyer, 1994). Meta-analyses of 14 and 3 studies that examined the relative risk of being involved in a crash due to arrhythmia and angina respectively showed that drivers that have the respective diseases have a 27% and 52% higher crash rate than drivers without any medical condition (Vaa, 2003).

2.3.6. Diabetes Mellitus

Diabetes is a disorder that is characterized by high blood sugar levels, especially after eating. The incidence of diabetes becomes much more common with increasing age, with 17-20% of 70 year olds having difficulty regulating glucose as compared with 1.5% of 20 year olds (Holland, Handley & Feetam, 2003). There are two types of diabetes: insulin dependent (type I) and non-insulin dependent (type II). The former are dependent on insulin injections, the latter can control blood sugar levels by diet, weight reduction, exercise and oral medication.

Estimates of the crash risk associated with diabetes used to be as high as twice the rate of average drivers. However, improved medications, better monitoring by diabetic patients of their own blood glucose levels, and improved understanding of diabetic control seem to have reduced the crash risk (Hansotia, 1993, cited in Holland, Handley & Feetam, 2003). An important drawback of tighter control of blood glucose levels is that hypoglycaemic episodes are now much more common. During these episodes with low blood sugar levels, cognitive functions are degraded. Even with only modest levels of hypoglycaemia at times when individuals may be totally unaware that they are hypoglycaemic (Waller, 1992). All in all, serious diabetes (treated with oral drugs or with insulin) is still one of the strongest predictors of crashes, showing a stronger relationship than other illnesses examined (Holland, Handley & Feetam, 2003). Persons with diabetes are also at higher risk of developing the eye disorders cataract, glaucoma and abnormalities that affect the retinal blood vessels (diabetic retinopathy), all affecting visual acuity and visual field (see *Section 2.3.1*).

2.3.7. Comorbidity

Many older adults suffer from more than one disease. In a study by Holte & Albrecht (2004) it was found that two out of three persons aged 60 years and above suffer from at least one illness. Nearly every second person suffers from more than one illness. Suffering from more than one disorder can reduce the driver's possibility to compensate for the effects of these disorders. In addition, suffering from more than one disease often means that multiple medication has to be prescribed (polypharmacy), which increases the likelihood of pharmacokinetic or pharmacological interactions (see *Section 2.4*).

2.4. Medication

Several studies have indicated that certain prescribed drugs increase the crash rate of drivers. These are, among others, benzodiazepines, tricyclic and 'second generation' antidepressants, painkillers (analgesics), and first generation antihistamines (Holland, Handley & Feetam, 2003). Older adults, however, are likely to exhibit altered sensitivity to medication. This altered sensitivity is most often in the direction of an increased effect, including side effects and adverse reactions, and the duration of action of a drug may be significantly prolonged due to a reduced clearance of the drug and its active metabolites (Holland, Handley & Feetam, 2003). Since many older adults suffer from more than one disease, they are also more likely to be prescribed multiple medication. The more different medicines that are being taken, the greater the likelihood of pharmacokinetic or pharmacological interactions. Medicines which are not prescribed but that can be obtained over-the-counter can add to this effect (Becker, 2000; Holland, Handley & Feetam, 2003).

In evaluating the possible impact of medication on driving, it should be taken into account that medication is prescribed for an illness, and that the illness may itself affect driving-related abilities. A particular medication could affect driving independently, it could worsen any deterioration in driving ability caused by the illness, but it could also act to *reduce* the risk to the patient caused by the illness. The vital point is not whether the specific drug has an effect on driving performance, but rather, whether the individual is capable of functioning safely having used it (Holland, Handley & Feetam, 2003).

2.5. Compensatory behaviour

The age-related functional limitations, disorders and medication described in the previous sections do not automatically lead to unsafe traffic behaviour. Other characteristics of older road users can prevent safety problems. They include the awareness of one's own limitations, driving experience, and compensatory behaviour such as driving when the roads are less busy or when it is daytime and dry. One can think of various reasons for older people having the possibility to compensate (Brouwer & Davidse, 2002; Brouwer, Rothengatter & Van Wolffelaar, 1988). In the first place, they often have more freedom in choosing when to travel. Various studies have shown that older adults more often choose to drive during daytime and dry weather (Aizenberg & McKenzie, 1997; Hakamies-Blomqvist, 1994c; McGwin & Brown, 1999; Smiley, 2004; Zhang et al., 1998). In the second place older people on average have a great deal of driving experience. The traffic insight they have acquired may give them the ability to anticipate on possible problematic situations. In the third place, the diminishing desire for excitement and sensation when getting older possibly plays a role. Older people, on average, less often drink-drive than younger adults and are generally more inclined to obey the traffic rules (Brouwer, Rothengatter & Van Wolffelaar, 1988; Hakamies-Blomqvist, 1994c).

When referring to the hierarchic structure of the driving task described by Michon (1971, 1985; see *Section 4.4.1*), possibilities for compensatory behaviour are offered especially on the higher task levels (Brouwer & Davidse, 2002). On these higher levels (strategic and tactic), there is hardly any pressure of time, which gives the driver enough time to make the right decisions. On the strategical level (i.e., when and where am I going to drive), the driver can decide to drive during daytime, thereby avoiding difficulties as a result of night-time visual acuity and sensitivity to glare. On the tactical level (i.e., how fast do I want to go?), the driver can decide to keep more distance to the vehicle in front in order to have more time to react. Another decision than can be made on the tactical level is to reduce speed well before approaching an (unfamiliar) intersection in order to have more time to perceive all aspects of the traffic situation, to interpret them and to decide on how to act. On the operational level (i.e., how and when to steer, which pedals to press), there is hardly any possibility to compensate. The driver has only tenths of seconds to decide on steering and braking. If he needs more time, he will have to take the proper decisions on the higher task levels, by keeping more distance to the vehicle in front (tactical level), or by travelling at less busy times of the day (strategical level).

There is, however, one important precondition for compensatory behaviour to be effective. The traffic environment has to enable the (older) driver to compensate (Brouwer, 1996, 2000). Buildings or curves close to an intersection, for example, take away the opportunity to take more time to perceive, interpret and operate. Similarly, drivers that tailgate the older driver will deprive him of the opportunity to take the time that he needs to drive safely.

Lastly, experience can only compensate for functional limitations to a certain degree. The possibility one has to compensate for one or more functional limitations is dependent on the extent to which functions concerned are affected, and on the quality of the functions or experiences that have to compensate for the deficit. For example, people can compensate for a restricted visual field by turning their head. However, if neck rotation is also restricted, compensation might not be good enough to fully compensate. With regard to the role that experience can play in compensating for functional limitations, Holland (2001, p. 38) argues that "experience contributes significantly to the ability to compensate for deficits at the manoeuvring [i.e., tactical] level, but only up to a certain point at which information processing related deficits begin to outweigh the experience advantage." She concluded this after having noted that declines in hearing, vision and reaction times start at the ages of 30 or 40 year, whereas people in their 40s and 50s still have the lowest crash rates. So it seems that their longer driving experience, greater caution and tolerance of other road users and lower competitiveness and lower aggression bring advantages that outweigh any slight decrement in abilities. However, by the late 60s and 70s, older drivers impairments seem to begin to outweigh any advantages they have accumulated with their years of experience and more cautious behaviour, and, combined with their increase in physical frailty, they are beginning to experience more risk on the roads (Holland, 2001).

3. Strategies to improve the older driver's safe mobility

Increases in the number of people aged 75 years and above, in the driving licence rates for older people, and in the mobility per older driver will increase the future number of fatalities among older drivers. The latter increase will, however, probably be toned down by reduced fatality rates due to future older drivers being more vital and experienced than those of today. Road safety measures can further reduce the fatality rate of older drivers in the future. In the following chapters of this thesis, the focus will be on two of those measures: adjustments to road design which reduce the complexity of traffic situations, and in-car driver assistance systems which compensate for the relative weaknesses of the older driver.

3.1. Introduction

The aim of this chapter is to look into the future and give a rough estimate of how the safety of older drivers will develop (*Section 3.2*). In addition, measures are described which may reduce future crash and injury rates for older drivers (*Section 3.3*). Out of the wide range of available measures, two types are selected for further research: adjustments to road design and in-car driver assistance systems. These measures will be studied in detail in the following chapters.

3.2. Factors which may influence future risks

The results of the analyses described in *Chapter 1* showed that the current fatality rate and fatal crash rate for drivers aged 75 and above is the largest of all drivers. Future crash and injury rates will not necessarily be the same. Various factors can lead to future increases or decreases of the presented rates. Examples are the age distribution of the population of the country in question, the number of people who own a driving licence, and their driving experience. If these factors change in the course of time, they will influence the future number of fatalities among older drivers. In *Section 3.2.1*, the developments in the past 20 years are used to predict future changes. Subsequently, in *Section 3.2.2*, an attempt is made to estimate the future share of older drivers in the total number of fatalities among drivers.

3.2.1. Past developments

Developments in the past twenty years in the mobility and safety of older drivers, coupled with the expected growth of the number of inhabitants aged 75 and above may provide some insight in future crash and injury rates. These developments are summarized in *Table 3.1* and described in the paragraphs below.

Index (1985=100)	People aged 75 and above	
	Male	Female
Inhabitants	149	144
Driving licences	270	510
Driver kilometres[1]	204	347
Seriously injured[1]	119	190
Injury rate[1]	58	55

[1] Because of large fluctuations, 3-year periods were used (1985-1987 vs 2004-2006).

Table 3.1. Developments in the past 20 years (1985 versus 2006).

Age distribution of the population

For a long time now, the group of those aged 65 and above has gradually grown. In the Netherlands, the size of this group increased from 1.7 million people in 1985 to 2.2 million in 2006. Prognoses of Statistics Netherlands show that this growth will continue for another 30 years. In 2040, 4.3 million people will be aged 65 or more (Statistics Netherlands, 2006). In comparison with the total size of the population, the share of those aged 65 and above will increase from 14.3% in 2006 to 25.0% in 2040. A substantial part of this group will be much older than 65. At this moment in time, approximately 1.1 million people are older than 74. Statistics Netherlands (2006) expects that this number will have doubled by 2040, resulting in 2.2 million people aged 75 and above. The percentage of people having difficulties in traffic due to functional limitations is clearly larger in this older group than it is in the group of people aged between 65 and 74.

Driving licences

The number of older adults that have a driving licence has increased substantially during the last two decennia. Within a period of twenty-one years, the number of driving licence holders among those aged 75 and above increased from 128,000 in 1985 to 420,000 in 2006. A comparison of the possession of driving licences among men and women teaches that the increase of the number of driving licences among older adults was clearly and mainly a case of the women catching up. For men aged 75 and above the number of driving licences increased by 'only' 270% (from 97,000 in 1985 to 262,000 in 2006), whereas for women aged 75 and above it increased by 510% (from 31,000 in 1985 to 158,000 in 2006). The group of older drivers has, thus, not only grown in numbers, but also changed in composition.

Mobility

The kilometres travelled by older drivers also increased substantially during the past twenty years. This growth has been the largest among those aged between 60 and 74 (from 4.7 billion driver kilometres in 1985 to 11.5 billion in 2006), followed by those aged 50-59 and those aged 75 and above. The development in the kilometres travelled by the 18-24 year olds deviated from that of the other age groups. The distances travelled by this age group strongly decreased, from 8.5 billion in 1985 to 4.9 billion in 2006. Again, trends between men and women differed. The largest increase in kilometres travelled is found among women aged 75 and above (from 0.1 billion driver kilometres in 1985 to 0.4 billion in 2006). By way of comparison, the increase among men of the same age group was from 0.7 billion driver kilometres in 1985 to 1.2 billion in 2006.

It may be expected that the future women of 75 years and above will drive an even larger number of kilometres. After all, those women that are now responsible for the strong increase in the number of driver kilometres in the younger age groups will eventually enter the age group of those aged 75 and above. It is not expected that they will give up the freedom given to them by their car.

The expectations expressed in this paragraph about the future developments in the kilometres travelled are based exclusively on the trends in the available data for the past twenty years. Any changes in the mobility patterns of older people as a result of, for example, an increase in e-commerce, have not been taken into account. Another factor that may influence the future number of fatalities among older drivers could be the transition of older drivers from a minority group with special needs and habits to one of the largest subgroups of drivers. This transition will probably affect the dynamics of the total traffic system, including the behaviour of other road users. The increasing probability of having to interact with an older driver may elicit profound changes in the behaviour of all drivers, as well as in patterns of interaction among the participants in the traffic system. As a result, the increasing participation of older drivers in traffic may lower the crash rates for older drivers (OECD, 2001).

3.2.2. Expectations about future crash and injury rates

A rough but nevertheless informative way of estimating future crash and injury rates is one in which the current share of older drivers is multiplied by the expected increase in its share in the population. Using this technique, Sivak et al. (1995) estimated that the share of older drivers (65 years and above) in the total number of U.S. drivers involved in fatal crashes in 2030 will be 19%, compared to 11% in 1990. For the Netherlands, the same calculation results in a share 14% of all drivers *involved in severe crashes* in 2030, compared to 9% in 1998 (see *Table 3.2*). If the same calculations are made for the *number of fatalities* among drivers, it turns out that in 2030 25% of all fatalities among drivers will be aged 65 or above, compared to 16% in 1998. These calculations assume that the shares of driving licence holders, kilometres travelled, crash rates, and fatality rates would remain the same between 1998 and 2030. However, the previous paragraphs taught that these assumptions are incorrect; the number of kilometres travelled by those aged 65 and above will increase faster than they will for younger people. As a result, the prognoses in *Table 3.2* may be used as a minimum for the expected shares of older drivers in the total number of drivers involved in severe crashes and in the total numbers of severely or fatally injured drivers.

Age	1996-1998			2010			2020			2030		
	Fatal	Severely injured	Involved in severe crash	Fatal	Severely injured	Involved in severe crash	Fatal	Severely injured	Involved in severe crash	Fatal	Severely injured	Involved in severe crash
20-24	18.7	18.7	15.7	18.1	18.1	15.2	18.1	18.1	15.2	16.7	16.7	14.0
25-29	17.9	17.6	16.5	13.3	13.1	12.3	14.0	13.8	12.9	13.6	13.4	12.6
30-39	20.0	23.6	24.5	16.2	19.1	19.8	14.7	17.3	18.0	15.3	18.1	18.8
40-49	13.5	14.3	15.9	14.2	14.9	16.7	11.6	12.2	13.6	10.7	11.3	12.6
50-59	9.8	10.4	11.2	11.1	11.7	12.7	11.6	12.3	13.3	9.7	10.3	11.1
60-64	3.9	3.7	3.5	5.5	5.3	5.0	5.4	5.2	4.9	5.7	5.5	5.2
65-74	8.6	6.6	5.6	9.2	7.1	6.0	12.0	9.2	7.9	12.8	9.8	8.4
75+	7.7	5.2	3.4	8.6	5.8	3.8	9.6	6.5	4.3	12.7	8.6	5.6
65+	16.3	11.8	9.0	17.8	12.9	9.9	21.6	15.7	12.1	25.5	18.4	14.0

Table 3.2. Prognosis of the shares of the various age groups in a) the total number of driver fatalities, b) the number of severely injured, and c) the total number of drivers involved in severe crashes, in 2010, 2020, and 2030.

3.2.3. Conclusions regarding future crash and injury rates

Increases in the number of people aged 75 years and above, in the driving licence rates for older people, and in the mobility per older driver will increase the future number of fatalities among older drivers. The latter increase will, however, probably be toned down by reduced fatality rates due to future older drivers being more vital and experienced than those of today. Road safety measures can further reduce the fatality rate of older drivers in the future.

3.3. Measures for a safer future: overview of remaining chapters

Future crash and injury rates, such as those estimated in *Section 3.2*, are not conclusive. They can still be influenced in various ways (see e.g., Langford & Oxley, 2006; Maycock, 1997; OECD, 2001). Measures that may lower future crash and injury rates for older drivers can be distinguished according to the way in which they influence these rates; either by reducing exposure to risk, by reducing crash involvement, or by reducing injury severity. Exposure to risk can be reduced by making sure that people do not drive in situations in which crash risks are elevated. Crash involvement can be reduced either by making the driving task easier or by improving the driver. Injury severity can be reduced by improved crashworthiness of vehicles and further development of safety devices. Having made a distinction between the various types of measures available does not imply that one type of measure has to be chosen. In fact the opposite is true; it is desirable to influence all components of crash and injury rates simultaneously.

The main focus of this thesis is on measures that reduce crash involvement by making the driving task easier. Two types of measures are studied in detail: adjusting road design to reduce the complexity of traffic situations (see *Section 3.3.1*), and in-car devices that assist the driver (see *Section 3.3.2*). The question of which assistive devices will be most effective in improving road safety is usually answered by looking at the available devices. In this thesis, however, the above question will be answered by looking at the demands. In order to identify the older driver's most important needs for support, a theoretical analysis will be conducted of the strengths and weaknesses of the older driver (*Chapter 4*). Having identified the most important needs for support, in the subsequent chapters the focus is on road design and in-car driver assistance systems as devices which may offer the desired types of support and improve safety by reducing workload and improving driving behaviour.

3.3.1. Adjusting road design to reduce the complexity of traffic situations

An infrastructure that takes into account the functional limitations that accompany ageing can contribute to a reduction of the crash involvement of older drivers. Taking into account the functional limitations means that the infrastructure provides the driver with enough time to observe, decide and act. Human factors research has provided general knowledge about design aspects that increase workload, and the principles of a sustainable safe traffic system have applied them to road design. However, more knowledge is needed to determine which aspects of the intersection design lead to an increased workload for older drivers, how this workload can be reduced to an acceptable level, and what this acceptable level is. One way of finding out which aspects of the intersection design lead to an increased workload, is by asking older drivers which design elements pose a problem to them. Benekohal, Resende, Shim, Michaels, and Weeks (1992), for example, asked older drivers which driving tasks they considered to become more difficult as they grow older. The tasks that were mentioned the most were (proportion of drivers responding in parentheses):

- reading street signs in towns (27%);
- driving across an intersection (21%);
- finding the beginning of a left-turn lane at an intersection (20%);
- making a left turn at an intersection (19%);
- following pavement markings(17%);
- responding to traffic signals (12%).

In addition, Benekohal et al. asked people to name the highway features that become more important as they age. These were:

- lighting at intersections (62%);
- pavement markings at intersections (57%);
- number of left-turn lanes at an intersection (55%);
- width of travel lanes (51%);
- concrete lane guides for turns at intersections (47%);
- size of traffic signals at intersections (42%).

Mesken (2002) posed similar questions to older drivers in the Netherlands. Manoeuvres which people had to perform in the proximity of intersections that were most often mentioned as being difficult were:

- making a left turn at an intersection without traffic lights;
- driving across an intersection without traffic lights;
- driving on a roundabout that has more than one lane.

The fact that some tasks are more difficult than others does not imply that the former more often result in a crash. Moreover, if younger drivers had answered the same questions, they may have come up with the exact same answers. Nevertheless, several answers correspond to the crash types that are over-represented among older drivers and the manoeuvres that preceded them (i.e., turning left, not yielding). In this thesis, leads for relevant road design elements will be traced by conducting a literature study on road design elements that appear to support the relative weaknesses of older road users as identified in *Chapter 4*, and by conducting an analysis of the differences between intersections at which many and those at which few crashes occurred involving older drivers (*Chapter 5*). Subsequently, several types of intersection design will be compared on their effects on driver workload and driver behaviour (*Chapter 6*).

3.3.2. In-car devices to assist the driver

Advanced Driver Assistance Systems (ADAS) can provide personal assistance in a traffic environment that cannot always take into account the opportunities and limitations of the older driver. Several studies have mentioned ADAS that may be able to provide tailored assistance for older drivers (see for example Bekiaris, 1999; Färber, 2000; Mitchell & Suen, 1997; Shaheen & Niemeier, 2001). Examples are collision avoidance systems, automated lane changing and merging systems, and blind spot and obstacle detection systems. The general opinion is that driver assistance systems have the potential to prolong the safe mobility of car drivers. However, attention must be paid to evaluation research that determines whether specific applications are indeed suitable for older drivers (Caird, Chugh, Wilcox & Dewar, 1998). Knowing which types of ADAS have the most potential to improve the safety of older drivers is not enough to actually improve their safety. Older drivers are more susceptible to the consequences of poorly defined ADAS than younger drivers (Stamatiadis 1994; cited in Regan et al., 2001). They generally need more time to carry out secondary tasks while driving (Green, 2001a). Therefore, the relative weaknesses of older drivers should also be taken into account while designing those types of ADAS that have the most potential to improve the safety of older drivers.

In *Chapter 7*, specific types of in-car driver assistance systems are described that appear to offer the desired types of support as identified in *Chapter 4*. In addition, it is discussed which conditions assistance systems should meet to actually improve the safety of older drivers. Topics included are user acceptance, design requirements for the human-machine interface, and prevention of negative side-effects. In *Chapter 8*, the results are described of a simulator study in which one specific driver assistance system was tested for its effects on driver workload and driver behaviour.

4. Theoretical framework to identify needs for support[4]

The aim of this chapter is to identify those driver tasks for which assistance is most desirable from a road safety point of view. It is assumed that the most promising assistive devices in this respect are those that support the relative weaknesses of the older driver. To identify the strengths and weaknesses of the older driver, a literature review was conducted. Various theoretical perspectives were examined, among which the human factors approach, cognitive psychology, and game theory. This resulted in a list of the relative weaknesses of the older driver and the difficulties that older drivers encounter in traffic as a result of these weaknesses. To be able to rate the relevance of the weaknesses to road safety, the weaknesses were then compared with crash data. Those weaknesses that have a substantial influence on road safety, as indicated by the percentage of crashes that could have been avoided if the weakness would not have existed, were considered to indicate a need for support.
It turned out that these weaknesses are: 1) reduced motion perception and contrast sensitivity, 2) restricted peripheral vision in combination with reduced neck flexibility, 3) reduced selective attention, and 4) reduced speed of processing information and decision making, reduced divided attention, and reduced performance under pressure of time. Based on the difficulties that older drivers encounter in traffic as a result of these weaknesses, a shortlist was composed of desired types of support. It is concluded that to improve the older driver's safe mobility, assistive devices should a) draw attention to approaching traffic, b) signal road users located in the driver's blind spot, c) assist the driver in directing his attention to relevant information, and/or d) provide prior knowledge on the next traffic situation.

4.1. Introduction

The aim of this chapter is to identify the driver tasks for which assistance is most desirable from a road safety point of view. It is assumed that the most promising assistive devices in this respect are those that support the relative weaknesses of the older driver. To identify the strengths and weaknesses of the older driver, a literature review is conducted. Various theoretical perspectives are examined, among which the human factors approach, cognitive psychology, and game theory (*Sections 4.2 to 4.5*). This results in a list of the relative weaknesses of the older driver and the difficulties that

[4] This chapter was based on chapters 2 and 3 of SWOV report R-2003-30 (Davidse, 2004a). Various parts of this chapter were published in IATSS Research, 30(1), 6-20 (Davidse, 2006), and presented at the first HUMANIST conference on driver needs (Davidse, 2004b), and at the International Conference on Transport and Traffic Psychology ICTTP in Nottingham (UK) (Davidse, 2004c).

older drivers encounter in traffic as a result of these weaknesses (*Section 4.6*). To be able to rate the relevance of the weaknesses to road safety, the weaknesses are then compared with crash data. Those weaknesses that have a substantial influence on road safety – as indicated by the percentage of crashes that could have been avoided if the weakness would not have existed – are considered to indicate a need for support. The result is a shortlist of desired types of support.

The theoretical framework that is used to identify the relative weaknesses of the older driver includes Fuller's task-capability interface model (*Section 4.2*), the human factors approach (*Section 4.3*), cognitive psychological models (*Section 4.4*), and game theory (*Section 4.5*). In the next sections, the main emphasis of each of these theories will be described, together with their "opinions" about the strengths and weaknesses of the older driver. While reading these sections, it should be kept in mind that these models and theories are used as a source of information as to what older people are relatively good and poor at (relatively poor can be interpreted as "worse than average", or "a higher chance of being one of the causes of crash occurrence") and not to test a hypothesis about some relationship. Therefore, the term 'framework' will be used instead of the terms 'model' and 'theory'. The reason for choosing these frameworks and not other ones, or not just one framework, is that the chosen frameworks are all considered to be relevant for describing traffic behaviour and, more importantly, because they are complementary. The latter will be shown in the next section, while describing Fuller's framework.

4.2. Fuller's task-capability interface model

4.2.1. A description of Fuller's conceptual framework

The task-capability interface model of Fuller is a framework that brings together the capabilities of the road user and the demands of the road environment (Fuller, 2000, 2001, 2005). The factors that determine the capabilities of the road user are depicted at the upper left of *Figure 4.1*, whereas the factors that determine the task demands of the road environment are depicted on the bottom right. The boxes that represent the driver component start off with the *constitutional features* of the individual, which include the mental and physical characteristics that can be affected by the process of ageing (e.g., reduced visual capabilities, increased perception-reaction time, reduced neck motion). Depending on the nature of the characteristic, these constitutional features can improve competence, but in case of mental or physical impairments they will generally deteriorate driving competence. Driving competence emerges from training, education and experience. Fuller (2000) refers to competence as the driver's attainment in the range of skills broadly described as roadcraft, a concept which includes control skills, ability to read the road (hazard detection and recognition), and anticipatory and defensive driving skills.

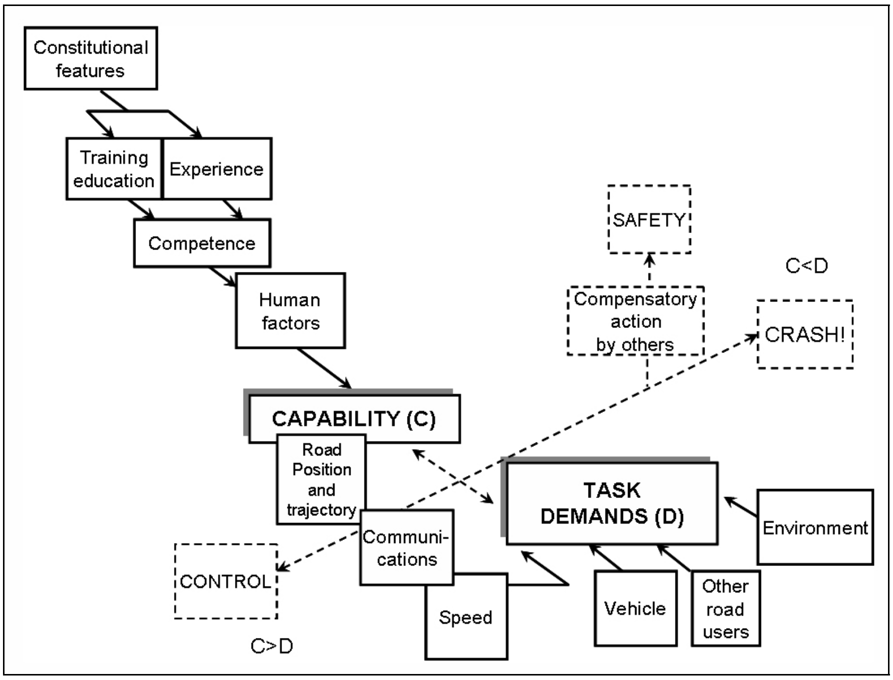

Figure 4.1. Fuller's task-capability interface model (Fuller, 2001).

A driver's actual (momentary) capability is not necessarily equal to his or her competence. Competence sets a limit on capability. However, capability may be further challenged by a range of variables which are collectively called human factors. These include fatigue, emotions, alcohol and other drugs, stress, distraction and level of motivation to perform the driving task optimally (Fuller, 2000). These human factors can be variable or temporary, whereas constitutional features are more or less fixed. The latter will only change as a result of disorders, diseases or age-related functional limitations.

The task demand of the traffic situation at hand is determined by the environment (i.e., road design, weather conditions, presence of buildings and/or trees), the vehicle one is driving in, driving speed, and the presence and behaviour of other road users. An example of an environmental element that can influence task demands are skew intersection angles; they reduce the time available for the driver to look, to interpret, to decide and to initiate the appropriate action. Other examples are weather conditions like fog and heavy rain that reduce visibility, and fellow road users that exert pressure to drive faster.

The most interesting feature of Fuller's framework is the concept of task difficulty. This concept is not explicitly shown in *Figure 4.1*, but is defined as the result of a confrontation of capabilities (C) and task demands (D). If the capabilities of the road user are higher than the task demands (C > D), the task will be easy and the driver will be in command of the situation. However, if capabilities are lower than task demands (C < D), the task will be too difficult and loss of control will occur (Fuller, 2000).

Another valuable feature of Fuller's framework is that it integrates the cognitive, motivational and social factors, the vehicle and environmental factors, and the human factors into one conceptual framework. As a result, Fuller's framework provides various leads for measures that may lower task difficulty. First of all, the driver has several opportunities to keep or regain control (i.e., to lower task difficulty): by lowering his driving speed, changing his road position or trajectory, by choosing an easier route or better driving conditions (e.g., clear weather, daytime), or by communicating with other drivers. The latter strategy will be discussed in more detail in *Section 4.5*, while describing the framework of game theory. Task difficulty can also be reduced by improving driving skills, for example through professional (re)training. Retraining can be aimed at improving bad driving habits, but it can also be aimed at improving useful field of view, or compensating for functional limitations such as visual deficits (see e.g., Ball & Rebok, 1994; Coeckelbergh, 2001). Another way of lowering task difficulty is by lowering task demands. The human-factors approach (see *Section 4.3*) is an excellent example of this strategy. The most obvious way of lowering task demands is by adjusting the road environment. However, vehicle adjustments such as the introduction of in-vehicle driver assistance systems can also lower task demands. Driver assistance systems can make the driving task easier by taking over parts of the driving task, such as navigation, lane keeping, or choosing the appropriate driving speed, or by improving capabilities in the sensory domain. Finally, if all this does not work in a particular situation and task demands are higher than the driver's momentary capabilities, other road users can intervene by taking compensatory actions, such as getting out of the way, thereby avoiding a collision.

4.2.2. Strengths and weaknesses of older drivers according to Fuller's framework

According to Fuller's task-capability interface model, the strength of humans is implied in their competences and momentary capabilities, and in the way they cope with discrepancies between their momentary capabilities and task demands. The better a driver copes with the latter discrepancies (by communicating with other road users, adjusting his position on the road and/or his speed), the more he is in control of his weaknesses. These weaknesses are the result of his mental and physical condition, and of variable human factors such as fatigue, emotions, alcohol and other drugs, stress, distraction and motivation.

Looking at the older driver, the abovementioned strengths and weaknesses of the average driver should be supplemented with the mental and physical condition that generally deteriorates as people age (*Chapter 2*). On the other hand, older drivers usually have a great deal of driving experience. This experience enables them to anticipate the situations they will encounter. Knowing beforehand what will happen will give them extra time to think and act, thereby (partly) compensating for possible mental and/or physical degeneration. It should be mentioned, however, that driving experience might get outdated. If so, it will not give accurate information on how to act in a certain situation anymore.

Another difference between the older adult and the average, somewhat younger driver, is that the older driver is better able to arm himself against the human factors that might influence his momentary capabilities. A first argument in favour of this is that older adults usually have a lower need for sensation seeking (Zuckerman, 1994). As a result, they will be less prone to manoeuvre themselves into risky (traffic) situations. Several studies have shown that older drivers indeed drive less often under the influence of alcohol than younger drivers do and that older drivers more often comply with traffic rules (Davidse, 2000; Hakamies-Blomqvist, 1994c). Furthermore, older adults might profit from the fact that they have more difficulties sharing their attention between various tasks. Having more difficulties sharing attention, they will be less inclined to combine driving with other not driving related activities such as worrying about problems at work, listening to or operating a radio or CD player, and having a (telephone) conversation (Brouwer, Rothengatter & Van Wolffelaar, 1992).

4.3.1. Most important lessons from Fuller's framework

One can conclude from Fuller's task-capability interface model that adjustments to the infrastructure and driver assistance systems can make the task of driving easier if they allow for the reduced capabilities of the older driver. If task demands are lowered, the older driver will still be in command of the situation, despite his reduced capabilities. These reduced momentary capabilities are primarily the result of his mental and physical condition.

The other theoretical perspectives that are included in the theoretical framework that is used in this thesis to identify the relative weaknesses of the older driver each focus on a different part of *Figure 4.1*. The human factors approach shows what the mental and physical capabilities of (older) people are, and how designers of roads, vehicles, and ADAS should take these (limited) capabilities into account. Cognitive psychology focuses on how people deal with differences between capabilities and task demands ("how can we make life easier?"). Game theory, the fourth theoretical perspective, focuses on how people anticipate the actions of others (communication).

4.3. Human factors approach

4.3.1. A brief description of the human factors approach

The human factors approach looks at the boundaries of human information acquisition and processing (see e.g., Sanders & McCormick, 1987; Wickens & Hollands, 2000). It focuses on human beings and argues that the machine (or task) should be designed to fit the human instead of the other way round. The most important cause of human errors according to this approach is that the demands of the system are not geared to the abilities of human beings. In order to prevent errors, designers of a task or system should allow for the physical and mental characteristics of people. In the tradition of the human factors approach, these characteristics are deduced from studies of the boundaries of sensory information acquisition, and the maximum amount of information which can be processed or remembered. A famous example is the finding that the maximum number of items that can be stored in short-term memory is equal to 7 ± 2, thus between 5 and 9 items (Miller, 1956; Sanders & McCormick, 1987: p. 62).

4.3.2. Strengths and weaknesses of older drivers according to the Human Factors approach

The most natural way of describing the strengths and weaknesses of older drivers from the perspective of the Human Factors approach is by looking at the various components of human information processing. As people age, information processing capacities generally decline. It should be kept in mind, however, that the age at which declines start as well as the rate at which these declines continue differ from person to person. *Chapter 2* gives a complete overview of the declines relevant for driving. A shorter version is included below.

The aspects of information processing that decline as people age are vision and perception, hearing, selective and divided attention, speed of information processing, muscle strength, and manual dexterity. Visual functions that decrease as people age are visual acuity, peripheral vision, visual acuity in poor light and darkness adaptation, contrast sensitivity, detection of movement, and colour vision (for a detailed description see Klein, 1991; Shinar, & Schieber, 1991; Sivak et al., 1995). It is evident that good vision is very important for safe driving. Motion perception, for example, is important for being able to detect vehicles driving on a crossing road and to estimate their speed, but it is also needed for being able to detect changes in the speed of vehicles straight ahead, that is, stopping, slowing down, speeding up, and reversing (Holland, 2001; Shinar & Schieber, 1991). For car drivers, hearing is perhaps not as critical a sense as vision, but it is potentially an important component of safe driving. As drivers age, they become less able to hear the higher frequencies which provide directional cues, and spatial sensitivity to sound is impaired as a result (Arnold, & Lang, 1995; Maycock, 1997). At the same time, it becomes more difficult for the older driver to filter out unwanted noises (Maycock, 1997).

The abovementioned age-related declines in sensory abilities have an impact on the input the driver receives from other road users and the infrastructure, but also from in-car driver assistance systems. Perceptual and cognitive processes are needed to select the appropriate information, interpret it, and make decisions which must then be translated into an appropriate driving action. Some of these processes decline as people grow older, including the ability to maintain vigilance, selective and divided attention, short-term memory, and information-processing speed (Brouwer, Waterink, Van

Wolffelaar, & Rothengatter, 1991; Maycock, 1997; Quilter, Giambra & Benson, 1983; Ranney & Pulling, 1990).

Physical abilities that decline as people age are reduced joint flexibility, reduced muscular strength, and reduced manual dexterity. These age-related changes can influence the ability to get in and out of a car, operate the vehicle, and can influence injury and recovery (Sivak et al., 1995). A reduction in manual dexterity can also interfere with programming in-car driver assistance systems that require coordinated finger movements (Eby, 1999).

4.3.3. Most important lessons from the Human Factors approach

The Human Factors approach tells us that several sensory, cognitive, and physical abilities decline as people age. However, the age at which declines start as well as the rate at which these declines continue differ from person to person. Adjustments to road design and in-car driver assistance systems can meet a need if they help the older driver to observe his environment. These assistive devices themselves should, however, also take the older driver's declined sensory abilities into account (e.g., contrasts used on roads and traffic signs, design of human-machine interfaces).

4.4. Cognitive psychological frameworks

4.4.1. A description of several cognitive psychological frameworks

Cognitive psychology goes one step further into the minds of people than the Human Factors approach. Whereas the latter approach focuses on the human being and his physical and mental characteristics, cognitive psychology stresses that people interpret the information they receive, and that their actions are almost always aimed at reaching explicit or implicit goals. As a result, the cognitive approach is especially suitable for analysing higher order functions such as problem solving, and decision making. Two theoretical frameworks that originate from cognitive psychology and are frequently mentioned in the literature on road user behaviour are Rasmussen's skill-rule-knowledge framework (1986), and the hierarchical structure of the driving task as described by Michon (1971). Both frameworks are described below. A third framework that is discussed below is that of situation awareness. The concept of situation awareness focuses on the mental picture that people have of the situation they find themselves in and how this picture can be distorted or improved by internal and external factors (see e.g., Endsley & Garland, 2000).

Rasmussen's skill-rule-knowledge framework

Rasmussen (1986) describes human behaviour by the extent to which the individual exerts conscious control on his actions. He distinguishes three types of behaviour which correspond to decreasing levels of familiarity with the environment or task (Reason, 1990). As familiarity decreases, the level of control shifts from skill-based to knowledge-based. The knowledge-based level comes into play in novel situations or when carrying out tasks for the very first time. The rules to play have to be determined, using conscious analytical processes and stored knowledge. This requires much mental effort. For those tasks for which rules are at hand but have not been used much, people function at the rule-based level. At this level, the available rules are consciously acted upon one by one. At the skill-based level, actions have become routines which consist of well-practised procedures. These procedures only have to be triggered and will then run automatically. Whereas task performance at the knowledge-based level is driven by goals, task performance at the skill-based level is triggered by sensory information.

Hierarchic structure of the driving task

Michon (1971; 1985) distinguishes three subtasks in driving: tasks on the strategic, tactic, and operational level. On the *strategical level*, the driver takes decisions about the route to take, the vehicle to use, and the time of departure. On the *tactical level*, the driver takes decisions about driving speed, whether it is safe to overtake or join traffic, and how to handle specific traffic situations such as crossing an intersection or passing road-works. On the *operational level*, the driver takes decisions that relate to vehicle control (i.e., steering, braking, and changing gears). These three levels are hierarchic in the sense that decisions that are made on the strategical level determine what has to be done on the tactical level, and that decisions that are made on the tactical level determine the activities on the operational level. However, the levels also differ in a temporal way. The activities that have to be carried out on the strategical level take the longest time (a few minutes or longer), but can usually be made without time pressure. Activities on the tactical level only last a few seconds, and slight time pressure is usually present on this level. Finally, activities on the operational level take less than a second and the task exerts a constant time pressure, as the driver has only limited time for avoiding or dealing with dangerous situations (Brouwer, 2002a; Hale, Stoop, & Hommels, 1990). Decisions on higher levels can either increase or decrease the probability of running into time pressure on the lower levels. Time pressure on the operational level can be reduced, for example, by keeping more distance to the vehicle in front (tactical level), or by travelling at less busy times of the day (strategical level).

In *Table 4.1*, the two hierarchical frameworks of Rasmussen and Michon are integrated into one matrix of tasks. The columns represent the different task levels of driving behaviour, and the rows represent the different levels of attentional control. The grey cells describe the tasks of the experienced driver, whereas the white cells describe those of the novice driver (Hale et al., 1990). Operational tasks are relatively soon operated at a skill-based level. Strategical tasks that relate to an unfamiliar situation require knowledge-based behaviour, even by experienced drivers.

	Strategical/Planning	Tactical/Manoeuvre	Operational/Control
Knowledge	Navigating in a strange town	Controlling a skid on icy roads	Learner on first lesson
Rule	Choosing between familiar routes	Passing other cars	Driving an unfamiliar car
Skill	Travelling from home to work	Negotiating familiar intersections	Vehicle handling in bends

Table 4.1. Examples of driving tasks classified according to Michon's hierarchical structure of the driving task and Rasmussen's skill-rule-knowledge framework (Adapted from Hale, Stoop, & Hommels, 1990: p. 1383).

Situation awareness

Situation awareness (SA) is about maintaining an accurate dynamic picture of the situation, for example, while driving a car. It is about "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" (Endsley, 1988, p. 97; cited in Endsley, 2000). This definition from Endsley already indicates that there are three levels of SA. The first level of SA is the level of perception of important information. At the second level of SA, people combine, interpret, store, and retain the collected information. Multiple pieces of information are integrated and their relevance to personal goals is determined (e.g., crossing an intersection). At the highest level of SA, information about the present situation is used to predict future events (level 3 SA). This ability to anticipate future events and their implications allows for timely decision making, and characterizes the skilled expert (Endsley, 2000). Several factors can influence the accuracy and completeness of a person's SA, including attention, goals, stress, workload, expectations, and mental models (see *Section 4.4.2*).

4.4.2. Strengths and weaknesses of older drivers according to cognitive psychological frameworks

It is much more difficult to point to the weaknesses of the older adult using cognitive psychological frameworks than it is using the Human Factors approach. In fact, the cognitive psychological frameworks of Rasmussen and Michon focus more on the *strengths* of drivers. According to these models, something inside human beings makes them good at reducing workload and reducing the probability of errors. However, this does not mean that people do this consciously.

According to Rasmussen's skill-rule-knowledge framework
According to Rasmussen's framework, one of the strengths of human beings is that they can keep (mental) workload under control by minimizing the mental effort needed for task performance. Human beings are able to do so because they can automate familiar tasks, which results in practically unconscious performance. Humans are perhaps at their weakest during knowledge-based task performance. Hale et al. (1990) hypothesize that drivers at rule- or skill-based level operate more homogeneously and predictably than those at a knowledge-base level. In a traffic environment in which people have to interact with others, unpredictable behaviour may lead to collisions. Assuming that this is correct, designers should try to prevent that people have to operate at the knowledge-based level. This means that they should pay particular attention to the rules which have to be used when abnormal situations occur, for example when road maintenance has to be carried out. As much as possible, drivers should be able to rely on common routines. If this cannot be guaranteed, the deviation must be signalled as dramatically as possible in order to break into the routine.

Although task performance at the skill-based and rule-based level is more predictable, it is not free from failures. Errors that are made at these levels of task performance are, however, relatively less frequent and easier to prevent. Errors at the skill-based level are called slips (and lapses). They are the result of correct intentions but incorrect actions. One knows what has to be done but the actual implementation is wrong. The latter being the result of inattention or overattention. No or too much attention is paid to the routine action one is carrying out (see e.g., Reason, 1990). Errors in rule- and knowledge-based behaviour occur during problem-solving activities, leading to incorrect intentions as well as incorrect actions. These types of errors are called mistakes. At the rule-based level, incorrect intentions can be caused by a wrong diagnosis which leads to the misapplication of good rules or the application of bad rules. An example of a wrong diagnosis is a tendency to overuse diagnoses that proved to be successful in the past. The accuracy/correctness of such a successful diagnosis will be tested first regardless of whether it is actually applicable to the current situation (for other examples of rule-based mistakes see Reason, 1990). At the knowledge-based level, incorrect intentions can occur as a result of insufficient knowledge and/or pressure of time. Situations in which both factors are represented can lead to various types of errors. An important source of these errors lies in selective processing of task information. Mistakes will occur if attention is given to the wrong features or not given to the right features (for more information about these and other examples of knowledge-based mistakes see Reason, 1990).

According to the hierarchic structure of the driving task

According to Michon's hierarchic structure of the driving task, one of the strengths of human beings is that they can keep (mental) workload under control by reducing time pressure. On the operational level, pressure of time is high, especially if one needs more time to decide as a result of declines in sensory abilities and/or decreased information processing capacities. This time pressure can be reduced by decisions on the higher levels. On the tactical level, the driver can decide to keep more distance to the vehicle in front in order to have more time to react. Another decision that can be made on the tactical level is to reduce speed well before approaching an (unfamiliar) intersection in order to have more time to perceive all aspects of the traffic situation, to interpret them and to decide on how to act. On the strategical level, the driver can decide to take the route with traffic lights instead of the one with signs which force him to decide for himself when it will be safe to cross traffic streams. In addition, he can decide to drive during daytime, thereby avoiding difficulties as a result of night-time visual acuity and sensitivity to glare.

One can think of various reasons why older people in particular have the possibility to compensate (Brouwer & Davidse, 2002; Brouwer, Rothengatter & Van Wolffelaar, 1988). In the first place, they often have more freedom in choosing when to travel. Various studies have shown that older adults more often choose to drive during daytime and dry weather (Aizenberg & McKenzie, 1997; Hakamies-Blomqvist, 1994c; McGwin & Brown, 1999;

Smiley, 2004; Zhang et al., 1998). In the second place older people on average have a great deal of driving experience. The traffic insight they have acquired may give them the ability to anticipate on possible problematic situations. In the third place, the diminishing desire for excitement and sensation when getting older possibly might play a role. Older people, on average, less often drink-drive than younger adults and are generally more inclined to obey the traffic rules (Brouwer, Rothengatter & Van Wolffelaar, 1988; Hakamies-Blomqvist, 1994c).

According to the concept of situation awareness

The theoretical basis of the concept of situation awareness is for a large part extracted from the fields of ergonomics and cognitive psychology. As a result, the relative weaknesses of human beings in the area of perception and cognitive abilities according to the concept of situation awareness are the same as those which were identified in the previous sections. This section describes what the effects of these weaknesses are on the acquisition of situation awareness.

For obtaining level 1 SA (perception) it is important that relevant information can be perceived optimally. Factors which may disturb optimal perception are bad visibility (e.g., fog), functional limitations in the area of perception, and attentional deficits, either caused by distraction or reduced selective and/or divided attention. In their study on the causes of pilot errors, Jones & Endsley (1996; cited in Endsley, 2000) found that 76% of all errors had its origin in problems in the perception of needed information. As a result, this first phase of obtaining SA appears to be the weakest link in obtaining good situation awareness.

One of the strengths of humans is, according to the concept of situation awareness, their use of mental models. These models are the result of experience. Experienced drivers have developed mental models of the vehicle they use and the traffic system they are driving in (i.e., road network, traffic rules, traffic participants). These models include schemata which describe prototypical situations. If a real-world situation matches a prototypical situation, the meaning of the real world situation will quickly be clear to the driver. This will assist in obtaining level 2 SA (comprehension) as well as level 3 SA (projection). Mental models and the schemata associated with them also assist the experienced driver with obtaining level 1 SA (perception): they direct the driver’s limited attention to relevant aspects of the situation.

Stating that experienced drivers can maintain their SA more efficiently than inexperienced drivers does not mean that an experienced driver will always have better SA. Experience can also have an adverse effect on SA. An experienced driver who relies too much on mental schemata to select and interpret information may misinterpret an unexpected situation or not even notice it (Endsley, 2000; Wickens, 2001). These errors match the ones that were discussed in the section on strengths and weaknesses according to Rasmussen's skill-rule-knowledge framework: as a result of habit formation, routine actions are also carried out in situations in which they are not appropriate, or changes in the situation at hand are not noticed. In cognitive psychology, such adverse effects of experience are known as negative transfer and attentional narrowing (see e.g., Johnson & Proctor, 2004; Wickens & Hollands, 2000).

Bolstad and Hess (2000) have examined the effects of age-related cognitive changes on the acquisition of SA. For each of the levels of SA, they have studied the effects of general slowing, decreasing processing resources, and inhibition. In addition, they have examined whether experience can compensate for any negative effects of ageing on SA. The results of Bolstad and Hess's exercise are summarised below. Note that, although Bolstad and Hess focus on the cognitive aspects of ageing, they point out that changes in sensory functions affect the acquisition of SA as well.

Age-related declines in selective and divided attention may influence the acquisition of level 1 SA through the reduced efficiency with which older people search the environment for relevant information, and the extent to which they can pay attention to different sources of information or perform more than one task at the same time. Both cognitive changes may have a negative effect on the quality and quantity of the information that people will have at their disposal. Selective attention appears to be particularly affected by ageing when the individual must search the environment for relevant information or when target information competes with other information in the environment. The impact of some attentional deficits can probably be made smaller with appropriate environmental supports to guide processing. Another way of guidance is provided by the mental models and schemata which were discussed earlier: they will also direct the driver's limited attention to relevant aspects of the situation. Apart from declines in selective and divided attention, cognitive slowing may also have a negative effect on the acquisition of level 1 SA. This may particularly be the case in complex situations where cues in the environment are changing at a relatively rapid, externally paced rate, straining older adults' capabilities to keep pace with the information flow (Bolstad & Hess, 2000).

The acquisition of level 2 SA, integration of selected information and existing knowledge in order to form a coherent and useful picture of the situation, is of course strongly dependent on the information that was selected in Stage 1 and has been stored in memory. Due to age-related cognitive changes, individuals may have either selected inappropriate information or been unable to select the appropriate information, thus affecting the nature of the information available to the individual. In addition, age-related difficulties in retrieving and utilizing information registered during Stage 1 may affect the creation of an accurate mental model.

For level 3 SA, the effect of cognitive changes is probably the largest in those situations in which it is not possible to fall back on existing knowledge and experience. When such knowledge is not available, and inferences that are necessary for future projections must take place in a more bottom-up fashion, age differences might be more prevalent due to the increased demands on working memory processes. In addition, it should be noted that the projection accuracy is only as good as the information which is used in that process. A low level 1 SA and level 2 SA will restrict the acquisition of level 3 SA.

4.4.3. Most important lessons from cognitive psychology

One can conclude that cognitive psychology offers several clues as to how the boundaries of human information processing can be compensated for. Not only by drivers themselves, but also by road authorities. Examples of compensatory actions that drivers can take are travelling at particular times, following a particular route, and/or driving at a lower speed. Another thing that cognitive psychology tells us is that driving experience (and other kinds of experiences) results in mental models that help the driver in choosing the action that is appropriate for the situation he is in. Elements of the traffic situation trigger the appropriate action without the driver having to take into consideration every possible action (see for example Wickens and Hollands, 2000). Designers should be aware of these mental models and the way they are triggered. If a (new) situation looks similar to a well-known situation but in fact is completely different and also requires different actions, mental models will work counterproductive. Therefore, mental models should be taken into account by road designers and designers of ADAS and their human machine interface.

4.5. Game theory

4.5.1. An introduction to game theory

Game theory is about decision making and anticipating the likely reaction of others (Von Neuman & Morgenstern, 1944). A famous example that originates from this theory is the so-called prisoner's dilemma in which suspects of a crime have to decide whether they should talk or remain silent about the other's contribution to the crime committed. The combination of their decisions (talk or remain silent) determines the length of their imprisonment. People who are involved in a game like this often have conflicting interests and attempt to prevail their interest over those of the others. To achieve that goal, they need information about the motives and intentions of the other ones involved. However, information is often not available. As a result, people base their decisions on the *likely* reaction of others.

A type of game that applies to traffic behaviour is the so-called *Chicken game*. Oye (1985) describes this game using the situation in which two drivers meet each other on a narrow road. If one of the drivers makes room for the other, he could be regarded as the 'chicken' whereas the other one may call himself the 'hero'. If neither of them is willing to make room, both drivers may suffer from damage to their car. If both drivers decide to make some room, loss of reputation will be minimized for both drivers.

Several factors can influence the outcome of a game. One factor that is described in literature is an existing balance of power. In the prisoner's dilemma, for example, one of the prisoners may hold a higher rank in the criminal organisation they both belong to. In traffic, differences in power can result from traffic rules (e.g., right of way), the type of vehicle people drive, or the type of road they are driving on. A second factor that may influence the outcome of a game is the extent to which 'players' can view the behaviour of the other(s) involved. Being visible to the other 'players' of the game may give people the opportunity to influence their behaviour. For example, drivers may approach an intersection at high speed, thereby enforcing right of way. A third factor is the willingness to cooperate. According to Oye (1985), this willingness depends on: 1) the value which players attach to the outcome of the game, 2) how many times the game is or will be played, and 3) the number of players involved. In traffic, the first factor is probably determined to a large extent by the desired driving speed, driving style, and state of mind (e.g., relaxed, in a hurry, irritated, tired). The number of times the game is played may influence the willingness to cooperate through the principle of tit for tat: if I have made room for another driver twice, I will not do it for the third time. The number of players that is involved in the game predominantly influences the complexity of the comparative assessment the drivers have to make.

4.5.2. Strengths and weaknesses of older drivers according to game theory

The traffic situation which was described in the previous section clearly explains the principles of game theory. However, it is not very useful for a description of the strengths and weaknesses of the older driver, especially if its purpose is to identify needs for support. After all, crashes on narrow roads which are caused by drivers who are not willing to make room for each other are not very common among older drivers. A traffic situation that applies more to the difficulties older drivers encounter in traffic is one in which several road users approach the same intersection and have to decide in which order they will cross the intersection. This situation will be used to identify the strengths and weaknesses of older people as they interact with others (see Heijer & Wiersma (2001) for a similar approach).

When approaching a major road, each of the road users will look around to see which other road users have arrived at the intersection at the same time, how they behave, in what way they pose a threat (i.e., mass and speed of their vehicle), and who has priority according to the traffic rules. Based on this information, the road users will work out who will be the first one to cross the intersection, who will be next, and when it will be their turn. For a safe transaction it is important that every road user can see all the other road users and that everyone knows what is expected of him. These preconditions will not always be satisfied. Age-related functional limitations such as declines in selective and divided attention, and reduced detection of movement may make it more difficult for older drivers to observe and interpret the behaviour of other road users. They may compensate for these limitations by approaching the intersection at a lower speed, which will give them more time to view the others and decide what to do. Fellow road users may very well misinterpret this behaviour. They may think the older driver is being polite or is just complying with the traffic rules and expect that he will therefore yield to them. As a result, they will be completely unprepared to start avoidance manoeuvres if the older driver nevertheless suddenly accelerates into the intersection area. Several examples of similar suboptimal communication between young and older drivers have been reported in studies of naturalistic driving situations: older drivers more often drove with an irregular and hesitant pace, they communicated less with other participants and were less often the first person to resolve a traffic conflict (Brendemühl, Schmidt & Schenk, 1988; Risser et al., 1988; cited in Brouwer & Ponds, 1994).

Although road users may not always understand each other, communication between road users still appears to be one of the reasons why the number of crashes in traffic is relatively low if compared with the general error rate for routine operations where care is required (Heijer & Wiersma, 2001). Therefore, if assistive devices are introduced to improve the safety of the (older) driver, they should not interfere with the natural communication between road users. In-car driver assistance systems often aim solely at the correction of errors of the users. This disregards both the error-compensating capacities of surrounding traffic and the possibilities to compensate for failures of others, which is not only inefficient but can also be dangerous because the actions of the assistance system may disturb these error-correcting processes (see also *Section 7.3.5*).

4.5.3. Most important lessons from game theory

One can conclude that, from a game theoretical perspective, people are relatively bad at perceiving all the relevant information that is needed to make the right decision. Assistive devices could provide support by giving timely information on who is arriving at the intersection and what is about to happen (including the priority regulation). In addition, they can help in making the right decision based on the available information. However, one important precondition for safe interventions by in-car assistive devices from a game theoretical perspective is that cars that have these devices will have to 'behave' the same way as they would have done if they were operated by humans. This means that they should not only take into account what their own "boss" does, but also anticipate actions of others. Otherwise, their behaviour might come across as behaviour of an alien or at least as antisocial behaviour to drivers not having the assistive device, which may result in crashes after all.

4.6. Driver needs

The above theoretical framework provided us with information about the relative weaknesses of the older adult. Note, however, that not every weakness of the driver has negative road safety consequences. After all, many weaknesses can be compensated for. Take for example restricted peripheral vision; that can be compensated for by increased movements of head and neck. Only when a combination of several weaknesses makes it impossible to take compensatory action or to act in the available time period, driving problems will arise. Depending on the circumstances (remember the compensatory action that fellow road users can take) these problems might in the end result in a crash.

We may state that the relative weaknesses of the older driver create an objective need for adjustments to road design and in-car driver assistance systems that offer driver support on these specific areas. This objective need for support can be formulated more precisely by indicating the driving-related difficulties that arise as a result of these weaknesses. By quantifying these difficulties based on how often they result in crashes, we also have a standard that can be used to rank the need for different kinds of support. *Table 4.2* shows the results of such an exercise. In horizontal direction, the table successively shows the weaknesses of the older adult, the difficulties he is faced with as a result of these weaknesses (accompanied by the extent to which these problems contribute to the total number of crashes), and the type of support that could prevent such driving-related difficulties. Knowledge of the weaknesses of the older driver is not only of use for the identification of their need for support, but also for the design of assistive devices: how to provide support. The weaknesses that should be taken into account when designing measures concerning the infrastructure and human machine interfaces for driver assistance systems are indicated by "(DESIGN)" in the right-hand column. In vertical direction, the table reflects the stages of information processing.

Weaknesses	**Driving related difficulties and their relevance to road safety**	**Assistance needed**
Vision and hearing		
Peripheral vision	**Overlooking other road users while merging or changing lanes (7: ++ OD)[1]**	**Signal or provide view of objects that are located in the driver's blind spot**
Night-time visual acuity	Difficulty seeing pedestrians and other objects at night and reading signs (x)	Artificially light objects (other road users and road design elements)
Sensitivity to glare	Temporary loss of visual information (x)	Prevent glare (DESIGN)
Contrast sensitivity	Difficulty reading signs and in-car displays and difficulty with depth perception and estimating the speed of other road users (11: + OD)	(DESIGN) **Draw attention to approaching traffic**
Colour vision	Difficulty discriminating between similar colours; relevant to reading signs and in-vehicle displays (x)	(DESIGN)
Motion perception	**Difficulty judging the movement of fellow road users and their approach speed (6: +++)**	**Draw attention to approaching traffic**
Hearing	Difficulty locating the direction of sounds and ignoring noise (x)	(DESIGN)
Cognitive processing and decision making		
Divided attention	Driving task performance gets worse when other tasks have to be performed simultaneously; see also 'speed of information processing and decision making' (x)	(DESIGN)
Selective attention	**Overlooking traffic signs and signals (3: ++)**	**Assist the driver in directing his attention to relevant information**
Speed of processing information and making decisions	**Reaction time increases as the complexity of the traffic situation increases (3: ++)**	**Provide prior knowledge on the next traffic situation**
Performing tasks consciously	Difficulty driving in an unfamiliar environment (x)	Provide prior knowledge on the next traffic situation

Table 4.2. Weaknesses of older adults, driving-related difficulties and assistance needed, prioritized by their relevance to road safety.

Weaknesses	Driving related difficulties and their relevance to road safety	Assistance needed
Physical changes		
Flexibility of head and neck	**Overlooking fellow road users when merging or changing lanes (7: ++ OD)**	**Signal or provide view of objects that are located in the driver's blind spot**
Manual dexterity and strength	Difficulty programming on instrument panels (x)	(DESIGN)
Interaction with other road users		
Performance under pressure of time	**Suboptimal decisions (3: ++)**	**Provide prior knowledge on the next traffic situation**
Insight in the behaviour of other road users	Difficulty predicting the intentions of other road users (14: +)	Draw attention to approaching traffic and its behaviour

[1] The text between the brackets refers to the data in Appendix B. The numbers correspond to the numbers preceding the needs for information and/or assistance in the Appendix (first column). The plus signs, "0" and "x" refer to the percentage of the total number of crashes that could be avoided if the need would be met: >10%=+++; 5-10%=++; 2,5-5%=+; < 2,5% = 0; x=no data available (second column of the Appendix). 'OD' (Older Driver) means that one plus sign is added to account for the underestimation of the number of crashes involving older drivers (third column of the Appendix). The most important needs for support are printed in bold. See text for further explanation.

Table 4.2 (continued). Weaknesses of older adults, driving-related difficulties and assistance needed, prioritized by their relevance to road safety.

The relevance of the driving-related difficulties (middle column) to road safety is derived from Malaterre and Fontaine (1993). They have investigated the relation between crash types and the need for information and assistance using in-depth crash data. The percentage of crashes that could be avoided by providing the driver with information that is relevant to a certain driving problem was used as an indicator of the relevance of that driving problem to road safety. In *Table 4.2* this relevance is expressed in terms of plus signs; the more plus signs, the more relevant it is to road safety (See *Appendix B* for the data of Malaterre and Fontaine).

Using the percentages of Malaterre and Fontaine (1993) has the disadvantage of them being based on the total number of crashes and therefore on the "average" road user. Several studies have indicated that older adults are more often involved in crashes while turning left and while merging (Aizenberg & McKenzie, 1997; Davidse, 2000; Hakamies-Blomqvist, 1993, 1994c; McGwin & Brown, 1999; Zhang et al., 1998). In this respect, the percentages of Malaterre and Fontaine underestimate the relevance to road safety of some of the driving-related difficulties of older adults. In *Table 4.2* this is corrected for by giving the relevant difficulties an extra plus sign (and the code OD).

Based on *Table 4.2*, we can conclude that the most important need for support, from a road safety perspective, stems from the following driving-related difficulties (printed in bold in *Table 4.2*) and weaknesses that cause them (relevant to 5% or more of the total number of crashes of older drivers):

a) difficulty judging whether fellow road users are moving and at what speed they approach the intersection (motion perception and contrast sensitivity);
b) overlooking other road users while merging and changing lanes (peripheral vision and flexibility of head and neck);
c) overlooking traffic signs and signals (selective attention);
d) reaction time increases as the complexity of the traffic situation increases (speed of processing information and decision making, divided attention, performance under pressure of time).

The right-hand column of *Table 4.2* describes the kind of assistance that is needed. These descriptions are simply derived from the driving-related difficulties. Only the type of assistance is mentioned, not the way in which the assistance could be provided or which existing road design elements or driver assistance systems already provide for it. Based on the abovementioned driving-related difficulties, the assistive devices most needed will:

a) draw attention to approaching traffic;
b) signal or provide view of road users located in the driver's blind spot;
c) assist the driver in directing his attention to relevant information; and/or
d) provide prior knowledge on the next traffic situation.

In addition, while designing measures concerning the infrastructure and human machine interfaces for driver assistance systems, people should take into account the older drivers' increased sensitivity to glare, and their reduced contrast sensitivity, colour vision, hearing, divided attention and manual dexterity and strength.

Section 5.3 and *Chapter 7* discuss assistive devices that already seem to provide the abovementioned types of support, or that may do so in the near future. *Section 5.3* focuses on road design elements that allow for the functional limitations of the older driver, whereas *Chapter 7* discusses relevant in-car driver assistance systems and the conditions they should meet to actually improve the safety of older drivers.

5. Intersection design and the older driver

The aim of this chapter is to identify those characteristics of intersections that may contribute to the over-representation of crashes at intersections in the total number of crashes that older drivers are considered legally responsible for. These characteristics were traced by looking at the functional limitations of older people and the demands they make on intersection design. It was assumed that if the design elements of an intersection allow for the functional limitations of older people, the crash involvement of older drivers will be low. If they do not allow for the older driver's functional limitations, passing that intersection will be difficult for older drivers, and the crash involvement of older drivers will be higher than average. The validity of these assumptions was tested by inspections of intersections that have different shares of crashes involving older drivers. In addition, a literature review was carried out on intersection design elements that appear to take the functional limitations of older drivers into account.
The intersection inspections indicated that priority regulation is a predictor of the crash involvement of older drivers. Crashes involving older drivers occur more often at yield-controlled intersections than at intersections with traffic lights. The literature review revealed that the following intersection design elements appear to allow for the older driver's functional limitations: a positive offset of opposite left-turn lanes, roundabouts, a high in-service contrast level for road markings, background plates for traffic lights, long sight distances, advance warning signs, and protected-only operations of traffic lights. However, the actual effect that they have on the safety of older drivers has hardly been tested yet.

5.1. Introduction

In this chapter, road design elements are discussed that appear to play a role in the difficulties that older drivers encounter in traffic (see *Table 4.2*). Given the overrepresentation of older drivers among crashes at intersections, the main focus is on intersection design elements. Two strategies are followed to look for intersection design elements that play a role in the difficulties that older drivers encounter: 1) a comparison of the characteristics of intersections that have different shares of crashes involving older drivers, and 2) a review of the literature on intersection design elements that take into account the functional limitations that are common in the older age group. The next two sections describe the results of these two strategies. In the last section of this chapter (*Section 5.4*), conclusions are drawn about adjustments to intersection layout that have the potential to improve the safety of older drivers.

5.2. A pilot study on the relationship between characteristics of intersections and crashes involving older drivers

5.2.1. Introduction

Older adult drivers (i.e., those aged 75 and above) distinguish themselves from the average road user by a higher physical vulnerability and a somewhat higher crash involvement. Because of these two factors, older adult drivers have a higher fatality rate. This fatality rate can be reduced by taking secondary safety measures (i.e., improve the crashworthiness of vehicles, promote the use of safety devices) and by taking measures that are specifically aimed at preventing those types of crashes that are overrepresented in the total number of crashes involving older drivers (Brouwer & Davidse, 2002; Maycock, 1997). The present study focuses on the latter opportunity to lower the fatality rate of older drivers.

The somewhat higher crash involvement of older adult drivers concerns a number of specific crash types, of which crashes at intersections, crashes while turning left and crashes as a result of failing to yield are the most important ones. Note that these three descriptions can actually describe the same crash. In short, research has shown that the crash type that is overrepresented among older drivers is one in which the older driver is turning left at an intersection and fails to yield (Aizenberg & McKenzie, 1997; Davidse, 2000; Hakamies-Blomqvist, 1993, 1994c; McGwin & Brown, 1999; Zhang et al., 1998). Therefore, to reduce the fatality rate of older drivers, focus should be on preventing crashes that occur while turning left and on preventing crashes as a result of failing to yield. According to Fuller's task-capability interface model (Fuller, 2000, 2001, 2005), crashes are likely to occur if task demands are higher than the capabilities of the driver (see *Section 4.2.1*). To prevent crashes from happening, demands and capabilities should be tuned to one another. Taking the demands of the road environment as a starting point, the aim of this study was to examine whether it would be possible to identify characteristics of intersections that coincide with a higher frequency of crashes involving older drivers. If that were the case, changing these characteristics would lower task demands. Assuming that the capabilities of the driver do not deteriorate any further, these lower task demands will ease the task of passing the intersection in question, resulting in a reduction of the number of crashes at intersections.

To identify characteristics of intersections that coincide with a higher frequency of crashes involving older drivers, two types of intersections were compared: (1) intersections at which relatively many crashes occurred involving older drivers, and (2) intersections at which no crashes occurred involving older drivers. The comparison of these intersections and their characteristics was directed by expectations regarding the factors that determine the difficulty of passing an intersection. Based on the literature on task difficulty, information processing, and ageing and driving (e.g., Fuller, 2000, 2001; Hendy, East & Farrell, 2001; Brouwer, 2002b), it was expected that for older drivers the difficulty of passing an intersection (i.e., crossing or turning left or right at it), and hence the likelihood of a crash, is determined by a combination of 1) the *complexity* of the traffic situation, 2) whether or not the driver has to take a *decision* with regard to road users that are about to cross his path (e.g., type of intersection, priority regulation or traffic lights that guarantee a protected left-turn), and 3) the availability of a proper *mental schema*. Given the capabilities of the older driver, the task of passing an intersection was only expected to be difficult if the traffic situation is complex *and* the driver has to decide on how to deal with traffic that is about to cross his path *and* the driver cannot bring his experience (and schemata) to the job. The complexity of a traffic situation was expected to increase with 1) the *amount of information* that has to be processed (e.g., number of lanes and traffic signs, presence of pedestrian crossings), 2) a reduction of the *quality of the information* (e.g., visibility of signs and pavement markings), and 3) the presence of *time pressure* (e.g., presence of trees, houses or cars that block the view of the intersection and reduce the time left to anticipate on what is coming). The complexity of the traffic situation is the factor that was expected to be the most sensitive to the age of the driver. Complex situations put a severe strain on the sensory, perceptual and cognitive capacities of the driver, and these capacities are often reduced in the older age group (see e.g., Brouwer & Ponds, 1994; Fisk & Rogers, 1997). For younger drivers, other factors were expected to play a role in the likelihood of crashes, such as whether or not the road layout offers drivers the opportunity to speed, and the type of factors which Fuller classified under the heading of human factors, such as emotions, alcohol and other drugs, stress, and distraction (see *Section 4.2.1*).

Based on the abovementioned expectations, it was expected that a higher crash involvement of older drivers would be connected with: a) a larger amount and/or poorer quality of traffic-related information (*complexity*), b) a larger number of decisions to be made by the driver (*decision*), and c) larger deviations from the common intersection layout (*experience and schemata*). However, there was not enough information available to define these hypotheses in more detail. For example, expecting that larger deviations from the common intersection design lead to higher task demands is one thing, but defining what the common intersection design is, is another. Therefore, it was decided to change the character of the study from an experimental study aimed at testing the abovementioned hypotheses to an exploratory study aimed at gathering information about intersections at which relatively many crashes occur in which older drivers are involved, and comparing the characteristics of these intersections with those of intersections at which relatively few crashes occur in which older drivers are involved.

While carrying out this exploratory study, apart from the task demands of passing a particular intersection and the capabilities of the driver, a third factor was taken into account that may influence the involvement of older drivers in crashes at a particular intersection: the older driver's exposure. Older drivers may pass certain intersections more often than others. This may be the result of facilities they do and do not use (e.g., library, hospital, school), but it may also be the result of consciously avoiding certain intersections. The latter may be connected with the perceived difficulty of passing them. One way or the other, exposure should also be taken into account when comparing intersections with different shares of crashes involving older drivers.

5.2.2. Method

Selection of intersections

Thirty intersections were selected using the road accident database of the Dutch Ministry of Transport, Public Works and Water Management: 15 intersections at which relatively many crashes involving older adult drivers occurred (Group Int_{old}; at least 30% of all crashes at that intersection) and 15 intersections at which no crashes involving older adults occurred (Group Int_{young}). For practical reasons, all intersections were located in the Dutch province of South Holland.

The intersections were selected based on the number of injury crashes that occurred on them in the period between 1990 and 2000, the latter year being the most recent year for which crash data were available at the time of selection (2001). To make sure that the assignment of an intersection to one of the two groups was based on solid data, at least 10 crashes had to have taken place at an intersection in the indicated period of 10 years for the intersection to be considered for inclusion in this study. The actual inclusion in this study depended on the percentage of crashes in which older drivers were involved. As this study was aimed at determining road design elements that raise the task difficulty of passing an intersection for older drivers, thus leading to an increased risk of errors and crashes caused by older drivers, the focus was on the age of the first registered collision partner. This collision partner often turns out to be the legally responsible one (see *Appendix A*). For every intersection in the province of South Holland, two numbers were calculated: 1) The total number of crashes in which the first collision partner was a car driver, and 2) the number of crashes in which the first collision partner was aged 65 or above. If the ratio between the latter and the former was 0.30 or higher, the intersection was included in the group of intersections called Int_{old}. If none of the first collision partners was 65 or older, the intersection was included in the group of intersections called Int_{young}. To avoid differences between these two groups of intersections that are merely related to differences in exposure, only those intersections were included in Int_{young} that had a comparable number of crashes in the period 1990-2000 as those which were included in Int_{old}.

The total number of crashes that took place at the selected intersections varied from 11 through 20. Intersections with relatively many crashes were not selected, as none of these intersections could be assigned to Int_{old}. Hence, the intersections included in Int_{young} may not be representative for all intersections with no crashes involving older drivers. In addition, note that in the rest of this section older drivers are those aged 65 and above. It would have been preferable to use the age limit of 75 to assign intersections to either Int_{old} or Int_{young}. However, it turned out that the use of the latter age limit would have resulted in a selection of intersections that was too small to be able to make any comparisons.

Data collection

To compare the two groups of selected intersections, several characteristics of each of the intersections were gathered during visits on the spot. Pictures were taken from each of the intersecting streets (from the perspective of a driver approaching the intersection, both at 50 m and 10 m before the intersection), and some general characteristics of the traffic flow were recorded manually (between 9:15 am and 15:15 pm). Back in the office, the information available from the pictures was coded into variables. These variables were considered to describe the factors that were expected to determine the difficulty of passing an intersection (amount and quality of traffic-related information, time pressure, number of decisions to make, intersection layout), to describe the use of the intersection, and to describe the surroundings which may influence the composition of the traffic flow.

Amount of traffic-related information:
1) total number of coloured items that is visible at the intersection (i.e., traffic signs and billboards); 2) total number of traffic lanes in the other approaching streets; 3) the intersecting roads have separate carriageways (yes/one/none); 4) cycle tracks available ("yes, separate-lying cycle tracks"; "yes, cycle-lanes that are part of the carriageway and separated from the rest by a broken line"; "no"); 5) pedestrian crossings available (yes/no); 6) cycle crossings available (yes/no); 7) special lanes for public transport available (yes/no).

Quality of traffic-related information:
1) visibility of delineation (good, poor, not visible); 2) availability of fixed lighting (yes/no); 3) availability of arrow pavement markings indicating lane configuration (yes/no); 4) left-turn lane available (yes/no); 5) angle at which intersecting streets meet (90 degrees; between 70 and 90 degrees, less than 70 degrees); 6) type of traffic lights (all have background plates, some have background plates, no background plates); 7) every lane has its own traffic light (yes/no).

Time pressure:
1) the driver's view of the intersection at a distance of 50 m and 10 m from the intersection (based on a picture: good versus blocked by shrubs, trees or buildings); 2) parked cars near the corners of the road (yes/no); 3) trees along the road (no/some/many); 4) number of motor vehicles passing the main road of the intersection within 15 minutes of time.

Number of decisions:
1) type of intersection (4-way intersection, T-junction, roundabout); 2) implementation of right of way (either by traffic lights, stop-controlled, yield-controlled, or the ordinary right goes before left); 3) operation of the traffic lights: protected left-turn available (yes/no).

Road characteristics that may conflict with experience:
1) road that has right of way is also intuitively the most important road (yes/no); 2) estimated average speed of motor vehicles driving on the main road of the intersection as compared to the speed limit (low, normal, high).

The intersection's user profile:
1) number of motor vehicles passing the main road of the intersection within 15 minutes of time (also mentioned at *time pressure*); 2) estimated average speed of motor vehicles driving on the main road of the intersection as compared to the speed limit (also mentioned at *experience*); 3) composition of road users in terms of transport mode (normal, many cyclists and/or pedestrians, many heavy goods vehicles; lots of public transportation (buses, trams) and pedestrians); 4) composition of road users in terms of age (percentage of older road users is: less than average, average, more than average).

Characteristics of the environment:
1) percentage of the population of the neighbourhood being 65 years old or older (Statistics Netherlands, 1999); 2) retirement home or hospital in the neighbourhood (yes/no); 3) the intersection is part of a route that leads to a popular destination such as the market, shops, the beach, or an amusement park (yes/no); 4) description of the immediate surroundings of the intersection and its crossing streets (residential area, shopping area, woody surroundings).

Data-analysis
To examine whether the road characteristics that were expected to raise task difficulty were indeed more prevalent at the intersections belonging to Int_{old} than at the intersections belonging to Int_{young}, their occurrence was compared by calculating frequencies for every coded variable. For those variables for which frequencies appeared to differ between Int_{old} and Int_{young}, differences were tested by calculating either an independent-samples t-test or Pearson's Chi-square.

5.2.3. Results

When visiting the selected intersections, 6 of the 30 selected intersections turned out to be under reconstruction or were otherwise not being used in the way they would have been in the period between 1990 and 2000 (e.g., because of a temporary detour, or an earlier reconstruction of the intersection). Twenty-four intersections remained, 13 intersections belonging to Int_{old} and 11 to Int_{young}. The general characteristics of these intersections are summarized in *Table 5.1*. As the various branches of an intersection do not give the same view of the intersection, and the drivers who were involved in crashes have not necessarily approached the intersection from the same branch, the characteristics of the intersections are described at the level of the branch. For each intersection, the number of entries is equal to the number of branches from which a driver could have approached the intersection. This results in 45 entries for Int_{old} and 38 entries for Int_{young}. Differences between frequencies for Int_{old} and Int_{young} that were tested for significance are printed in bold.

Table 5.1. Summary of the characteristics of intersections included in Int_{old} and Int_{young} (percentages refer to valid cases).

	Int_{old}	**Int_{young}**	
Amount of traffic-related information			
Mean number of visible coloured items (median)	**7.0 (5.0)**	**9.1 (9.0)**	*
Mean number of traffic lanes in other approaching streets	**5.9 (5.0)**	**8.1 (9.5)**	*
Separate carriageways on intersecting street			
Yes, both left and right	62%	63%	
Yes, at one side (left or right)	4%	11%	
No	33%	25%	
Cycle tracks			
Yes, separate lying cycle-tracks	47%	47%	
Yes, non-compulsory cycle-lanes	23%	18%	
No	30%	34%	
Mean number of cycle and pedestrian crossings (median)	6.7 (6.0)	7.8 (5.5)	
Lanes for public transport (Yes)	**18%**	**37%**	**ns**
Quality of traffic-related information			
…*Visibility of delineation*			
Good	**63%**	**27%**	
Poor	**33%**	**65%**	**
Not visible	**5%**	**8%**	
Fixed lighting at the intersection (Yes)	100%	100%	
Arrow pavement markings indicate lane configuration (Yes)	**28%**	**46%**	**ns**

	Int_{old}	Int_{young}	
Left-turn lane available (where turning left is allowed) (Yes)	20%	26%	
Angle at which intersecting streets meet			
90 degrees	95%	97%	
70 - 90 degrees	5%	-	
< 70 degrees	-	3%	
Every traffic light has a background plate (Yes)	60%	55%	
Every lane has its own traffic light (Yes)	100%	100%	
Time pressure			
View of the intersection			
Good at 50 m and 10 m	**81%**	**51%**	**
Blocked at 50 m and/or 10 m	**19%**	**49%**	
Parked cars near the corner (Yes)	**26%**	**53%**	*
...*Trees along the road*			
No	33%	34%	
Some trees	44%	58%	
Many trees	23%	8%	
Mean number of motor vehicles passing per 15 min (median)	**197** (177)	**239** (186)	**ns**
Number of decisions			
Type of intersection			
Roundabout	9%	10%	
T-junction	33%	24%	
4-way intersection	58%	66%	
Implementation of right of way			
Traffic lights	**22%**	**55%**	
of which protected left-turn (if allowed)	78%	69%	
Stop-controlled	**4%**	**0%**	**
Yield-controlled	**38%**	**24%**	
Driver has right of way (no traffic lights)	**36%**	**21%**	

Table 5.1 (continued). Summary of the characteristics of intersections included in Int_{old} and Int_{young} (percentages refer to valid cases).

	Int_{old}	Int_{young}	
Characteristics that may conflict with experience			
Right of way according to expectations (Yes)	100%	100%	
Average speed compared to speed limit			
Low	15%	16%	
Normal	67%	66%	
High	18%	18%	
Intersection's user profile			
Composition in terms of transport modes			
Normal	**77%**	**8%**	**
Many pedestrians/cyclists	**19%**	**32%**	
Many heavy goods vehicles	**5%**	**32%**	
Many buses/trams	**0%**	**27%**	
Composition in terms of age			
% of older road users smaller than average	**21%**	**0%**	*
Average % of older road users	**46%**	**54%**	
% of older road users larger than average	**33%**	**46%**	
Characteristics of the environment			
Percentage of the population that is aged 65 or above	**25%**	**15%**	**
Retirement home or hospital in neighbourhood (Yes)	40%	35%	
Part of a route to a popular destination (Yes)	37%	16%	
Immediate surroundings			
Residential area	28%	14%	
Shopping area	33%	43%	
Woody surroundings	19%	11%	
Through road	21%	32%	
* $p < 0.05$; ** $p < 0.01$			

Table 5.1 (continued). Summary of the characteristics of intersections included in Int_{old} and Int_{young} (percentages refer to valid cases).

Of the various types of traffic-related information that were studied, only the mean number of visible coloured items and the mean number of traffic lanes in the other approaching streets differed significantly between Int_{old} and Int_{young} were. However, the direction in which these variables differed was opposite to the one that was expected: There were more visible coloured items and more traffic lanes to scan at the intersections included in Int_{young} than there were at the intersections included in Int_{old}.

As far as the quality of the traffic-related is concerned, visibility of delineation was the only variable whose values significantly differed between Int_{old} and Int_{young}. Again, the direction was opposite to the one that was expected. The quality of the pavement markings was better at the intersections included in Int_{old} than it was at the intersections included in Int_{young}.

Of the variables that were expected to describe the general time pressure brought about by the road environment, only view of the intersection and parked cars near the corner of the street had values that significantly differed between intersections included in Int_{old} and Int_{young}. Opposite to what was expected, the view of the intersection was worse at streets approaching the latter intersections, and parked cars at the corner(s) of the approaching streets were more often (one of) the cause(s) of the obstructed views of these same intersections.

The only variable whose values confirmed our expectations about the task difficulty of intersections, was the one that indicates the implementation of right of way. Traffic lights, which reduce the number of decisions that a driver has to take to a minimum, were less often present at intersections included in Int_{old} than they were at intersections included in Int_{young}. The former intersections were more often regulated by means of traffic signs (i.e., stop, yield or priority-signs).

Intersection characteristics that may conflict with experience were hardly found at any of the selected intersections, neither at the intersections included in Int_{young}, nor at the intersections included in Int_{old}.

Background variables indicated that Int_{old} and Int_{young} differed significantly on two aspects of the composition of road users. The latter group of intersections included more intersections that were used by many heavy goods vehicles and public transportation. The former group included more intersections at which the percentage of older drivers passing the intersection was smaller than average. Strange enough, the percentage of people living in the neighbourhood that are aged 65 and above was *higher* for the intersections included in Int_{old} than it was for the intersections included in Int_{young}. Looking at those three intersections that appear to be used by relatively few older drivers, one intersection is located in a neighbourhood in which only 10% of the people is aged 65 or above (in 1999). The other two intersections are located in a neighbourhood in which either 37% or 43% of the people is aged 65 or above, the latter actually being the highest percentage of older people living in the neighbourhood of the included intersections.

5.2.4. Discussion

It was expected that the crash risk of older drivers would increase with the complexity of the traffic situation, provided that drivers have to make decisions with regard to road users that are about to cross their path, and provided that drivers cannot use their experience to make these decisions. These expectations were only confirmed for one of the intersection characteristics which were expected to determine whether drivers have to make decisions with regard to other road users: implementation of right of way. Traffic lights were expected to reduce the number of decisions to a minimum, whereas yield-controlled intersections were expected to increase the number of decisions to make. It turned out that at intersections at which no crashes occurred in which older drivers were involved (Int_{young}), traffic was more often regulated by means of traffic lights than it was at intersections at which relatively many crashes occurred in which older drivers were involved (Int_{old}). At the latter intersections, traffic was more often regulated by means of yield signs.

Intersection characteristics that conflict with experience were hardly found at any of the selected intersections. This could indicate that (older) drivers could always use their experience and select the proper mental schema without being misled by the intersection layout. If this was the case, the automatically selected schema will then have directed the selection of necessary information (see *Section 4.4.2*), and will therefore have reduced the influence that complexity of the traffic situation has on task difficulty and on the crash risk of older drivers. As a result, for the selected intersections, the amount of traffic-related information that was visible while approaching an intersection, the quality of the information, and the time pressure that was imposed on the driver would have been less relevant for the prediction of the number of crashes in which older drivers were involved.

Nevertheless, it is interesting to note that according to the characteristics that were expected to determine the amount of traffic-related information, the quality of traffic-related information, and the time pressure that is imposed on drivers, the intersections included in Int_{young} appeared to be more complex than the ones included in Int_{old}. At the former intersections there were more coloured items and traffic lanes to scan, pavement markings were less visible, and the drivers' view of the intersection was more often obstructed, for example by cars that were parked near the corner of the street.

So if it is assumed that the correct characteristics were selected to describe the factors that determine task difficulty, the results of this pilot study indicate that the crash involvement of older drivers at intersections cannot be explained by the concept of task difficulty. However, the small-scale and exploratory nature of this study does not make it a valid instrument for testing hypotheses. The emphasis in this study was more on gathering data on a broad range of characteristics that may differ between two sets of intersections than on systematically testing the influence that specific characteristics have on factors that are relevant for task difficulty. The latter type of analysis asks for a more structured collection of data in an environment that is less subject to external influences. The next two examples illustrate that the present study did not meet these demands, and illustrate that the design of this study may have influenced study outcomes.

First of all, the characteristics of the selected intersections were gathered in 2003, whereas the crashes which led to the selection of those same intersections took place somewhere between 1990 and 2000. The latter period of time was used to make sure that the assignment of an intersection to one of the two groups was based on solid data. However, a serious drawback of using such a long time period is that the characteristics of an intersection may have been altered between the moment of the crash and the moment of data collection. Especially since the frequency of crashes at a road stretch or an intersection is an indicator for the necessity to reconstruct the location in question. Naturally, this applies for both groups of intersections, and there is no apparent reason for intersections included in Int_{old} to have been altered more than intersections included in Int_{young}. However, the specific design elements and/or characteristics of the traffic flow that may have contributed to the occurrence of crashes in the past, may have been different for intersections included in Int_{old} and intersections included in Int_{young}, thereby leading to different types of alterations. Increased traffic flows at the latter intersections may have urged traffic designers to install traffic lights, whereas reduced visibility of pavement markings at the former intersections may have urged road authorities to add new or other sorts of paint.

Second, most intersection and street characteristics had to be read from pictures of the selected intersections. For some of those characteristics it was difficult to assess the correct value only having the disposal of two pictures of the branch in question. The visibility of pavement markings was one of them. It was only possible to evaluate the contrast between pavement markings and the carriageway. Whether the pavement markings were made of retro reflective paint was difficult to evaluate. Another characteristic that was difficult to assess, was the availability of a separate green phase for traffic turning left (protected left-turn). If there was a separate lane for traffic turning left, and this lane had a separate signal that pointed to the left, it was assumed that traffic turning left did not have to yield to through traffic that was approaching from the opposite direction. This means that the traffic lights were then expected to provide a protected left-turn.

If task difficulty as defined above cannot explain the difference in the percentage of crashes with older drivers, the most obvious alternate explanation is a difference in the percentage of people using the intersections included in Int_{old} and Int_{young} that is aged 65 or above. There was indeed a difference between the age compositions of the users of the selected intersections, but the direction was opposite to the one expected based on the number of crashes in which older drivers were involved. At the intersections included in Int_{young} the percentage of older users was estimated to be average or higher than average, whereas at some of the intersections included in Int_{old} this percentage was estimated to be smaller than average. It should be noted, however, that these estimates were not based on counts, but were merely guesstimates made by a colleague who visited all the intersections and made all the photographs.

5.3. A literature review on intersection design elements that allow for the functional limitations of the older driver[5]

5.3.1. Introduction

An infrastructure that takes into account the functional limitations that accompany ageing can contribute to a reduction of the crash involvement of older people. Taking into account the functional limitations means that the infrastructure provides the driver with enough time to observe, decide and

[5] This section was based on chapter 3 of SWOV report R-2002-8 (Davidse, 2002).

act. In this section, the focus will be on those design elements that are relevant to the needs as identified in *Section 4.6*. Those intersection design elements will be discussed that fit the most important needs for assistance, as well as those that take into account the older drivers' increased sensitivity to glare, and their reduced contrast sensitivity, colour vision, and divided attention. The latter were mentioned as being important to allow for while designing assistive devices (see right column of *Table 4.2* 'DESIGN'; hearing, and manual dexterity and strength are not considered to be relevant for intersection design). *Table 5.2* summarizes these functional limitations and the relevant road design elements that appear to take them into account. These two sets are connected by the factors which are expected to determine task complexity and task difficulty (see *Section 5.2.1*).

Functional limitations	**Relevant factor**	**Relevant road design elements**
Peripheral vision and flexibility of head and neck	Quality of the information	Angle at which streets meet
Night-time visual acuity and sensitivity to glare	Quality of the information	Fixed lighting Design of traffic signals
Contrast sensitivity and motion perception	Quality of the information	Assistance for turning left Contrast of pavement markings Design of traffic signs and signals Design of street-name signs
Colour vision	Quality of the information	Design of traffic signs and signals
Divided attention	Number of decisions	Type of intersection (roundabout)
Selective attention	Amount of information	Placement of traffic signs
Speed of information processing, divided attention, and performance under pressure of time	Time pressure	Angle at which streets meet Lane-use control signs Type of intersection (roundabout) Placement of traffic signs Fixed lighting

Table 5.2. Functional limitations of the older adult, and relevant road design elements.

Specific measures that apply to these intersection design elements are described in the next paragraphs. Most of these measures have been selected from the 'Older Driver Highway Design Handbook' by Staplin, Lococo & Byington (1998) and its second edition 'Highway Design Handbook for Older Drivers and Pedestrians' (Staplin, Lococo, Byington & Harkey, 2001). However, since these handbooks were primarily based on the situation in the

United States of America, and the infrastructure in these states is rather different from the one in Europe, all measures have been thoroughly screened with the help of Dutch engineers (Davidse, 2002). The measures were screened on the possibility and desirability to translate them to the European situation. Only those measures and recommendations that were judged to be suitable for the European situation, that were consistent with the Sustainable Safety policy in the Netherlands, and that were related to intersections in built-up areas are included in the next paragraphs.

5.3.2. Intersection design

Intersections can be defined as traffic situations that require complex judgements of speed and distance, and simultaneous activities under pressure of time. Older adults generally have more difficulties in meeting these requirements than younger drivers have (*Chapter 2*). Intersection design elements that may be beneficial to older drivers in this respect are (Staplin, Lococo, Byington & Harkey, 2001):

- Elements that provide a good and early view of the intersection;
- Elements that assist the driver in making a left turn;
- Roundabouts.

View of the intersection
At the approach of an intersection, the view of other traffic approaching the intersection is largely determined by the angle at which crossing streets meet. The optimal angle is one of 90 degrees. A smaller angle makes it more difficult to get an overview of the intersection and to notice other road users. Road users can compensate for these difficulties by turning their head a bit more. However, as older adults generally have restricted head and neck mobility, they will have more trouble with intersections where streets meet at a small angle. Therefore, a right angle junction is in particular important for older road users.

Apart from the fact that older adult drivers have more trouble overlooking the intersection because of a restricted mobility of head and neck, they also need more time to react (increased perception-reaction time). A restricted view of the intersection, not only because of a small angle between the intersecting roads, but also as a result of shrubs, trees and buildings blocking the view of the intersection, leaves the driver little time to overlook the intersection and therefore also little time to react. The resulting pressure of time probably causes more problems for older drivers than for younger drivers. Therefore, a shorter sight distance or stopping sight distance probably has more adverse consequences for older adult drivers than for younger drivers. Traffic designers can resolve this problem by using a longer perception-reaction time (prt) when calculating sight triangles and the stopping sight distances, with a minimum prt of 2.5 second (CROW, 1998a; Staplin, Lococo, Byington & Harkey, 2001).

Assistance for turning left

Crashes while making a left turn represent the most important type of crash in the total number of crashes involving older adult drivers (see *Section 1.3*). These crashes are often the result of failing to yield. In case of older adult drivers this may be caused by a wrong judgement of the speed of the approaching vehicle, a wrong judgement of the gap needed to join the traffic flow, or simply not noticing the approaching vehicle (Davidse, 2002; Dingus et al., 1998). These causes are associated with several of the functional limitations that accompany old age, such as having trouble with motion and depth perception, and a decline in divided and selective attention.

Signalised intersections

At signalised intersections, failure to yield and any crashes resulting from it can probably be prevented by protected-only operations of the traffic signals. In that case, drivers that want to turn left can do so without having to decide when it is safe to cross traffic approaching from the opposite direction, as the latter are waiting behind a red traffic light. In addition, current guidelines recommend a *leading* protected left-turn (see e.g., CROW, 1998a). This means that during each cycle of the traffic lights, traffic turning left gets a green light before traffic that drives straight on. This order results in less crashes and fits in with the expectations of the driver. To reduce confusion during an intersection approach, current guidelines recommend the use of a separate signal for each lane of traffic (CROW, 1998a). This satisfies the older drivers' need for information on lane assignment (see *Lane-use control signs*). Finally, the length of the all-read clearance interval should allow for the slower information processing of older adults. This interval gives drivers the opportunity to leave the intersection area after the amber phase before conflicting streams of traffic arrive (Staplin, Lococo & Byington, 1998; CROW, 1998a, p. 150).

Stop- and yield-controlled intersections
At stop- and yield-controlled intersections having opposite left-turn lanes (and at intersections where protected-only operations are not possible, e.g., because of an unacceptable reduction in capacity), Staplin et al. (2001) suggest that safety could be improved by adjusting the left-turn lane geometry. Opposite left-turn lanes and the traffic that uses these lanes can restrict the left-turning driver's view of oncoming traffic in through lanes. The level of blockage depends on how the opposite left-turn lanes are aligned with respect to each other, as well as the type and size of the vehicles in the opposing queue. Restricted sight distance can be minimized or eliminated by shifting opposite left-turn lanes to the right (positive offset) so that left-turning drivers do not block each other's view of oncoming traffic (Staplin, Harkey, Lococo & Tarawneh, 1997). *Figure 5.1* shows the difference between opposite left-turn lanes that are exactly aligned (i.e., no offset) and the situation where the opposite left-turn lane is shifted to the right (i.e., positive offset).

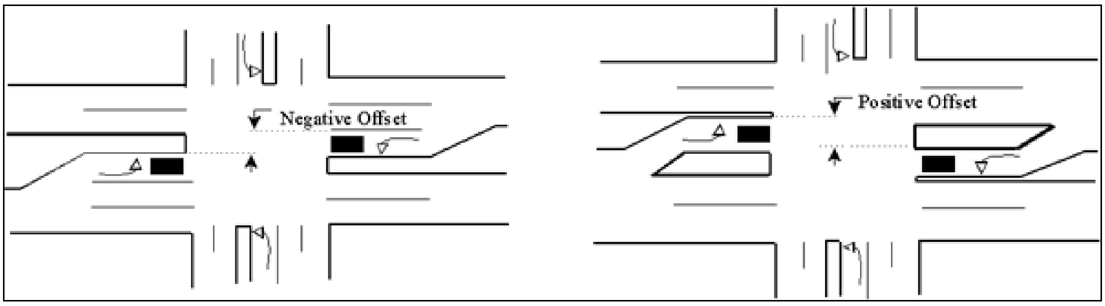

Figure 5.1. No offset versus positive offset (Staplin et al., 2001).

It is not so much the degree of positive offset that matters, as does the sight distance that results from a certain positive offset. Left-turn lanes frequently used by heavy lorries need a larger offset, since these lorries have a more adverse effect on sight distance. McCoy, Navarro and Witt (1992) have developed an approach that can be used to compute the amount of offset that is required to minimize or eliminate the sight restriction caused by opposing left-turn vehicles. Where the provision of unrestricted sight distance is not feasible, Staplin et al. (2001) recommend to compute stopping sight distance using a perception-reaction time of 2.5 second to allow for the slower information processing of older adults.

A possible negative side effect of a positive offset of canalized left-turn lanes (e.g., a parallel or tapered left-turn lane between two medians) is the potential for wrong-way manoeuvres by drivers turning left from an intersecting minor road. To prevent this, the usual precautions against wrong-way driving can be taken, such as using (a) signs that indicate one-way traffic, (b) equipping canalized left-turn lanes with lane-use arrows and a white stop bar at the end of the lane, (c) using a retro reflective pavement marking to describe the path through the turn, and (d) using reflective paint and other treatments to delineate median noses in order to increase their visibility and improve driver understanding of the intersection design and function (De Niet & Blokpoel, 2000; Staplin, Lococo & Byington, 1998).

Roundabouts

Several advantages of the abovementioned road design elements are combined in modern roundabouts: left turns are completely eliminated, the driver has fewer decisions to make because of one-way traffic and yield-at-enter, lower speeds allow for more time to decide and act, and view of the intersection is not restricted by small angles between intersecting streets (Davidse, 2000; Staplin et al., 2001). Therefore, roundabouts may be very relevant for the problems older drivers encounter when passing intersections. All the more so, because roundabouts not only reduce the number of crashes (see e.g., Elvik, 2003; Van Minnen, 1990), but as a result of lower speeds also reduce the severity of crashes, which would be especially beneficial to older road users (Robinson et al., 2000).

However, there are a few drawbacks. First of all, roundabouts are relatively new to drivers and older adults are at a disadvantage in responding to novel, unexpected stimuli (Davidse, 2000; Staplin et al., 2001). This might even lead older drivers to avoid roundabouts. Simms (1992) reports avoidance of roundabouts by drivers over 70 (even in the United Kingdom), although it is unclear whether the roundabouts that were reported as being avoided were only multi-lane or also single-lane. Mesken (2002) did make a distinction between single-lane and multi-lane roundabouts when asking older adults to indicate what they regarded as difficult traffic situations: whereas 22% of the drivers mentioned multi-lane roundabouts, only 3% mentioned single-lane roundabouts. So it appears that older drivers prefer single-lane roundabouts. However, as the application of a multi-lane roundabout is a matter of capacity need, and the alternative of a multi-lane roundabout is a – generally less safe – signalized intersection, the application of multi-lane roundabouts is in a sense unavoidable.

Other design elements of roundabouts that may be particularly important for older drivers pertain to the way streets are connected to the roundabout, and to the distance between a roundabout and cyclist or pedestrian crossings. Both design elements are related to the view of traffic. As regards the connection of streets to a roundabout, Brouwer, Herland, and Van der Horst (2000) state that right angle connections are more effective in reducing driving speed, and provide a better view of the traffic on the roundabout for drivers that are about to turn onto the roundabout, than do tangential connections. To ensure that drivers who leave the roundabout have a good view of cyclists and pedestrians that have right of way, the angle between the driver and cyclist or pedestrian crossings at connecting streets should also be 90 degrees. This angle can only be obtained if the crossing is placed at approximately one length of a car from the circulation area (i.e., the traffic lane on the roundabout; Linderholm, 1996, cited in Brouwer, Herland & Van der Horst, 2000; CROW, 1998b, 2002). More generally, it can be emphasized that the traffic control devices and physical layout and appearance of roundabouts need to be uniform from one installation to another (Lord, Schalkwijk, Staplin & Chrysler, 2005). This gives (older) drivers the opportunity to gain experience with roundabouts, and at the same time develop mental schemata for managing roundabouts that help them safely negotiate not only roundabouts that are situated in their own town, but also those that are situated in another town (see e.g., Wouters, Slop, Lindeijer, Kuiken & Roendersloot, 1995).

5.3.3. Traffic signs and road markings

As people age, visual functions decline as well as the ability to separate important from unimportant information (selective attention) and the ability to divide attention between, for instance, different aspects of the road scene (*Chapter 2*). This probably makes it more difficult to detect traffic signs and obstacles. Road design elements can anticipate these difficulties by providing appropriate placement and legibility of traffic signs (e.g., street-name signs), conspicuousness of obstacles (e.g., kerbs, medians, and traffic islands), and recognizable intersection control (who has right of way) and lane assignment (Staplin et al., 2001).

Street name signing

The importance of the legibility of street name signs has to do with the time and effort needed to read the name of the street. Factors which influence the legibility of street-name signs are among others, contrast, luminance, font, letter height, letter width and interletter and interword spacing (Staplin et al., 1998). These factors become more important as the eyesight of a road user becomes worse. Older drivers, because of their age-related deterioration of visual functions, need more contrast, a higher level of background luminance and larger letter sizes than younger drivers to achieve the same level of comprehension (Olson, Sivak & Egan, 1983). This can be accomplished by raising the requirements for letter size and retro reflectivity of street-name signs.

Since older adult drivers need more time to act (turning into a street) after having received directional information (e.g., a street name), the placement of street-name signs is probably also important: older adults should have sufficient time to prepare and execute their actions. Both visibility and prior notification can provide the driver with some extra time to act. This can probably be accomplished by placing street-name signs post-mounted along the side of the road and using advance street name signs to improve the visibility of street name signs on major roads and grade-separated junctions. When different street-names are used for different directions of travel on an intersection, Staplin et al. (2001) recommend to separate the names on intersection street name signs and to accompany them by directional arrows.

Lane-use control signs

The decelerated perception-reaction time of older adult drivers that is responsible for the earlier mentioned extra time that older drivers need to act, requires timely warnings of changes in lane configuration. Arrow pavement markings that can provide this kind of information have the disadvantage of being liable to wear, being less visible in bad weather conditions and can be covered by cars at the intersection. Therefore, Staplin et al. (1998) recommended to use overhead lane-use control signs in advance of the intersection as a supplement to pavement markings. Drivers should be able to read these signs at least 5 seconds in advance of the intersection (at operating speed; 50 m at 36 km/h), regardless of the specific lighting, channelization or delineation treatments implemented at the intersection.

"One-way" and "yield" signing

Other elements of the intersection the older adult driver should be informed about as early as possible, are the obligatory direction of travel and right of way. Research has shown that older adult drivers are overrepresented in wrong-way movements (see e.g., Blokpoel & De Niet, 2000; Crowley & Seguin, 1986). This overrepresentation can be explained by the older drivers' reduced peripheral vision and their decreased selective attention. To compensate for these deficits, it appears to be important to give the most relevant information a prominent place in the road environment. This can be accomplished by more conspicuous signs, realized through provision of multiple or advance signs, as well as by placing signs in the driver's field of vision and using signs that are larger in size and have a higher level of retro reflectivity (Staplin et al., 2001). To prevent wrong-way driving these recommendations are particularly relevant for signs indicating one-way roads and 'no entry'. However, the same applies to traffic signs indicating stop-and yield-controlled intersections, since crashes resulting from failure to yield are also overrepresented among crashes involving at-fault drivers of the age of 75 and older (Aizenberg & McKenzie, 1997; Davidse, 2000; Zhang et al., 1998). More important, Council & Zegeer (1992, cited in Staplin, Lococo & Byington, 1998) found that "young-old" drivers (65-74 years old) and "old-old" drivers (75 years and older) more frequently failed to yield and more often disregarded the stop-sign than a comparison group did (30-50 years old).

Road marking and delineation of median islands and other discontinuities
Road markings help the driver to maintain the correct lane position and give him a preview of the course of the road ahead. Because of their decreased contrast sensitivity (and their extended perception-reaction time) older drivers need a higher contrast between pavement markings and carriageway to be able to see the markings and have still enough time to act upon them (Staplin et al., 2001). The same applies to the delineation of discontinuities, such as curbs of traffic islands and medians. The results of several focus group discussions have indicated that older adults have difficulties in seeing these discontinuities, resulting in a possibility of running over them (Benekohal et al., 1992; Staplin, Lococo & Sim, 1990; Staplin et al., 1997).

Studies in the United States have indicated that driver performance – measured by the probability of exceeding lane limits – was optimized when the perceived brightness contrast between pavement markings and the carriageway was 2.0 (Allen, O'Hanlon & McRuer, 1977; Blackwell & Taylor, 1969). This means that pavement markings should be at least three times as bright as the carriageway. However, these studies were not specifically focused on the accommodation of older drivers. Another study compared the performance of the top 5 percent of 25-year-olds (the best performing younger drivers) with the bottom 5 percent of 75-year-olds (the worst performing older drivers). Taking the contrast requirements for the latter group into account, Staplin et al. (2001) recommend a minimum in-service contrast level of 3.0 between the painted edge of the carriageway and the road surface for intersections without overhead lighting. For intersections with overhead lighting they state that a minimum in-service contrast level of 2.0 is sufficient.

In addition to the provision of a painted edgeline on the road surface, Staplin et al. (2001) recommend that all curbs at intersections (including median islands and other raised canalization) be delineated on their vertical face and at least a portion of the top surface. Vertical surfaces should be introduced by cross-hatched pavement markings.

5.3.4. Traffic signals and fixed lighting

As far as traffic signals and fixed lighting are concerned, the older drivers' need for increased levels of luminance and contrast should be weighed against their sensitivity to glare.

Traffic signals
Since background plates provide more contrast between the traffic light and its direct surroundings without increasing the risk of blinding, they compromise between lighting, contrast and glare and are a good alternative to increased intensity of light. Current Dutch guidelines indicate that background plates should only be omitted when the available space is such that the plate would be too close to the carriageway (CROW, 1998a, p. 753; s.n., 1997, Article 1.11). Glare can be further reduced by reducing the intensity of traffics signals during darkness, except when this is unnecessary or undesirable because of the (fixed) lighting of the surroundings (s.n., 1997).

Fixed lighting
Lighting is more important to older adults than to the average road user. Both the reduced pupil size and yellowing of the lens of the older adult reduce the amount of light reaching the retina. A consequence of this reduced retinal illumination is that sources must be of higher intensity to be seen at night (e.g., Olson, 1993). Furthermore, timely warnings of unexpected situations and changes in lane configuration and lane width are helpful to older adults because of their increased perception-reaction time and these warnings can be provided for by lighting these areas. Therefore, Staplin et al. (2001) recommend fixed lighting installations (a) where the potential for wrong-way movements is indicated through crash experience or engineering judgement; (b) where twilight or night-time pedestrian volumes are high; and (c) where shifting lane alignment, turn-only lane assignment, or a pavement-width transition forces a path-following adjustment at or near the intersection.

5.3.5. General principles of relevant road adjustments

The intersection design elements that were discussed in this section have in common that they allow for the functional limitations that are more common in the group of older drivers. Three ways of allowing for functional limitations can be distinguished:

- Reduce time pressure by giving the road user more time to observe, base decisions on these observations, and act accordingly. Examples are longer sight distances, and advance warning signs (lane configuration, yield signs).
- Improve the visibility of important features of the intersection. Examples are positive offsets of opposite left-turn lanes, high contrast levels for road markings, background plates for traffic lights, and fixed lighting.
- Allow drivers to perform tasks sequentially instead of simultaneously. Examples are roundabouts, and protected-only operations of traffic lights.

Although these design elements have been selected for their capacity to increase the safety of older road users, they will also make a contribution to the safety of other road users. Measures that give the driver more time to observe things and to base decisions on these observations make the driving task easier for all road users. The reduced complexity of the driving task will probably reduce the number of human errors, and in the end possibly also the number of crashes. The fact that adjustments that benefit older road users also have positive effects on the safety of other road users, is an additional argument for taking such measures.

5.4. Conclusions regarding intersection design elements that take the older driver into account

In this chapter, two strategies were followed to look for intersection design elements that play a role in the difficulties that older drivers encounter in traffic: 1) inspections of intersections that have different shares of crashes involving older drivers, and 2) a review of the literature on intersection design elements that appear to take the functional limitations of older drivers into account.

The intersection inspections were guided by the concept of task difficulty. It was expected that the crash risk of older drivers would increase with the complexity of the traffic situation, provided that drivers have to make decisions with regard to road users that are about to cross their path, and provided that drivers cannot use their experience to make these decisions. These expectations were only confirmed for one of the intersection characteristics that were expected to determine the need for decision making with regard to other road users: implementation of right of way. It turned out that at intersections at which no crashes occurred in which older drivers were involved, traffic was more often regulated by means of traffic lights than it was at intersections at which relatively many crashes occurred in which older drivers were involved. At the latter intersections, traffic was more often regulated by means of yield signs. The other hypotheses could not be accepted, either because the direction of the relationship was counter to expectations, or because there was no relation at all.

The intersection inspections that were carried out within the scope of this thesis had a rather exploratory character and the number of intersections that were inspected was relatively small. However, the concept of task difficulty and its application to the difficulty of passing intersections deserve it to be studied in a more systematic way. Using structured data collection, future studies should test the hypotheses regarding factors that contribute to task difficulty (complexity, need for decision making, and proper mental schemata) as well as those regarding specific intersection characteristics that determine the complexity of a traffic situation (amount and quality of traffic-related information, and time pressure). Ideally, these studies should be preceded by a study that helps to determine the direction in which specific design elements contribute to the complexity of a traffic situation. One could argue, for example, that some increases of the amount of traffic-related information do not add to the complexity of a situation but rather reduce it. A separate traffic lane for vehicles turning left or for cyclists, for example, increases the number of lanes to scan but on the other hand structures the information by dividing the carriageway into different sections that are used by different types of road users planning to execute different manoeuvres.

The literature review taught that road design elements that appear to allow for one or more age-related functional limitations include a positive offset of opposite left-turn lanes, conversion of intersections into roundabouts, high in-service contrast levels for road markings, background plates for traffic lights, long sight distances, advance warning signs, and protected-only operations of traffic lights. However, the actual effect that these adjustments have on the safety of older drivers has hardly been tested yet. Two exceptions are recent experiments by Shechtman et al. (2007) and Classen et al. (2007). They evaluated the effects of a positive offset of opposite left-turn lanes and protected only-operations of traffic lights on driving behaviour in a driving simulator and instrumented car respectively. Neither of the adjustments had a significant effect on driving behaviour.

6. Effects of intersection design on workload and driving performance of older drivers[6]

In a driving simulator, ten older (70–88 years) and thirty younger (30-50 years) drivers were guided across intersections that differed in terms of a) layout (3-way intersection, 4-way intersection, dual carriageway, or roundabout), b) priority regulation, and c) view of the intersection. Hypotheses with regard to the factors that influence the difficulty of passing intersections by older drivers were tested by comparing workload and driving performance between different types of intersections and between different age groups. Intersection layout turned out to be the best predictor of variations in workload. Three-way intersections that only had a side-street at the left-hand side of the driver turned out to be the easiest intersections to pass, whereas four-way intersections with dual carriageways were the most difficult to manage. Workload was higher for older drivers for all types of intersections. No interaction effects were found. Results on driving performance were less conclusive.

6.1. Introduction

Research on crashes involving older drivers – those aged 75 and above – has shown that the crash type that is most common in this group occurs while they are turning left (Aizenberg & McKenzie, 1997; Davidse, 2000; Hakamies-Blomqvist, 1993, 1994c; McGwin & Brown, 1999; OECD, 2001; Zhang et al., 1998). Possible causes of these crashes are the intersection design, functional limitations of the individual and the incompatibility of these two factors. This study focuses on the role that incompatibility of intersection design and functional limitations plays in the driving performance of older drivers. The incompatibility of intersection design and functional limitations boils down to the extent to which the intersection design takes into account the functional limitations of a part of the population of road users. To study this incompatibility, we will make use of the concept of task difficulty.

Fuller has described the concept of task difficulty in detail (Fuller, 2000, 2001, 2005). According to his model, task difficulty is the result of a confrontation of capabilities and task demands. If the capabilities of a road user are higher than the task demands, the task will be easy and the driver will be in command of the situation. However, if task demands are higher than his capabilities, the task will be too difficult and loss of control will occur. Fortunately, the driver has several opportunities to keep or regain control (i.e., to lower task difficulty): by lowering his driving speed, changing his

[6] An abbreviated version of this chapter will be submitted to a relevant scientific journal.

road position or trajectory, by communicating with other drivers, or – at an earlier stage – by choosing an easier route or better driving conditions (e.g., clear weather, daytime). Apart from the (older) driver, other road users can take compensatory actions as well, such as getting out of the way, thereby avoiding a collision. A third way of reducing the chance that collisions will occur is by lowering task demands through an adjusted design of the infrastructure and/or vehicle adjustments and technologies. The present study evaluates the possibilities of lowering task demands through adjustments to the design of intersections. A related study discusses the merits of in-car driver assistance systems (Davidse, Van Wolffelaar, Hagenzieker & Brouwer, 2007; see also Davidse, 2006).

Using literature on task difficulty, information processing, ageing and driving (e.g., Fuller, 2000, 2001; Hendy, East & Farrell, 2001; Brouwer, 2002b), Davidse (2007) has attempted to describe the task difficulty of passing intersections. That is, crossing or turning left or right at them. She expects that the difficulty of passing an intersection is a combination of 1) the *complexity* of the traffic situation, 2) the availability of a proper *mental schema*, and 3) whether or not the driver has to take a *decision* with regard to road users that are about to cross his path (e.g., side-street or not, priority regulation or traffic lights that guarantee a protected left-turn). More specifically, she expects that the task of passing an intersection will only be difficult if the traffic situation is complex *and* the driver cannot bring his experience (and schemata) to the job *and* the driver has to decide on how to deal with traffic that is about to cross his path.

Davidse (2007) also defined the complexity of a traffic situation. She expects complexity to increase with 1) the *amount of information* that has to be processed (e.g., number of lanes and traffic signs, presence of pedestrian crossings), 2) a reduction of the *quality of the information* (e.g., visibility of signs and pavement markings), and 3) the presence of *time pressure* (e.g., presence of trees, houses or cars that block the view of the intersection and reduce the time left to anticipate on what is coming). As such, complex situations put a severe strain on the sensory, perceptual and cognitive capacities of the driver. These capacities are often reduced in the older age group (see e.g., Brouwer & Ponds, 1994; Fisk & Rogers, 1997). Examples are decreased divided and selective attention, reduced contrast sensitivity, and reduced speed of information processing. As a result of these functional limitations, the complexity factor may play a more important role in the task difficulty of passing intersections by older drivers than it will in the task difficulty of passing these same intersections by younger drivers. However, the availability of proper mental schemata can compensate for functional limitations. If a(n) (older) driver is confronted with a complex traffic situation that is very familiar to him and for which he has the right schemata, there will be no need to analyse every aspect of the situation in detail. His schemata will direct the selection of necessary information, thereby reducing task difficulty. In a similar way, task difficulty is also reduced if the driver does not have to decide on how to deal with traffic that crosses his path, either because there is no traffic or because traffic signals guarantee a protected left-turn.

Returning to Fuller's model of task difficulty, the abovementioned functional limitations and mental schemata define the capabilities of the driver, whereas the complexity of the traffic situation and the need for deciding how to deal with traffic that is about to cross his path define the task demands. We expected that the task of passing a complex intersection at which one has to deal with other road users and for which schemata do not fit, will sooner be (too) difficult for older drivers than it will be for younger drivers (provided that both groups have considerable driving experience). The complexity of the situation will sooner overask the older drivers' functional capacities than those of a younger driver. As a result, older drivers will make relatively more errors than younger drivers. At intersections at which there is no need to decide on how to deal with other road users, such as intersections at which the driver has right of way, differences between the driving performance of older drivers and younger drivers will not exist.

In the present study, the validity of the abovementioned hypotheses was tested. More specifically, the aim was to identify those intersection characteristics that have the largest impact on the complexity of the situation and on task difficulty. With that aim, a simulator environment was designed in which participants were guided across intersections that differed in terms of a) layout (3-way intersection, 4-way intersection, dual carriageway, roundabout), b) priority regulation, and c) view of the intersection, and d) traffic density on the street or lane to cross or join. These intersection characteristics were intended to represent the factors 'complexity' and 'need to decide how to deal with other road users' that were expected to determine task difficulty. Workload and driving performance were expected to reflect differences in task difficulty.

To measure workload, a secondary task was introduced. This secondary task consisted of a peripheral detection task (PDT; see e.g., Van Winsum, Martens & Herland, 1999); a task that is based on the idea that the functional visual field decreases with increasing workload. Performance on this task was inferred from the reaction time of the driver and the fraction of signals that they missed. Increases in the difficulty of the primary task (i.e., passing an intersection) were expected to result in higher reaction times and fractions missed.

Primary task performance was inferred from crashes, route-errors, and safety of the participant's decisions. The latter was measured by the extent to which traffic that had right of way had to decelerate when the participant was passing an intersection. Deceleration of these 'other vehicles' was considered to be the precursor of a crash. If the drivers of those vehicles would not have reacted, a crash would have taken place. As such, the deceleration of other vehicles is the 'compensatory action by others' that is mentioned in Fuller's model (2001) as the factor that can prevent crashes from happening in case capabilities of a driver are lower than the driving task demands in that particular situation.

A second aim of this study was to identify those intersection characteristics that discriminate between the performance of older and younger drivers. Therefore, both older (70 years and older) and younger persons (30-50 years old) were invited to participate in the experiment. The age boundaries of the first group were chosen as a compromise between the preferred group of people aged 75 and above – the group of older adults that has a fatality rate which is higher than average (OECD, 2001; SWOV, 2005) – and the availability of participants of a certain age. The group of people aged 30-50 was chosen as the comparison group. People of this age group were expected to have considerable driving experience and not yet to be confronted with functional limitations. Realizing that ageing is a process that does not start at the same age for every person nor continues at the same rate, with the result that drivers having the same age – as in years since birth – can differ in the number and severity of their functional limitations, age was both considered chronologically and functionally (for a discussion on the prediction of functional age see Birren & Renner, 1977, p. 15-17). Functional age was based on scores on three tests of cognitive functioning, relating to reaction time, selective attention, and visual-motor coordination. Persons scoring well on the average of all tests were considered to be functionally younger, whereas persons scoring relatively poor on them were considered to be functionally older.

To summarize expectations, functionally older drivers were expected to have more difficulties crossing complex intersections at which they have to decide how to deal with other road users than functionally younger drivers do. We expected that these differences in difficulties would be reflected in differences in experienced workload and safety of driver decisions. In addition, we expected an intersection to be more complex a) if it was connecting more streets and traffic lanes, b) if there was no other priority regulation than right goes before left, and c) if the view of the intersection was blocked by cars, buildings or trees. Knowing which design elements of intersections are responsible for task demands that overask the capabilities of the older driver will give road authorities the opportunity to adapt the infrastructure to the demands of tomorrow's driver population.

6.2. Method

6.2.1. Participants

Participants were recruited by means of a newspaper article about the driving simulator, and by advertisements in supermarkets. Participants had to be either between 30 and 50 years of age or 70 years of age or older. Thirty-three older adult drivers (70 to 88 years of age; $\mu = 75.2$, $\sigma = 4.8$; 26 males, 7 females) and seventy-two younger drivers (28 to 51 years of age; $\mu = 39.2$, $\sigma = 6.6$; 41 males, 31 females) participated in this study. All participants had at least 5 years of driving experience and passed a test on sensitivity to simulator sickness (Motion Sickness/Simulator Sickness Screening Form MSSF; see Hoffman, Molino & Inman, 2003).

After being selected based on their chronological age, participants were grouped according to their functional age. Functional age was based on scores on three tests of cognitive functioning, relating to reaction time, selective attention, and visual-motor coordination (Determination Test© S1 [Schuhfried, 2003], Tachistoscopic Traffic Test Mannheim for Screen TAVTMB© S1 [Biehl, 2003], and adaptive tracking task [see e.g., Ponds, Brouwer & Van Wolffelaar, 1988; Withaar & Brouwer, 2003] respectively). We used the median reaction time provided by the Determination Test©, the overview score of the TAVTMB© and the performance on the second trial (third trial when considering the practice trial) of the adaptive tracking task.

These three scores were first converted into normal scores (z-scores) and then averaged (after making sure that scores on all tests were scaled in the same order, high scores indicating better performances than low scores). After having ranked participants according to their average score, participants that were in the lowest quartile (having the lowest average scores) were assigned to the oldest functional age group, and participants in the highest quartile (highest averages) were assigned to the youngest functional age group. Remaining participants (50% of all participants) were assigned to the "in-between"-group that we called 'functionally middle-aged'.

	Functional age			Total
	Young	Middle	Old	
Young (30-50)	27	42	2	71[a]
Old (70+)	1	8	24	33
Total	28	50	26	104

[a] One chronologically young person did not complete the cognitive tests and could therefore not be assigned to one of the functional age groups.

Table 6.1. Comparison of chronological and functional age groups (number of participants).

6.2.2. Procedure

All participants who had shown interest in participating in the study by ringing us or sending an e-mail were called back to test them on sensitivity to simulator sickness and to check their driving experience. Those who appeared not to be sensitive to simulator sickness as indicated by never or seldom being sick while travelling by plane, train, boat or as a passenger at the back seat of a car (see Hoffman, Molino & Inman, 2003), and who had more than five years of driving experience were invited to participate in this study. Those willing to participate were informed about the experimental procedure and received some extra information by mail, as well as an informed consent form, a questionnaire on driving behaviour and information on how to find the driving simulator that was located in the University Medical Centre in Groningen (UMCG).

Participants were invited twice to the UMCG. During their first visit, they returned the completed questionnaire and their signed informed consent form, they were administered the three tests on cognitive functioning (see

Section 6.2.1), and they drove in the driving simulator for about 10 minutes as an extra test on sensitivity to simulator sickness. Thirty-three subjects (15 older and 18 younger participants) did not feel comfortable driving in the simulator car as indicated by their score on a questionnaire on simulator sickness (based on the SSQ; Kennedy, Lane, Berbaum & Lilienthal, 1993). Therefore, they were not invited for the second visit to the UMCG.

During their second visit, the remaining participants first went for a short familiarization drive (3.5 km) in the driving simulator. After that, they twice drove a 35-minute route in the simulator car (16 or 18 km; see *Section 6.2.4*), once without and once with the support of an advanced driver assistance system (for the behavioural effects of the support system see Davidse, Van Wolffelaar, Hagenzieker, and Brouwer (2007)). The order of the drives was counterbalanced between subjects (see *Section 6.2.5*). Between the first and second drive, participants had a break of 45 minutes. Before the beginning of each drive, participants were asked to adjust the seat's position to make sure they could reach the pedals, and were instructed orally about what was expected from them during the drive that was about to start. They had to follow route instructions and were asked to try to adhere to the speed limit that was generally 50 km/h. After each drive, subjects had to fill in a questionnaire on motion sickness (based on the SSQ; Kennedy et al., 1993) and one on subjective workload (RSME; Zijlstra & Mulder, 1985).

Despite the earlier tests on simulator sickness, 15 participants (6 older, 9 younger drivers) felt sick while driving the simulator car during their second visit. Another 17 subjects did not complete the second part of the experiment because they were not able to participate in the span of time in which the second visits were planned. As a result, behavioural data were available from 40 participants: 10 chronologically older adult drivers (70 to 88 years of age; μ = 75.5, σ = 6.2; 8 males, 2 females) and 30 chronologically younger participants (30 to 50 years of age; μ = 39.3, σ = 5.9; 22 males, 8 females). In terms of functional age, data were available from 10 functionally younger participants (30 to 70 years of chronological age; μ = 39.1; σ = 12.2; 7 males, 3 females), 20 functionally middle-aged participants (32 to 71 years of chronological age; μ = 42.6; σ = 8.6; 16 males, 4 females), and 10 functionally older participants (37 to 88 years of chronological age; μ = 69.2; σ = 16.9; 7 males, 3 females). Those not capable of participating in the second part of the experiment, either because of serious symptoms of simulator sickness during the 10-minute drive at their first visit or because of a full agenda, received 10 € for their participation in the first part of the experiment. All other participants received 20 € for their participation in the experiment, regardless of having completed all the drives that were planned for their second visit.

6.2.3. Driving simulator

The simulator used was a fixed base driving simulator located at the Neuropsychology unit of the Department of Neurology of the UMCG. The simulator configuration consisted of an open cabin mock-up containing a force-feedback steering wheel, gas-, clutch- and brake pedals, and audio speakers for driving sounds. In front of the mock-up were three projection modules resulting in a 180 degrees horizontal and 45 degrees vertical out-window projection screen of 4.5 m in diameter.

The computer system consisted of five PCs: Three PCs for graphical rendering, one for traffic simulation and one for system control with a graphical user interface for the simulator operator. Traffic simulation was based on 'autonomous agents' technology. This kind of technology models the simulated participants (i.e., all traffic surrounding the simulator driver) as self-governing intelligent objects that show natural and normative driver behaviour. Normative behaviour implies basically safe and correct traffic behaviour as a default condition. The agents possess functions to perceive the world around them, process this information according to their behavioural rules and act adequately on the perceived circumstances (Van Wolffelaar & Van Winsum, 1995; Kappé, Van Winsum & Van Wolffelaar, 2002). This means, for example, that the simulated cars that surround the simulator driver recognize roads on which they have right of way, that as a result of this, they will not yield to traffic from the right on these roads, unless the respective traffic does not yield to them and a crash would occur if they themselves would not react.

6.2.4. Route

The experiment consisted of two suburban drives preceded by a familiarization drive. During all drives, participants received route instructions orally. The route led the participants across several intersections, which differed in terms of a) layout (3-way intersection, 4-way intersection, dual carriageway, or roundabout), b) priority regulation, c) view of the intersection, d) traffic density on the road or lane to cross or join, and e) speed of traffic driving on the road or lane to cross or join. These intersection characteristics were expected to determine the task difficulty of passing the intersection: the main independent variable of this study. To prevent order effects, two routes were used. Both routes contained the same intersections, but in a different order. The routes can be described as having the same 8-shape (see *Figure 6.1*), with Route 1 starting with the lower round followed by the upper round (total of 16 km), and Route 2 starting with the upper round followed by the lower round (total of 18 km). The lower round had relatively many intersections at which view of the intersection was blocked by buildings, whereas the upper round had relatively many intersections of wide roads with dual carriageways. The routes were randomly assigned to participants after having ranked and matched participants according to their scores on the SSQ (scored after the test drive during their first visit) and the Determination test© (see *Section 6.2.5*). The ranking was done to make sure that any effects found on functional age would not be caused by group assignment and to make sure that withdrawal from the study as a result of simulator sickness would affect all groups equally.

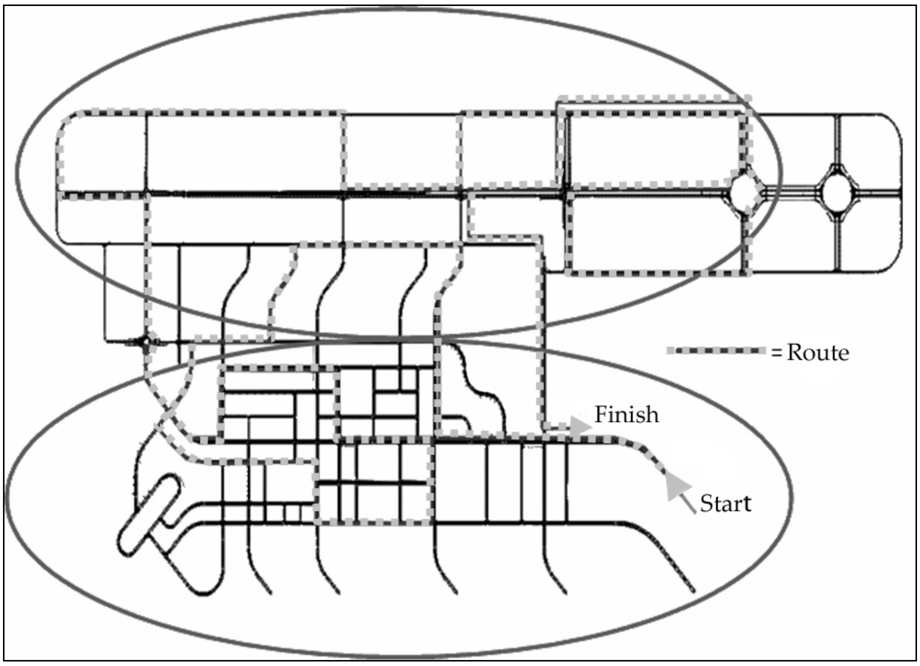

Figure 6.1. Sketch of the road network and the route participants had to drive.

6.2.5. Design and data-analysis

The experiment was set up using a 3x2xn mixed between-within design. Functional age was the classificatory variable (young, middle-aged and old), and driver support (yes or no) and intersection design (various types of intersections; see *Section 6.2.4*) were the experimental variables (see *Table 6.2*). Within-subjects comparisons were made to test whether the dependent variables workload, general driving performance, and safety of driver decisions differed while passing different types of intersections, and whether these types of behaviour were affected when the same intersections were encountered while being supported by a driver assistance system. Between-subjects comparisons were made to test whether workload, general driving performance, and safety of decisions on different types of intersections differed between age groups, and whether support by a driver assistance system had a differential effect on the behaviour of different age groups. In this chapter, the results regarding intersection design are presented. The results regarding driver support are described in *Chapter 8*.

	No ADAS			ADAS		
	Several types of intersections			Several types of intersections		
	Workload	Driving performance	Safety of decisions	Workload	Driving performance	Safety of decisions
Young drivers				(Chapter 8)		
Middle-aged drivers						
Older drivers						

Table 6.2. Experimental design.

To make sure that order effects would not affect study results, timing of the treatments (i.e., driver support and intersection design) was varied across participants. Driver support could be offered during their first or second experimental drive, and intersections could be offered in two different series (*Route*). This resulted in four different treatments (see *Table 6.3*). Participants were randomly assigned to these treatments after having ranked and matched the participants according to 1) their score on the simulator sickness questionnaire (SSQ) which they had filled in after their first test drive, and 2) their median reaction time as indicated by the Determination Test©. The actual assignment to treatments took place by counting from 1 (Treatment I) to 4 (Treatment IV), starting with the participant having the lowest scores on both SSQ and Determination Test©. The fifth participant was again assigned to Treatment I, the sixth to Treatment II, and so forth. This was done separately for the young and old chronological age group. Since not all subjects that were invited for the second part of the experiment were able to come, some groups turned out to be larger than others. Dropout because of simulator sickness during the second part of the experiment caused further reduction of the number of participants, and contributed to unequal cell sizes as well (see *Table 6.3*).

1st drive – 2nd drive	Route 1	Route 2
No support – with support	I (7)	III (12)
With support – no support	II (9)	IV (12)

Table 6.3. Number of participants per treatment group.

6.2.6. Data-sampling

General driving performance of the participants was measured by waiting position before passing an intersection, acceleration and speed while passing an intersection, and number of route-errors. Safety of driver decisions of participants was measured by crashes between participants and surrounding traffic, and by the deceleration of the latter vehicles if they had right of way at intersections the participant was passing. Deceleration of these 'relevant' vehicles was considered to be the precursor of a crash. If the other driver would not have reacted, a crash would have taken place (see *Section 6.2.3*).

The deceleration of surrounding traffic having right of way was measured both at the moment the participant started passing the intersection (Acc_Pre), and at the moment he had just crossed the path of the other vehicle or had turned and was driving in front of him (Acc_Post). Deceleration data could be either positive (the vehicle was accelerating), zero (the vehicle maintained speed), or negative (the vehicle was decelerating). Two derived deceleration measures were analysed further: the average deceleration of all relevant vehicles at the moment the participant drove off with the intention to pass the intersection (average Acc_Pre), and an indicator of whether one of the relevant vehicles had to decelerate either before or after the participant had passed the intersection (Acc_Crit: 0 if none of them had to decelerate, 1 if one of them had to decelerate). The latter measure indicated whether the decision to pass the intersection had been unsafe or not, whereas the former measure indicated the degree of unsafety at the time the participant drove off. The lower the Acc_Pre, the harder one or more relevant vehicle(s) had had to brake to prevent a collision.

Workload was measured by performance on a secondary task while passing the intersection. The secondary task consisted of a peripheral detection task (PDT; see e.g., Van Winsum, Martens & Herland, 1999 for a description of this task). While driving, a small red square was presented on the simulator screen in front of the participant during one second. Subjects were required to respond as soon as they detected the red square by pressing a microswitch that was attached to the index finger of their left hand. Reaction time was measured in milliseconds. If a reaction time had not been detected by the system within 2.5 s from the onset of the stimulus, this was coded as a missed signal. Series of signals were presented during the approach and passing of a selected number of intersections and while driving on three straight road sections. The 28 selected intersections were representative for the total group of 71 intersections, at the same time preventing participants having to perform the detection task at every intersection they passed. The onset of a series of signals was announced with a bell tone. During the series of signals (one series per intersection), on average every 3.5 s, with random variation between 3 and 4 s, a stimulus was presented at a horizontal angle of 10 to 20 degrees to the left of the line between the eyes of the participant and the centre of the screen. Stimuli were presented at a vertical angle of 3 degrees above the horizon. Average reaction time and fraction of missed signals per intersection (number of missed signals divided by total number of sent signals while passing the relevant intersection) were used as workload indices for the intersections. Higher reaction times and higher fractions of missed signals were interpreted as being the result of a higher workload.

Baseline reaction times and fractions missed were collected at the start of the first experimental drive. While the simulator car was parked at the beginning of the route, and the participant was sitting in the driver seat, one series of twenty stimuli was presented. On average every 4 s, with random variation between 3 and 5 s, a stimulus was presented at a horizontal angle of 10 to 20 degrees to the left of the line between the eyes of the participant and the centre of the screen. Again, participants were instructed to press the button as soon as they saw the stimulus. A second baseline was provided by the straight road sections at which the same series of stimuli were shown as during the approach and passing of the selected number of intersections. This second baseline differed from the first one in three ways: 1) participants were driving, 2) it always took place during the same drive as in which the relevant intersection data were gathered (no support), whereas the first baseline also could have taken place at the start of the drive in which driver support was available, and 3) the frequency at which the stimuli were presented was every 3.5 s instead of every 4 s. Practise on the PDT was provided during the familiarization run.

6.3. Results

In this section, between-subjects comparisons focus on functional age. Within-subjects comparisons focus on the effects of different types of intersections and manoeuvres.

6.3.1. General driving performance

Waiting position before passing an intersection, and acceleration and speed while passing an intersection were averaged per required driver manoeuvre: crossing a street while driving straight ahead, joining traffic after turning left or right, or turning left in front of an approaching vehicle. Age groups only differed in their waiting position before entering the intersection. Functionally old participants generally stopped two meters further away from the intersection to decide whether it was safe to join traffic after turning left or right than both young and middle-aged participants did ($t(18) = -3.188$, $p = 0.005$ and $t(28) = -2.739$, $p = 0.011$ respectively). In addition, while stopping in front of the intersection before crossing it, functionally old participants had a lateral position that was closer to the side of the road than both young and middle-aged participants had ($t(11) = 2.405$, $p = 0.036$ and $t(12) = 2.840$, $p = 0.015$ respectively). Acceleration and speed while passing intersections did not differ between age groups.

6.3.2. Workload

Before any of the analyses with regard to workload were carried out, all average reaction times – those averaged per intersection as well as those averaged per baseline – were first corrected for missing data. Initially, average reaction times represented the average of the reaction times for those stimuli to which participants had reacted within 2.5 s. If a participant had not reacted within 2.5 s after the onset of a stimulus, the reaction time for that stimulus was coded as missing, and the corresponding average reaction time per intersection or baseline was based on a lower number of stimuli. A reason for not having reacted within 2.5 s could either be not having noticed the stimulus or not having reacted quickly enough. In both cases, no attentional capacity was left to notice and or react to the stimulus in time. Had the stimulus been presented for a longer span of time, or had we waited for a longer period of time before considering the reaction time as missing, at last the participant would have reacted. Then, his reaction time would have exceeded 2.5 s. Therefore, we recalculated the average reaction times by replacing all missing reaction times by 2.5 s, regarding that reaction time (of 2.5 s) as an underestimation of the real reaction time (for a similar approach see Brouwer, 1985).

Baseline reaction times and fractions missed

Before focusing on the effects of intersection design, baseline reaction times and fractions missed of the different functional age groups were compared. For the first baseline measurement of workload (without driving), mean reaction times and fractions missed did not differ between the functional age groups (*Figure 6.2*). However, when participants had to combine the peripheral detection task with the primary task of driving on a straight road section (second baseline), differences emerged. While driving on a straight road section, functionally old participants had slightly higher reaction times and fractions missed than functionally young ($t(12) = -2.374$; $p = 0.036$ and $t(12) = -1.941$; $p = 0.076$ respectively (*df*s adjusted for unequal variances)) and functionally middle-aged participants ($t(10) = -2.502$; $p = 0.031$ and $t(10) = -2.274$; $p = 0.046$ respectively (*df*s adjusted for unequal variances)). This differential effect of adding a driving task to the peripheral detection task points at an interaction effect: all participants had higher reaction times and fractions missed when they had to combine the secondary task with the primary driving task, but the secondary task performance of the functionally older participants was affected the most (see *Figure 6.2*).

The existence of an interaction effect was confirmed by the results of mixed between-within analyses of variance (see *Table 6.4*). Between-subjects analyses of variance showed that functional age significantly affected baseline reaction times and fractions missed ($\eta^2 = 0.286$ and $\eta^2 = 0.243$ respectively; these partial eta's squared show the proportion of the variance in the dependent variable (reaction time and fraction missed respectively) that can be attributed to the independent variable in question (functional age)). Within-subjects analyses of variance showed that type of baseline measurement ($\eta^2 = 0.719$ and $\eta^2 = 0.375$ respectively) and the interaction of functional age and type of baseline ($\eta^2 = 0.220$ and $\eta^2 = 0.273$ respectively) also significantly affected reaction time and fraction missed.

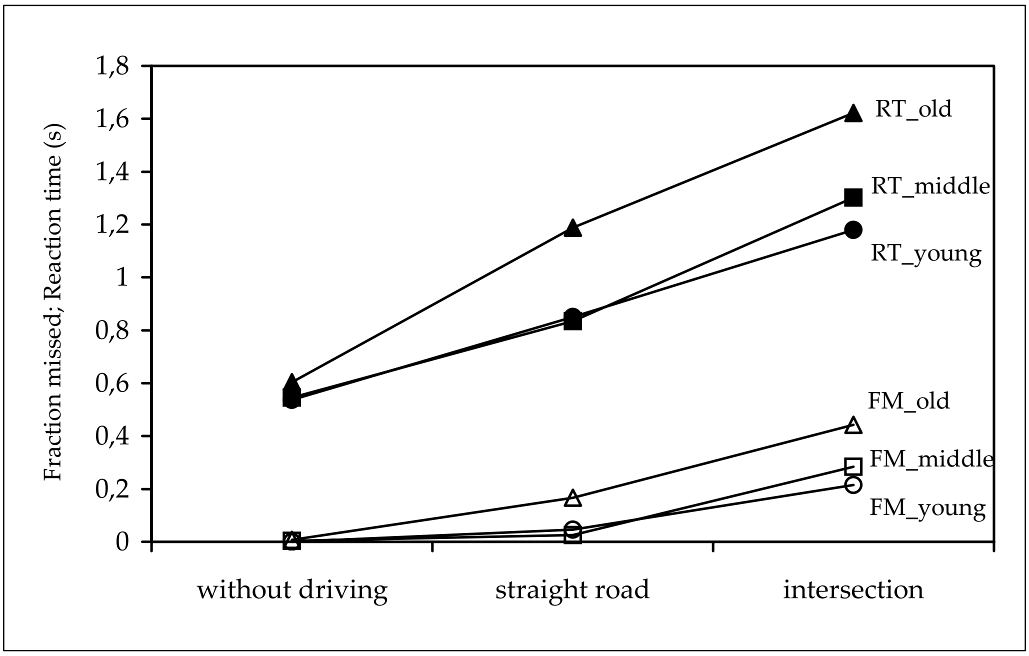

Figure 6.2. Reaction time and fraction missed per age group and time of measurement.

		PDT reaction time	PDT fraction missed
Functional age	*F* *df* *p*	7.205 2, 36 0.002**	5.792 2, 36 0.007**
Baseline	*F* *df* *p*	91.910 1, 36 < 0.000001**	21.558 1, 36 0.00004**
Baseline * Functional age	*F* *df* *p*	5.078 2, 36 0.011*	6.755 2, 36 0.003**
* p < 0.05; ** p < 0.01			

Table 6.4. Results of mixed between-within ANOVAs for two baseline measurements.

While passing intersections, mean reaction times and fractions missed increased further for all functional age groups (*Figure 6.2*). Differences between age groups, however, remained more or less the same. When considering the passing of intersections as being a third baseline, one that indicates the average difficulty of passing intersections regardless of the intersection design, mixed between-within analysis of variance showed results very similar to those in *Table 6.4*. However, when just comparing the second and third baseline measurements in a separate mixed between-within analysis of variance, the interaction effect of baseline and functional age was no longer significant. Generally speaking, the task of passing intersections was more difficult than the task of driving on a straight road section, and both tasks were more difficult for functionally older drivers than they were for functionally young en middle-aged participants. However, the increase in workload was the same for all functional age groups.

Effect of intersection characteristics on workload

To study the effects of intersection characteristics on workload, mean reaction times and fractions missed per intersection were averaged over intersections that were expected to be the same based either on (a) their priority regulation, (b) the driver's manoeuvre, (c) intersection layout, or (d) sight distance (see *Section 6.2.4*). *Table 6.5* shows the categories of each classification in the expected order of difficulty, with the easiest category at the top of each column and the most difficult category at the bottom.

Priority regulation (N_{int} = 28)	**Driver's manoeuvre (N_{int} = 23)**	**Intersection layout (N_{int} = 23)**	**Sight distance (N_{int} = 23)**
Right of way (n_{int} = 5)	Turn right (n_{int} = 2)	3-way intersection, left-side (┤) (n_{int} = 4)	Normal (n_{int} = 17)
Yield to approaching (n_{int} = 9)	Enter a roundabout (n_{int} = 2)	3-way intersection, right-side (├) (n_{int} = 3)	Restricted view (n_{int} = 6)
Yield to left (n_{int} = 4)	Turn left in front of approaching traffic (n_{int} = 9)	Roundabout (n_{int} = 2)	
Yield to all (n_{int} = 4)	Crossing without right of way (n_{int} = 4)	3-way intersection, T-junction (┬) (n_{int} = 4)	
Right-before-left (one side-street) (n_{int} = 3)	Turning left while crossing the street (n_{int} = 6)	4-way intersection, dual carriageways (n_{int} = 5)	
Right-before-left (two side-streets) (n_{int} = 3)		4-way intersection (n_{int} = 5)	

Table 6.5. Classifications of intersections (number of intersections per category).

The first category of priority regulation, right of way, is the only category that includes intersections at which participants had right of way. These intersections were excluded from the categories of the other intersection characteristics. As the need to decide on how to deal with other road users was expected to be an important prerequisite for complexity of the traffic situation to influence driver behaviour, having right of way was considered to be the easiest way of passing an intersection, regardless of the other characteristics of the intersection. Therefore, the category of right of way can be added to each classification as its first and easiest category.

Between-subjects analysis of variance showed that functional age significantly affected reaction time and fraction missed (See *Table 6.6 All intersections*; $\eta^2 = 0.265$ and $\eta^2 = 0.268$ respectively). Post hoc Bonferroni tests showed that functionally older participants had longer reaction times and higher fractions missed than both functionally younger ($p = 0.004$ and $p = 0.003$ respectively) and functionally middle-aged participants ($p = 0.017$ and $p = 0.019$ respectively). To test whether reaction times and fractions missed differed for different types of intersections, the categories of the intersection characteristics shown in *Table 6.5* were regarded as repeated measurements. Separate mixed between-within analyses of variance were carried out for each characteristic of the intersections. The results of all ANOVAs showed a significant main effect of functional age (see *Table 6.6*; Partial eta's squared ranging from 0.232 to 0.253 for reaction time and from 0.209 to 0.227 for fraction missed). The intersection characteristics significantly affected reaction times and fractions missed as well, except for sight distance. This intersection characteristic did not affect reaction time, but it did affect fraction missed.

The characteristic that had the largest influence on variation in reaction time, was intersection layout ($\eta^2 = 0.355$). Post hoc Bonferroni tests showed that left-side 3-way intersections – the intersections that were expected to be the easiest according to this characteristic – indeed led to significantly shorter reaction times than roundabouts ($p = 0.0002$), T-junctions ($p = 0.00002$) and 4-way intersections ($p < 0.000001$ for intersections with dual carriageways and $p = 0.000001$ for regular 4-way intersections). Only right-side 3-way intersections did not lead to significantly higher reaction times. On their turn, right-side 3-way intersections led to significantly shorter reaction times than T-junctions ($p = 0.04$) and 4-way intersections with dual carriageways ($p = 0.0002$), and both roundabouts and T-junctions led to significantly shorter reaction times than 4-way intersections with dual carriageways (p = 0.00001 and p = 0.02 respectively).

Intersection layout also had a large influence on variation in fraction missed (η^2 = 0.321), but the influence of intersection sight distance was slightly higher (η^2 = 0.337). As regards intersection layout, left-side 3-way intersections also led to significantly lower fractions missed than roundabouts (p = 0.006), T-junctions (p = 0.0003) and 4-way intersections (p < 0.000001 for intersections with dual carriageways and p = 0.00002 for regular 4-way intersections). Right-side 3-way intersections, roundabouts and T-junctions led to significantly lower fractions missed than 4-way intersections with dual carriageways (p = 0.0004, p = 0.000001, and p = 0.03). As regards intersection sight distance, intersections at which participants had normal view of cross traffic led to significantly higher fractions missed than intersections on which participants' view of cross traffic was restricted (p = 0.0001).

Interaction effects of functional age and intersection characteristics were not significant. Trends in reaction time and fraction missed were the same for all age groups (see *Figure 6.3*).

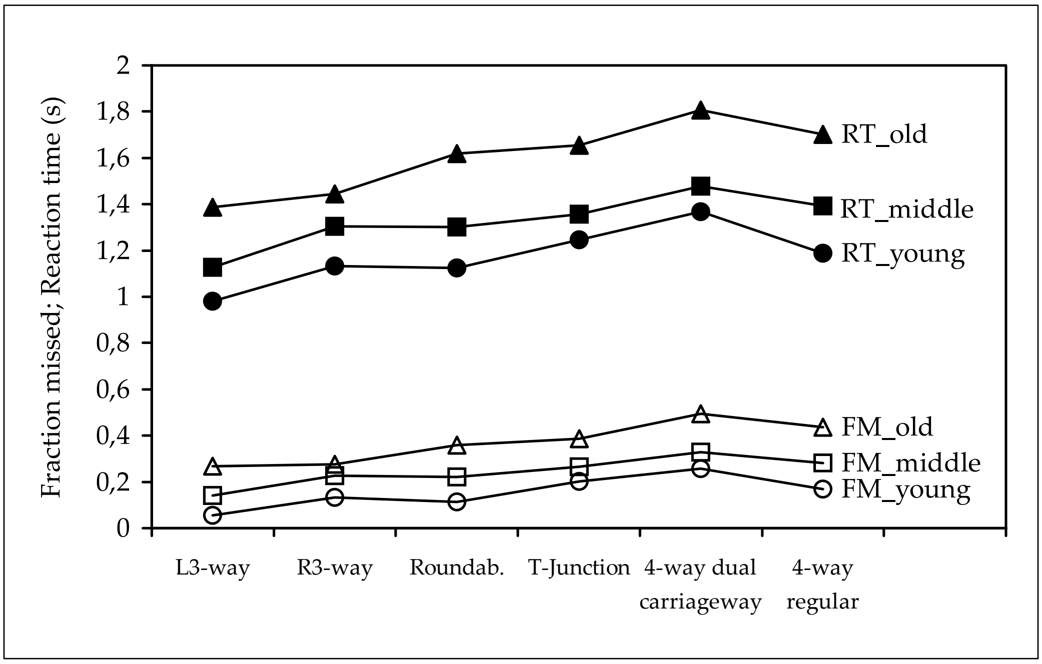

Figure 6.3. Reaction time and fraction missed per age group and intersection layout.

Intersection characteristic		Workload (pdt)		Safety of driver decisions	
		Reaction time	Fraction missed	Acc_Pre	Acc_Crit
All intersections					
Functional age	*F* *df* *p*	6.662 2, 37 0.003**	6.769 2, 37 0.003**	0.492 2, 37 0.615	0.566 2, 37 0.573
Priority regulation					
Functional age	*F* *df* *p*	6.085 2, 36 0.005**	5.298 2, 36 0.010**	2.583 2, 33 0.091	0.830 2, 36 0.444
Priority	*F* *df* *p*	3.008 4, 133[a] 0.024*	2.534 3, 124[a] 0.052*	16.204 2, 65[a] 0.000002**	47.091 3, 83[a] <0.000001**
Priority * Functional age	*F* *df* *p*	1.019 7, 133[a] 0.423	0.879 7, 124[a] 0.524	1.795 4, 65[a] 0.142	0.708 5, 83[a] 0.607
Driver's manoeuvre					
Functional age	*F* *df* *p*	5.595 2, 36 0.008**	4.760 2, 36 0.015*	0.739 2, 34 0.485	0.452 2, 36 0.640
Manoeuvre	*F* *df* *p*	5.466 3, 111[a] 0.001**	6.321 3, 99[a] 0.001**	23.226 3, 93[a] <0.000001**	57.757 2, 87[a] <0.000001**
Manoeuvre * Functional age	*F* *df* *p*	0.728 6, 111[a] 0.631	0.725 6, 99[a] 0.620	0.823 5, 93[a] 0.546	0.417 5, 87[a] 0.830
Intersection layout					
Functional age	*F* *df* *p*	5.955 2, 36 0.006**	5.205 2, 36 0.010*	1.960 2, 33 0.157	0.570 2, 36 0.571
Type of Intersection	*F* *df* *p*	19.806 5, 180 <0.000001**	17.026 5, 180 <0.000001**	17.171 3, 85[a] < 0.000001**	41.950 3, 124[a] <0.000001**
Type Int * Functional age	*F* *df* *p*	0.717 10, 180 0.708	0.726 10, 180 0.699	2.133 5, 85[a] 0.067	0.735 7, 124[a] 0.641

* p < 0.05; ** p < 0.01
[a] Greenhouse-Geisser epsilon adjustment for degrees of freedom was used

Table 6.6. Results of 2x3 repeated ANOVAs for different intersection characteristics.

Intersection characteristic		Workload (pdt)		Safety of driver decisions	
		Reaction time	Fraction missed	Acc_Pre	Acc_Crit
Sight distance					
Functional age	*F* *df* *p*	5.589 2, 37 0.008**	5.360 2, 37 0.009**	0.027 2, 37 0.974	0.752 2, 37 0.478
Sight	*F* *df* *p*	0.054 1, 37 0.817	18.781 1, 37 0.0001**	0.700 1, 37 0.408	13.025 1, 37 0.001**
Sight * Functional age	*F* *df* *p*	0.210 2, 37 0.811	0.912 2, 37 0.410	0.532 2, 37 0.592	0.388 2, 37 0.681
Combination of intersection characteristics and necessary manoeuvres					
Functional age	*F* *df* *p*	6.349 2, 36 0.004	5.630 2, 36 0.007	0.732 2, 34 0.489	0.630 2, 36 0.539
Combi	*F* *df* *p*	12.924 7, 252 <0.000001**	10.611 5, 176[a] <0.000001**	28.076 4, 143[a] <0.000001**	59.509 4, 146[a] <0.000001**
Combi * Functional age	*F* *df* *p*	0.843 14, 252 0.622	0.682 10, 176[a] 0.736	1.083 8, 143[a] 0.379	0.402 8, 146[a] 0.920
* p < 0.05; ** p < 0.01 [a] Greenhouse-Geisser epsilon adjustment for degrees of freedom was used					

Table 6.6 (continued). Results of 2x3 repeated ANOVAs for different intersection characteristics.

So far, intersection characteristics have been investigated in isolation of each other. As a result, intersections that were grouped together for the analysis of one characteristic, were sometimes split up for the analysis of another characteristic. As a matter of fact, some intersections were even 'easy' according to one characteristic and 'difficult' according to another (on an imaginary 6-point scale from very easy to very difficult). Of course, the effects of different intersection characteristics on workload cannot be looked at in isolation of each other nor in isolation of the manoeuvre the driver has to make at the intersection. To give an example, passing an intersection is probably easier when having right of way than it is when having to yield to cross traffic, and both are probably easier when driving straight ahead than when having to turn left at the intersection. To account for this interaction of intersection characteristics and manoeuvres, intersections were also grouped together according to the combination of characteristics that pertained to them, and the manoeuvre the driver had to carry out. For grouping purposes, intersections and the necessary manoeuvres were first scored on whether participants had to: 1) pay attention to other traffic participants before passing the intersection (yes/no), 2) think about what is left and right (yes/no), 3) turn the steering wheel (yes/no), and 4) turn in front of a traffic stream (0-3 streams). Total scores ranged from zero to six. Intersections were then grouped according to their total score. In order of difficulty (from very easy to very difficult), the resulting categories were (n_{int} = number of intersections):

- (IM1) Right of way ($n_{int} = 5$)
- (IM2) Yield to approaching traffic on a 3-way intersection while turning left (┤) ($n_{int} = 4$)
- (IM3) Yield to approaching traffic on a 4-way intersection while turning left ($n_{int} = 5$)
- (IM4) Enter a roundabout ($n_{int} = 2$)
- (IM5) Yield to traffic from the right while crossing an intersection ($n_{int} = 3$)
- (IM6) Cross a major road or turn right onto it ($n_{int} = 3$)
- (IM7) Turn left at a 3-way intersection (┬) ($n_{int} = 3$)
- (IM8) Turn left at a 4-way intersection ($n_{int} = 3$)

Again, mixed between-within analysis of variance showed that functional age significantly affected reaction time ($F(2, 36) = 6.349$; $p = 0.004$; $\eta^2 = 0.261$) and fraction missed ($F(2, 36)=5.630$; $p = 0.007$; $\eta^2 = 0.238$). Post hoc Bonferroni tests showed that functionally older participants had longer reaction times than functionally younger and functionally middle-aged participants ($p = 0.004$ and $p = 0.037$ respectively), and that their fractions missed were higher than those of functionally younger participants ($p = 0.006$).

The combined intersection and manoeuvre characteristics (*IM*) also significantly affected reaction time and fraction missed (see *Table 6.6*). However, the proportion of the variance in the dependent variables reaction time and fraction missed that can be attributed to this newly created variable ($\eta^2 = 0.264$ and $\eta^2 = 0.228$ respectively) is lower than it was for the previously described variable of intersection layout ($\eta^2 = 0.355$ and $\eta^2 = 0.321$ respectively). Moreover, results of the post hoc Bonferroni tests for the latter variable were more consistent with the expected difficulty of various intersection layouts (see third column of *Table 6.5*) than results of the post hoc Bonferroni tests for the combined intersection and manoeuvre characteristics were with their expected order. As a result, reaction times and fractions missed per combination of intersection characteristics and necessary manoeuvres (see *Figure 6.4*) did not show the gradually increasing lines which were established for reaction times and fractions missed per type of intersection layout (*Figure 6.3*).

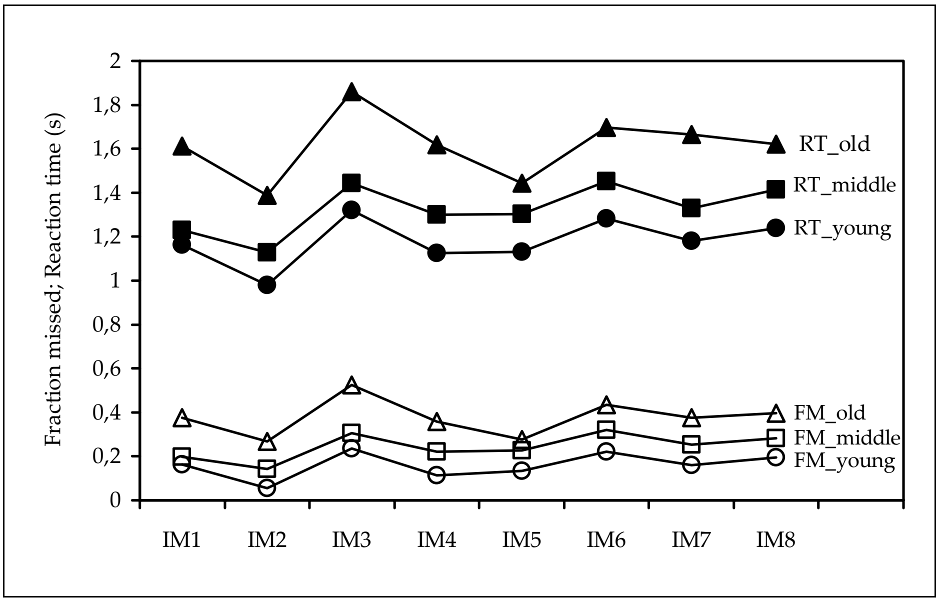

Figure 6.4. Reaction time and fraction missed per age group and intersection layout.

6.3.3. Safety of driver decisions

Having calculated the Acc_Pre and Acc_Crit per intersection (see *Data-sampling*), both measures were averaged over intersections that were expected to be the same based either on (a) their priority regulation, (b) the driver's manoeuvre, (c) intersection layout, or (d) sight distance. In addition, both measures were averaged over those intersections having the same combination of intersection characteristics and necessary manoeuvres (*IM*). Averaging Acc_Crit over several intersections resulted in values that varied between 0 and 1. The closer the value was to 1, the more often the participant had made an unsafe decision at that type of intersection. Average Acc_Pre had a wider range of values, with negative values indicating unsafe behaviour of the participant at that type of intersection, and positive values indicating safer behaviour. Note that the deceleration measures Acc_Crit and Acc_Pre were only calculated for intersections at which participants had to yield to other vehicles. At the same time, collection of data was not longer restricted to those intersections at which participants were confronted with a secondary task (i.e., PDT). As a result, the actual intersections used to measure workload and safety of driver decisions were not always the same.

However, intersections were expected to be exchangeable as long as they were identical according to the intersection characteristic being studied.

Between-subjects analysis of variance showed that functional age did not affect the average deceleration of relevant vehicles (i.e., those having right of way) at the moment participants started passing an intersection (Acc_Pre). The proportion of unsafe decisions per intersection type (Acc_Crit) was not affected by functional age either (see *Table 6.6*). Separate mixed between-within analyses of variance for the various intersection characteristics led to the same conclusion: age did not affect the safety of driver decisions. However, the various intersection characteristics did influence the degree of deceleration and the proportion of unsafe decisions (see *Table 6.6*). The only exception was *sight distance*. This intersection characteristic did not affect the average deceleration of relevant vehicles at the moment the participant drove off with the intention to pass the intersection, although it did affect the proportion of unsafe decisions (η^2 = 0.260). All other intersection characteristics had partial eta's squared ranging from 0.329 to 0.452 for deceleration values and ranging from 0.538 to 0.623 for proportion of unsafe decisions. The combination of intersection characteristics and necessary manoeuvres (IM) had the largest influence on variation in both proportion of unsafe decisions and deceleration of relevant vehicles. Post hoc Bonferroni tests showed that almost all types of intersections had significantly different proportions of unsafe decisions. Only IM2, IM6 and IM8 had similar proportions of unsafe decisions, and IM3 and IM5. The trends were, however, different from the ones expected beforehand. Three intersection types that were expected to be of medium difficulty (IM3 to IM5) turned out to be the ones that most often led to unsafe decisions. The intersections that were expected to be the most difficult (IM6 to IM8) only seldom led to unsafe decisions (see *Figure 6.5*).

This lack of correspondence between expected difficulty and safety of driver decisions could have been the result of an intersection classification that does not reflect the actual difficulty of passing the respective types of intersections. After all, analyses of workload data already showed that the results of post hoc Bonferroni tests for the combined intersection and manoeuvre characteristics did not correspond with the expected order of easy and difficult intersections (see *Section 6.3.2*). However, when comparing the proportions of unsafe decisions for intersections classified according to an intersection characteristic that turned out to be a better predictor of task difficulty (i.e., intersection layout) the same pattern emerged (see *Figure 6.6*).

The only types of intersections that had the same interrelationship for expected difficulty as well as for experienced workload and proportions of unsafe decisions were T-junctions and 4-way intersections with dual carriageways. The latter type of intersection was expected to be more difficult than the former, and also led to significantly higher reaction times, higher fractions missed, and higher proportions of unsafe decisions than the former ($p = 0.02$, $p = 0.03$ and $p = 0.001$ respectively).

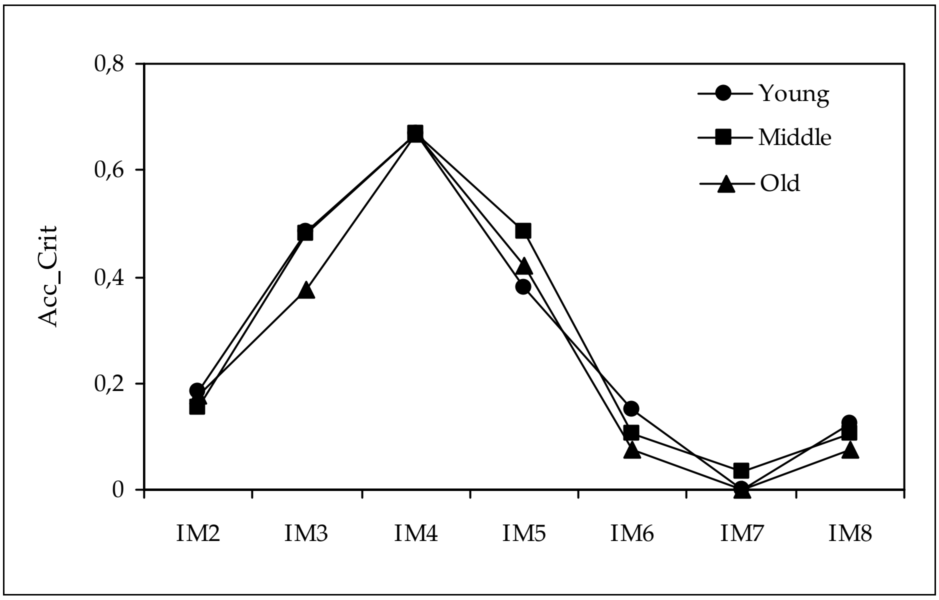

Figure 6.5. Proportion of unsafe decisions per age group and combination of intersection characteristics and necessary manoeuvres (IM).

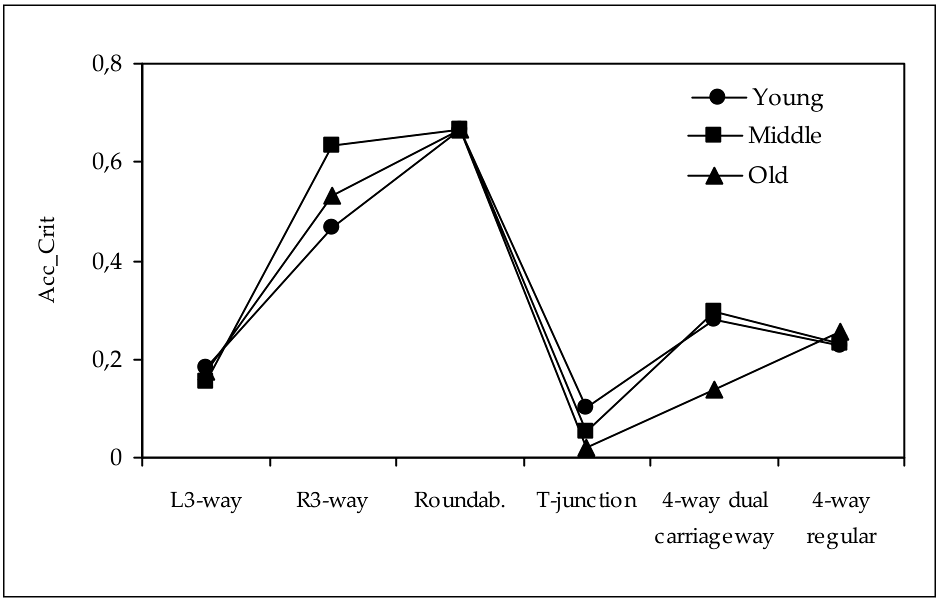

Figure 6.6. Proportion of unsafe decisions per age group and intersection layout.

Unsafe decisions can either lead to crashes or to near-misses. *Table 6.7* shows the number of crashes that actually occurred while participants were driving the simulator car, classified according to the layout of the intersection at which the crashes occurred. Note that there were twice as much functionally middle-aged drivers as there were functionally young or functionally old drivers. Most of the crashes occurred at regular 4-way intersections. A closer inspection of the specific intersections at which these crashes occurred, revealed that six out of seven of those crashes occurred at intersections that were controlled by traffic-lights. Some occurred because a participant turned left on green and collided against an approaching vehicle that also had a green light, others occurred because one of the drivers had passed a red light.

		L3-way	R3-way	Roundabout	T-junction	4-way dual carriageway	4-way regular
Crashes	Young	0	1	1	0	0	2
	Middle-aged	1	0	1	0	0	4
	Old	0	0	1	0	0	1
Route errors	Young	1	0	0	1	0	0
	Middle-aged	3	0	0	0	1	0
	Old	4	0	2	0	2	1

Table 6.7. Number of crashes and route errors per functional age group and type of intersection.

Another type of error that seemed to coincide with the complexity of the intersections, was route error. A total of 15 route errors occurred, 2 made by functionally young drivers, 4 by functionally middle-aged, and 9 by functionally older drivers (*Table 6.7*). Two intersections were responsible for half of these route errors. One of those intersections was actually designed to provoke route errors. It was a three-way intersection at which participants were not allowed to continue on the street they were driving on. They had to turn left, but this was not announced by the route-information. A sign indicating that it was not allowed to enter the street in front of them was the only clue that was available for participants to decide how to proceed (see *Figure 6.7, upper picture*). Four drivers missed this clue and drove straight on instead of turning left. The other traffic situation that misled four drivers, consisted of a major road having two intersections at only 50 m apart from each other (see *Figure 6.7, lower picture*). Participants had to turn left at the first one. However, some participants thought that the street at the left had dual carriageways. As a result, they drove along to the second street at their left-hand side.

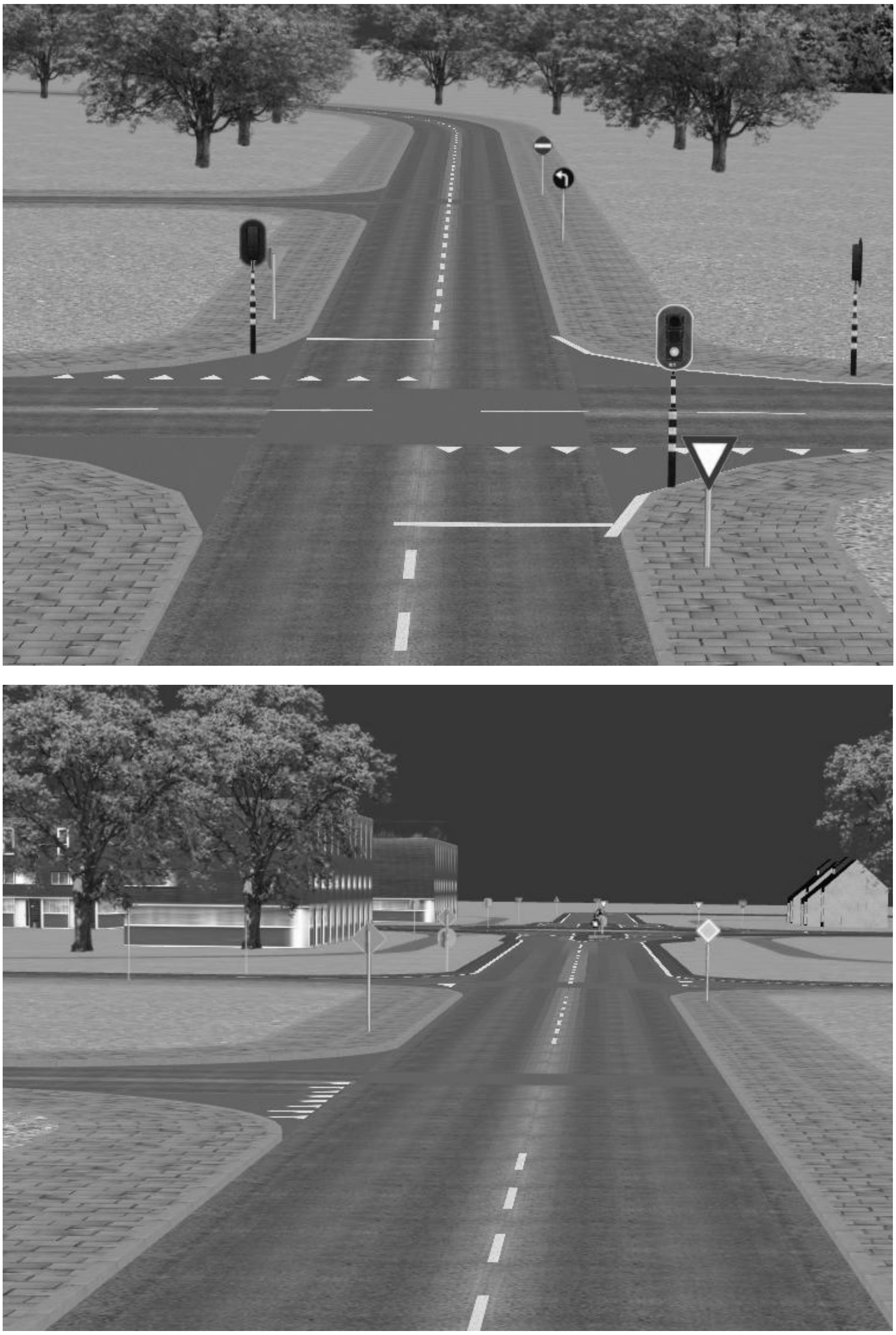

Figure 6.7. Examples of intersections which led to route-errors.

6.4. Discussion and conclusions

The aim of this study was to identify those intersection characteristics that have the largest impact on the difficulty of passing intersections, as indicated by driver workload and safety of driver decisions. A distinction was made between the performance of functionally young and functionally older drivers. The latter group of drivers was expected to have more difficulties passing complex intersections than the younger group. The complexity of an intersection was expected to increase with the number of streets and lanes it connects, and to be dependent on the type of priority regulation and the participants' view of the intersection.

6.4.1. Intersection characteristics

The results of this study showed that intersection layout, priority regulation, as well as driver manoeuvres influenced the difficulty of passing intersections. Intersection layout was the best predictor of variations in workload. Three-way intersections that only had a side-street at the left-hand side of the driver turned out to be the easiest intersections to pass, whereas four-way intersections with dual carriageways were the most difficult to manage. The abovementioned characteristics had the same effect on the workload of functionally young and functionally old participants. Functionally old participants had longer reaction times than functionally young participants, and an increase in the complexity of the intersections to pass led to longer reaction times for both functionally old and functionally young drivers. However, the difference between the reaction times of these age groups stayed the same (see *Section 6.4.2*).

The participants' view of the intersection did not affect workload as indicated by reaction times on a secondary task. However, this intersection characteristic did affect another indicator of secondary task performance, fraction missed. If buildings or trees obstructed the drivers' view of the intersection, drivers reacted to more stimuli than when their view of the intersection was not restricted. This may indicate that it is more difficult to pass intersections of which drivers have a good view while approaching it than it is to pass intersections at which buildings and/or trees obstruct the drivers' view of the intersection. However, as the participants' view of the intersection only affected fraction missed and not reaction time, the higher fractions missed which were found for intersections that were better visible may also have been the result of a larger amount of visual information. Having the opportunity to also look at cars and signs that are situated at the left and right side of the intersection, participants may have completely overlooked the stimuli that were presented at a more central location of the screen.

Results on the safety of driver decisions showed different trends for the difficulty of passing the various types of intersections. According to these data, turning left or right at a T-junction hardly ever led to unsafe decisions, whereas passing roundabouts and crossing three-way intersections with a side-street at the driver's right-hand side most frequently led to unsafe decisions. Considering the reputation of roundabouts as one of the safest types of intersections (Elvik, 2003; Elvik & Vaa, 2004; Ogden, 1996), these last results were unexpected. Moreover, these results were unexpected given the results on workload. Participants had shorter reaction times and lower fractions missed while passing roundabouts than while passing several other types of intersections.

This discrepancy between the results on workload and safety of driver decisions may have been caused by behavioural adaptation. Participants may have been less alert while passing 'easy' intersections and extra alert while passing 'difficult' intersections, thus being keener on avoiding errors at the latter. Another explanation for the unexpected results concerning safety of drivers' decisions lies in the collection of deceleration data (i.e., those data that were used to determine the safety of driver decisions). In this study, it was assumed that in case our participants failed to yield to vehicles that had right of way, the latter vehicles would decelerate to avoid a collision. However, with hindsight there may have been other reasons for them to decelerate. As a matter of fact, surrounding traffic also decelerated in case they had to take a bend. This other reason for decelerating, which was not related to the safety of participants' decisions, appeared to be more prevalent at some intersections than at others. At roundabouts, for example, a part of the surrounding traffic had route instructions that made them leave the roundabout at the same spot as where participants were about to enter the roundabout. As the intelligent surrounding traffic knows that it has to reduce speed to take a bend safely, those vehicles that had to leave the roundabout were decelerating for another reason than for the participant not yielding to them. Similarly, at three-way intersections with a side-street at the driver's right-hand side, all vehicles coming out of these side-streets were confronted with a T-junction at which they had to turn left or right and thus had to reduce speed. Unfortunately, it was not possible to eliminate the deceleration data of those vehicles that were decelerating because of a bend. Therefore, route instructions for surrounding traffic and the resulting speed reductions of these vehicles may have exaggerated the proportion of unsafe driver decisions at roundabouts and three-way intersections with a side-street at the driver's right-hand side.

6.4.2. Functional age

With regard to functional age it was found that functional age affects workload as soon as people start driving. The reaction times of drivers of different functional age groups were the same when they had to carry out a detection task while they were sitting in a parked simulator car. However, when performing the same task while driving, functionally old drivers had longer reaction times than both functionally young and middle-aged drivers. This can be attributed to the age-related increase in the cost of dividing attention (see e.g., McDowd, & Craik, 1988; McDowd, Vercruyssen & Birren, 1991; Salthouse, 1991). As traffic situations got more difficult, the workload of all drivers increased further. However, this increase in workload did not increase with functional age. An interaction effect was only established for the increased effort needed to combine the primary and secondary task. In that case, functionally old drivers experienced a higher increase in workload than young drivers did. Whereas functional age did affect workload, this age effect was not established for safety of decision making. All age groups appeared equally capable of deciding whether it was safe to cross or join other traffic streams.

The fact that functional age only affected workload and not safety of driver decisions, can be the result of three related things. First of all, it may indicate that our functionally older drivers were capable of adequately compensating for their increased reaction time. Another explanation may be that our simulator environment did not sufficiently put our drivers to the test. Perhaps task demand should have been higher to overask the capabilities of the functionally older driver and affect the safety of his decisions. On the other hand, our functionally older drivers may have been too young to find a safety effect of intersection design. After all, they were people who still drove on a regular basis and did not have considerable functional limitations. Therefore, it is recommended that future studies investigating the differential effects of intersection design on driver behaviour of older and younger drivers either include drivers with more severe functional limitations or confront drivers with traffic situations that are more difficult to pass.

Crashes in which older drivers are involved probably occur in traffic situations that are more difficult to handle. An essential element that makes these situations more difficult may be the fact that they trigger the wrong mental schemata. If a situation looks similar to a well-known situation but in fact is completely different and requires other actions for safely passing the intersection, mental schemata will work counterproductive. They will lead to the selection of inappropriate actions and will therefore make the task more difficult instead of making it easier. It would be interesting to check this assumption by evaluating the design of intersections at which many crashes occur in which older drivers were involved. The question to be asked would be whether there is something in the design of the intersection or in the design of the approaching streets that triggers mental schemata that do not fit the actual situation. The pilot study that was reported in *Section 5.2* has shown that such an exercise asks for a well-organized examination based on a structured list of elements that may trigger mental schemata. As a matter of fact, the examination could be considered to be the psychological version of a black-spot analysis or its proactive counterpart the road safety audit.

6.4.3. Limitations

There are a number of limitations of this study which should be mentioned. First, the proportion of unsafe driver decisions may have been affected by route instructions for surrounding traffic and the resulting speed reductions of these vehicles (see *Section 6.4.1*).

Second, the secondary task that was used for measuring workload could have measured more than that. One of the benefits of the introduction of a secondary task is that it indicates whether task difficulty indeed differed between various experimental conditions (see e.g., Teasdale, Cantin, Desroches, Blouin & Simoneau (2004), and Van Winsum, Martens & Herland (1999) for similar results on the effects of road design on secondary task performance). However, a secondary task can also distort the results of an experiment. The addition of a secondary task can, for example, influence the primary task (Kantowitz & Simsek, 2001). In the present study, this could have occurred as a result of visual distraction or interference with regular driving-related scanning behaviour and as a result of interference with steering behaviour. To prevent the former – participants paying too much attention to the area in which stimuli were going to be presented – we instructed participants to consider the task of driving as the most important one. If they saw one of the stimuli on the screen they should press the button, but otherwise they should pay attention to the traffic situation just the way they would in real traffic. To prevent the peripheral detection task from affecting steering behaviour, the button participants had to press was attached to the index finger in such a way that it did not interfere with the arm movements that are necessary for turning the steering wheel. However, there were some indications of reverse interference. It appeared that during difficult manoeuvres – turning right into a narrow road with cars lined up in the lane for traffic driving in the opposite direction – participants did not have any time left to press the button to indicate that they had seen the stimulus. As a result, secondary task performance may not only have reflected mental workload at these intersections, but also physical workload. Similarly, secondary task performance may not only have pointed at differences between participants' capabilities to cope with high workloads, but may also have pointed at differences between participants' motor abilities.

6.4.4. Conclusions

As this study showed that intersection characteristics are a good predictor of the difficulty of intersections, the difficulty of passing real-life intersections could be reduced by opting for those types of intersections which lead to lower workloads while passing them. That is, for example, 3-way intersections instead of 4-way intersections. Moreover, the presented data on the interaction effects of functional age and intersection design have confirmed that opting for intersections that are more easy to pass by older drivers will benefit all drivers. After all, intersections that were the most difficult to pass for older drivers were also the most difficult for younger drivers. Therefore, as suggested by Maycock (1997) and Holland (2001), adjustments to road design that help the older driver will benefit all. Every driver has his weak moments at which he is less capable of selecting the relevant information to interpret the traffic situation, either because of functional limitations, mental distraction or fatigue. Traffic situations that are less difficult in the first place, will reduce the negative safety effects of such suboptimal capabilities. Of course, measures regarding road design should not be considered in isolation. Other measures aimed at improving road safety, such as education to improve the driver and crashworthy vehicles to reduce injury severity, should accompany adjustments to road design (Davidse, 2000; Wegman & Aarts, 2006).

7. Advanced driver assistance systems that fit the needs of the older driver[7]

Based on the earlier identified weaknesses and their relevance to road safety, it was concluded that to have the most potential to improve the road safety of older drivers, advanced driver assistance systems (ADAS) should: a) draw attention to approaching traffic, b) signal road users located in the driver's blind spot, c) assist the driver in directing his attention to relevant information, and/or d) provide prior knowledge on the next traffic situation. Systems that appear to provide one or more of these kinds of support are: 1) collision warning systems aimed at intersections, 2) automated lane changing and merging systems, 3) reversing aids, 4) in-vehicle signing systems, 5) intelligent cruise control, and 6) a system that gives information on the characteristics of complex intersections the driver is about to cross. This chapter describes these systems based on what they do, what their advantages and disadvantages are, whether they are already on the market, whether they have been tested by older drivers, and if so, what effects the systems had on driving behaviour. In addition, it discusses what the preconditions are for these ADAS to actually improve road safety. It is concluded that conclusions cannot be drawn yet about whether certain ADAS can improve the safety of older drivers. Although systems have been developed that appear to fit the needs of the older driver, many are still being developed and not much research has been done on user acceptance and the effects on road user behaviour.

7.1. Introduction

Starting from the needs for support that were identified at the end of *Chapter 4*, this chapter discusses advanced driver assistance systems (ADAS) that may be able to provide the desired types of support. As the needs for support were based on the functional limitations of older people and their relevance to road safety, driver assistance systems that provide the desired types of support are considered to be the systems that have the most potential to improve the safety of older drivers. *Section 7.2* discusses these systems.

The mere fact that an advanced driver assistance system provides one or more of the desired types of support is, however, not enough to actually improve the safety of the older driver. Other aspects of the assistance system,

[7] This chapter was based on chapter 4 of SWOV report R-2003-30 (Davidse, 2004a). Various parts of this chapter were published in IATSS Research, 30(10), 6-20 (Davidse, 2006), and presented at the first HUMANIST conference on driver needs (Davidse, 2004b) and at the International Conference on Transport and Traffic Psychology ICTTP in Nottingham (UK) (Davidse, 2004c).

such as user acceptance and design of the human machine interface are equally important. These aspects are dealt with in *Section 7.3*.

This chapter closes of with an evaluation of the merits and demerits of currently available ADAS as means to improve the safety of older drivers (*Section 7.4*).

7.2. Evaluation of ADAS

Several studies have mentioned ADAS that might be able to provide tailored assistance for older drivers (see for example Bekiaris, 1999; Färber, 2000; Mitchell & Suen, 1997; Shaheen & Niemeier, 2001). In this section, the focus will be on those ADAS that fit the needs as identified in *Section 4.6*. The desired functionalities that were listed in that section are summarized in *Table 7.1*, followed by the driver assistance systems that appear to incorporate them. In the next paragraphs, each of these systems will be described based on what they do, what their pros and cons are, whether they are already on the market, whether they have been tested by older drivers, and if so what the results of these tests were[8].

Desired functionality	**ADAS**
Draw attention to approaching traffic	- Collision warning systems aimed at intersections - Automated lane changing and merging systems
Signal road users located in the driver's blind spot	- Automated lane changing and merging systems - Blind spot and obstacle detection systems
Assist the driver in directing his attention to relevant information	- In-vehicle signing systems - Special intelligent cruise control
Provide prior knowledge on the next traffic situation	- Systems that give information on the characteristics of complex intersections the driver is about to cross

Table 7.1. Desired functionalities and ADAS that appear to offer them (adapted from Mitchell & Suen, 1997).

[8] This section describes the situation as it was in 2004.

7.2.1. Collision warning systems for conflicts at intersections

Collision avoidance systems that would be most useful for older drivers will draw the attention of the driver to traffic that approaches the same intersection. Such a collision warning system fits the most important driving difficulty of older drivers: turning left at an intersection. However, intersections also represent the most complex situation to analyse for collision detection, since vehicles can approach from ahead or either side, and can continue straight through the intersection or turn. Consequently, Mitchell and Suen (in 1997) expected equipment to protect against collisions on intersections to take the longest time to develop.

By now, the Japanese Ministry of Land, Infrastructure and Transport has tested a prototype of a system that seems to offer the desired functionalities. The system that was tested is the so-called "Smart Cruise System" (also known as the Advanced Cruise-Assist Highway System AHS), a system that offers seven support services, among which a support system for prevention of crossing collisions and a support system for prevention of right turn collisions (in Japan one drives on the left side of the road). All services were tested separately on a proving ground, amongst others paying attention to safety effects and the convenience for users (Ministry of Land, Infrastructure and Transport, 2002). The effectiveness of the two abovementioned services that would be particularly useful for older drivers was verified by means of a questionnaire. The support for prevention of crossing collisions was found useful by 73% of the users, and the support for prevention of right turn collisions was found useful by 88% of the users (Mizutani, 2001). New tests in 2002, which were aimed at examining the technical feasibility of real-world implementation of the AHS subsystems for support at intersections, showed that problems occurred in the detection of vehicles and in the road-to-vehicle communication. Future research will therefore focus on the reallocation of functions to the infrastructure and the vehicle (Mizutani, 2003).

Another collision warning system that has been tested and that was aimed at the prevention of crashes on intersections, was developed for the DRIVE-II-project EDDIT (Elderly and Disabled Drivers Information Telematics). This system was simulated and tested in a driving simulator. It provided the driver with a colour light indication of whether the next gap in the stream of traffic was long enough to allow a safe turning manoeuvre to be made. If the gap was at or longer than a selected threshold of 6 seconds, a green light indicated that it was safe to make a turn, otherwise the light changed to red. It remained red until the on-coming vehicle passed the test car, whereupon the device measured the gap to the next vehicle in the on-coming traffic stream. The collision warning system was only active when the test car was stationary and waiting to turn (Oxley & Mitchell, 1995).

The safety effects of the simulated system were inferred from time to collision. The test results showed that time to collision was smaller when subjects were using the system than when they were not. So the system resulted in more near misses. Apparently, the system sometimes advised older drivers to accept a gap that was shorter than the ones they would choose. The time needed to make the turn could play a role here; some drivers made their turning manoeuvre relatively slowly. Based on these results, Oxley (1996) recommends that a collision warning system should have the gap adjustable to match individual driver requirements (e.g., reaction times): uniform settings would be at best unhelpful, at worst dangerous.

All the older participants said that they found the system useful or very useful at night. By day, 63% of the older drivers found it useful or very useful. At the same time, two thirds of the participants considered the information provided by the warning system to be incorrect. Gaps that were safe according to the system were regarded as unsafe and vice versa. Nevertheless, over one third of the participants indicated that the system would make them more confident. Only one participant indicated that he would probably drive more having the system installed. About half of the older drivers would be willing to pay for the system (Oxley & Mitchell, 1995).

Dingus, Jahns, Horowitz and Knipling (1998) argue that crashes at intersections are the result of not noticing crossing vehicles, and not of misjudging the safety of gaps to join or cross. From this point of view, informing the driver about safe gaps to join would not be the most effective way of preventing crashes at intersections. After all, the system that was evaluated in the EDDIT-project was only active when the test car was stationary and waiting to turn, and not when the driver was under the impression that there was no traffic at the intersecting street and kept on driving. Therefore, it is expected that the type of collision warning system that only indicates that traffic is approaching the intersection will have greater positive road safety effects than a system that indicates that it is safe to cross.

7.2.2. Automated lane changing and merging

Equipment for automated lane changing and merging will assist the driver in selecting a gap and also take care of the actual changing or merging. These systems go further than just informing or warning the driver: they take over vehicle control for a short period of time. Such kind of support is currently not available (Kobayashi, Yuasa, Okamoto, & Horii, 2002). Mitchell and Suen (1997) expected these systems only to be available between 2010 and 2030.

A simplified form of assistance for lane changing and merging is being offered by collision warning systems. Regan, Oxley, Godley, and Tingvall (2001) discuss lane-change collision warning (LCCW) systems and lane-change collision and avoidance (LCCWA) systems. As their names already suggest, the first system only alerts the driver to objects in the vehicle's blind zones, whereas the second system also automatically steers away from the object. In this respect, the latter comes closer to automated lane changing and merging systems. According to Regan et al., only LCCW systems are currently available on the market.

Evaluation studies of the use of LCCW systems by older adults are not available yet (Regan at el., 2001). In general, LCCW systems have several disadvantages, such as high false alarm rates and the close lateral proximity of vehicles that makes it hard for a driver to safely steer away from an object after being warned by the system (Dingus, Jahns, Horowitz & Knipling, 1998).

7.2.3. Blind spot and obstacle detection

The LCCW systems that were described in the previous section alert the driver for vehicles located in the blind spots of their own vehicle while driving at high speeds. A type of system that provides a similar kind of support, detects objects close to a slow-moving vehicle. These systems can prevent the kind of crashes that can occur while parking. In comparison to the other crash types, this type of crash has less relevance for road safety, both in terms of occurrence and crash severity. However, older adults may be inhibited from driving because of these crashes or from travelling to certain destinations because of the problems they will experience while parking.

In the EDDIT-project that was mentioned earlier, two types of reversing aids were tested. Both reversing aids used sensors that were attached to the rear bumper. These sensors determined the presence of any objects behind the car, and their distance to the rear bumper. This distance was shown to the driver by means of coloured lights (red, amber and green) that were attached either to the dashboard or the shelf (visible in the rear-view mirror). The red light turned on if the object was closer than 0.5 m. One of the systems also had a warning tone that accompanied the light signal if the object was closer than 1 m.

Both reversing aids enabled the older drivers to park much closer to objects and therefore to park more easily in small parking spaces. In terms of safety effects, differences between driving with and without the reversing aids were small. During the first attempts to drive with the reversing aids, the number of collisions was higher than before (i.e., driving without the system installed). However, these collisions could be attributed to getting used to the system.

The older drivers' responses to both reversing aids were very positive. The majority found them useful and easy to use. The majority of the drivers was also willing to pay for the systems. The price they were willing to pay matched the market price of the systems (Oxley, 1996). Some improvements of the systems that the drivers would like were: detection of objects next to the car (in addition to objects behind the car), and a (louder) warning tone to accompany the light signal (Oxley & Mitchell, 1995).

7.2.4. In-vehicle signing systems

The projection of road signs in the vehicle uses the technology of transmitting the content of a road sign from the roadside to a vehicle and of displaying a replica of the sign, either on a screen in the dashboard or via a head up display. That way, the driver's attention will be drawn to the (most important) available signs, the signs can be read more easily, and they will be available for a longer period of time. According to Mitchell and Suen (1997), a drawback of these systems is that widespread application will require national or international standards for the transmission of roadside information, and considerable investment in road side transmitters.

Another drawback of in-vehicle sign information system (ISIS), is that they tend to focus the driver's attention to in-vehicle displays and away from the roadway (Lee, 1997). According to Lee, the ease of processing ISIS information may compensate for this shift in attention, particularly since ISIS displays will not be subject to environmental factors (rain, snow, and fog) that can obscure roadway signs. However, a greater proportion of the driver's attention will now be in-vehicle, potentially leaving insufficient attention for environmental scanning. Due to the functional limitations of the older driver, especially their increased difficulty to divide attention between the basic driving task and other activities, ISIS could have more adverse effects on the older adult's driving behaviour. The location of the in-vehicle display and the way the information is provided are important factors as to whether the safety effects of the in-vehicle signs and warnings will be positive or negative (Luoma & Rämä, 2002; Pauzié, 2002; Perel, 1998; Stamatiadis, 1998).

Luoma and Rämä (2002) have carried out a study in which they tested an information system that presents a selection of the road signs on a display in the vehicle. The signs that were presented to the driver referred to the speed limit, children, and cyclists. Each new sign was preceded by a warning tone. The presented information was offered in four different ways: a) a picture of the sign, b) a picture of the sign combined with an auditory description of the meaning of the sign, c) a picture of the sign combined with auditory feedback based on driver behaviour, or d) a picture of the sign combined with a complete instruction of what the driver is supposed to do (e.g., reduce speed and mind cyclists) for all drivers. The information system was built into an instrumented vehicle. Participants had to cover a route four times with this car. Every time they drove the route they received the information in another way. The order in which the different ways of presentation were offered to the participants was the same for each participant (i.e., no counterbalancing). The route they had to follow was indicated by a navigation system that was part of the same information system. At the end of the experiment, participants were asked to rate the usefulness of the presented information, to rate the effectiveness of the information compared to conventional signing, and to indicate whether they would buy the system if it would present the information in the way they preferred.

As regards the usefulness of the different elements of the information system, participants rated the navigation function, the visual presentation of the signs, and the warning tone very useful. The presentation form that was rated the highest was the sole use of a picture (a), followed by a picture with driver-oriented feedback (c). Participants were in general the least positive about the picture that was combined with a complete instruction about what to do (d). Older participants (aged 59-86) were, however, more positive about this presentation form than younger participants (aged 18-23).

Eighty-nine percent of the participants were of the opinion that the information system increased the effect of traffic signs and improved traffic safety. On the other hand, many participants reported driving problems while using the system. The most frequently reported problems included unintentional speed reductions and late detection of other road users, vehicles or obstacles on the road. Effects on general driving behaviour were not investigated in this study.

When participants were asked to indicate whether they would be willing to buy a system that presented the information in the way they preferred the most, 75% of the participants indicated that they would. The price they were willing to pay for the system varied from 34 to 504 Euro, with an average of 200 Euro. Older participants were less willing to pay for the system. Whereas all younger participants were willing to pay for the system, only half of the older participants were, and they would also pay less for the system than the younger participants would.

7.2.5. Intelligent cruise control

Systems that offer intelligent cruise control (ICC) (also known as Adaptive Cruise Control (ACC)) not only see to it that the vehicle maintains the same speed, but also incorporate a distance keeping function. Depending on the type of ICC, the system will alert the driver or take over the control of the brakes and the accelerator (see e.g., Hoetink, 2003). Mitchell and Suen (1997) describe a type of ICC that would also reduce speed in response to signals from the road environment. Examples of such signals would be the local speed limit, yield signs, a red traffic light, or a railway crossing. Systems that adapt the speed of the car in response to the local speed limit belong to the category of Intelligent Speed Adaptation (ISA). These systems do not specifically fit the needs of the older driver. However, a system that anticipates the presence of yield signs, stop signs, and/or traffic lights by reducing speed, may contribute to the prevention of an error that is connected with the crash involvement of older drivers: not yielding. The reduced driving speed offers the driver more time to assess the traffic situation and to act accordingly. These systems can be considered as a special type of ICC. Examples of such systems have been developed as part of the research initiative INVENT and will be tested in the PReVENT Project INTERSAFE.

7.2.6. Driver information systems

Entenmann and Küting (2000) have described a system that gives the driver information about the intersections that he is about to cross. This information system is a navigation system that not only gives route descriptions, but also provides timely information on the crucial elements of the next traffic situation. By giving the driver very early and sequential information, the driver will be able to build up a mental picture of what to expect, at a moment at which his workload is still low. This mental picture will give him the possibility to direct his attention to the most important traffic elements. Given their functional limitations as described in *Chapter 2* and *4*, a support system that provides this kind of information could be especially useful for older drivers. In fact, the driver information system was actually designed for this group of drivers.

The system proposed by Entenmann and Küting (2000) was only supposed to provide information if the driver arrived at complex intersections. The complexity of intersections was to be derived from the number of traffic lanes, the number of traffic signs and signals, and the yearly number of crashes on the intersection. The information that is provided by the driver information system should be restricted to an indication of the complexity of the intersection, the number of traffic lanes and the traffic objects that deserve attention (e.g., a pedestrian crossing). Since digital maps do not contain this kind of information, Entenmann et al. (2001) carried out a pilot-study to explore the possibilities of adding the abovementioned information to digital maps. This pilot-study was carried out in the framework of the NextMAP project, a partnership of map providers and car manufacturers. It turned out that it was technically feasible to collect and digitise the information that was needed.

As part of the same pilot-study, Entenmann et al. (2001) also carried out a field test to investigate the user acceptance of this kind of driver information system and its effects on driving behaviour. The device that was actually used in this test, supported the driver in adjusting the vehicle speed to the speed limit, in selecting the appropriate lane, and in negotiating intersections. The published test results state that “the information about lanes, speed limits and priority regulations was very beneficial for the driver in demanding urban traffic situations and was very well accepted. The additional information eases the driving task significantly and increases driving safety compared to a standard navigation system" (Entenmann et al., 2001).

7.3. Preconditions for safe use of ADAS

Knowing which types of ADAS have the most potential to improve the safety of older drivers is not enough to actually improve their safety. The systems will have to be accepted by the user, they will have to be bought, used and trusted, the driver has to be able to understand the information the ADAS is sending to him (via a display or sound), in case more than one ADAS is installed in a car the systems should work together instead of fighting for the attention of the driver and giving him conflicting information, and the support provided by the system(s) should not have any negative safety consequences on other elements of the driving task nor on the behaviour of other drivers. All these preconditions will be dealt with in the next paragraphs.

7.3.1. User acceptance

The results of the EDDIT-study showed that the older drivers that participated in this study were to a large extent willing to consider using and buying the devices that were tested. Moreover, the amount of money they were willing to pay was roughly the same as the market price of the various devices. These findings are consistent with the results of a survey on the purchase behaviour of older adults when buying a car. This survey showed that older adults in general buy smaller cars. However, the cars they buy have more extras than the cars that younger drivers buy. It turns out that older adults are willing to pay for extras such as power steering and electric window control under the condition that these extras meet an existing need (Oxley & Mitchell, 1995).

In a Swedish study (Viborg, 1999), similar results were found. When asked about their attitudes towards 15 in-car information systems, older drivers (65 year olds and older) had a more positive attitude towards the presented ADAS than younger drivers (30-45 year olds). Systems that older adults more often rated as useful as compared to younger drivers, were automatic speed adjustment systems (adjustment to the speed limit or to slippery and foggy conditions), automatic distance adjustment systems, a system that warns the driver by a signal when it is unsafe to cross an intersection, and a system that warns the driver when it is unsafe to turn left at an intersection. Since the first two systems (partly) take over vehicle control, it seems that older drivers are more willing to accept enforcing systems.

De Waard, Van der Hulst, and Brookhuis (1999) arrived at the same conclusion based on the results of their simulator study on the behavioural effects of an in-car tutoring system. In this study, drivers received auditory and visual clues when they were speeding, not coming to a stop before a stop sign, running a red light, or entering a one-way street on the wrong side. Older (60–75 year olds) as well as younger drivers (30–45 year olds) committed fewer offences when the system gave feedback messages. However, whereas the older participants were pleased with the messages, the younger participants disliked the system.

The abovementioned research results on user acceptance indicate that it is likely that the ADAS that were discussed in the previous sections will be accepted by older drivers as a means to improve their safety. However, whether the introduction of one of these systems will actually result in a reduction of the number of crashes will also be dependent on the design of the particular system.

7.3.2. Design principles for the human machine interface

Older drivers are more susceptible to the consequences of poorly defined ADAS than younger drivers (Stamatiadis 1994; cited in Regan et al., 2001). They generally need more time to carry out secondary tasks while driving (Green, 2001a). Hence it is critically important to bear in mind the possibilities and limitations of older drivers while designing the human machine interface for ADAS (Regan et al., 2001). There are several reports available that describe the current guidelines (see Green (2001b) for an overview). Caird, Chugh, Wilcox, and Dewar (1998) have summarized these guidelines and in addition to that included a section on older driver guidelines. The latter design guidelines are summarized in *Table 7.2* along with the functional limitations of older adults they take into account. Note that these functional limitations include those which were mentioned in *Table 4.2* of *Section 4.6* as being important to take into account while designing human machine interfaces for driver assistance systems (DESIGN).

Functional limitations	Relevant design principles
General sensory deficits	Use redundant cues, like auditory, visual and tactile feedback
Visual acuity	Increase character size of textual labels
Colour vision	Use white colours on a black background
Night-time visual acuity	Use supplemental illumination for devices used in low-light conditions
Sensitivity to glare	Use matt finishes for control panels and antiglare coating on displays
Hearing	Use auditory signals in the range of 1500-2500 Hz range
Contrast sensitivity and motion perception	Where depth perception is important, provide non-physical cues, such as relative size, interposition, linear position and texture gradient
Selective attention	Enhance the conspicuousness of critical stimuli through changes of size, contrast, colour or motion
Perception-reaction time	Give the user sufficient time to respond to a request by the system and provide advanced warnings to provide the driver with enough time to react to the on-coming traffic situation
Hand dexterity and strength	Use large diameter knobs, textured knob surfaces and controls with low resistance

Table 7.2. Functional limitations and relevant design principles (based on Caird et al., 1998 and Gardner-Bonneau & Gosbee, 1997).

Whereas the guidelines in *Table 7.2* all have been selected based on the older adult's functional limitations, it should be kept in mind that designers should also take advantage of the experience that older drivers have. This can be accomplished by using features that are common to them, such as traffic-related icons or features that are common to other products used by older adults (Gardner-Bonneau & Gosbee, 1997).

7.3.3. ADAS that work together

So far, various ADAS have been discussed in isolation; while describing the working of the various systems as well as while discussing their effects on driving behaviour. However, the installation of several systems in one car might introduce new problems. It might lead to several displays in the car fighting for the attention of the driver. The driver will have to divide his attention over the various displays, leading to an observation task that is more complex. Older drivers will suffer the most from that, since age differences become more evident as tasks are becoming more complex. This will result in longer reaction times (see e.g., McDowd & Craik, 1988; Stelmach & Nahom, 1992). Simultaneously sent messages will increase the pressure on the driver even further. In sum, the presence of several, independently functioning systems increases workload, leading to an effect in the opposite direction of what was the objective of the implementation of the ADAS: reducing workload.

Some sort of coordination between the installed ADAS might overcome these difficulties (ETSC, 1999). In addition, it can also prevent systems to send conflicting instructions or, even worse, to carry out conflicting actions. The coordination between systems can be implemented in different ways. Heijer et al. (2001) suggested that ADAS should support the driver in a set of problematic situations instead of separate ADAS that each support the driver in a different situation. Another way of implementing coordination between ADAS uses mediation by a system that decides when which system is allowed to pass what kind of information in what kind of way. Several examples of mediators have been described in the literature (Färber & Färber, 2003; Montanari et al., 2002; Piechulla et al., 2003; Vonk, Van Arem & Hoedemaeker, 2002; Wheatley & Hurwitz, 2001). Most of the mediators use an algorithm to decide whether the workload of the driver is low enough to allow him to receive information from one of the connected systems. Car data (e.g., driving speed, use of steering wheel, use of windscreen wipers, use of headlights) form the input for the algorithm. Dependent on the corresponding level of workload (low, medium or high) and the importance ascribed to the systems that want to inform the driver (e.g., safety system, route information, telephone call), the algorithm does or does not directly pass on the information that has been sent by one of the systems installed. Messages that are not important enough to be passed on directly will be put on hold. Ideally, all messages will be sent to the same display.

7.3.4. Side-effects: human-out-of-the-loop and behavioural adaptation

The ultimate goal of ADAS – in the scope of this thesis – is to improve the safety of the older driver. This not only means that the supported (sub)task should be executed more safely, it also means that the support given should not have any negative safety consequences on the other elements of the driving task. Possible side-effects that are mentioned in the literature are "human-out-of-the-loop", disturbances in the construction of situation awareness and behavioural adaptation (see for example Hoc, 2000).

Human-out-of-the-loop

The driving task can be seen as a continuous cycle of perception, decision making and action. Each cycle, the driver selects the information that he needs to perform his task, he evaluates the selected information using his knowledge, experience, preferences and emotions, and acts accordingly, thereby changing his environment. Subsequently, these changes can be observed, which closes the loop: there is a dynamic interaction between the driver and his environment (Michon, 1989). If a part of the driving task is taken over by some ADAS (i.e., some part of the task is automated), the driver can be put out of the loop. This can lead to various consequences: loss of skills, reduced alertness and loss of situation awareness, and the transition from a driver who carries out the work himself to a driver who supervises the system. Unfortunately, humans are not as good at supervising as they are at carrying out the actions themselves (Carsten, 2000; Endsley & Kiris, 1995; Wickens & Hollands, 2000).

The negative consequences of automation of the driving task can be prevented by letting the ADAS support the driver instead of replacing him (Heijer et al,. 2001). Whereas Endsley and Kiris (1995) have shown that complete automation of a task leads to a loss of situation awareness, Heijer et al. argue that the implementation of supportive ADAS would improve the situation awareness of the driver, especially by improving the perception of the driver. Besides that, the use of supportive systems will preserve the skills of the driver, which is especially important in case of system failure (Heijer et al., 2001; Janssen, 2000; see Shebilske, Goettle & Garland [2000, p. 317] for a theoretical underpinning).

Behavioural adaptation

Another factor that may influence the risk reduction that can be expected as a result of the introduction of a support system, is behavioural adaptation. The phenomenon of behavioural adaptation implies that people adapt their behaviour to some of the improvements of a system by taking larger risks (See Dragutinovic, Brookhuis, Hagenzieker, and Marchau (2005) for an overview of the behavioural adaptation effects in response to Advanced Cruise Control). The term behavioural adaptation originates from Evans (1991), but the phenomenon is also known under the terms risk compensation and risk homeostase (Wilde, 1982). According to Howarth (1993), risk reductions are more likely to be achieved if the safety measures that are implemented are not directly associated with risk reduction and if warning systems give clear and timely warnings about situations and actions that are really risky. The opposite scenario could lead to increased risks: speed limits that are so cautious that they are ignored can result in drivers also ignoring warning signs that actually do indicate a real danger.

Taking larger risks is not the only form of behavioural adaptation that can accompany the introduction of safety measures. Other forms of behavioural adaptation (or modification) that are described in the literature are generalization of behaviour, delegation of responsibility and diffusion of behaviour (Broughton, 1994). *Generalization of behaviour* means that behaviour that is suitable in certain situations is also displayed in situations in which it is not suitable. For example, infrastructure-based ITS which allow drivers on certain roads to drive at a constant, high speed for a long period of time (in a train of cars), can make normal speeds at regular roads look like a snail's pace. As a result, speeds at the latter roads will also increase (Broughton, 1994; Janssen, 2000).

Delegation of responsibility means that the driver's trust in a driver assistance system is so big that he becomes less attentive. In combination with a restricted understanding of what the system does and does not do, this may cause the driver to also rely on the system in situations in which the system does not work (either because the current task does not belong to its functionalities or because the system fails). It is clear what the road safety consequences will be if a traffic situation asks for a reaction, the driver assistance system cannot interfere, and the driver does not realize that he himself has to react or realizes this too late because he is not alert enough. Stanton and Marsden (1997; cited in ETSC, 1999) have demonstrated the reality of this scenario in a simulator study: more than half of the participants were not capable of reacting effectively after a simulated collision warning system failed.

The last form of behavioural adaptation, *diffusion of behaviour*, refers to the imitation of the behaviour of other drivers. An example of diffusion of behaviour is that the behaviour that is shown by drivers that have a certain system installed in their car (e.g., short gaps, high speeds) is being imitated by drivers that do not have the system at their disposal (ETSC, 1999).

A form of behavioural adaptation that could arise among older adults, is *withdrawal of compensation behaviour*. This can be illustrated by the introduction of vision enhancement systems. Older drivers generally compensate for their impaired night-time visual acuity and sensitivity to glare by avoiding to drive at night. As a result, the number of crashes involving older drivers at night is relatively low (Aizenberg & McKenzie, 1997; Hakamies-Blomqvist, 1994b, 1994c; McGwin & Brown, 1999; Zhang et al., 1998). When the large-scale introduction of night vision enhancement systems makes older adults drive again at night, this will increase their mobility and improve their quality of life. However, it has to be seen whether the use of night vision enhancement systems will provide a similar risk compensation for impaired night-time visual acuity as does the older driver's compensation strategy of not driving at night (Caird et al., 1998; Smiley, 2000).

As adaptive behaviour will not necessarily manifest itself during evaluations in simulators or during field tests, it is difficult for designers to anticipate the influence of behavioural adaptation on the effects of newly designed ADAS. All they can do is use the available knowledge on behavioural adaptation, and design the application in such a way that it can easily be adjusted if driver behaviour gives rise to that (Howarth, 1993).

7.3.5. Interaction between drivers with and without ADAS

Automation of (elements of) the driving task does not only affect the isolated behaviour of the supported driver (i.e., the driver that has the system installed in his car). It can also influence interactions between the supported driver and other road users. Driver support may, for example, lead to cars that – in the eyes of other road users – act like an alien. This "extraterrestrial behaviour" can cause confusion among these other road users, which might result in negative road safety consequences (Heijer et al., 2001). These problems will particularly occur in the period between no and full implementation of the system, a period that can last a couple of decades (ETSC, 1999). In the meantime, systems that automate (parts of) the driving task should be designed in such a way that they imitate the traffic behaviour of real drivers as much as possible.

7.4. Conclusions regarding ADAS that can improve the safety of older drivers

Conclusions cannot be drawn yet about whether certain ADAS can improve the safety of older drivers. Although systems have been developed that appear to fit the needs of the older driver, many are still being developed and not much research has been done on user acceptance and the effects on road user behaviour.

However, some preliminary conclusions can be drawn based on the evaluation of systems in *Section 7.2*. Collision warning systems for conflicts at intersections, for example, appear to be useful provided that system settings can be adjusted to match the reaction time of the driver. Besides that, there are indications that the safety effects of collision warning systems will be larger for systems that warn the driver for approaching traffic than for systems that just let the driver know when the gap between crossing vehicles is large enough to join or cross the traffic stream. The latter systems usually leave it up to the driver to notice approaching vehicles and to yield to them.

Systems that assist the driver while parking may not be so relevant for reducing the fatality rate of older drivers, but older drivers find them very useful and are also prepared to pay for them. Automated lane changing and merging systems are systems that have not been developed yet.

Examples of systems that assist the driver in paying attention to relevant information, are systems that project roadside traffic signs inside the vehicle. These systems are known as in-vehicle sign information systems. They give the driver a better and longer view of the sign. The drawback is that the driver's attention is temporarily diverted from the road. Caution is therefore required when in-vehicle information systems are introduced. The position of the in-vehicle display (either a display on the dashboard or a projection on the front windscreen) and the manner in which the information is presented will determine whether these systems are good or bad for road safety.

Systems which adjust vehicle speed in the vicinity of traffic lights, yield signs, and/or railway crossings, also draw the driver's attention to relevant information about the traffic situation and give him more time to react. These systems may be seen as special types of intelligent cruise control. Examples of such systems have been developed within the framework of a demonstration project. In a follow-up project, users will test prototypes.

The last system that was evaluated, an information system that assists the driver in safely passing complex traffic situations, has especially been developed as assistance to older drivers (Entenmann & Küting, 2000). It is a promising idea to provide the driver with step by step information in time to anticipate on coming events. The test results indicate that older drivers appreciate this system more than an ordinary navigation system, and that the system also has more positive road safety effects (Entenmann et al., 2001).

In the above discussion of driver assistance systems for older drivers, only those systems were mentioned whose functionality have the most potential to improve the safety of this group of road users. As a result of this, three systems that are frequently mentioned in the literature about older drivers and ADAS were not dealt with:

1) Night-time vision enhancement systems (UV headlights or infrared technology);
2) Navigation systems;
3) Mayday systems that automatically send the vehicle location to an emergency service in the case of a breakdown, crash, or other emergency.

These systems are helpful for drivers who have difficulties driving in darkness, those who have difficulties driving in an unfamiliar area, and those who have feelings of insecurity respectively. Therefore, these systems are especially suitable for improving the *mobility* of older drivers. Mayday systems can also shorten the time before receiving medical treatment, thereby reducing injury severity (Caird, 2004a). The other two systems may reduce crash rate by compensating for impaired night-time acuity or by preventing searching. However, whether or not these systems will lead to a reduction in the number of injuries among older drivers depends on the size of the crash rate reduction, which should be larger than the increase in exposure as a result of system usage.

Returning to the ADAS that are aimed at an improvement of the safety of the older driver, much research remains to be done. First of all, initiatives like those of Entenmann and Küting (2000) and the EDDIT-project (Oxley & Mitchell, 1995) will have to be followed to arrive at a situation in which more ADAS are being developed that are aimed at the special safety needs of older drivers. Besides that, existing ADAS should more often be evaluated using both younger and older drivers. Only then it will be possible to draw conclusions on whether the systems that seem to have the best potential to improve the safety of older drivers, actually do improve the older driver's safety. As Green (2001a) states, older drivers experience considerably more difficulty in completing telematics tasks, and therefore it is essential that safety and usability evaluations focus on them. If the older drivers are able to complete a task safely and easily, then other drivers will be able to as well.

In the next chapter, a simulator study is described in which some of the ADAS that are considered to be the most promising for improving the safety of older drivers were examined on their effects on driving behaviour and workload of, and acceptance by younger and older drivers.

8. Effects of a driver support system on workload and driving performance of older drivers[9]

This study examined the extent to which driving performance of ten older (70-88 years old) and thirty younger participants (30-50 years old) improved as a result of the support of a specific driver assistance system. While driving a suburban route in a driving simulator, a system provided the driver with prior knowledge on the next intersection by informing him about 1) priority regulation, 2) safe gaps to join or cross, 3) obstructed view of the intersection, or 4) an unexpected road situation. The system was evaluated in terms of effects on workload, driving performance, and user acceptance. The effects of the support system were compared between participants that differed in functional age, which was based on scores on three tests of cognitive functioning, relating to reaction time, selective attention, and visual-motor coordination.

Messages regarding the priority regulation, obstructed view of an intersection, and safe gaps to join or cross traffic streams led to fewer and/or less decelerations of relevant other vehicles. These decelerations were considered to be precursors of a collision; fewer and less decelerations can therefore be regarded as safer driving behaviour. The message regarding an unexpected one-way street led to fewer route-errors. In general, effects of the messages were the same for functionally young, middle-aged and old drivers. Workload was not reduced by the driver support system.

User acceptance was measured by a questionnaire that was administered to the participants both before and after they had experienced driving with the support system. At first, functionally old drivers were more positive about the usefulness and satisfying character of messages regarding safe gaps to join or cross, on obstructed views of the intersection, and on unexpected road situations. After the actual experience with the support system, opinions changed and age differences seemed to disappear.

8.1. Introduction

In the coming decades, there will be growing numbers of older drivers – those aged 75 and above – suffering from functional limitations that reduce the quality of driving performance. Various studies have indicated that Advanced Driver Assistance Systems (ADAS) might provide tailored assistance for older drivers (see e.g., Färber, 2000; Mitchell & Suen, 1997; Shaheen & Niemeier, 2001). Taking into account functional limitations such as decreased divided and selective attention, reduced flexibility of neck and

[9] An abridged version of this chapter, which focussed on the results regarding user acceptance was presented at the second HUMANIST conference on driver needs (Davidse, Quist, Hagenzieker, & Brouwer, 2006). A similar but revised version will be submitted to a relevant scientific journal. Another abridged version of this chapter, which will focus on the results regarding effects on workload and driver performance, will be submitted to another scientific journal.

trunk, reduced motion perception and reduced speed of information processing, Davidse (2004a; 2006) concluded that to have the biggest potential to improve the safety of older drivers, ADAS should:

a) draw attention to approaching traffic;
b) signal objects located in the driver's blind spot;
c) assist the driver in directing his or her attention to relevant information; and/or
d) provide knowledge on the next traffic situation.

Systems that appear to provide one or more of these kinds of support are: 1) collision warning systems aimed at intersections, 2) automated lane changing and merging systems for motorways, 3) in-vehicle signing systems, and 4) intelligent cruise control that reduces the speed of the car in the presence of yield signs, stop signs, or traffic lights (Davidse, 2004a, 2006; Mitchell & Suen, 1997).

Unfortunately, none of these systems is on the market yet and the number of initiatives to develop ADAS that are aimed at the special safety needs of older drivers is very limited. Two exceptions are the European DRIVE-II-project EDDIT (Elderly and Disabled Drivers Information Telematics) in which several systems were developed for and tested by older drivers (Oxley, 1996; Oxley & Mitchell, 1995) and a study by Entenmann et al. (2001) in which a system was tested that assists the driver in crossing complex intersections. The systems that were tested in the EDDIT-project included route guidance systems, reversing aids, emergency alert systems, night vision enhancement systems, and a system that helps selecting gaps in traffic streams that are large enough to join or cross that particular traffic stream. The driver information system tested by Entenmann et al. is a navigation system that not only gives route descriptions, but also provides the driver with timely information on the crucial elements of the next traffic situation. The idea behind this information system is that by giving the driver very early and sequential information, the driver will be able to build up a mental picture of what to expect, at a moment at which his workload is still low (Entenmann & Küting, 2000). This mental picture will provide the opportunity to direct attention to the most important traffic elements, as a result of which workload at the intersection will be reduced. Given the functional limitations commonly occurring in the older age group, such as decreased selective attention and reduced speed of information processing, a support system that provides this kind of information can be especially useful for this age group.

In the present study, the functions of the driver information system of Entenmann and Küting (2001) were combined with the 'gap selecting'-function tested in the EDDIT-project. A driver assistance system was tested which not only provided the driver with information on speed limits, one-way streets, and priority regulations, but also actively warned the driver to reduce speed when approaching an intersection at which the sight on the crossing street was obstructed by buildings, and which indicated when it was safe to join or cross traffic streams at busy intersections. Analogous to the idea of Entenmann and Küting, this assistance system was intended to reduce workload at the intersection by timely informing the driver about what to expect. If the driver either consciously or subconsciously knows what to expect, it is more likely that he will select the correct mental schema for safely passing the intersection. This mental schema will simplify the driving task and will prevent errors. The present study was designed to evaluate the driver assistance system in this respect. The system was evaluated in terms of effects on workload, driving performance, and user acceptance.

While evaluating the system, the effects on driving behaviour were compared between older (70 years and older) and younger persons (30-50 years old). The age boundaries of the first group were chosen as a compromise between the preferred group of people aged 75 and above – the group of older adults that has a fatality rate which is higher than average (OECD, 2001; SWOV, 2005) – and the availability of participants of a certain age. The group of people aged 30-50 was chosen as the comparison group. People of this age group were expected to have considerable driving experience and not yet to be confronted with functional limitations. As the information provided by our information system was selected based on the functional limitations of older drivers, it was expected that older drivers would benefit more from the information given in terms of reduced workload and, as a result, would also be more willing to accept the system. Realizing that ageing is a process that does not start at the same age for every person nor continues at the same rate, with the result that drivers having the same age (as in years since birth) can differ in the number and severity of their functional limitations, age was both considered chronologically and functionally (for a discussion on the prediction of functional age see Birren & Renner, 1977, p. 15-17). Functional age was based on scores on three tests of cognitive functioning, relating to reaction time, selective attention, and visual-motor coordination. Persons scoring well on the average of these three tests were considered to be functionally younger, whereas persons scoring relatively poor on them were considered to be functionally older.

The support system that was evaluated was designed to reduce workload and improve driving performance. To measure whether timely information about what to expect indeed reduced mental workload, a secondary task was introduced (see e.g., Wickens & Holland, 2000 and Kantowitz & Simsek, 2001 for the merits of secondary-task performance as an indicator of workload). This secondary task consisted of a peripheral detection task (PDT; see e.g., Van Winsum, Martens & Herland, 1999). While driving the simulator car, participants had to detect a signal that was sent to the screen. As soon as they detected the signal, they had to press a button that was attached to the index finger of their left hand. Performance on this secondary task was inferred from the reaction time of the drivers. In addition, subjective workload was measured. At the end of each drive, participants were asked to rate the difficulty of the task they had just completed (i.e., driving the simulator car with or without the support system installed) on a scale from 0 to 150 (Rating Scale Mental Effort (RSME); Zijlstra & Van Doorn, 1985). Primary task performance was inferred from crashes, route-errors, and safety of the participant's decisions. The latter was measured by the extent to which traffic that had right of way had to decelerate when the participant was passing an intersection. Deceleration of these 'other vehicles' was considered to be the precursor of a crash. If the drivers of those vehicles would not have reacted, a crash would have taken place.

In general, we hypothesized that functionally older drivers would benefit more from the information provided by the support system than functionally younger drivers would. We expected that this benefit would be reflected in experienced workload, in safety of driver decisions, and in appreciation of the support system. More specifically, we expected that there would be an interaction effect of age and driver support leading to a) a relatively larger decrease in workload for functionally older participants, b) a relatively larger increase in the safety of driver decisions of functionally older participants, and c) a higher appreciation of the support system by older participants.

8.2. Method[10]

8.2.1. Participants

Participants were recruited by means of a newspaper article about the driving simulator, and by advertisements in supermarkets. Participants had to be either between 30 and 50 years of age or 70 years of age or older. Thirty-three older adult drivers (70 to 88 years of age; $\mu = 75.2$, $\sigma = 4.8$; 26 males, 7 females) and seventy-two younger drivers (28 to 51 years of age; $\mu = 39.2$, $\sigma = 6.6$; 41 males, 31 females) participated in this study. All participants had at least 5 years of driving experience and passed a test on sensitivity to simulator sickness (Motion Sickness/Simulator Sickness Screening Form MSSF; see Hoffman, Molino & Inman, 2003).

After being selected based on their chronological age, participants were grouped according to their functional age. Functional age was based on scores on three tests of cognitive functioning, relating to reaction time, selective attention, and visual-motor coordination (Determination Test© S1 [Schuhfried, 2003], Tachistoscopic Traffic Test Mannheim for Screen TAVTMB© S1 [Biehl, 2003], and adaptive tracking task [see e.g., Ponds, Brouwer & Van Wolffelaar, 1988; Withaar & Brouwer, 2003] respectively). We used the median reaction time provided by the Determination Test©, the overview score of the TAVTMB© and the performance on the second trial (third trial when considering the practice trial) of the adaptive tracking task. These three scores were first converted into normal scores (z-scores) and then averaged (after making sure that scores on all tests were scaled in the same order, high scores indicating better performances than low scores). After having ranked participants according to their average score, participants that were in the lowest quartile (having the lowest average scores) were assigned to the oldest functional age group, and participants in the highest quartile (highest averages) were assigned to the youngest functional age group. Remaining participants (50% of all participants) were assigned to the "in-between"-group that we called 'functionally middle-aged'.

[10] This section is identical to *Section 6.2*, except for the subsections on Procedure (*8.2.2*), Driver assistance system (*8.2.6*), Data-sampling (*8.2.7*), and Questionnaires (*8.2.8*).

	Functional age			Total
	Young	Middle	Old	
Young (30-50)	27	42	2	71[a]
Old (70+)	1	8	24	33
Total	28	50	26	104

[a] One chronologically young person did not complete the cognitive tests and could therefore not be assigned to one of the functional age groups.

Table 8.1. Comparison of chronological and functional age groups (number of participants).

8.2.2. Procedure

Participants were recruited by means of a newspaper article about the driving simulator, and by advertisements in supermarkets. All participants who had shown interest in participating in the study by ringing us or sending an e-mail were called back to test them on sensitivity to simulator sickness and to check their driving experience. Those who appeared not to be sensitive to simulator sickness as indicated by never or seldom being sick while travelling by plane, train, boat or as a passenger at the back seat of a car (see Hoffman, Molino & Inman, 2003), and who had more than five years of driving experience were invited to participate in this study. Those willing to participate were informed about the experimental procedure and received some extra information by mail, as well as an informed consent form, a questionnaire on driving behaviour including questions on appreciation of a hypothetical driver support system (see *Questionnaire*), and information on how to find the driving simulator that was located in the University Medical Centre in Groningen (UMCG).

Participants were invited twice to the UMCG. During their first visit, they returned the completed questionnaire and their signed informed consent form, they were administered the three tests on neuropsychological functioning (see *Section 8.2.1*), and they drove in the driving simulator for about 10 minutes as an extra test on sensitivity to simulator sickness. Thirty-three subjects (15 older and 18 younger participants) did not feel comfortable driving in the simulator car as indicated by their score on a questionnaire on simulator sickness (based on the Simulator Sickness Questionnaire (SSQ); Kennedy, Lane, Berbaum & Lilienthal, 1993). Therefore, they were not invited for the second visit to the UMCG.

During their second visit, the remaining participants first went for a short familiarization drive (3.5 km) in the driving simulator. After that, they twice drove a 35-minute route in the simulator car (16 or 18 km; see *Section 8.2.4*), once without and once with the support of an advanced driver assistance system (see *Section 8.2.6*). The order of the drives was counterbalanced between subjects (see *Section 8.2.5*). Between the first and second drive, participants had a break of 45 minutes. Before the beginning of each drive, participants were asked to adjust the seat's position to make sure they could reach the pedals, and were instructed orally about what was expected from them during the drive that was about to start. They had to follow route instructions and were asked to try to adhere to the speed limit that was generally 50 km/h. After each drive, subjects had to fill in a questionnaire on motion sickness (based on the SSQ; Kennedy et al., 1993) and one on subjective workload (Rating Scale Mental Effort (RSME); Zijlstra & Van Doorn, 1985). After they had driven the simulator car equipped with the simulated support system, they also had to fill in a questionnaire regarding their opinion of the support given. This questionnaire included the same items on user acceptance as were included in the questionnaire that they filled in before their first visit to the UMCG (see *Section 8.2.8*).

Despite the earlier tests on simulator sickness, 15 participants (6 older, 9 younger drivers) felt sick while driving in the driving simulator during their second visit. Another 17 subjects did not complete the second part of the experiment because they were not able to participate in the period in which the second visits were planned. As a result, behavioural data were available from 40 participants: 10 chronologically older adult drivers (70 to 88 years of age; μ = 75.5, σ = 6.2; 8 males, 2 females) and 30 chronologically younger participants (30 to 50 years of age; μ = 39.3, σ = 5.9; 22 males, 8 females). In terms of functional age, data were available from 10 functionally younger participants (30 to 70 years of chronological age; μ = 39.1; σ = 12.2; 7 males, 3 females), 20 functionally middle-aged participants (32 to 71 years of chronological age; μ = 42.6; σ = 8.6; 16 males, 4 females), and 10 functionally older participants (37 to 88 years of chronological age; μ = 69.2; σ = 16.9; 7 males, 3 females). Those not capable of participating in the second part of the experiment, either because of serious symptoms of simulator sickness during the 10-minute drive at their first visit or because of a full agenda, received 10 € for their participation in the first part of the experiment. All other participants received 20 € for their participation in the experiment, regardless of having completed all the drives that were planned for their second visit.

8.2.3. Driving simulator

The simulator used was a fixed base driving simulator located at the Neuropsychology unit of the Department of Neurology of the UMCG. The simulator configuration consisted of an open cabin mock-up containing a force-feedback steering wheel, gas-, clutch- and brake pedals, and audio speakers for driving sounds. In front of the mock-up were three projection modules resulting in a 180 degrees horizontal and 45 degrees vertical out-window projection screen of 4.5 m in diameter.

The computer system consisted of five PCs: Three PCs for graphical rendering, one for traffic simulation and one for system control with a graphical user interface for the simulator operator. Traffic simulation was based on 'autonomous agents' technology. This kind of technology models the simulated participants (i.e., all traffic surrounding the simulator driver) as self-governing intelligent objects that show natural and normative driver behaviour. Normative behaviour implies basically safe and correct traffic behaviour as a default condition. The agents possess functions to perceive the world around them, process this information according to their behavioural rules and act adequately on the perceived circumstances (Van Wolffelaar & Van Winsum, 1995; Kappé, Van Winsum & Van Wolffelaar, 2002). This means, for example, that the simulated cars that surround the simulator driver recognize roads on which they have right of way, that as a result of this, they will not yield to traffic from the right on these roads, unless the respective traffic does not yield to them and a crash would occur if they themselves would not react.

8.2.4. Route

The experiment consisted of two suburban drives preceded by a familiarization drive. During all drives, participants received route instructions orally. The route led the participants across several intersections, which differed in terms of a) layout (3-way intersection, 4-way intersection, dual carriageway, or roundabout), b) priority regulation, c) view of the intersection, d) traffic density on the road or lane to cross or join, and e) speed of traffic driving on the road or lane to cross or join. These intersection characteristics were expected to determine the task difficulty of passing the intersection (for the effects of intersection characteristics on driving performance see Davidse, Van Wolffelaar, Hagenzieker & Brouwer (2006). To prevent order effects, two routes were used. Both routes contained the same intersections, but in a different order. The routes can be described as having the same 8-shape (see *Figure 8.1*), with Route 1 starting with the lower round followed by the upper round (total of 16 km), and Route 2 starting with the upper round followed by the lower round (total of 18 km). The lower round had relatively many intersections at which view of the intersection was blocked by buildings, whereas the upper round had relatively many intersections of wide roads with dual carriageways. The routes were randomly assigned to participants after having ranked and matched participants according to their scores on the SSQ (scored after the test drive during their first visit) and the Determination test© (see *Section 8.2.5*). The ranking was done to make sure that any effects found on functional age would not be caused by group assignment and to make sure that withdrawal from the study as a result of simulator sickness would affect all groups equally.

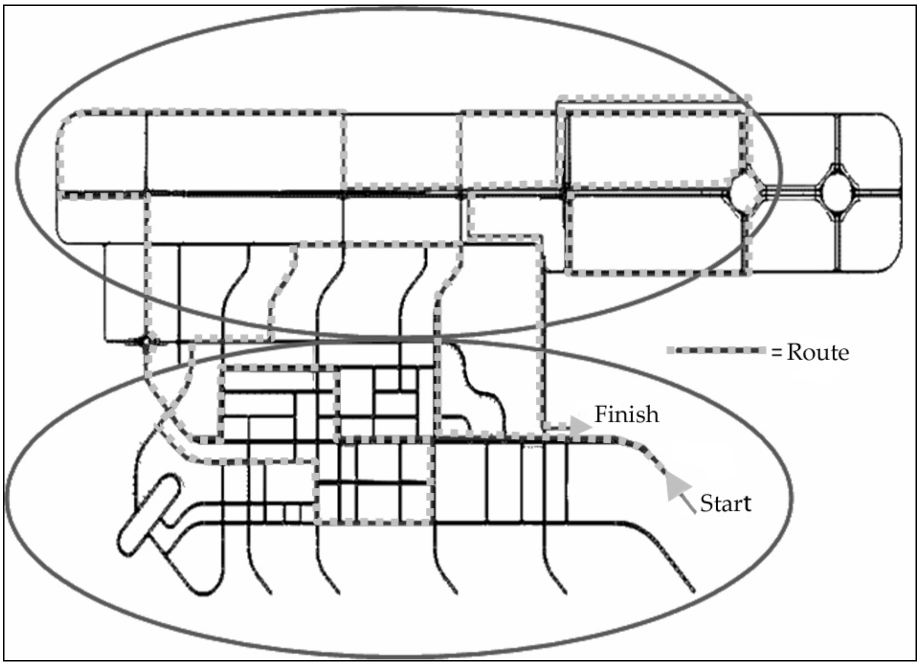

Figure 8.1. Sketch of the road network and the route participants had to drive.

8.2.5. Design and data-analysis

The experiment was set up using a 3x2xn mixed between-within design. Functional age was the classificatory variable (young, middle-aged and old), and driver support (yes or no) and intersection design (various types of intersections; see *Section 8.2.4*) were the experimental variables (see *Table 8.2*). Within-subjects comparisons were made to test whether the dependent variables workload, general driving performance, and safety of driver decisions differed while passing different types of intersections, and whether these types of behaviour were affected when the same intersections were encountered while being supported by a driver assistance system. Between-subjects comparisons were made to test whether workload, general driving performance, and safety of decisions on different types of intersections differed between age groups, and whether support by a driver assistance system had a differential effect on the behaviour of different age groups. In this article, the results regarding driver support are presented. The results regarding intersection design were described in *Chapter 6.*

	No ADAS			ADAS		
	Several types of intersections			Several types of intersections		
	Workload	Driving performance	Safety of decisions	Workload	Driving performance	Safety of decisions
Young drivers						
Middle-aged drivers						
Older drivers						

Table 8.2. Experimental design.

To make sure that order effects would not affect study results, timing of the treatments (i.e., driver support and intersection design) was varied across participants. Driver support could be offered during their first or second experimental drive, and intersections could be offered in two different series (*Route*). This resulted in four different treatments (see *Table 8.3*). Participants were randomly assigned to these treatments after having ranked and matched the participants according to 1) their score on the simulator sickness questionnaire (SSQ) which they had filled in after their first test drive, and 2) their median reaction time as indicated by the Determination Test©. The actual assignment to treatments took place by counting from 1 (Treatment I) to 4 (Treatment IV), starting with the participant having the lowest scores on both SSQ and Determination Test©. The fifth participant was again assigned to Treatment I, the sixth to Treatment II, and so forth. This was done separately for the young and old chronological age group. Since not all subjects that were invited for the second part of the experiment were able to come, some groups turned out to be larger than others. Dropout because of simulator sickness during the second part of the experiment caused further reduction of the number of participants, and contributed to unequal cell sizes as well (see *Table 8.3*).

1st drive – 2nd drive	Route 1	Route 2
No support – with support	I (7)	III (12)
With support – no support	II (9)	IV (12)

Table 8.3. Number of participants per treatment group.

8.2.6. Driver assistance system

The simulated driver assistance system provided prior knowledge on the next traffic situation by informing the driver about one of four aspects of that particular situation:

1) whether the driver has right of way,
2) whether it is safe to join or cross traffic,
3) whether the driver will have a good view of cross-traffic, and
4) whether there are any deviating traffic rules or road situations (e.g., different speed limit or one-way street).

All of the information was communicated orally. The information was only provided if it was relevant and with a maximum of one message per intersection. Messages regarding right of way were only sent if priority regulation had changed because of turning left or right, or if the driver was approaching a major road. Messages regarding changed speed limits were only sent if the limit had changed from 50 to 70 km/h and the driver had not changed his speed accordingly. Messages regarding restricted view and messages regarding major roads were only sent if driving speed was higher than 30 km/hour, assuming the driver had already adjusted his behaviour if he was driving slower. Likewise, messages regarding safe gaps to join or cross traffic streams were only sent if driving speed was less than 2 km/h and the driver was less than 10 m away from the intersection. To make sure drivers had enough time to act upon messages regarding major roads, restricted view and one-way streets, these messages were passed on to the driver at a distance of 130 m before arriving at the intersection (or as soon as possible in case of shorter road stretches).

8.2.7. Data-sampling

General driving performance of the participants was measured by waiting position before passing an intersection, acceleration and speed while passing an intersection, and number of route-errors. Safety of driver decisions of participants was measured by crashes between participants and surrounding traffic, and by the deceleration of the latter vehicles if they had right of way at intersections the participant was passing. Deceleration of these 'relevant' vehicles was considered to be the precursor of a crash. If the other driver would not have reacted, a crash would have taken place (see *Section 8.2.3*).

The deceleration of surrounding traffic having right of way was measured both at the moment the participant started passing the intersection (Acc_Pre), and at the moment he had just crossed the path of the other vehicle or had turned and was driving in front of him (Acc_Post). Deceleration data could be either positive (the vehicle was accelerating), zero (the vehicle maintained speed), or negative (the vehicle was decelerating). Two derived deceleration measures were analysed further: the average deceleration of all relevant vehicles at the moment the participant drove off with the intention to pass the intersection (average Acc_Pre), and an indicator of whether one of the relevant vehicles had to decelerate either before or after the participant had passed the intersection (Acc_Crit: 0 if none of them had to decelerate, 1 if one of them had to decelerate). The latter measure indicated whether the decision to pass the intersection had been unsafe or not, whereas the former measure indicated the degree of unsafety at the time the participant drove off. The lower the Acc_Pre, the harder one or more relevant vehicle(s) had had to brake to prevent a collision. Having calculated the Acc_Pre and Acc_Crit per intersection, both measures were averaged over intersections that were expected to be the same based on the messages that were sent to the driver. Acc_Crit then varied between 0 and 1. The closer the value was to 1, the more often the participant had made an unsafe decision at that type of intersection. Acc_Pre had a wider range of values, with negative values indicating unsafe behaviour of the participant at that type of intersection, and positive values indicating safer behaviour.

Workload was measured by performance on a secondary task while passing the intersection. The secondary task consisted of a peripheral detection task (PDT; see e.g., Van Winsum, Martens & Herland, 1999 for a description of this task). While driving, a small red square was presented on the simulator screen in front of the participant during one second. Subjects were required to respond as soon as they detected the red square by pressing a microswitch that was attached to the index finger of their left hand. Reaction time was measured in milliseconds. If a reaction time had not been detected within 2.5 s from the onset of the stimulus, this was coded as a missed signal. Series of signals were presented during the approach and passing of a selected number of intersections and while driving on three straight road sections. The 28 selected intersections were representative for the total group of 71 intersections, at the same time preventing participants having to perform the detection task at every intersection they passed. The onset of a series of signals was announced with a bell tone. During the series of signals (one series per intersection), on average every 3.5 s, with random variation between 3 and 4 s, a stimulus was presented at a horizontal angle of 10 to 20 degrees to the left of the line between the eyes of the participant and the centre of the screen. Stimuli were presented at a vertical angle of 3 degrees above the horizon. Average reaction time and fraction of missed signals per intersection (number of missed signals divided by total number of sent signals while passing the relevant intersection) were used as workload indices for the intersections. Higher reaction times and higher fractions of missed signals were interpreted as being the result of a higher workload.

Baseline reaction times and fractions missed were collected at the start of the first experimental drive. While the simulator car was parked at the beginning of the route, and the participant was sitting in the driver seat, one series of twenty stimuli was presented. On average every 4 s, with random variation between 3 and 5 s, a stimulus was presented at a horizontal angle of 10 to 20 degrees to the left of the line between the eyes of the participant and the centre of the screen. Again, participants were instructed to press the button as soon as they saw the stimulus. A second baseline was provided by the straight road sections at which the same series of stimuli were shown as during the approach and passing of the selected number of intersections. This second baseline differed from the first one in three ways: 1) participants were driving, 2) it always took place during the same drive as in which the relevant intersection data were gathered (same support condition), and 3) the frequency at which the stimuli were presented was every 3.5 s instead of every 4 s. Practise on the PDT was provided during the familiarization run.

Before any of the analyses with regard to workload (see *Section 8.2.5*) were carried out, all average reaction times – those averaged per intersection as well as those averaged per baseline – were first corrected for missing data. Initially, average reaction times represented the average of the reaction times for those stimuli to which participants had reacted within 2.5 s. If a participant had not reacted within 2.5 s after the onset of a stimulus, the reaction time for that stimulus was coded as missing, and the corresponding average reaction time per intersection or baseline was based on a lower number of stimuli. A reason for not having reacted within 2.5 s could either be not having noticed the stimulus or not having reacted quickly enough. In both cases, no attentional capacity was left to notice and or react to the stimulus in time. Had the stimulus been presented for a longer span of time, or had we waited for a longer period of time before considering the reaction time as missing, at last the participant would have reacted. Then, his reaction time would have exceeded 2.5 s. Therefore, we recalculated the average reaction times by replacing all missing reaction times by 2.5 s, regarding that reaction time (of 2.5 s) as an underestimation of the real reaction time (for a similar approach see Brouwer, 1985).

8.2.8. Questionnaires

During the experiment, participants had to fill in several questionnaires, two of which pertained to acceptance of the driver support system. Both questionnaires included composite questions on the appreciation of information about four aspects of traffic situations: priority regulation, safe gaps, restricted view, and unexpected road situations. The composite questions were adopted from Van der Laan, Heino and De Waard (1997). For each type of information provided by the support system, nine questions were posed: five questions related to the usefulness of the information (items 1, 3, 5, 7, and 9; see *Table 8.4*), and four to the satisfaction it gave (items 2, 4, 6, and 8). These composite questions were included both in the questionnaire that participants had to fill in before their first visit to the UMCG and in the one they had to fill in after they had driven the simulated car equipped with the support system (second visit). The first time they answered the composite questions they were asked to appreciate a hypothetical system. This system and the information it would give, was described in the introduction to the relevant composite question:

"Imagine that you have a system installed in your car that indicates whether you will have to yield at an intersection. This information is presented loud and clear. Try to imagine how you would react to this kind of information and how you would appreciate such a system. Subsequently, answer the next nine questions."

The second time, they were asked to appreciate the system that had supported them while driving the simulator car.

My judgement of information on … is: *(please place an X on every line)*

1	useful	___ ___ ___ ___ ___	useless
2	pleasant	___ ___ ___ ___ ___	unpleasant
3	bad	___ ___ ___ ___ ___	good
4	nice	___ ___ ___ ___ ___	annoying
5	effective	___ ___ ___ ___ ___	unnecessary
6	irritating	___ ___ ___ ___ ___	likeable
7	assisting	___ ___ ___ ___ ___	worthless
8	undesirable	___ ___ ___ ___ ___	desirable

Table 8.4. Nine items of the composite questions.

Other questions that were included in the questionnaires related to difficulties participants generally encounter while driving, comfort systems they have installed in their car (radio, telephone, navigation system), use of electronic devices in daily life (e.g., teletext, Internet, mobile phone, ticket machine, cash dispenser), appreciation of the way information was provided by the support system (audibility, comprehensibility, timing, trustworthiness), and willingness to buy and use the system if it were on the market.

8.3. Results regarding effects on workload and driver performance

In this section, between-subjects comparisons focus on functional age. Within-subjects comparisons focus on the effects of the driver support system. First of all, baseline workload values for the different functional age groups are established. After that, the effects of the driver support system are described, starting with the overall effects of the system on workload and general driving behaviour, followed by the effects per type of message. The section ends with the results regarding participants' appreciation of the driver support system.

8.3.1. Baseline values for secondary task performance

Before focusing on the effects of driver support, baseline reaction times and fractions missed of the different functional age groups were compared. For the first baseline measurement of workload (without driving), mean reaction times and fractions missed did not differ between the functional age groups (see *Table 8.5*). However, when participants had to combine the peripheral detection task with the primary task of driving on a straight road section, differences between mean reaction times and fractions missed emerged (second baseline). While driving on a straight road section with the support system installed, functionally old participants had slightly higher reaction times and fractions missed than functionally young ($t(12) = -2.654$; $p = 0.021$ and $t(11) = -2.749$; $p = 0.018$ respectively (*df*s adjusted for unequal variances)) and functionally middle-aged participants ($t(10) = -2.885$ $p = 0.016$ and $t(10) = -2.898$; $p = 0.016$ respectively (*df*s adjusted for unequal variances)). This differential effect of adding a driving task to the peripheral detection task points at an interaction effect; all participants had higher reaction times and fractions missed when they had to combine the secondary task with the primary driving task, but the secondary task performance of the functionally older participants was affected the most.

The existence of an interaction effect was confirmed by the results of mixed between-within analyses of variance (see *Table 8.6*). Between-subjects analysis of variance showed that functional age significantly affected baseline reaction times and fractions missed ($\eta^2 = 0.343$ and $\eta^2 = 0.342$ respectively; these partial eta's squared show the proportion of the variance in the dependent variable (reaction time and fraction missed respectively) that can be attributed to the independent variable in question (functional age)). Within-subjects analysis of variance showed that type of baseline measurement ($\eta^2 = 0.733$ and $\eta^2 = 0.432$ respectively) and the interaction of functional age and type of baseline ($\eta^2 = 0.260$ and $\eta^2 = 0.373$ respectively) also significantly affected reaction time and fraction missed.

		Young	Middle-aged	Old
Baseline 1	Reaction time	0.537	0.546	0.604
	Fraction missed	0.000	0.004	0.007
Baseline 2, ADAS	Reaction time	0.899	0.887	1.323
	Fraction missed	0.042	0.041	0.263

Table 8.5. PDT reaction times and fractions missed for baseline measurements.

		PDT reaction time	PDT fraction missed
Functional age	*F* *df* *p*	9.393 2, 36 0.001**	9.360 2, 36 0.001**
Baseline	*F* *df* *p*	98.831 1, 36 < 0.000001**	27.354 1, 36 0.000007**
Functional age x Baseline	*F* *df* *p*	6.325 2, 36 0.004**	10.709 2, 36 0.0002**
* p < 0.05; ** p < 0.01			

Table 8.6. Results of mixed between-within ANOVAs for baseline measurements.

8.3.2. General effect of driver support

The general effect of driving with the support system installed, was determined by comparing the average workload at intersections while driving with and without the support system installed, and by comparing average speed and lateral position, number of crashes, number of route errors and trip duration (see *Table 8.7*). In addition, general driving performance at intersections was compared between drives with and without driver support (i.e., waiting position, acceleration and speed). Paired samples-tests showed that driver support only affected one aspect of workload for only two of the functional age groups. Functionally younger drivers had longer reaction times while driving with the support system installed ($t(9) = -2.691$, $p = 0.025$), and functionally middle-aged drivers had slightly higher fractions missed ($t(18) = -2.074$, $p = 0.053$). Subjective workload was not affected by the support system. Driving performance at intersections was also the same when driving with or without the support system installed.

	No support			Support		
	Young (n=10)	Middle-aged (n=20)	Old (n=10)	Young (n=10)	Middle-aged (n=20)	Old (n=10)
Average reaction time at intersections (s)	1.180	1.297	1.622	1.256	1.367	1.666
Average fraction missed at intersections	0.215	0.281	0.443	0.246	0.320	0.452
Subjective workload total trip (RSME)	53	47	56	54	47	53
Mean waiting distance before passing intersections (m)	12.0	10.6	12.0	11.5	12.3	13.5
Mean lateral position before passing intersections (cm)[a]	- 11	- 21	-36	-8	-10	-40
Mean acceleration at intersections (m/s^2)	0.75	0.80	0.72	0.79	0.74	0.75
Mean speed at intersections (km/h)	25.94	25.49	25.67	25.99	25.35	25.86
Number of crashes	4	6	2	1	1	7
Number of route errors	2	4	9	2	9	10

[a] Negative values indicate a lateral position that is closer to the side of the road.

Table 8.7. Comparison of overall data for drives with and without ADAS.

8.3.3. Messages regarding priority regulation

Dependent on the priority regulation in force, three different messages were sent to the driver. After turning left or right, the driver was either told that from that moment on he was riding on a major road and therefore had right of way (*RoW*), or that on that road traffic should yield to vehicles approaching from the right (*YtR*). Per drive, these messages were sent 7 and 14 times respectively. The third message was sent if participants were approaching a major road (*AMR*). This last message was only sent if the participant was driving at a speed that was higher than 30 km/h, assuming the driver had already adjusted his behaviour if he was driving slower. As a result, some participants received this message more often than others. Frequencies varied from 9 to 12. Relying on the rule that persons that drove less than 30 km/h did not receive this message, functionally older drivers approached major roads at a lower speed than younger drivers. Whereas

90% of the functionally young and 68% of the functionally middle-aged drivers received the maximum number of warnings, only 30% of the functionally old drivers did.

Workload

To study the effects of messages regarding priority regulation on workload, mean reaction times and fractions missed per intersection were averaged over intersections that had the same priority regulation. Note that participants did not necessarily receive a message before arriving at each of those intersections, either because of their low approach speed or because they had already received the message regarding *RoW* or *YtR* at another intersection since they had turned left or right.

Mixed between-within analyses of variance showed that workload at intersections differed between age groups for all types of priority regulation (see *Table 8.8*). Post hoc Bonferroni tests showed that functionally young participants had lower reaction times than functionally old participants at all three types of intersections ($p = 0.004$ for *RoW*; $p = 0.016$ for *YtR*; $p = 0.040$ for *AMR*). At intersections where participants were driving on a major road (*RoW*), reaction times of functionally middle-aged drivers were also lower than those of functionally old participants ($p = 0.004$). Age effects for fractions missed were only found for *RoW* and *YtR*. At the former, functionally young and middle-aged participants had lower fractions missed than functionally old participants ($p = 0.007$ and $p = 0.022$ respectively). At the latter, functionally younger participants had lower fractions missed than functionally old participants ($p = 0.033$).

Within-subjects analyses of variance showed that only messages regarding the participant's approach of a major road (*AMR*) affected workload. The effect was contrary to what was expected; driver support caused increased reaction times and higher fractions missed. Interaction effects of functional age and driver support were not significant.

	PDT reaction time				PDT fraction missed			
	dfs	*F*	*p*	η^2	*dfs*	*F*	*P*	η^2
RoW								
Functional age	2, 36	7.885	0.001**	0.305	2, 36	6.033	0.005**	0.251
ADAS	1, 36	2.545	0.119	0.066	1, 36	1.749	0.194	0.046
Functional age x ADAS	2, 36	0.256	0.776	0.014	2, 36	0.246	0.783	0.014
YtR								
Functional age	2, 36	4.728	0.015*	0.208	2, 36	3.801	0.032*	0.174
ADAS	1, 36	2.192	0.147	0.057	1, 36	1.232	0.274	0.033
Functional age x ADAS	2, 36	0.005	0.995	0.000	2, 36	0.010	0.990	0.001
AMR								
Functional age	2, 36	3.398	0.044*	0.159	2, 36	2.795	0.074	0.134
ADAS	1, 36	8.083	0.007**	0.183	1, 36	6.703	0.014*	0.157
Functional age x ADAS	2, 36	0.903	0.414	0.048	2, 36	1.426	0.254	0.073
* p < 0.05; ** p < 0.01								

Table 8.8. Results of mixed between-within ANOVAs for messages regarding priority regulation.

General driving behaviour

Driving behaviours that can be affected by messages regarding priority regulation are the waiting position before passing an intersection (distance from the intersection), and acceleration and speed while passing the intersection. Being reminded that they have to yield to traffic from the right (*YtR*) or to traffic on a major road (*AMR*), participants may come to a stop sooner and/or might cross the intersection at a lower speed. On the other hand, being reminded that they are driving on a major road (*RoW*), participants may pass intersections at higher speeds. The only effect of driver support that appeared to exist, was driving speed. Participants travelled at slightly lower speeds (1.25 km/h) if they had been told that they had to yield to traffic from the right (*YtR*) than when they were passing these same intersections without the system being installed ($F(1,37) = 3.925$, $p = 0.055$, $\eta^2 = 0.096$). A trend in the opposite direction was found for messages regarding driving on major roads (*RoW*). On these roads, participants passed intersections at slightly higher speeds (0.70 km/h) if the system was installed than when it was not installed ($F(1,37) = 3.100$, $p = 0.087$, $\eta^2 = 0.077$).

Safety of decisions

Having calculated the Acc_Pre and Acc_Crit per intersection (see *Section 8.2.7*), both measures were averaged over intersections that were expected to be the same based on their priority regulation. Mixed between-within analyses of variance showed that messages regarding the approach of a major road (*AMR*) affected the deceleration of vehicles at the moment the participant drove off with the intention to pass the intersection (Acc_Pre). The relevant vehicles (i.e., those having right of way) decelerated less during the drives during which participants were supported, than during the drives without driver support (see *Table 8.9* for means and standard errors; $F(1, 37) = 5.493$, $p = 0.025$, $\eta^2 = 0.129$). The same effect was found for the messages *RoW* that told participants that they themselves were driving on a major road ($F(1, 37) = 4.299$, $p = 0.045$, $\eta^2 = 0.104$). However, this effect only related to those intersections at which participants, while driving on a major road, turned left into a minor road. The other intersections at major roads were not included in this particular analysis. Nevertheless, it is not quite clear why the *RoW-messages* would affect the safety of a decision to turn in front of an approaching vehicle.

Messages regarding right of way for traffic approaching from the right (*YtR*) affected the frequency of unsafe decisions (Acc_Crit). Unsafe decisions occurred less frequently while being supported than while not being supported ($F(1, 37) = 9.437$, $p = 0.004$, $\eta^2 = 0.203$).

Functional age did not affect the safety of decisions, neither as a main effect nor as part of an interaction effect. For those messages that significantly improved the safety of driver decisions, all functional age groups showed the same trend.

	Acc_Pre (lower value = less safe decisions)		Acc_Crit (higher value = fewer safe decisions)	
	Mean	Standard error	Mean	Standard error
RoW				
No support	-0.113	0.056	0.224	0.030
Support	0.057*	0.042	0.183	0.026
YtR				
No support	-0.457	0.066	0.331	0.028
Support	-0.331	0.081	0.227**	0.022
AMR				
No support	0.005	0.042	0.108	0.018
Support	0.130*	0.033	0.100	0.018
* p < 0.05; ** p < 0.01				

Table 8.9. Means for safety of driver decisions per priority regulation, without and with driver support.

8.3.4. Messages regarding safe gaps to join or cross

At twelve intersections, participants were supported in selecting a safe gap to join or cross traffic. These intersections, which were regarded as the most difficult ones of the whole route, were chosen based on the amount and speed of traffic on the lane(s) to cross, and the obstructed view of this traffic and/or the number of lanes to cross. Dependent on the size of the gaps between crossing vehicles, participants received the message that it was safe to turn or cross after the next vehicle. Whether the size of a gap was large enough to safely cross or turn was dependent on the traffic stream the participant had to cross. Gaps had to be at least 6.5 s between vehicles coming from the left, and at least 9.5 s between vehicles coming from the right or coming from the opposite direction before messages were sent (similar values were used by Oxley & Mitchell, 1995). To prevent messages from being sent too soon or to participants that had already decided to pass the intersection, messages were withheld if participants were further away from the intersection than 10 m, or if they were driving faster than 2 km/h. Consequently, participants that selected shorter gaps to cross traffic streams than the support system did received less messages than the maximum number of 12. Surprisingly, with an average of 8 messages per participant, the group of functionally old participants received the fewest messages. Functionally young and functionally middle-aged participants received an average of 10 messages regarding safe gaps to join or cross the traffic stream.

Workload

Mixed between-within analyses of variance of workload data only showed a main effect of functional age for reaction time and an interaction effect of functional age and support for fraction missed (see *Table 8.10*). However, none of the post hoc Bonferroni tests for differences between functional age groups were significant. After a distinction was made between intersections at which participants had to turn onto a major road and those at which participants, while driving on a major road, turned left into a minor road, it turned out that these intersections and the messages that were given in their vicinity affected age groups differently. The differences between the reaction times and fractions missed of functionally old participants on the one hand and functionally young and middle-aged participants on the other, were much larger while turning left *into a minor* road than while turning *onto a major* road. This was mainly caused by high reaction times and fractions missed of the functionally old participants while turning left into a minor road without the support system installed. If being supported, these reaction times and fractions missed of the functionally old participants were slightly lower, however, this difference was not significant. By contrast, functionally middle-aged participants had relatively high reaction times and fractions missed while turning *onto major* roads and being supported by the driver assistance system. As a matter of fact, their fraction missed significantly increased as a result of the support system. As a result of these two trends, the main effect of functional age was much stronger for the intersections at which participants had to turn left from a major road into a minor road ($F(2, 36) = 6.147$, $p = 0.005$, $\eta^2 = 0.255$ for reaction time and $F(2, 36) = 4.804$, $p = 0.014$, $\eta^2 = 0.211$ for fraction missed) than it was for the intersections at which participants turned onto a major road ($F(2, 36) = 1.747$, $p = 0.189$, $\eta^2 = 0.088$ and $F(2, 36) = 1.289$, $p = 0.288$, $\eta^2 = 0.067$). The main effect of driver support and the interaction effect of functional age and driver support were not significant for these two 'types of actions', neither for reaction time nor for fraction missed.

	PDT reaction time				PDT fraction missed			
	dfs	*F*	*p*	η^2	*dfs*	*F*	*P*	η^2
Gap								
Functional age	2, 36	3.434	0.043*	0.160	2, 36	2.609	0.087	0.127
ADAS	1, 36	3.176	0.083	0.081	1, 36	1.841	0.183	0.049
Functional age x ADAS	2, 36	1.722	0.193	0.087	2, 36	3.598	0.038*	0.167

* p < 0.05

Table 8.10. Results of mixed between-within ANOVAs for messages regarding safe gaps.

General driving behaviour

Driving behaviours relevant to messages regarding safe gaps to join or cross are the participants' acceleration and speed while passing the intersection. Drivers should not cross or turn slower when acting upon the advice of the support system than they would if they had selected the gap on their own. Otherwise, acceptance of a gap that would normally be large enough to cross or join traffic would still lead to unsafe situations. Mixed between-within analyses of variance showed that none of the main effects were significant; neither age nor support affected the participant's acceleration or speed while passing the intersection. The only effect that turned out to be significant was the interaction effect for acceleration ($F(2, 37) = 5.947$, $p = 0.006$, $\eta^2 = 0.243$). Whereas functionally young and old participants accelerated slightly faster while driving with the support system installed, functionally middle-aged participants accelerated slower.

Separate mixed between-within analyses of variance for the two actions that were distinguished in the section on workload showed that the interaction effect for acceleration was only significant for those situations in which participants turned left into a minor road ($F(2, 37) = 7.829$, $p = 0.001$, $\eta^2 = 0.297$). At these intersections, functionally young participants accelerated faster if they were supported, whereas functionally middle-aged participants accelerated slower. The acceleration of functionally old participants was not affected by driver support. These extra analyses also indicated that at these same intersections, participants turned at a higher speed (1.09 km/h) if they were supported than when they were not supported. That is, there was a main effect of driver support for participants' speed at the intersections at which participants turned left into a minor road ($F(1, 37) = 7.631$, $p = 0.009$, $\eta^2 = 0.171$).

Safety of decisions

Mixed between-within analyses of variance for deceleration measures Acc_Pre and Acc_Crit showed that assistance in gap selection only affected the average deceleration of vehicles at the moment the participant drove off with the intention to pass the intersection (Acc_Pre). The relevant vehicles (i.e., those having right of way) had to decelerate less on average during the drives during which participants were supported, than during the drives without driver support (see *Table 8.11* for means and standard errors; $F(1, 37) = 6.753$, $p = 0.013$, $\eta^2 = 0.154$). In that respect, assistance in gap selection appeared to improve the safety of driver decisions. This main effect of support was also significant for both previously distinguished actions ($F(1, 37) = 6.791$, $p = 0.013$, $\eta^2 = 0.155$ for turning onto a major road, and ($F(1, 37) = 4.299$, $p = 0.045$, $\eta^2 = 0.104$ for turning left into a minor road). In case of turning onto a major road, the gap selection related to gaps between crossing vehicles. In case of turning left into a minor road, gap selection related to gaps between oncoming vehicles. Note that the latter action concerns the same situations as for which it was unclear why *RoW-messages* would affect the safety of driver decisions (see *Section 8.3.3*). Evidently the improved safety of driver decisions at these intersections was brought about by messages regarding safe gaps to cross oncoming vehicles. Functional age did not affect the safety of decisions, neither as a main effect nor as part of an interaction effect.

	Acc_Pre (lower values = less safe decisions)		Acc_Crit (higher values = fewer safe decisions)	
	Mean	Standard error	Mean	Standard error
Gap				
No support	- 0.042	0.042	0.157	0.021
Support	0.123*	0.038	0.124	0.018
* p < 0.05				

Table 8.11. Means for safety of gap selection, without and with driver support.

8.3.5. Messages regarding an obstructed view of the intersection

At three intersections, participants' attention was drawn to the obstructed view of the intersection. This message was only sent if the participant was driving at a speed that was higher than 30 km/h. As a result, some participants received this message more often than others. Except for two functionally middle-aged participants, all participants received all three messages. The other two participants only received two of them.

Workload

Data on workload was available for one intersection. Mixed between-within analyses of variance showed that reaction times and fractions missed while passing this intersection did not differ between support condition ($F(1, 34) = 1.344$, $p = 0.254$, $\eta^2 = 0.038$ and $F(1, 34) = 0.635$, $p = 0.431$, $\eta^2 = 0.018$ respectively) nor between functional age groups ($F(2, 34) = 2.483$, $p = 0.099$, $\eta^2 = 0.127$ and $F(2, 34) = 1.592$, $p = 0.218$, $\eta^2 = 0.086$ respectively).

General driving behaviour

Driving behaviours that can be affected by messages regarding obstructed view of the intersection are the participants' waiting position before passing the intersection (distance from the intersection), and their speed while passing the intersection. The former indicator was only available for both support conditions for 26 participants. As the waiting position was only determined if participants had made a full stop, this means that some participants kept on driving while passing all three intersections even though they had no view of the intersection. Given the fact that on each of these intersections participants had to yield to traffic approaching from the right, not coming to a stop was even more dangerous. Taking the average for the drives with and without driver support, 10% of the functionally young, 18% of the functionally middle-aged, and 35% of the functionally old participants did not stop at any of the intersections.

For those that did stop, waiting position did not differ between support conditions ($F(1, 23) = 0.409$, $p = 0.529$, $\eta^2 = 0.017$). Looking at all participants – those that did and did not stop – driving speed on the intersection tended to be lower (1.39 km/h) when driving with the support system installed than when driving without the support system installed ($F(1, 36) = 3.886$, $p = 0.056$, $\eta^2 = 0.097$). Differences between age groups were not significant, neither for driving speed nor for waiting position.

Safety of decisions

Mixed between-within analyses of variance for deceleration measures Acc_Pre and Acc_Crit showed that messages regarding obstructed view of the intersection only affected the proportion of unsafe decisions to pass these intersections (Acc_Crit). This proportion was smaller during drives at which participants were supported than during drives at which no support was available (see *Table 8.12* for means and standard errors; $F(1, 36) = 4.680$, $p = 0.037$, $\eta^2 = 0.115$). The interaction effect of functional age and driver support was also significant ($F(2, 36) = 4.371$, $p = 0.020$, $\eta^2 = 0.195$). It turned out that functionally middle-aged participants had by far the largest decrease in the proportion of unsafe decisions (0.32 without support versus 0.04 with support). The effects of driver support on the proportion of unsafe decisions made by functionally young and functionally old participants were not significant.

	Acc_Pre (lower values = less safe decisions)		Acc_Crit (higher values = fewer safe decisions)	
	Mean	Standard error	Mean	Standard error
View of the intersection				
No support	- 0.446	0.203	0.250	0.034
Support	- 0.309	0.236	0.145*	0.030
* p < 0.05				

Table 8.12. Means for safety of view of the intersection, without and with driver support.

8.3.6. Messages regarding changed speed limits or one-way streets

Messages regarding changed speed limits were sent if the limit had changed from 50 to 70 km/h and the driver had not changed speed accordingly. Driving speeds and the appropriateness of sending a message were checked on three road stretches. The number of messages per participant varied from 1 to 3. Whereas 80% of the functionally young and 90% of the functionally middle-aged drivers received the maximum number of messages, only 50% of the functionally old drivers did. The message regarding an unexpected one-way road was always sent in the support condition. The participant received the message as soon as he was within a distance of 55 m of the respective intersection; just after he had passed an other intersection.

Workload

Data on workload were available for one intersection for both messages regarding speed and messages regarding a one-way street. Mixed between-within analyses of variance showed that the message regarding speed did not affect workload; neither reaction time nor fraction missed was affected (see *Table 8.13*). Age did affect workload. Functionally older participants had higher reaction times and fractions missed than both functionally young (p = 0.004 and p = 0.011) and functionally middle-aged participants (p = 0.002 and p = 0.004). Another mixed between-within analysis of variance showed that the message regarding a one-way street had affected reaction time. Reaction times were longer if passing the intersection while being supported. The main effect of driver support was not significant for fraction missed, but the trend pointed in the same direction (i.e., an increased workload).

	PDT reaction time				PDT fraction missed			
	dfs	*F*	*p*	η^2	*dfs*	*F*	*p*	η^2
Speed								
Functional age	2, 35	8.183	0.001**	0.319	2, 35	7.116	0.003**	0.289
ADAS	1, 35	0.505	0.482	0.014	1, 35	0.064	0.801	0.002
Functional age x ADAS	2, 35	0.737	0.486	0.040	2, 35	1.344	0.274	0.071
One-way street								
Functional age	2, 34	1.196	0.315	0.066	2, 34	0.104	0.901	0.006
ADAS	1, 34	5.369	0.027*	0.136	1, 34	2.129	0.154	0.059
Functional age x ADAS	2, 34	0.317	0.731	0.018	2, 34	0.017	0.983	0.001
* p < 0.05; ** p < 0.01								

Table 8.13. Results of mixed between-within ANOVAs for messages regarding speed and one-way street.

General driving behaviour

Driving behaviours that can be affected by messages regarding speed and one-way streets are speed on road stretches and route errors respectively. The number of route errors at the intersection with a one-way street was smaller during drives with the support system installed. Without driver support four participants – two functionally middle-aged and two functionally old participants – entered the one-way street despite the ‘do not enter-sign', whereas only one functionally middle-aged participant did so after being warned by the support system.

The safety of driver decisions was not analysed for these messages, as messages regarding higher speed limits and messages regarding the allowed direction of traffic were considered to be more related to driver comfort and route errors than to driver safety.

8.4. Results regarding user acceptance

Before analysing the answers to the questionnaire on user acceptance, reliability analyses were performed to test whether the items of the composite questions on user acceptance could be combined into the two subscales on system appreciation described by Van der Laan, Heino and De Waard (1997): usefulness and satisfaction (see *Section 8.2.8*). As can be seen in *Table 8.14*, all coefficients (Cronbach's alpha) were well above 0.80, indicating that inter-item consistency of the subscales was high (Walsh & Betz, 1990), and item scores could be combined safely into one subscale score.

	Before (n=105)		After (n=40)	
	Usefulness	Satisfying	Usefulness	Satisfying
Right of way	.88	.91	.89	.94
Safe gap	.91	.93	.91	.93
View of the intersection	.92	.93	.90	.89
Deviating rules or situations	.92	.92	.92	.87

Table 8.14. Reliability coefficients (Cronbach's α) for usefulness and satisfying subscales.

Subscale scores were computed for each time of measurement and type of message by taking the average of the scores on the items belonging to that subscale (see *Table 8.15*). Item scores ranged from 2 to -2, positive scores indicating that participants considered the message as useful or 'nice to have' (satisfying).

	Before (n=105)		After (n=40)		Difference (n=40)[a]	
	Usefulness	Satisfying	Usefulness	Satisfying	Usefulness	Satisfying
Right of way	0.37	-0.28	0.57	0.08	0.23	0.48
young	0.41	-0.33	0.64	0.15	0.18	0.53
middle	0.30	-0.44	0.53	0.04	0.28	0.68
Old	0.46	0.06	0.58	0.08	0.16	0.05
Safe gap	0.20	-0.22	0.05	-0.29	-0.18	0.00
Young	-0.17	-0.61	0.02	0.00	0.08	0.55
Middle	0.27	-0.22	-0.07	-0.48	-0.41	-0.25
Old	0.52	0.27	0.30	-0.23	0.02	-0.05
View of the intersection	0.52	-0.10	0.49	-0.10	0.08	0.15
Young	0.27	-0.29	0.32	-0.38	0.08	-0.03
Middle	0.47	-0.33	0.57	-0.09	0.24	0.41
Old	0.93	0.56	0.50	0.15	-0.26	-0.20
Deviating rules or situations	0.43	-0.13	0.61	0.28	0.18	0.38
Young	0.22	-0.44	0.64	0.33	0.18	0.30
Middle	0.26	-0.34	0.70	0.30	0.60	0.75
Old	1.05	0.66	0.40	0.20	-0.68	-0.28

[a] Difference scores (after - before) were calculated using data of only those participants that completed all parts of the experiment. Their before-scores on the usefulness and satisfying subscales were more negative than those for all participants together. Tests of differences between before-scores of participants that only filled in the first questionnaire (n=65) and those who filled in both (n=40) were, however, not significant.

Table 8.15. Usefulness and satisfying scores for each type of message.

Differences in user acceptance between age groups were analysed separately for opinions beforehand and afterwards (between-subjects). To examine whether experience with the messages affected user acceptance, within-subjects analyses of variance and mixed between-within analyses of variance were carried out. In addition, the support system was evaluated in terms of audibility, comprehensibility, timing, trustworthiness, and the willingness of people to buy it, based on the answers to the other questions that were presented to the participants (see *Section 8.2.8*).

8.4.1. Age differences

Between-subjects analyses of variance showed that functional age significantly affected the initial opinions about the support system (see *Table 8.16*). Before having experienced the support system, functionally old participants were more positive than functionally younger participants about all types of messages, except for messages regarding priority regulation. Post hoc Bonferroni tests showed that functionally old participants were significantly more positive about the usefulness of messages regarding obstructed views of intersections than functionally young participants were (*p* = 0.048). In addition, they considered messages regarding safe gaps as more satisfying than functionally young participants did (*p* = 0.006), and considered messages regarding obstructed views of intersections more satisfying (young vs old, *p* = 0.005; middle-aged vs old, *p* = 0.001), and messages regarding deviating rules or situations more useful and satisfying than both functionally young and functionally middle-aged participants did (*useful*: young vs old, *p* = 0.010; middle-aged vs old, *p* = 0.005; *satisfying*: young vs old, *p* = 0.00005; middle-aged vs old, *p* = 0.00003).

Intersection groups			Beforehand (n=105)		Afterwards (n=40)	
			Usefulness	Satisfying	Usefulness	Satisfying
Priority regulation						
	Functional age	*F* *df* *p*	0.327 2, 101 0.722	2.199 2, 101 0.116	0.052 2, 37 0.949	0.035 2, 37 0.965
Safe gaps to join or cross						
	Functional age	*F* *df* *p*	2.933 2, 101 0.058	5.136** 2, 101 0.008	0.448 2, 37 0.642	0.653 2, 37 0.527
View of the intersection						
	Functional age	*F* *df* *p*	3.182* 2, 101 0.046	7.969** 2, 101 0.001	0.272 2, 37 0.763	0.817 2, 37 0.449
Deviating rules or situations						
	Functional age	*F* *df* *p*	6.131** 2, 101 0.003	13.292** 2, 101 0.00001	0.330 2, 37 0.721	0.053 2, 37 0.949
* p < 0.05; ** p < 0.01						

Table 8.16. Between-subjects analyses of variance of average usefulness and satisfying scores before and after participants experienced the support system.

After having received these types of messages from a support system while driving the simulator car, all age effects disappeared (see *Table 8.16*). It should be mentioned, however, that the between-subjects analyses of data on appreciation beforehand were based on the opinions of more participants than the analyses of data on appreciation afterwards. The former analyses were based on data of all 105 participants, whereas the latter were based solely on data of those who were not susceptible to simulator sickness and were able to come to the UMCG twice (40 participants; see *Section 8.2.2*). Between-subjects analyses of data on appreciation beforehand of only those participants that completed all parts of the experiment, showed no age effects at all. Thus the opinions of the 40 participants for which no age effects were found *after* they had experienced the support system did not significantly differ between age groups in the first place: there were no age effects to disappear.

8.4.2. Effect of having experienced the support system

As regards the mere effect of having experienced the driver support system, within-subjects analysis of variance for the group of 40 participants that completed all parts of the experiment showed that satisfaction of messages regarding priority regulation and satisfaction of messages regarding deviating rules or situations had significantly increased after having experienced the support system ($F(1,39) = 5.261$, $p = 0.027$, $\eta^2 = 0.119$ and $F(1,39) = 5.351$, $p = 0.026$, $\eta^2 = 0.121$ respectively). At first, participants were negative about the satisfaction these types of messages would give, afterwards they were neutral about the satisfying character of messages regarding priority regulation and slightly positive about messages regarding deviating rules or situations.

Taking into account the functional ages of the participants, mixed between-within analyses of variance showed that the effect of experience on satisfaction of messages regarding priority regulation disappeared ($F(1,37) = 3.501$, $p = 0.069$, $\eta^2 = 0.086$). Functionally young and middle-aged participants were indeed more positive about these messages after having experienced them (i.e., not being negative anymore), but functionally old participants were as neutral about it as beforehand. The other effect of experience that was significant for all participants regardless of age, that on satisfaction of messages regarding deviating rules or situations, was not significant either when taking functional age into account ($F(1,37) = 2.520$, $p = 0.121$, $\eta^2 = 0.064$), but the interaction effect of functional age and experience was ($F(2,37) = 3.719$, $p = 0.034$, $\eta^2 = 0.167$). This interaction effect was also significant for *usefulness* of messages regarding deviating rules or situations ($F(2,37) = 5.495$, $p = 0.008$, $\eta^2 = 0.229$). At first, functionally old participants were more positive than functionally young and middle-aged participants about the usefulness of messages regarding deviating rules or situations, and the satisfaction they would give. However, after having experienced these messages functionally old participants became less positive about them, whereas the younger age groups became more positive. Paired samples-tests showed that these effects of experience on user acceptance were only significant for the functionally middle-aged (*usefulness*: $t(19) = 2.917$, $p = 0.009$; *satisfaction*: $t(19) = 3.729$, $p = 0.001$).

Opinions about the two other types of messages ('safe gaps' and 'view of the intersection') were not affected by experience. Opinions regarding their usefulness and their satisfying character remained the same, both in general and when taking the functional age of the participants into account.

8.4.3. Effect of driver characteristics

To find out more about the participants that were positive about the system, independent samples-tests were carried out using background variables such as number of disorders, number of situations that people avoid, number of manoeuvres they have difficulties with, number of manoeuvres for which they would like driver support, and daily use of technical devices (e.g., cash machine, teletext, mobile phone, internet). For each background variable, two groups were made that were compared on their opinions about a hypothetical system and on their opinions after they had experienced the system. To adjust for the fact that per time of measurement and group comparison 8 tests were carried out (two for each type of message: usefulness and satisfaction), a Bonferroni correction was used (0.05/8 = 0.00625; 0.01/8 = 0.00125; 0.001/8 = 0.000125). Significant differences were found in the opinions about the hypothetical system between participants not having any disorders and those who had one or more, between participants not having difficulties with any manoeuvres or only with one manoeuvre and those having difficulties with two or more manoeuvres, and between participants not needing any help or only wanted assistance with one manoeuvre and those who wanted assistance with two or more manoeuvres (see *Table 8.17*; asterisks indicate significant differences between groups of participants). As expected, participants who had more disorders, or who had difficulties with more manoeuvres or who would like to have assistance with several manoeuvres were more positive about the hypothetical assistance systems than participants without any disorders, difficulties or desire for assistance. No differences were found in opinions after participants had experienced the system(s).

		Diseases and disorders		Having difficulties with certain manoeuvres		Some assistance would be nice	
		None (n=90)	One or more (n=15)	No or only one (n=43)	Yes, with two or more (n=62)	No or only with one manoeuvre (n=50)	Yes, with two or more (n=55)
Priority regulation	Usefulness	0.23	1.20***	0.02	0.62**	0.00	0.71***
	Satisfaction	-0.43	0.63***	-0.61	-0.04*	-0.67	0.08***
Safe gaps	Usefulness	0.07	0.93*	-0.31	0.55***	-0.23	0.58**
	Satisfaction	-0.34	0.48**	-0.70	0.12***	-0.71	0.23***
View of the intersection	Usefulness	0.41	1.19***	0.20	0.74	0.21	0.80*
	Satisfaction	-0.19	0.43	-0.40	0.11	-0.49	0.25**
Deviating rules/situations	Usefulness	0.35	0.91	0.17	0.61	0.11	0.72*
	Satisfaction	-0.22	0.40	-0.45	0.09*	-0.44	0.15*
* p < 0.05; ** p < 0.01; *** p < 0.001							

Table 8.17. Means for usefulness and satisfying subscales per type of message, for groups of participants that differ on the number of disorders, on the number of manoeuvres they have problems with, or on the number of manoeuvres they would like to be assisted with.

8.4.4. System evaluation

Most participants were positive about the audibility and comprehensibility of the messages. Except for one participant, everyone was very well able to hear the messages. Eighty-five per cent of the participants indicated that the messages were also easy to understand and that it was easy to act upon them. This does not mean that they always did act upon them. Only 18% said that they always followed the advice of the support system. Another 63% frequently followed the system's advice.

One of the reasons for not following the system's advices may be that participants did not always trust them. Thirty-five per cent of the participants trusted the advices only occasionally or never. Two participants indicated that it depended on the type of messages; they always trusted traffic rules, but never safe gaps to join or cross. As regards the timing of the messages, participants' opinions differed to a greater extent. Whereas 38% of the participants considered the timing of the messages to be correct, 20% found that messages came too soon, and 35% found that messages (occasionally) came too late. This aspect of participants' opinions about the system was clearly related to functional age. Whereas 70% of the functionally young participants considered the timing of the messages to be correct or found messages came too soon, 60% of the functionally old participants considered them to come too late.

If asked whether they would buy the system if it were on the market, 35% of the participants gave an affirmative answer. Half of them was willing to pay for it. If they had the system installed in their car, 30% indicated that they would be more inclined to drive in an unfamiliar city.

8.5. Discussion and conclusions

In this study, a driver support system was evaluated in terms of effects on workload, general driving behaviour and safety of driver decisions, as well as in terms of user acceptance. The driver support system was simulated while participants drove in a fixed base driving simulator, and provided the driver with information regarding priority regulation, safe gaps to join or cross traffic streams, obstructed views of intersections, one-way streets and changed speed limits. The effects of the support system were compared between participants that differed in functional age, which was based on scores on three tests of cognitive functioning, relating to reaction time, selective attention, and visual-motor coordination.

8.5.1. Effects on workload and driver performance

The results of this study showed that all three safety-related messages increased the safety of driver decisions. Messages regarding the priority regulation, obstructed view of an intersection, and safe gaps to join or cross traffic streams led to fewer and/or less decelerations of relevant other vehicles. These decelerations were considered to be precursors of a collision. Fewer and less decelerations can be regarded as safer decisions. The message regarding an unexpected one-way street led to fewer route-errors. In general, effects of the messages were the same for functionally young, middle-aged and old drivers. The only interaction effect that was established concerned messages regarding an obstructed view of the intersection. Functionally middle-aged participants appeared to profit the most from these messages as far as the safety of driver decisions was concerned.

Workload was not reduced by the driver support system. To the contrary, messages regarding the approach of a major road and messages regarding an unexpected one-way street even led to an increased workload as indicated by reaction times on a secondary task. Interaction effects of driver support and functional age were not established for workload. However, functional age did affect workload in general. In most cases, functionally old participants had higher workloads than functionally young participants (see e.g., Ponds, Brouwer & Van Wolffelaar, 1988, and McDowd & Craik, 1988 for similar results). This seems to be the mere result of having to carry out two tasks simultaneously. The reaction times of drivers of different functional age groups were the same when they had to carry out a detection task while they were sitting in a parked simulator car. However, when performing the same task while driving, functionally old drivers had longer reaction times than both functionally young and middle-aged drivers. A related study showed that as traffic situations got more difficult, the workload of all drivers increased further. However, this increase in workload did not increase with functional age. An interaction effect was only established for the increased effort needed to combine the primary and secondary task (Davidse, Van Wolffelaar, Hagenzieker & Brouwer, 2007; see *Chapter 6*).

Driver support also affected general driving behaviour. Messages regarding an obstructed view of the intersection and messages which reminded participants that they had to yield to traffic from the right led to lower driving speeds on the corresponding intersections. Messages regarding safe gaps that were sent to participants who, while driving on a major road, turned left in front of oncoming vehicles, led to higher speeds while passing the intersections.

For some messages, the actual delivery of the message was dependent on the behaviour of the participant. Messages regarding the approach of a major road or an obstructed view of the intersection, for example, were only sent if the participant drove at a speed that was higher than 30 km/h, assuming the driver had already adjusted behaviour to the local circumstances if he was driving slower. As a result, the average number of messages received by participants could vary. Surprisingly, functionally old participants received the fewest messages regarding safe gaps, the approach of a major road, and changed speed limits. A possible explanation for the first type of messages may be that older drivers stopped further away from the intersection to look for safe gaps in the traffic stream. A related study that examined other data of this same experiment showed that functionally old participants generally stopped two meters further away from the intersection to decide whether it was safe to join traffic after turning left or right than both young and middle-aged participants did (13.8 m versus 11.7 m and 11.8 m respectively; see Davidse, Van Wolffelaar, Hagenzieker & Brouwer, 2007 or *Chapter 6*). As messages regarding safe gaps to join traffic were only given if participants were within a distance of 10 m from the intersection (see *Section 8.2.6*), a different waiting distance appears to be a plausible explanation for functionally old participants receiving fewer messages.

Fewer messages regarding the approach of a major road may be the result of compensatory behaviour at the tactical level. Functionally old participants may have started reducing their speed sooner (i.e., at a larger distance to the intersection) to compensate for their increased perception-reaction time. However, there is no guarantee that older participants restricted this compensatory behaviour to intersections at which they were approaching a major road. In other words, if older drivers approached intersections with a major road at lower approach speeds, this does not necessarily mean that they were aware of the fact that they had to yield to all traffic on the intersecting road. Unfortunately, data sampling did not enable us to determine whether participants reduced speeds at the same distance to the intersection regardless of the type of intersection they approached. Nevertheless, the above results are convincing enough to stress the fact that system settings should be adjustable to the owner's general driving behaviour. Otherwise, drivers will not be able to trust system performance. Similar conclusions can be drawn from the participants' opinions about the timing of messages. Whereas 70% of the functionally young participants considered the timing of messages to be correct or found messages came too soon, 60% of the functionally old participants considered them to come too late. As Oxley (1996) concluded in his evaluation of the collision warning system that was tested in the EDDIT-project: uniform settings would be at best unhelpful, at worst dangerous.

The support system that we evaluated was designed to reduce workload and improve driving performance. Whereas the latter improvement was established, a reduced workload was not shown. This could be the result of the new task that was added to the driving task. After all, the driver has to listen to and process the information that is offered by the assistance system. This extra task may increase workload, thereby counteracting the effects of the support system. However, the increased workload as a result of the extra task is expected to be only temporary. Therefore, longer evaluation periods are needed to establish the net effect of the system on driver workload. Such an evaluation will also provide insight in the influence that behavioural adaptation may have on effects on driving performance.

Another factor that may have influenced workload values, is the combined measurement of workload during the approach of an intersection and the actual passing of the intersection. Our system provided the driver with timely information about an important element of the intersection he was approaching in order to give him more time to process the information and to decide how to act upon it. The idea behind it was that if the driver knows what to expect, it is more likely that he will select the correct mental schema for safely passing the intersection. This mental schema will simplify the driving task and will prevent errors. As a result, the support system may increase workload during the approach of the information, but it is likely to decrease workload during the actual passing of the intersection. In the present study, the peripheral detection task that was used to measure workload, started on average 100 m before the intersection and stopped 30 m after the intersection. As a result, the differential effects of the two abovementioned processes could not be disentangled. Future studies can anticipate this by carrying out separate workload measurements for the approach and passing of intersections.

8.5.2. User acceptance

Having a positive effect on the safety of driving behaviour is only one of the preconditions for driver assistance systems to be successful in improving the safety of a specific group of road users. To obtain that goal, driver assistance systems should also be used and trusted, and the driver should be able to understand the information the support system is sending to him. The results of this study showed that drivers of different functional age groups differed in their opinions about the usefulness and satisfying character of a hypothetical intelligent driver support system that was described to them. This concerned three of the four types of information offered by the system. Functionally old drivers were more positive about the usefulness and satisfying character of messages regarding safe gaps to join or cross, obstructed views of the intersection, and deviating traffic rules or road situations (different speed limit, one-way street), but were as positive about the usefulness of messages regarding priority regulation as the other age groups. After the actual experience with the support system, opinions changed and age differences seemed to disappear. Younger drivers tended to become more positive while older drivers tended to become less positive.

The only type of messages for which the interaction of experience and age was significant, were messages regarding deviating rules or situations. Before they actually experienced messages regarding deviating rules or situations, functionally young and middle-aged participants did not very much like this type of message. Afterwards, they were much more positive about it, whereas the functionally old participants had become less positive about it. However, the experience of receiving this type of messages was not the only plausible explanation for the interaction effect. Unfortunately, the questions about the appreciation of this type of messages differed between the questionnaire administered beforehand and the one that was administered afterwards. Both questions were preceded by an example of a deviating road situation. Initially, the deviating road situation that was described was about a crossing cycle path on which cyclists could arrive from left as well as from right. However, while programming the experiment it turned out that it was not possible yet to include cyclists as traffic participants in the simulator environment. Therefore, other deviating rules or situations had to be included in the questionnaire that was to be administered afterwards: deviating rules or situations the participants had actually experienced. The rules and situations which were described in the second questionnaire related to changed speed limits and one-way streets. Since messages regarding changed speed limits were only provided if the speed limit had risen from 50 to 70 km/h *and* participants had not already altered their speed accordingly, functionally younger participants might have been more interested in knowing they were allowed to drive faster than functionally old drivers were.

Other studies that evaluated attitudes towards support systems showed that younger drivers were *less* positive about messages regarding speed limits than older drivers. For example, Viborg (1999) found that one of the hypothetical support systems that were more often rated as useful by older as compared to younger drivers, was an automatic speed adjustment system (adjustment to the speed limit or to slippery and foggy conditions). However, this system seems to be restrictive, whereas our system stimulated drivers to increase speed in order to keep up with the traffic flow. One of the systems our functionally older participants were positive about, the one that would give advice on safe gaps to join or cross a traffic stream, was also rated positively by Viborg's older drivers. They were positive about a system that warns the driver by a signal if it is unsafe to cross an intersection, and about a system that warns the driver if it is unsafe to turn left at an intersection. Similar results were found by Oxley & Mitchell (1995). They tested the safety effects of and attitudes towards a system that provided the driver with a colour light indication of whether the next gap in the stream of traffic was long enough to allow a safe turning manoeuvre to be made. All the older adult subjects said that the system was useful or very useful at night. By day, 63% of the older drivers found it useful or very useful. About half of the older drivers would be willing to pay for the system.

In the present study, 35% of the participants was willing to buy the system if it were on the market. Half of them was willing to pay for it. Most participants were positive about the audibility and comprehensibility of the messages. Except for one participant, everyone was very well able to hear the messages. Eighty-five per cent of the participants indicated that the messages were also easy to understand and that it was easy to act upon them. This does not mean that they always did act upon them. Only 18% said that they always followed the advice of the support system. Another 63% frequently followed the system's advice. One of the reasons for not following the system's advices may be that participants did not always trust them. Thirty-five per cent of the participants trusted the advices only occasionally or never. Two participants indicated that it depended on the type of messages; they always trusted traffic rules, but never safe gaps to join or cross.

8.5.3. Limitations

Simulator sickness had a large influence on the reduction of the initial number of persons that participated in this study. Despite screening for sensitivity to simulator sickness, as much as 46% of the participants dropped out because they felt sick while driving the simulator car. Although high dropout rates due to simulator sickness are not uncommon, one of our concerns was that this dropout could have affected study results, especially since dropout rates differed for the various functional age groups (29% for young, 46% for middle-aged, and 58% for old participants). Therefore, we tested whether study results would have been the same if all analyses had been performed using only those participants (n=40) that completed all parts of the experiment. The only study results that were not solely based on these 40 participants were the results that pertained to the between-subjects effect of functional age on the appreciation of hypothetical support (before-measurement). These results showed significant age effects for three of the four types of information offered by the support system. When replicating these analyses using only the appreciation data of the 40 participants that completed all parts of the experiment, no age effects were found at all. It turned out that the functionally old participants that completed all parts of the experiment tended to be more negative than those that only completed the first part of the experiment; the opinions of the former group more resembled those of the younger participants. This shows that simulator sickness can cause selective dropout of participants, thereby affecting the representativeness of the sample (see also Edwards, Caird, Lamsdale, & Chisholm, 2004).

Selective dropout may lead to the wrong conclusions about user acceptance of systems that could improve driver safety, or even worse, to wrong conclusions about the effectiveness of driver assistance systems to improve the driving behaviour of a specific group of road users. To prevent this, simulator sickness should be countered by using experimental procedures that not only include screening procedures for sensitivity to simulator sickness, but also address other factors that might add to simulator sickness, such as simulator configuration (size of the screens, amount of motion cues), and general aspects of the driving environment (proximity of buildings and trees, number of turns, degrees of curvature). Controlling the latter factor is a major challenge when designing an experiment that evaluates the effectiveness of driver assistance systems that support turning left at (sub)urban intersections.

8.5.4. Conclusions

Overall, the findings indicate that all three safety-related messages that were given by the in-car driver assistance system increased the safety of driver decisions: messages regarding the priority regulation, obstructed view of an intersection, and safe gaps to join or cross traffic streams led to fewer and/or less decelerations of relevant other vehicles. The message regarding an unexpected one-way street led to fewer route-errors. No differences were found between the effects on driver behaviour of young and older drivers. Therefore, the evaluated driver assistance system appears to have a positive safety effect for all age groups.

Contrary to expectations, none of the support messages reduced workload, and some even increased it. As this is probably the result of the new task that was added to the driving task (listening to and processing the information of the assistance system), it is expected to wear off over time.

Functionally old drivers were more positive about the usefulness and satisfying character of messages regarding safe gaps to join or cross, obstructed views of the intersection, and deviating traffic rules or road situations (different speed limit, one-way street), but were as positive about the usefulness of messages regarding priority regulation as the other age groups. After the actual experience with the support system these opinions changed and age differences seemed to disappear. However, another age effect was introduced. Whereas 70% of the functionally young participants considered the timing of messages to be correct or even found that messages came too soon, 60% of the functionally old participants considered them to come too late. This stresses the fact that system settings should be adjustable.

Summary, discussion and general conclusions

In this thesis, the main focus was on assistive devices that may improve and prolong the safe mobility of older drivers. Older drivers form a group of road users that is getting more and more attention in road safety research and policy. An important reason for this growing interest is the increase in the percentage of older people in the future population of most developed countries (OECD, 2001). Furthermore, the number of older drivers will increase as a result of the increasing percentage of driving licence holders among the older adults, and senior drivers continuing to drive actively longer than before (Hakamies-Blomqvist, Sirén, & Davidse, 2004; Jette & Branch, 1992). The attention for older drivers is also based on a concern for the road safety implications of a growing population of older drivers. Especially since several studies have indicated that the fatality rate of older drivers is above average; as a group their number of road fatalities per kilometre driven is higher (see e.g., Davidse, 2000; Maycock, 1997; OECD, 2001). Without countermeasures taken, an increase in the total number of road fatalities is a realistic scenario. The research presented in this thesis focussed on measures that reduce crash involvement by making the driving task easier. Two types of measures were studied in detail: adjusting road design to reduce the complexity of traffic situations, and in-car devices that assist the driver. Both are considered assistive devices that have the potential to improve road safety as well as resolve the activity limitations and participation restrictions to which age-related functional limitations may lead.

The main research questions of this thesis related to a general description of the current and future safety of older drivers, the characteristics of older drivers that may influence their safety, the most important needs for support that result from these characteristics, and assistive devices that may provide the desired support.

This chapter starts with a summary of the answers to these questions. First, a concise description is given of the current safety of older drivers and the characteristics of older drivers that may be of influence on that safety. After that, the main conclusions are given on the most promising assistive devices for improving the safety of older drivers. Theoretical models played an important role in determining which assistive devices would be needed to improve the safety of older drivers. In the third section of this chapter, their role is evaluated. The fourth section deals with a methodological aspect, the use of a driving simulator to determine the effects of assistive devices on driving performance and workload of older drivers. In the fifth and last section, measures are described that are complementary to the measures that played the leading role in this thesis.

A concise description of the safety of older drivers

In the Netherlands, the fatality rate of drivers aged 75 and above is the largest of all drivers (*Chapter 1*). Their injury rate is the second highest, after those aged 18-24. As in other developed countries, the high fatality rate of older drivers is mainly the result of their increased physical vulnerability; they are more vulnerable to personal injury in the event of a crash. In the second place, older drivers are over-represented in multi-vehicle crashes at intersections. These crashes particularly occur when the older driver has to turn left across a lane of traffic (turn right in left-driving countries). Not only are older adults over-involved in such crashes, they are also significantly more frequently legally responsible for those crashes, often because they failed to yield. The consequences of these crashes, in which the older driver's car is typically hit with high speed by a vehicle coming from the driver's side, are often serious, particularly for the older driver. The latter being the result of the point of impact as well as the increased vulnerability of older people.

The over-involvement of older people in crashes has been associated with age-related declines in visual and cognitive functions. There are few indications that a decline in visual and cognitive functions as part of normal ageing has negative road safety consequences. Only in the case of moderate and severe visual and cognitive limitations resulting from age-related disorders and diseases such as eye disorders and dementia does the relation between functional limitations and crash involvement become visible (*Chapter 2*). Whatever the nature of the functional limitations, their final common effects are often quite similar: an increase in the time needed to prepare and execute a driving manoeuvre and a decreased ability to perform different activities in parallel (Brouwer & Ponds, 1994).

Although significant functional limitations affect only a small part of the population, this part is expanding and will continue to do so in the next few decades. In the Netherlands, the number of people aged 65 and above will increase from 2.3 million in 2006 to 4.3 million in 2040 (Statistics Netherlands, 2006). In comparison with the total size of the population, the share of those aged 65 and above will increase from 14.3% in 2006 to 25.0% in 2040. A substantial part of this group will be much older than 65. At this moment in time, approximately 1.1 million people are older than 74. Statistics Netherlands (2006) expects that this number will have doubled by 2040, resulting in 2.2 million people aged 75 and above. Especially in the latter age group, the percentage of people having difficulties in traffic due to functional limitations is quite large (*Chapter 3*).

The conclusion of the first three chapters of this thesis is that the factors associated with the safety of older drivers in the Netherlands are similar to those described in the international literature (see e.g., Hakamies-Blomqvist, 1993, 1994a; Langford & Koppel, 2006; McGwin & Brown, 1999; Nagayama, 1992; OECD, 1985, 2001; Zhang, Fraser, Lindsay, Clarke & Mao, 1998). The question remained, however, which assistive devices would be most effective in improving their safety without sacrificing their mobility.

Assistive devices: demand and supply

The question of which assistive devices are able to improve road safety is usually answered by looking at the available devices. This is especially the case for in-car driver assistance systems. In this thesis, however, the above question was answered by looking at the demands. In order to identify the older driver's most important needs for support, a theoretical analysis was conducted of the strengths and weaknesses of the older driver (*Chapter 4*). It was assumed that to improve the safety of older drivers, assistive devices should support their relative weaknesses by correcting or compensating for them. Moreover, these weaknesses should be relevant to road safety. The theoretical analysis resulted in a list of the relative weaknesses of the older driver and the difficulties that older drivers encounter in traffic as a result of these weaknesses. In order to rate the relevance of these weaknesses to road safety, the weaknesses were compared with crash data. Those weaknesses that have a substantial influence on road safety, as indicated by the percentage of crashes that could have been avoided if the weakness would not have existed, were considered to indicate a need for support. It turned out that these (sets of) weaknesses are: 1) reduced motion perception and contrast sensitivity, 2) restricted peripheral vision in combination with reduced neck flexibility, 3) reduced selective attention, and 4) reduced speed of processing information and decision making, reduced divided attention and reduced performance under pressure of time. *Table 1* links these weaknesses with the driving-related difficulties they may cause, and the resulting needs for support (*Chapter 4*).

Relative weaknesses	Driving-related difficulties	Needs for support
Contrast sensitivity and motion perception	Difficulty reading signs and in-car displays, and difficulty with depth perception, judging the movement of fellow road users and estimating their speed	Draw attention to (speed of) approaching traffic
Peripheral vision and flexibility of head and neck	Overlooking other road users while merging or changing lanes	Signal or provide view of road users located in the driver's blind spot
Selective attention	Overlooking traffic signs and signals	Assist the driver in directing his attention to relevant information
Speed of information processing, divided attention, and performance under pressure of time	Reaction time increases as the complexity of the traffic situation increases	Provide prior knowledge on the next traffic situation

Table 1. Most important needs for support, and the weaknesses and driving-related difficulties that create them.

Assistive devices that appear to fit the most important needs for support are summarized in *Table 2*. A distinction is made between road design elements that allow for the weaknesses of the older driver (*Section 5.3*), and in-car devices that assist the driver (*Chapter 7*).

Relative weaknesses	Relevant road design elements	In-vehicle assistance systems
Contrast sensitivity and motion perception	Assistance for turning left Contrast of pavement markings Design of traffic signs and signals Design of street-name signs	Collision warning systems for intersections Automated lane changing and merging systems
Peripheral vision and flexibility of head and neck	Angle at which streets meet	Automated lane changing and merging systems Blind spot and obstacle detection systems
Selective attention	Placement of traffic signs	In-vehicle signing systems Special intelligent cruise control
Speed of information processing, divided attention, and performance under pressure of time	Angle at which streets meet Lane-use control signs Type of intersection (roundabouts) Placement of traffic signs Fixed lighting	Systems that give information on the characteristics of complex intersections the driver is about to cross

Table 2. Road design elements and in-vehicle assistance systems that appear to fit the needs of the older driver.

Regardless of the type of assistive devices – adjustments to road design or in-car driver assistance systems – the suggested devices have hardly been tested yet on their effects on workload for and driver performance of older drivers. Exceptions are recent experiments by Shechtman et al. (2007) and Classen et al. (2007) in which the effects were evaluated of some of the adjustments to intersection design proposed by Staplin, Lococo, Byington, and Harkey (2001; see *Table 2*), and evaluations of the effects of the use of ITS by older drivers in the EDDIT-project (Oxley & Mitchell, 1995), in a study by Entenmann et al. (2001), and in a study by Caird et al. (2006).

Effects on workload and safety: results of a simulator study

In this thesis, the effects of both adjustments to intersection design and functions of a simulated in-car assistance system were evaluated in a driving simulator. As regards adjustments to road design, the effects were tested of different types of intersection layout, priority regulation and sight distance (*Chapter 6*). The in-car driver assistance system that was tested (*Chapter 8*), was designed to support the driver in four driving-related tasks, namely recognizing the type of priority regulation, assessing safe gaps to join or cross traffic, anticipating short sight distances, and noticing deviating traffic rules of road situations (i.e., change of speed limit and one-way street). Workload was measured by performance on a secondary task, and driver performance was measured by waiting position before passing intersections, acceleration and speed while passing intersections and safety of driver decisions. The latter was measured by crashes between participants and surrounding traffic, and by the precursor of crashes, that is, deceleration of surrounding traffic in order to prevent crashes.

The results regarding intersection characteristics showed that intersection layout, priority regulation, as well as driver manoeuvres influenced the difficulty of passing intersections. Intersection layout was the best predictor of variations in workload. Three-way intersections that only had a side-street at the left-hand side of the driver turned out to be the easiest intersections to pass, whereas four-way intersections with dual carriageways were the most difficult to manage.

The results regarding the in-car driver assistance system are summarized in *Table 3*. All three safety-related messages increased the safety of driver decisions. Messages regarding the priority regulation, obstructed view of an intersection, and safe gaps to join or cross traffic streams led to fewer and/or less decelerations of relevant other vehicles. The message regarding an unexpected one-way street led to fewer route-errors.

Type of message	**Workload** (+ = higher workload)	**Safety of driver decisions** (+ = safer decisions)
Priority regulation Right of Way Yield to Right Approaching Major Road	 0 0 +	 + + +
Safe gaps	0	+
Short sight distances	0	+
Deviating situation: one-way street	+	Fewer route errors

Table 3. Effects of in-car assistance systems.

Differential effect of functional age

As the assistive devices described above were selected based on the relative weaknesses of the older driver, it was expected that older drivers would benefit more from their support than younger drivers would. That is, it was expected that people with functional limitations will benefit more from the support provided by the selected assistive devices than people with no functional limitations. Therefore, functional age rather than chronological age was used to compare workload and driving performance between age groups. Functional age was based on scores on three tests of cognitive functioning, relating to reaction time, selective attention, and visual-motor coordination. Persons scoring well on the average of these three tests were considered to be functionally young, whereas persons scoring relatively poor on them were considered to be functionally old. People scoring in between were considered to be functionally middle-aged. Although it turned out that the majority of the chronologically older people was also functionally old, there were some exceptions. One of the chronologically old participants even appeared to be functionally young. At the same time, two of the chronologically young participants appeared to be functionally old. This underlines the importance of a personal approach in decisions about fitness to drive.

It was found that functional age affects workload as soon as people start driving. The mean reaction times of drivers of different functional age groups were the same when they had to carry out a detection task (secondary task) while they were sitting in a parked simulator car. However, when performing the same task while driving (primary task), functionally older drivers had longer mean reaction times than both functionally young and middle-aged drivers. As traffic situations got more difficult as a result of changes in the intersection design, the workload of all drivers increased further. However, this increase in workload did not increase with functional age. An interaction effect was only established for the increased effort needed to combine the primary and secondary task. In that case, functionally older drivers experienced a higher increase in workload than younger drivers did.

Driver support as offered by the in-car driver assistance system did not reduce workload. To the contrary, messages regarding the approach of a major road and messages regarding an unexpected one-way street even led to an increase in driver workload as indicated by reaction times on a secondary task (see *Table 3*). Interaction effects of driver support and functional age were not established.

Whereas functional age did affect workload, this age effect was not established for safety of driver decisions. All age groups appeared equally capable of deciding whether it was safe to cross or join other traffic streams, regardless of the difficulty of the intersection design. As regards the effect of the driver support system on safety of decisions, it was found that all safety-related messages increased the safety of driver decisions for all age groups. The only interaction effect that was established concerned messages regarding an obstructed view of the intersection. Functionally middle-aged participants appeared to profit the most from these messages.

The fact that functional age only affected workload and not safety of driver decisions, and that no interaction effects were found between functional age and intersection design, can be the result of three related matters. First of all, it may indicate that our functionally older drivers were capable of adequately compensating for their increased reaction time. Another explanation may be that our simulator environment did not sufficiently put our drivers to the test. Perhaps task demand should have been higher to overask the capabilities of the functionally older driver and affect the safety of his decisions. On the other hand, our functionally older drivers may have been too young. After all, they were people who still drove on a regular basis and did not have considerable functional limitations. Therefore, future studies investigating the differential effects of intersection design on driver behaviour of older and younger drivers should include drivers with more severe functional limitations and confront them with traffic situations that are more difficult to pass.

User acceptance

Having a positive effect on the safety of driving behaviour is only one of the preconditions for in-car driver assistance systems to be successful in improving the safety of a specific group of road users. To obtain that goal, driver assistance systems should also be used and trusted, and the information that it provides should also be understood by its users (*Chapter 7*). Therefore, the evaluation of the in-car driver assistance system described in this thesis also included user acceptance testing. The results of these tests showed that drivers were moderately positive about the usefulness of messages regarding priority regulation, obstructed views of the intersection, and deviating traffic rules or road situations, and neutral about the usefulness of messages regarding safe gaps to join or cross traffic. In general, drivers were not as positive about the satisfaction the messages gave as they were about their usefulness. They were actually a bit negative about this aspect of the messages. The actual experience with messages regarding priority regulation and deviating traffic rules resulted in more positive opinions about the satisfaction these types of messages give (*Chapter 8*).

Returning to the opinions about the hypothetical systems as they were described to the participants before they had experienced them, it turned out that functionally old drivers were more positive about the usefulness and satisfying character of messages regarding safe gaps to join or cross, obstructed views of the intersection, and deviating traffic rules or road situations (different speed limit, one-way street), but were as positive about the usefulness of messages regarding priority regulation as the other age groups. Similarly, participants who had more disorders, or who had difficulties with more manoeuvres or who would like to have assistance with several manoeuvres were more positive about the hypothetical assistance systems than participants without any disorders, difficulties or desire for assistance. After the actual experience with the support system, opinions changed and age differences seemed to disappear. Younger drivers tended to become more positive while older drivers tended to become less positive.

Some of these findings are not consistent with those of other studies (e.g., De Waard, Van der Hulst, & Brookhuis, 1999; Viborg, 1999). As discussed in *Chapter 8*, this can be caused by differences in the types of messages which were sent to the drivers (driving too fast vs. driving too slow) and by regression to the mean.

As regards the willingness to buy the system that was "installed" in the simulator car, 35% of the participants indicated that they were willing to buy the system if it were on the market. Half of them was willing to pay for it. Most participants were positive about the audibility and comprehensibility of the messages. Except for one participant, everyone was very well able to hear the messages. Eighty-five per cent of the participants indicated that the messages were also easy to understand and that it was easy to act upon them. This does not mean that they always did act upon them. Only 18% said that they always followed the advice of the support system. Another 63% frequently followed the system's advice. One of the reasons for not following the system's advices may be that participants did not always trust them. Thirty-five per cent of the participants trusted the advices only occasionally or never. Two participants indicated that it depended on the type of messages; they always trusted information about traffic rules, but never about safe gaps to join or cross.

Summary of main findings

As regards the safety of older drivers in the Netherlands, it was found that:

- The fatality rate of drivers aged 75 and above is the largest of all drivers in the Netherlands.
- The high fatality rate of older drivers is mainly the result of their increased physical vulnerability.
- Older drivers are over-represented in crashes at intersections and more often legally responsible for these crashes, often because they fail to yield. These crashes particularly occur when the older driver has to turn left.
- In general, there are few indications that a decline in visual and cognitive functions as part of normal ageing has negative road safety consequences. Most drivers can compensate for these declines. In case of moderate or severe functional limitations due to age-related disorders and diseases, older drivers need more time to prepare and execute a driving manoeuvre and have more difficulties performing different activities in parallel.

- The current number of inhabitants aged 75 and above in the Netherlands will be doubled by 2040, resulting in 2.2 million people of that age.
- The number of older drivers will not only increase because of the ageing of the population but also because of an increase in the percentage of licence holders among older adults in general, and older women in particular.

The fatality rates of older drivers can be influenced in various ways. The main focus of this thesis was on measures that reduce crash involvement by making the driving task easier. Two approaches were studied in more detail: adjusting road design to reduce the complexity of traffic situations, and in-car devices that assist the driver.

With regard to road design it was found that:
- Older drivers are more often involved in crashes at intersections at which traffic is regulated by means of yield signs than they are at intersections at which traffic is regulated by means of traffic lights.
- Adjustments to road design that appear to be particularly beneficial to older drivers include a positive offset of opposite left-turn lanes, high in-service contrast levels for road markings, long sight distances, advance warning signs, and conversion of intersections into single-lane roundabouts.
- Intersection layout, priority regulation, as well as driver manoeuvres influence the difficulty of passing intersections.
- Intersection layout is the best predictor of variations in workload. Three-way intersections that only have a side-street at the left-hand side of the driver are the easiest intersections to pass, whereas four-way intersections with dual carriageways are the most difficult to manage.
- A reduction in the complexity of intersections leads to shorter reaction times for both functionally old and functionally young drivers. Therefore, adjustments to road design that reduce workload for older drivers will also be beneficial for younger drivers.

With regard to in-car driver assistance systems it was found that:
- Collision warning systems for intersections, in-vehicle signing systems, special intelligent cruise control, and systems that provide information on the characteristics of complex intersections the driver is about to cross appear to have the most potential to improve the safety of older drivers. However, many of these systems are still being developed and

not much research has been done on user acceptance and effects on road user behaviour.

- Messages regarding priority regulation, obstructed view of an intersection, and safe gaps to join or cross traffic streams increase the safety of driver decisions for all age groups. Informative messages regarding unexpected one-way streets lead to fewer route-errors. These messages are currently not provided by existing ADAS such as ACC or navigation systems, but they could possibly be added to them in the future.
- Contrary to expectations the abovementioned messages did not reduce workload; some even increased driver workload. As this is probably the result of the new task that was added to the driving task (listening to and processing the information offered by the assistance system), it is expected to wear off over time.
- Functionally old drivers were initially more positive about the usefulness and satisfying character of most of the messages that were specifically designed for them than the younger age groups were about these same messages. However, after having experienced them opinions changed and age differences disappeared.
- Drivers who have more disorders, have difficulties with more manoeuvres, or would like to have assistance with several manoeuvres were more positive about the abovementioned messages than drivers without any disorders, difficulties or desire for assistance.
- Whereas the majority of the functionally young drivers considered the timing of messages to be correct or even found that messages came too soon, most of the functionally old considered them to come too late. Therefore, system settings should be adjustable.

Implementation in the real world

Road adjustments and/or in-car driver assistance?

A (policy) question may be which kind of assistance would be preferable: adjustments to road design or in-car assistance systems. In my opinion, the answer should be that they complement each other and that both types of measures should be taken. Although the adjustments to road design have been selected for their capacity to increase the safety of older road users, they will also make a contribution to the safety of other road users. Measures that give the driver more time to observe things and to base decisions on these observations make the driving task easier for all road users. The reduced complexity of the driving task will probably reduce the number of human errors, and in the end possibly also the number of crashes. The fact that road adjustments that benefit older road users also have (smaller) positive effects on the safety of other road users, is an additional argument for taking such measures (*Chapter 5*). Furthermore, the proposed adjustments fit in with the principles of a sustainable safe traffic system (see Wegman & Aarts, 2006), which is the current practice in road safety policy in the Netherlands. However, there is probably a cut-off point below which a task becomes so easy that some drivers will start showing risk compensation, for example by means of speeding (Evans, 1991; Wilde, 1982). Therefore, there will be a limit to easing the driving task by way of road adjustments. For those drivers that need extra or more specific help, an in-car assistance system can adjust the driving task to the possibilities of that individual driver. Moreover, it is imaginable that some functional limitations require assistance which cannot be given by way of road adjustments. As a result, in-car driver assistance systems offer an extra opportunity to prolong the safe driving career of older people, without creating a road infrastructure that is 'too easy' for other road users.

On the other hand, whereas it was concluded in *Chapter 7* that only very few of the in-car driver assistance systems that appear to be most beneficial to the safety of older drivers are currently available, adjustments to road design can readily be implemented as long as there is the money and the opportunity (i.e., new roads, maintenance of existing roads) to do so. Nevertheless, it appears that there is an increase in the number of initiatives to develop systems that are especially designed for the older driver and to improve the design of existing systems to allow for the functional limitations of the older drivers. Moreover, recent developments appear to fit in with the systems that are expected to be the most promising ones from a road safety point of view (*Table 2*). One example is a system that Nissan is currently testing. This Japanese car manufacturer has announced a 30-month experiment, which started in October 2006, in which several functions will be tested, among which a "vehicle alert" which tells drivers that another vehicle is moving too fast at an intersection at which buildings and/or trees obstruct the drivers' view of cross traffic. In this situation a voice message warns the driver: "Car approaching from left (or right)". Nissan hopes to commercialise the system by 2010 (New Scientist Tech, 2006). The "vehicle alert"-function is comparable to the alert for short sight distances and a good substitute for the "safe to join or cross"-function of the system which was tested in *Chapter 8*. The other functions tested in *Chapter 8*, messages regarding priority regulation and regarding deviating traffic rules and situations, can probably be included in navigation systems. Entenmann et al. (2001) have carried out a pilot-study to explore the possibilities of adding design-related information such as priority regulation to digital maps, and it turned out that it was technically feasible to collect and digitise this kind of information (*Chapter 7*).

Prerequisites for success

The conclusion of the above is that in-car driver assistance systems can potentially prolong the safe mobility of older drivers. A drawback of these systems is, however, that whereas they are deployed to simplify the driving task, reduce workload and improve safety, using them may actually increase workload and have negative safety consequences as well. This may be the result of an improper design of the system's human-machine interface (HMI), the installation of several independent systems in one car, or loss of situation awareness due to complete automation of one part of the driving task which may place the human out of the continuous cycle of perception, decision making and action (*Chapter 7*). As Heijer et al. (2001) have indicated, the latter threat may be taken away by letting ADAS support the driver instead of replacing him. The second threat, several independent systems in one car fighting for the attention of the driver, may be averted by including a mediating system which decides when which system is allowed to pass what kind of information in what kind of way (see e.g., Montanari et al., 2002; Piechulla, Mayser, Gehrke & König, 2003; Vonk, Van Arem & Hoedemaeker, 2002; Wheatley & Hurwitz, 2001). In order to prevent that a poorly designed HMI nullifies the potential safety effect of an in-car driver assistance system, the design of this interface should allow for the functional limitations of the older driver. Those design principles that are relevant to the functional limitations of older drivers have been summarized in *Table 4*. Note that these principles are relevant for not only the design of the HMI of in-car driver assistance systems, but also for the design of specific road elements such as legibility of street name signs, contrast of road markings, and placement of road signs (*Chapter 5*).

Functional limitations	**Relevant design principles**
General sensory deficits	Use redundant cues, like auditory, visual and tactile feedback.
Visual acuity	Increase character size of textual labels on traffic signs and in-vehicle displays.
Colour vision	Use white colours on a black background for in-vehicle displays.
Night-time visual acuity	Use supplemental illumination for in-car devices used in low-light conditions, retro reflective road signs, and fixed lighting at intersections with high traffic or pedestrian volumes.
Sensitivity to glare	Use matt finishes for control panels and antiglare coating on in-vehicle displays, and reduce the intensity of traffics signals during darkness.
Hearing	Use auditory signals in the range of 1500-2500 Hz range.
Contrast sensitivity and motion perception	Where depth perception is important for information on in-vehicle displays, provide non-physical cues, such as relative size, interposition, linear position and texture gradient. As regards road design, use a minimum in-service contrast level of 3.0 for pavement markings, background plates to help accentuate traffic lights, and a positive offset of opposing left-turn lanes.
Selective attention	Enhance the conspicuousness of critical stimuli through changes of size, contrast, colour or motion.
Perception-reaction time	Give the user sufficient time to respond to a request by the in-vehicle assistance system and provide advanced warnings to provide the driver with enough time to react to the on-coming traffic situation. As regards road design, this can be accomplished through multiple or advance traffic signs.
Hand dexterity and strength	Use large diameter knobs, textured knob surfaces and controls with low resistance.

Table 4. Functional limitations and relevant design principles for road design elements and in-vehicle displays (based on Caird et al., 1998, Gardner-Bonneau & Gosbee, 1997, and Staplin et al., 2001).

Value of the theoretical framework

Theoretical models played an important role in determining which assistive devices would be needed to improve the safety of older drivers. Assuming that to improve the safety of older drivers, assistive devices should support their relative weaknesses, a theoretical analysis was conducted of the strengths and weaknesses of the older driver. The theoretical framework that was used to identify the relative weaknesses of the older driver included Fuller's task-capability interface model, ideas that originate from the human factors approach, cognitive psychological models, and game theory (*Chapter 4*). Fuller's task-capability interface model (2001) has the advantage that it integrates the physical, cognitive, motivational and social factors of road users as well as the vehicle and environmental factors into one conceptual framework. As a result, it provides insight into the interrelationships between these factors. It makes one realize that turning a certain wheel of the 'system' also has implications for the direction of another. A (substantial) decrease in the capabilities of a driver asks for a reduction of the demands posed by the traffic system. Otherwise the driving task will become too difficult, and errors are more likely to occur.

Fuller's model also provides insight into the available ways for reducing task demands or improving capabilities: training and education (e.g., about compensatory behaviour and the influence of medication), letting the car assist the driver, adjustments to road design, and/or informing other road users about the older drivers' possibilities and limitations. The other models included in the theoretical framework were used for putting in the details to warrant the quality of specific measures. Which strengths and weaknesses of older drivers should be taken into account while designing assistive devices for them? What are, for example, the boundaries of older adults' information processing and what does that mean for the design of human-machine interfaces and road signs (human factors approach)? How do older drivers compensate for decreased capabilities, and what are the implications of mental schemata that trigger the appropriate action for the design of intersections (cognitive psychology)? How do decreased capabilities and the use of in-car driver assistance systems affect the interaction with other road users (game theory)? In comparison to the other theoretical models, game theory was a relatively new player in the field of road safety research. Hence, there was not much literature available on how to apply the principles of game theory to decision making and anticipating the likely reaction of others in traffic. However, the attempts made in *Chapter 4* to link research results regarding the interaction between road users with the principles of game theory taught us that such exercises are fruitful for gaining insight into the interaction between road users. It would be interesting to have a closer look at some of the topics that emerged from the analysis of the strengths and weaknesses of older drivers according to the framework of game theory. More specifically, future studies may look at the interaction between road users and determine whether there are age-related differences in the way people communicate with other road users, and whether older drivers apply different rules for communication. Are they, for instance, more inclined to take right of way or is the opposite true and are they more inclined to yield in case of doubt?

On a more general level, it would be interesting to determine whether the factors that – according to Fuller's task-capability interface model – determine task difficulty are all equally important for all groups of road users. Some factors may be more important for older drivers, whereas others may be more important for younger drivers. In *Section 5.2.1*, it was argued that the complexity of a traffic situation is the factor that becomes more important as people age. Complex situations put a severe strain on the sensory, perceptual and cognitive capacities of the driver, and these capacities are often reduced in the older age group. For younger adult drivers, other factors were expected to play a role in the likelihood of crashes, such as whether or not the road layout offers drivers the opportunity to speed, and factors like emotions, alcohol and other drugs, stress, and distraction. Submodels are welcome that zoom in on the specific issues relevant for particular groups of drivers. These models will be particularly useful for designing measures that are tailored to the needs of the group in question.

Older people driving in simulators

As the implementation of measures concerning road design, and the development of prototype assistance systems are very expensive, both types of assistive devices were evaluated in a simulated environment using a fixed base driving simulator. Although the use of a driving simulator to evaluate driving behaviour has several advantages over testing in the real world, such as low costs, experimental control, and driver safety (see e.g., Kaptein, Theeuwes & Van der Horst, 1996; Lee, Cameron & Lee, 2003; Nilsson, 1993), it can also have disadvantages. Two potential disadvantages are the ecological validity of the experiment and the incidence of simulator sickness.

Ecological validity

One of the major concerns in using driving simulators to measure road user behaviour is the generalizability of research results to real traffic, also known as ecological validity (see e.g., Kaptein, Theeuwes & Van der Horst, 1996; Neale & Liebert, 1986; Nilsson, 1993; Slick, Tran & Cady, 2005). To ensure the ecological validity of an experiment, the face validity or fidelity of the simulated world should be high. The driving simulator that was used for the experiments described in *Chapter 6* and *8* gave us ample opportunity to design a world that resembles the real world. It allows researchers to design their own road network, to add their own types of houses, add signs and markings, and, more important, it includes self-governing intelligent vehicles that show natural and normative driver behaviour. For the experiments that were described in *Chapter 6* and *8*, an existing road network was used and a city was built around it, using houses, shops, trees, and ponds. The surrounding traffic was given instructions on the route they had to follow and the speed they should maintain. It was not necessary to instruct them about priority regulations, as they were able to deduce them from the design of the roads. The result was a simulator world that was just like the real world on a weekday with many people driving through the city. The comments of the participants confirmed this. They were talking to the other vehicles just like people do in real traffic, and they really felt like they were going for a drive. To give an example of the latter, one of the older participants said while entering the simulator room for her second drive "Let me first take a candy, as I always do that when I am going for a drive".

However, there is more to ecological validity of the experimental setting than making sure that it looks real. Vehicle operation is an important element as well, especially for older drivers. Research by Lundberg & Hakamies-Blomqvist (2003) suggests that, at least for older drivers with cognitive deterioration, "the need to adapt to an unfamiliar vehicle represents a supplementary cognitive load that may compromise their driving ability and the validity of the assessment". They concluded this after having compared the outcomes of driving tests in which people were allowed to drive in their own car with those of driving tests in which people were obliged to use the car of the driving test facility. The percentage of drivers who failed the test was significantly larger in the second group. The use of a driving simulator to study driving behaviour may have the same adverse effects. Although in our experiments people sat in a real car seat, used a force-feedback steering wheel, mechanically transmitted gas-, clutch- and brake pedals, and the transmission of the simulator car was adapted to match the experience of the participant, the operation of the simulator car will have been different from their own car, just as driving another person’s vehicle is. In some participants, this was more evident than in others. Their engine frequently cut out due to inadequate handling of the clutch and/or their steering behaviour was inaccurate. Vehicle operation was not one of the coded variables, but (functionally) older participants seemed to have more difficulties operating the simulator car than younger participants. This fits in with the increased cognitive rigidity of older people (see e.g., Brouwer & Ponds, 1994; Brouwer, Rothengatter & Van Wolffelaar, 1988).

As the design of the experiments ensured that within-subjects comparisons were made to evaluate the effects of the assistive devices, and the order of the route across the intersections and the drives with and without the assistance system were counterbalanced, the main study results were not likely to be affected by the use of an unfamiliar (simulator) car. However, comparisons between functional age groups may have been affected. The only effect that was found for functional age group was a general effect of workload which appeared as soon as people started driving the simulator car (*Chapter 6*). This effect was attributed to the age-related increase in the cost of dividing attention. The size of the effect may have been exaggerated, however, by the sensory-motor secondary (or tertiary) task of adapting to an unfamiliar vehicle. Increased difficulty of driving situations and related vehicle handling did not increase the differences between functional age groups any further.

Dropout as a result of simulator sickness

As with ‘natural’ motion sickness, simulator sickness is caused by a mismatch between sensed and expected motion cues (Farmer, Van Rooij, Riemersma, Jorna & Moraal, 1999). In case of a fixed-base driving simulator, visual cues tell the driver that he is moving, whereas vestibular cues tell him that he is standing still. Sensitivity to motion sickness varies largely among humans. Women, for example, are somewhat more sensitive to motion sickness than men (Wertheim, 1997). Symptoms of motion and simulator sickness are: nausea, vertigo, sleepiness, cold sweats, pallor and saliva flow (Farmer et al., 1999; Moroney & Moroney, 1999). Despite extensive screening for sensitivity to simulator sickness using the Motion Sickness/Simulator Sickness Screening Form (Hoffman, Molino & Inman, 2003), simulator sickness led to a large reduction of the initial number of persons that participated in the simulator studies described in this thesis. As much as 46% of the participants dropped out because they felt sick while driving the simulator car. High dropout rates are not uncommon. Caird (2004b) has made an inventory of simulator studies using older participants and their dropout rates. It turned out that dropout rates varied from 40 to 75%. Nevertheless, one of the concerns during the simulator studies that were described in *Chapter 6* and *8* was that dropout could have affected study results, especially since dropout rates differed significantly between functional age groups (29% for young, 46% for middle-aged, and 58% for old participants). As there was one questionnaire that was filled in by all participants, both those who turned out to be sensitive to simulator sickness and those who were not, we were able to compare some of the characteristics of these two groups of participants. Apart from differences in group composition due to significantly higher dropout rates for functionally old as well as female participants, it turned out that the functionally old participants that completed all parts of the experiment tended to be more negative about the driver support system than those that only completed the first part of the experiment. This shows that simulator sickness can cause selective dropout of participants which may affect the representativeness of the sample used to test the opinions about or behavioural effects of certain countermeasures (see also Edwards, Caird, Lamsdale, & Chisholm, 2004 and Freund & Green, 2006).

To prevent this, simulator sickness should be countered by using experimental procedures that not only include screening procedures for sensitivity to simulator sickness, but also address other factors that might add to simulator sickness, such as simulator configuration (size of the screens, amount of motion cues), and general aspects of the driving environment (proximity of buildings and trees, number of turns, degrees of curvature). It may even involve reducing the fidelity of the simulated environment (see *Ecological validity*), as there are some indications that increased fidelity leads to a higher incidence of simulator sickness (Kennedy, Hettinger & Lilienthal, 1990). Future studies could, for example, reduce the amount of visual motion cues by introducing fog as soon as the driver has taken the decision to join or cross traffic, and put the driver in a new position on a straight road stretch before removing the fog (Van Winsum, personal communication). Another solution would be to slowly build up the amount of visual cues in the course of the drive in order to reduce the participant's sensitivity to simulator sickness (Busscher, Van Wolffelaar & Brouwer, 2007).

Complementary measures

In previous paragraphs, various driver assistance systems and adjustments to road design were discussed that appear to improve the safety of older drivers. These types of measures are complementary to each other and it was argued that they both should be taken. Adjustments to road design and use of in-car driver assistance systems cannot prevent, however, that some road users at a certain moment in their lives will become unfit to drive. Therefore, a procedure for a timely exit from active traffic participation, when functional limitations become too severe to compensate, does remain necessary. Ideally, the decision to stop driving should be left to the drivers themselves. However, not every individual is aware of limitations in fitness to drive. For example, in the case of dementia or right hemisphere stroke, persons often do not have a clear picture of their limitations. It is, therefore, important to provide support for decisions to drive less or not at all. This applies not only to the older drivers themselves, but also to their family, and to doctors and psychologists responsible for medical examination. As argued by Brouwer and Withaar (1997) and Hakamies-Blomqvist, Henriksson and Falkmer (1998), an obligatory medical or on-road examination is only justifiable if it is restricted to patient categories with a substantially increased crash risk. To achieve such a procedure, more knowledge is needed in a number of areas. In the first place, knowledge is required about high-risk patient groups. Some high-risk groups, such as people suffering from mild dementia, have already been defined. For other disorders, more specific definitions of subpopulations who indeed form a high-risk group must be determined. Having defined high-risk groups, it is then important to apply test methods within these groups that can validly and reliably select those individuals who actually display dangerous driving behaviour. Research is needed to further develop these assessment methods. Those individuals who have been shown to display dangerous driving behaviour must then be declared unfit to drive unless aids (i.e., assistive devices or training) are available that can compensate for the functional limitations that accompany their disorder or disease. Further research is needed to develop and evaluate these aids.

If driving a car is indeed not longer a safe option, alternative means of transport should be made available to ensure the mobility of older people. Examples of alternative means of transport are conventional public transport services, bus service routes, taxis, and dial-a-ride services for door-to-door travel. No single form of transport provides mobility for all people under all circumstances. A family of services is needed that enables travellers to select the one that best suits their requirements for a particular journey (OECD, 2001).

For those who are still fit to drive but nevertheless get involved in a crash, improved crashworthiness of vehicles and further development of safety devices are important to reduce injury severity. As regards crashworthiness, current crash-test dummies and models are based on average fit people. Test dummies capable of modelling the effects of an older occupant are needed to be able to take into account the older occupants' frailty when testing and improving vehicle safety. In addition, occupant protection should be enhanced by further development of seat belts and airbags, particularly through force-limiting features. A safety device that is likely to be especially relevant for the protection of older drivers is the airbag that protects the head and chest in side-collisions such as crashes when turning left in which older drivers are overrepresented (i.e. side-impact protection systems).

The same group of drivers, those who are still fit to drive, can also be supported through another way of easing the driving task: by improving their driver performance through education. Training programmes provide a good opportunity for informing the older driver of the physical and cognitive changes that accompany ageing, difficulties that may arise in traffic as a result of these changes, and how to modify driving strategies to avoid these difficulties.

To acknowledge all factors that Fuller (2001) incorporated in his task-capability interface model, attention should also be paid to the other road users, that is, those who may meet older drivers in traffic. By giving them information on the difficulties older drivers experience in traffic, they may be able to anticipate better on the older drivers' behaviour, and help to prevent future crashes.

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Appendix A

Assumptions made while determining which driver was responsible for a crash

In order to determine which crash opponent was responsible for a crash, several assumptions have been made. One assumption was that the first driver mentioned on the police registration form was responsible for the crash. Although this seems to be an arbitrary choice, there are the necessary indications that this assumption is correct. In the past, instructions on the crash registration form were that the first party should be the party responsible for the crash. Although this no longer applies to the present Dutch police registration form, this procedure is probably still being followed. This can be deduced from the causes being attributed to crash opponents. Each crash opponent who is considered to be (partly) responsible is allotted a "cause". If one of the crash opponents is not regarded as being responsible, he is allotted a "no cause" code. *Table A.1* shows the distribution of causes between the two crash opponents in all collisions between two cars that have resulted in an injury during the period 1994-1998.

First crash opponent	Second crash opponent		
	With 'cause' ('responsible')	No 'cause' ('innocent')	Total
With 'cause' ('responsible')	7.4%	89.8%	97.2%
No 'cause' ('innocent')	1.5%	1.2%	2.8%
Total	8.9%	91.0%	100%

Table A.1. Distribution of causes between the two crash opponents in all injury crashes between two cars in the period 1994-1998.

It shows that in more than 97% of all injury crashes, the first crash opponent had been allotted a "cause" code and was, therefore, indeed regarded as being (partly) responsible for the crash. In less than 2.8% of the crashes in which the first crash opponent had not been allotted a "cause" code, this was allotted to the second crash opponent (1.5%) or to neither of them (1.2%).

Appendix B

	Needs regarding information and/or assistance	Percentage of the total number of crashes that could have been avoided if the need had been satisfied	Is this percentage higher for crashes older drivers are involved in?[1]
Monitoring driver and vehicle condition			
1.	Driver status (fatigue, driving under the influence of alcohol or drugs)	8,4 %	
2.	Vehicle status (mechanical defects)	1,1 %	
Timely detection			
3.	Timely detection of a road-related difficulty	5,0 %	
4.	Obstacle detection	4,4 %	
5.	Timely detection of oncoming road users that are not visible due to trees, building, etcetera	7,1 %	
6.	Timely detection of road users that are on an intersecting lane at an intersection	19,1 %	OD
7.	Detection of road users that are hidden in vehicle blind spots	4,0 %	OD
8.	Detection of pedestrians	5,8 %	OD
Estimating time and speed			
9.	Correctly assessing speeds in relation to road conditions	3,7 %	
10.	Timely assessment of speed differences between the vehicles in front and ones own vehicle	3,9 %	
11.	Estimating the collision course with cross traffic	0,9 %	OD
12.	Assessing gaps when overtaking or changing lane	0,6 %	OD
13.	Assessing gaps when joining or cutting across a traffic flow	0,6 %	OD

Table B.1. Needs regarding information and assistance and the percentage of crashes that could be avoided if the need would be met (adapted from Malaterre and Fontaine, 1993).

Needs regarding information and/or assistance		Percentage of the total number of crashes that could have been avoided if the need had been satisfied	Is this percentage higher for crashes older drivers are involved in?[1]
Predicting the behaviour of other road users			
14.	Predicting the behaviour of other road users regarding yielding and stopping	4,7 %	
15.	Predicting the manoeuvres of other road users	7,3 %	
16.	Predicting the behaviour of pedestrians	1,9 %	
Being able to control one's vehicle			
17.	Vehicle control	1,8 %	

[1] OD (Older Driver) in the right column means that the percentage mentioned in the middle column is an underestimation of the percentage that could be avoided of the total number of crashes older drivers are involved in.

Table B.1 (continued). Needs regarding information and assistance and the percentage of crashes that could be avoided if the need would be met (adapted from Malaterre and Fontaine, 1993).

Samenvatting

Dit proefschrift gaat over de mogelijkheden die infrastructurele aanpassingen en bestuurdersondersteuningssystemen bieden om de veilige en onafhankelijke mobiliteit van ouderen te verbeteren. De nadruk ligt op maatregelen die de veiligheid van oudere automobilisten kunnen verbeteren doordat ze compenseren voor leeftijdgerelateerde functiestoornissen. Daar waar in het vervolg wordt gesproken over ouderen of oudere automobilisten gaat het steeds over personen van 75 jaar en ouder. De aandacht voor deze leeftijdsgroep komt voort uit hun relatief hoge overlijdensrisico. Een nadere analyse van dit overlijdensrisico maakt deel uit van dit proefschrift.

De hoofdstukken uit dit proefschrift behandelen in totaal drie hoofdvragen:

- Hoe kan de verkeersveiligheid van oudere automobilisten worden omschreven en welke kenmerken van ouderen zijn mogelijk van invloed op hun rijprestatie? (*Hoofdstuk 1 t/m 3*)
- Welke leeftijdgerelateerde functiestoornissen hebben de grootste invloed op de rijprestatie en veiligheid van oudere automobilisten? (*Hoofdstuk 4*)
- Welke wegkenmerken en bestuurdersondersteuningssystemen kunnen voor deze functiestoornissen compenseren? (*Hoofdstuk 5 t/m 8*)

Hoofdstuk 1 geeft een overzicht van de verkeersveiligheid van oudere automobilisten. Achtereenvolgens komen het overlijdensrisico, de ongevalsbetrokkenheid, de lichamelijke kwetsbaarheid, de verantwoordelijkheid voor ongevallen, en de belangrijkste ongevalstypen aan bod. Daarnaast wordt ingegaan op de rol van de gemiddelde rijervaring, de vraag of oudere automobilisten een groter gevaar vormen voor andere verkeersdeelnemers dan jongere automobilisten, verschillen tussen mannen en vrouwen, en wordt een vergelijking gemaakt tussen de kans op letsel voor verschillende vormen van verkeersdeelname. De conclusie die aan het eind van dit hoofdstuk wordt getrokken is dat oudere automobilisten vooral kwetsbaar zijn. Als ze bij een ongeval betrokken zijn, dan is de kans groter dat ze als gevolg van dat ongeval overlijden. Dit komt doordat ze fysiek kwetsbaarder zijn dan jongeren. Daarnaast lijken ouderen een iets grotere kans te hebben om bij een verkeersongeval betrokken te raken dan jongere automobilisten, en lijken ze – in juridische zin – ook iets vaker de 'schuldige' partij te zijn. Dit betreft dan vooral ongevallen op kruispunten. Ouderen zijn relatief vaak betrokken bij ongevallen die ontstaan als ze linksaf willen slaan. Door rekening te houden met de lichamelijke kwetsbaarheid van ouderen kan de kans op overlijden worden verlaagd. Daarbij valt te denken aan zij-airbags (SIPS) en andere maatregelen die het letsel beperken als er onverhoopt een ongeval plaatsvindt. Aangezien ouderen ook een rol lijken te spelen bij het ontstaan van de ongevallen waarbij ze betrokken zijn, is de veiligheid van oudere automobilisten waarschijnlijk ook te verbeteren door maatregelen te nemen die gericht zijn op het voorkomen van díe ongevallen waarbij zij vaker betrokken zijn: kruispuntongevallen. Daarvoor moet eerst duidelijk zijn waardoor deze ongevallen ontstaan. De oorzaak kan liggen in de algemene kenmerken van de oudere automobilist, in het ontwerp van kruispunten, en in de verenigbaarheid van deze twee elementen (i.e., kunnen oudere automobilisten wel omgaan met de eisen die (bepaalde typen) kruispunten aan hen stellen). Elk van deze oorzaken wordt in dit proefschrift nader bestudeerd.

In *Hoofdstuk 2* wordt ingegaan op de fysieke en mentale kenmerken van de oudere automobilist. De verschillende leeftijdgerelateerde functiestoornissen worden besproken, evenals de leeftijdgerelateerde aandoeningen die de rijgeschiktheid kunnen beperken. Alleen in het geval van ernstige sensorische, perceptuele en/of cognitieve functiestoornissen is er een verhoogde kans om bij een ongeval betrokken te raken. Dit is bijvoorbeeld het geval bij functiestoornissen als gevolg van oogaandoeningen zoals cataract (staar) en glaucoom (verhoogde oogdruk) en bij ziekten zoals dementie. In andere gevallen kunnen ouderen door compensatiegedrag vaak nog goed in het verkeer functioneren. Zo is bekend dat ze vaak niet in het donker rijden om problemen met verblinding en nachtblindheid te voorkomen, en dat ze lastige verkeerssituaties vermijden.

Hoofdstuk 3 werpt een blik in de toekomst. Het aantal ouderen in Nederland zal de komende decennia fors stijgen: van 1,1 miljoen 75-plussers in 2006 naar 2,2 miljoen in 2040. Het aantal oudere automobilisten zal een nog grotere stijging te zien geven, aangezien niet alleen het aantal ouderen stijgt, maar ook het percentage ouderen dat in het bezit is van een rijbewijs. Vooral onder oudere vrouwen zal het rijbewijsbezit stijgen. Deze stijging is de afgelopen twintig jaar al ingezet; sinds 1985 is het rijbewijsbezit onder oudere vrouwen vervijfvoudigd. Door deze toename van het aantal oudere automobilisten zal het toekomstige aantal verkeersdoden onder oudere automobilisten ook stijgen. De verwachting is echter dat deze stijging getemperd wordt door een lager overlijdensrisico voor toekomstige ouderen, doordat zij vitaler zijn en meer rijervaring hebben dan de ouderen van nu.

Verkeersveiligheidsmaatregelen kunnen het overlijdensrisico van toekomstige ouderen verder verlagen. Het vervolg van dit proefschrift gaat in op twee specifieke maatregelen: infrastructurele aanpassingen en bestuurdersondersteuningssystemen die de rijtaak vergemakkelijken.

In *Hoofdstuk 4* wordt nagegaan op welke punten ondersteuning van de rijtaak het meest gewenst is. Daarbij wordt als uitgangspunt genomen dat ondersteuning van de rijtaak alleen tot een verbetering van de verkeersveiligheid kan leiden als de relatief zwakke punten van de automobilist worden ondersteund. Om te achterhalen wat de zwakke en sterke punten van de oudere automobilist zijn, worden vier theoretische invalshoeken bestudeerd: Fullers taakbekwaamheidsmodel, de ergonomische benadering, de cognitief psychologische benadering en die van de speltheorie. Het resultaat is een lijst met de relatief zwakke punten van de oudere automobilist en de problemen die hij daardoor in het verkeer kan ondervinden (zie *Tabel 4.2*). Vervolgens wordt een inschatting gemaakt van de relevantie die deze zwakke punten hebben voor de verkeersveiligheid. Hiervoor zijn gegevens van Malaterre en Fontaine (1993) gebruikt over het percentage ongevallen dat voorkomen zou kunnen worden als in een bepaalde informatiebehoefte van de mens zou worden voorzien (zoals informatie over voertuigen die zich in de dode hoek bevinden). De conclusie is dat de volgende vier (combinaties van) zwakke punten van de oudere automobilist het meest relevant zijn voor de verkeersveiligheid:

- verminderde waarneming van beweging en contrastgevoeligheid;
- beperkte perifere visie en afgenomen flexibiliteit van de nek;
- afgenomen selectieve aandacht;
- tragere informatieverwerking en besluitvorming, afname van de verdeelde aandacht en slechtere prestatie onder tijdsdruk.

Daarbij moet wel worden opgemerkt dat deze relatief zwakke punten lang niet altijd tot ongevallen leiden. Veel zwakke punten kunnen namelijk worden gecompenseerd. Verkeersproblemen zullen pas ontstaan wanneer er sprake is van een combinatie van verschillende zwakke punten die compensatie binnen de beschikbare tijd onmogelijk maakt. Problemen die voortkomen uit de bovengenoemde zwakke punten kunnen worden voorkomen door hulpmiddelen die respectievelijk:

- de aandacht richten op naderend verkeer;
- attenderen of zicht geven op verkeersdeelnemers die zich in de dode hoek bevinden;

- aandacht richten op relevante verkeerselementen zoals verkeersborden en verkeerslichten;
- vroegtijdig informatie verstrekken over de eerstvolgende verkeerssituatie zodat er meer tijd is om te anticiperen op wat komen gaat.

In hoofdstuk 5 en 6 wordt nader ingegaan op infrastructurele maatregelen die dergelijke hulp kunnen bieden. *Hoofdstuk 5* bespreekt kruispuntkenmerken die een rol lijken te spelen bij de problemen die ouderen in het verkeer ondervinden. Deze worden op twee manieren opgespoord: 1) via een vergelijking van de kenmerken van kruispunten waar relatief veel en relatief weinig ongevallen met ouderen plaatsvinden, en 2) via een literatuurstudie naar kruispuntkenmerken die rekening lijken te houden met leeftijdgerelateerde functiestoornissen. Uit de vergelijking van kruispuntkenmerken blijkt dat kruispunten waar relatief veel ongevallen met ouderen plaatsvinden minder vaak voorzien zijn van verkeerslichten dan kruispunten waar geen ongevallen met ouderen plaatsvinden, terwijl het verkeer op de eerstgenoemde kruispunten vaker geregeld wordt door middel van voorrangsborden. Voorbeelden van kruispuntkenmerken die rekening lijken te houden met de functiestoornissen die vaker voorkomen onder ouderen zijn een positieve asverspringing van tegenovergelegen linksafstroken (zie *Figuur 5.1*), een goed onderhouden contrasterende belijning, grote zichtafstanden, vooraankondiging van belangrijke verkeersborden zoals die welke aangeven dat men een voorrangsweg nadert, rijstrookborden boven de rijbaan, en enkelstrooksrotondes.

Hoofdstuk 6 beschrijft de resultaten van een simulatorstudie waarin verschillende typen kruispunten zijn vergeleken op hun effect op de taakbelasting en veiligheid van beslissingen van oudere en jongere automobilisten. Tien oudere (70-88 jaar) en dertig jongere automobilisten (30-50 jaar) reden in een rijsimulator een route die hen langs verschillende typen kruispunten leidde. Deze kruispunten verschilden in ontwerp (3- of 4-taks kruispunt al dan niet met gescheiden rijbanen, of een rotonde), in voorrangsregeling, en/of in zicht op het kruispunt (al dan niet geblokkeerd door bomen of huizen). Het ontwerp van het kruispunt blijkt de beste voorspeller te zijn van verschillen in taakbelasting (gemeten aan de hand van de reactietijd op een neventaak). Drietakskruisingen met alleen een zijstraat aan de linkerkant van de automobilist blijken het makkelijkst om te passeren, terwijl viertakskruisingen met gescheiden rijbanen de meeste inspanning vergen. Dit geldt voor beide leeftijdsgroepen. Oudere automobilisten hadden tijdens het rijden in de rijsimulator weliswaar een langere reactietijd dan jongere automobilisten, maar dit verschil blijkt al te ontstaan zodra ze gaan rijden en wordt niet groter tijdens het passeren van moeilijkere kruispunten.

In hoofdstuk 7 en 8 wordt nader ingegaan op bestuurdersinformatie-systemen die de gewenste ondersteuning (zie *Hoofdstuk 4*) zouden kunnen bieden. In *Hoofdstuk 7* worden specifieke systemen beschreven die de gewenste ondersteuning reeds lijken te bieden. Dit zijn botswaarschuwings-systemen voor conflicten op kruispunten, systemen voor automatisch invoegen en/of wisselen van rijstrook, parkeerhulpsystemen, systemen die borden en waarschuwingstekens in het voertuig projecteren, bijzonder intelligente cruise control, en systemen die informatie verstrekken over de kenmerken van te passeren complexe kruispunten. Voor elk van deze systemen wordt aangegeven wat ze precies doen, wat hun voor- en nadelen zijn, of ze al op de markt zijn, of ze zijn getest door ouderen en zo ja, welk effect het systeem had op hun rijgedrag. De belangrijkste conclusie van dit hoofdstuk is dat veel van de systemen die de gewenste ondersteuning lijken te bieden nog in ontwikkeling zijn en er daardoor nog te weinig onderzoek is gedaan naar de acceptatie en gedragseffecten van deze systemen om te kunnen zeggen of het gebruik van deze systemen daadwerkelijk tot een verbetering van de verkeersveiligheid van oudere automobilisten zal leiden. Daarnaast geeft dit hoofdstuk een overzicht van de voorwaarden waaraan systemen moeten voldoen opdat ze in de toekomst de veiligheid van oudere automobilisten kunnen verbeteren. Deze voorwaarden hebben betrekking op het ontwerp van de mens-machine interface, de onderlinge afstemming tussen verschillende systemen, de keuze tussen ondersteunen of overnemen van delen van de rijtaak, het rekening houden met verschillende vormen van gedragsadaptatie, en het voorkomen van verwarring bij medeweggebruikers.

Hoofdstuk 8 beschrijft de resultaten van een simulatorstudie waarin het effect wordt onderzocht van vier verschillende boodschappen van een bestuurdersondersteuningssysteem op de taakbelasting en veiligheid van beslissingen van oudere en jongere automobilisten. Dezelfde tien oudere (70-88 jaar) en dertig jongere automobilisten (30-50 jaar) als genoemd in *Hoofdstuk 6* reden in een rijsimulator met en zonder hulp van een gesimuleerd ondersteuningssysteem. Tijdens de rit waarbij het ondersteuningssysteem was ingeschakeld wees het systeem de bestuurder bij het naderen van lastige kruispunten via gesproken boodschappen op de geldende voorrangsregeling, of het veilig is om in te voegen of over te steken, op het beperkte zicht op het kruisende verkeer, of op afwijkende verkeersregels of verkeerssituaties (i.e., wijziging in de snelheidslimiet of eenrichtingsverkeer). De informatie werd alleen verstrekt wanneer deze relevant was en met een maximum van één boodschap per kruispunt. De drie eerstgenoemde boodschappen blijken voor zowel oudere als jongere automobilisten tot veiliger beslissingen te leiden. De boodschap over eenrichtingsverkeer leidt tot minder routefouten. Overigens wordt geen van de bovengenoemde boodschappen op dit moment aangeboden door bestaande bestuurdersondersteuningssystemen zoals geavanceerde cruise control of navigatiesystemen. De benodigde functionaliteit zou in de toekomst echter wel aan dergelijke systemen kunnen worden toegevoegd.

Tegen de verwachtingen in blijken de verstrekte boodschappen niet tot een afname van de taakbelasting te leiden. In sommige gevallen was er zelfs sprake van een toename van de taakbelasting. Dit komt vermoedelijk doordat er met het bestuurderssysteem een nieuwe taak aan de rijtaak wordt toegevoegd, namelijk het luisteren naar en verwerken van de aangeboden informatie. De verwachting is dat de verhoging van de taakbelasting als gevolg van deze extra taak slechts tijdelijk zal zijn. Een langere evaluatieperiode zal moeten uitwijzen of dit inderdaad het geval is. Oudere automobilisten zijn bij voorbaat in ieder geval positief over de verschillende boodschappen die het systeem geeft. Ze zijn in eerste instantie ook positiever over het systeem dan jongere automobilisten. Nadat ze ervaring met het systeem hebben opgedaan wijzigen de meningen echter enigszins en verdwijnen deze leeftijdsverschillen. De ervaring met het systeem levert wel een ander leeftijdseffect op. Daar waar de meerderheid van de jongere automobilisten vond dat de boodschappen op tijd of zelfs te vroeg kwamen, vonden de meeste oudere automobilisten dat de boodschappen te laat kwamen. Dit wijst erop dat de instellingen van ondersteuningssystemen moeten kunnen worden aangepast aan de persoonlijke voorkeur van de automobilist.

In het afsluitende hoofdstuk worden de belangrijkste bevindingen nogmaals op een rijtje gezet en wordt ingegaan op de consequenties die zij hebben voor het verkeersveiligheidsbeleid en toekomstig onderzoek. Het feit dat zowel aanpassingen aan de infrastructuur als bestuurdersondersteuningssystemen bij lijken te dragen aan een vereenvoudiging van de rijtaak roept de vraag op welk type maatregel de voorkeur zou moeten krijgen. Het antwoord dat op deze vraag wordt gegeven is dat de genoemde maatregelen complementair zijn en dat beide maatregelen genomen zouden moeten worden. Aanpassingen aan de infrastructuur hebben als voordeel dat ze direct kunnen worden toegepast. Bestuurdersondersteuningssystemen hebben als voordeel dat ze de rijtaak nog verder kunnen aanpassen aan de mogelijkheden en beperkingen van de individuele automobilist. Daarmee creëren zij een extra mogelijkheid om de veilige mobiliteit van ouderen zo lang mogelijk in stand te houden. De veiligheidswinst die beide maatregelen kunnen opleveren beperkt zich echter niet tot de groep van oudere automobilisten. Ook jongere automobilisten lijken gebaat bij de vereenvoudiging van de rijtaak die beide maatregelen teweegbrengen. De verwachting is echter dat de veiligheidswinst groter zal zijn bij ouderen.

Aanpassingen aan de infrastructuur en het gebruik van bestuurdersondersteuningssystemen kunnen echter niet voorkomen dat individuen op een bepaald moment niet langer veilig als automobilist aan het verkeer kunnen deelnemen. Daarom blijft het noodzakelijk dat er een goede procedure is die bepaalt wanneer een individu moet stoppen met autorijden. Om tot een goede procedure te komen is echter wel meer kennis nodig. In de eerste plaats gaat het om kennis over risicogroepen. Sommige risicogroepen zijn al bekend, zoals mensen met een matige of ernstige vorm van dementie. Voor andere functiestoornissen en aandoeningen moet worden bepaald welke subpopulaties inderdaad een verhoogd ongevalsrisico hebben. Wanneer deze risicogroepen gedefinieerd zijn is het van belang over testmethoden te beschikken die in staat zijn om op valide en betrouwbare wijze die individuen te selecteren die daadwerkelijk gevaarlijk rijgedrag vertonen. Nader onderzoek is nodig om deze testmethoden verder te ontwikkelen. Als mensen inderdaad gevaarlijk rijgedrag blijken te vertonen moeten ze ongeschikt worden verklaard, tenzij hulpmiddelen beschikbaar zijn waarmee functiestoornissen kunnen worden gecompenseerd.

Als de auto echt geen veilige optie meer is, moeten ouderen de beschikking kunnen hebben over andere vormen van vervoer. Voor diegenen die nog wel fit genoeg zijn om te blijven autorijden maar desalniettemin betrokken raken bij een ongeval is het van belang dat voertuigconstructies en beveiligingsmiddelen rekening houden met de lichamelijke kwetsbaarheid van ouderen. Tot slot is er ook een rol weggelegd voor educatie en voorlichting. Ouderen kunnen worden geïnformeerd over de fysieke en mentale veranderingen die gepaard gaan met het ouder worden, over de problemen die zij daardoor in het verkeer kunnen ondervinden en de strategieën die zij kunnen hanteren ter voorkoming van deze problemen. Educatie en voorlichting kunnen echter ook worden ingezet om andere weggebruikers te informeren over de problemen die ouderen in het verkeer kunnen ondervinden. Dit stelt hen in staat om te anticiperen op het gedrag van de oudere automobilist en waar nodig in te grijpen om eventuele ongevallen te voorkomen. Daarmee kunnen ook zij hun steentje bijdragen aan de veilige mobiliteit van ouderen.

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Curriculum Vitae

Ragnhild Davidse werd in 1971 in Oost-Souburg geboren en behaalde in 1989 haar VWO-diploma aan de CSW in Middelburg. De eerste jaren van haar universitaire studie bracht ze in Utrecht door. Zij behaalde daar zowel haar propedeuse in de Algemene Sociale Wetenschappen als die in de Psychologie. Voor haar afstudeerrichting Methoden en Technieken van Psychologisch Onderzoek stapte ze over naar de Rijksuniversiteit Leiden. In 1995 rondde zij daar haar studie Psychologie af, met als bijvak Functieleer. Het eerste jaar na haar studie was ze als onderzoeker werkzaam bij het Centrum voor Wetenschaps- en Technologiestudies (CWTS) van de Rijksuniversiteit Leiden. In 1996 trad zij in dienst van de Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV), waar zij eerder ook haar stageonderzoek verrichtte. Tot 1999 hield zij zich bij de SWOV vooral bezig met algemene analyses van de verkeersonveiligheid en de gegevens die daarvoor nodig zijn. Sindsdien heeft ze zich verdiept in verschillende deelterreinen, zoals de relatie tussen weginrichting en het gedrag van weggebruikers, methoden voor onderzoek naar de oorzaken van verkeersongevallen, en ouderen in het verkeer. Het onderzoek op dit laatste terrein mondde uit in dit proefschrift.

List of publications related to this thesis

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