



# Older Drivers 2018



## CONTENTS

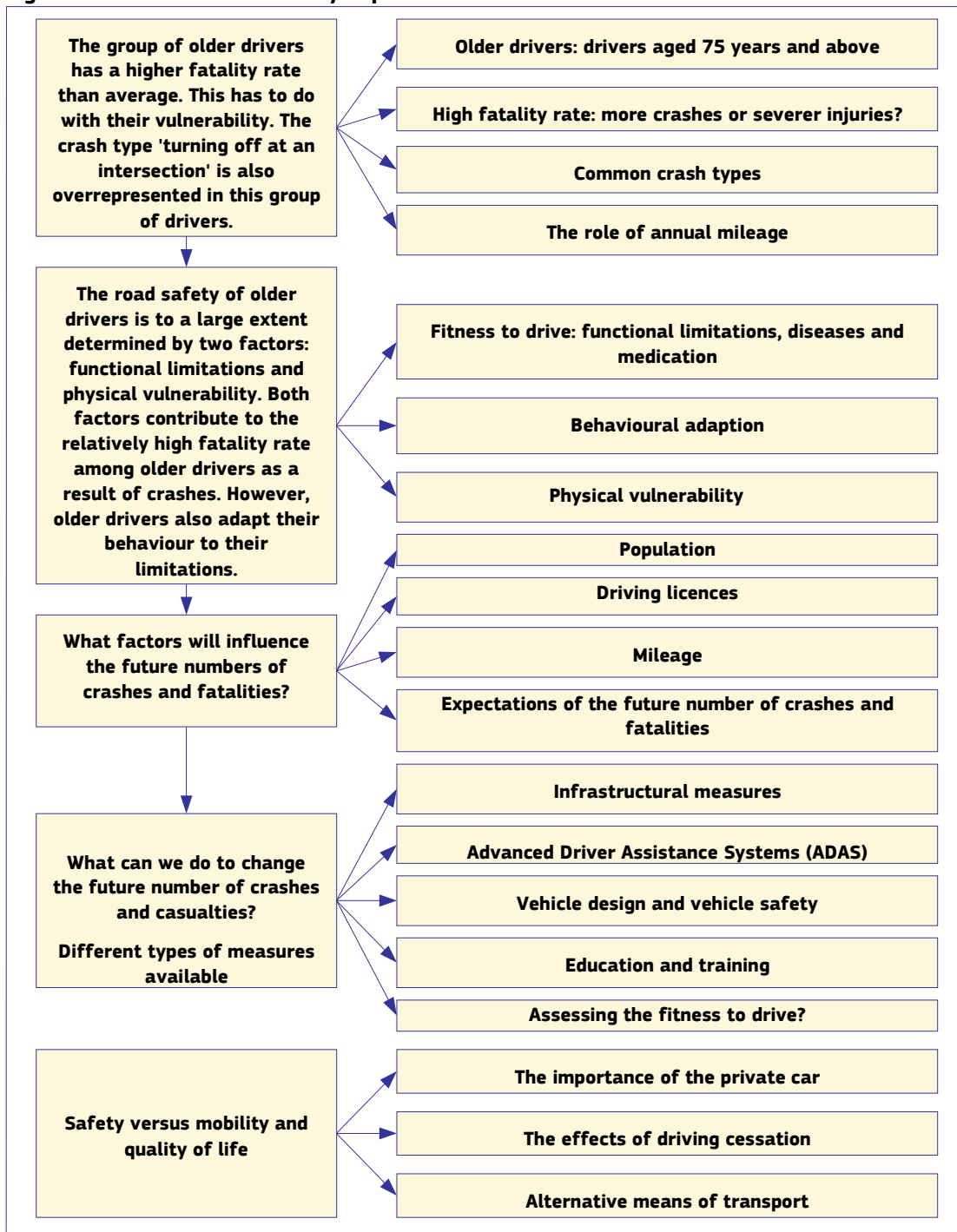
1	Overview	4
2	Older drivers: Risky or at risk?	6
2.1	Older adult drivers: drivers aged 75 and above	7
2.2	High fatality rate: more crashes or more severe injuries?	8
2.2.1	Fatality rate versus injury rate for different age-groups	9
2.2.2	Crash rate of older drivers in comparison with other age-groups	10
2.2.3	Fatality ratio of older drivers in comparison with other age-groups	11
2.3	Common crash types among older drivers	11
2.4	Role of annual mileage	12
3	Functional limitations and physical vulnerability	12
3.1	Functional limitations, diseases and medication	13
3.1.1	Age-related functional limitations and their relevance to road safety	14
3.1.2	Age-related disorders that can restrict fitness to drive	16
3.1.3	Medication	19
3.2	Behavioural adaptation	19
3.3	Physical vulnerability	20
4	Factors influencing the future number of fatalities among older drivers	20
4.1	Population	20
4.2	Driving licences	21
4.3	Mileage	21
4.4	Expectations of the future number of crashes and fatalities	22
5	Improving older driver safety	22
5.1	Infrastructural measures	23
5.1.1	Intersection design	24
5.1.2	Road signs and markings	27
5.1.3	Traffic lights and fixed lighting	29
5.1.4	Exits and entries of motorways	29
5.2	Advanced Driver Assistance Systems (ADAS)	32
5.2.1	ADAS for crash avoidance	33
5.2.2	ADAS for enhanced mobility and lower injury severity	34
5.2.3	User acceptance	34
5.2.4	Pre-conditions for safe use of ADAS by older drivers	34
5.3	Vehicle design and vehicle safety	36
5.3.1	Vehicle design	37
5.3.2	Vehicle safety	37
5.4	Education/training	38
5.4.1	Informing the older driver	38
5.4.2	Training the older driver	38
5.5	Assessing fitness to drive	39
5.5.1	Licensing procedures for older drivers	39
5.5.2	Consultation of doctors	42

# Older Drivers

6	<i>Safety versus mobility and quality of life</i>	42
6.1	The importance of the private car	43
6.2	The effects of giving up driving	43
6.3	Alternative means of transport	44
	<i>References</i>	45

## 1 Overview

Figure 1: Outline of road safety aspects of older drivers



### Who is at risk?

Older drivers (drivers aged 75 years and above) have the second highest fatality rate of all age-groups. At the same time, they are not so much a risk to others, but they are at risk themselves due to their frailty and vulnerability to the personal injury or risk of death in the event of a road traffic crash (OECD, 2004). As a result, older drivers have a relatively high fatality rate, but their injury rate is much lower. Data from the Netherlands illustrates this: the fatality rate (over

distance) for car drivers aged 75 years and over is more than 5 times higher than for the average for all ages, whereas their injury rate is 2 times higher. The conclusion that the older driver is not a danger to others should not limit the development of road safety measures targeting older drivers. Nor can the claim be made that all drivers are sufficiently safe to continue driving. This depends on the physical and mental condition of the individual.

Older drivers are over-represented in side-impacts at intersections, where typically the older driver turns against oncoming traffic with right of way on the main road. Countermeasures need to target this crash type which will become increasingly common as the population ages. Older drivers are under-represented in crashes involving loss of control or collisions due to speeding, risky overtaking or driving under the influence of alcohol.

## **Functional limitations and physical vulnerability**

The road safety of older road users is to a large extent determined by three factors, the main ones being functional limitations and physical vulnerability which both contribute to the relatively high fatality rate for older road users in road crashes. Functional limitations can increase crash risk, whereas higher physical vulnerability increases injury severity. A third reason for the high fatality rate of older adults seems to be their low annual mileage. In general, drivers travelling fewer kilometres have higher crash rates per kilometre compared to those driving more kilometres (“low mileage bias”, see e.g. Janke, 1991; Hakamies, Raitanen & O’Neill, 2002). These three explanations for the high fatality rate for older drivers are most probably connected, with the physical and mental condition of the driver – his functional limitations – having the greatest influence on the other two factors. That is, drivers who have a medical condition are also likely to be more fragile than other (older) drivers and will also drive less frequently or at least drive shorter distances.

As road users age – a process that starts at different times depending on the individual – functional limitations and disorders occur which may increase their road traffic crash rate. This is particularly the case in the decline of motor functions such as muscle strength, finely tuned coordination and the ability to adapt to sudden changes in bodily position. There are few indications that a decline in visual and cognitive functions, as part of normal ageing, also has road safety consequences. 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.

Functional limitations and age-related disorders do not automatically lead to unsafe traffic behaviour since older road user behaviour and other characteristics often prevent road safety problems. These include being aware of one’s limitations, long-driving experience, and compensation behaviour such as driving when the roads are less busy or when it is daytime and dry. However, notwithstanding behavioural compensation, once a crash occurs, older drivers are more vulnerable than younger drivers and their injuries will be more severe given any given impact.

## **Factors that will influence future developments**

Various factors can influence the future developments in the number of fatalities among older drivers. These factors can be divided into autonomous factors and road safety measures. Examples of autonomous factors are the age composition of the population, the number of older

adult driving licence holders, their mobility, and their driving experience. If these factors change over time they will influence the future number of fatalities among older drivers.

Expected increases in the number of people aged 75 years and above, in rates of licensed older drivers and in the mobility of older drivers will increase older driver fatalities. However, these increases will be ameliorated by reduced fatality rates as older drivers become more vital and experienced than those of today. Road safety measures can further reduce the fatality rate of older drivers into the future. Examples of measures are described in the next section. More information on older pedestrians and cyclists can be found in the Erso web text on Pedestrians and Cyclists.

## **Measures that can reduce future fatality rates**

Several types of measures are available to influence the future number of fatalities amongst older drivers. Given the physical vulnerability of older drivers, measures are needed that can reduce injury severity, such as improvements in active and passive vehicle safety. Measures that can reduce the older driver crash involvement also contribute to a reduction of their fatality rate. Examples of the latter type of measures include changes to road infrastructure, driver assistance systems, and providing education and training. In the case of a progressive decline of functions, training and adaptation of the infrastructure and the vehicle can no longer compensate for reduced fitness to drive. Therefore, in addition, a procedure is needed that will lead to a timely cessation of the driving career. Such measures involve licensing procedures and consultation of the medical profession regarding fitness to drive.

## **Safety versus mobility and quality of life**

The introduction of driving assessment requirements which result in older drivers losing their driving licence when they can still drive a car safely is undesirable for a variety of reasons. Firstly, the fatality rate for older cyclists and pedestrians is many times greater than that for older car drivers. Consequently, they are safer in a car. In addition, older people often will have stopped cycling, partly because of loss of balance. Saying farewell to their car often is also a farewell to part of their social lives. As a result, the loss of driving privileges can cause considerable distress and a lowering of self-esteem and dignity, as well as create difficulties for daily activities, shopping and social contact.

The availability of a means of transport other than the car is one of the most important ways to maintain older people's mobility. However, no single form of transport provides mobility for all people under all circumstances. Therefore, a variety of services is needed that enables travellers to select the one that best suits their requirements for a particular journey. These services include: public transport services including bus service routes, taxis, and the Dial-a-Ride service; an appropriate bicycle infrastructure, and an accessible pedestrian infrastructure for journeys on foot or by wheelchair or mobility scooter.

## **2 Older drivers: Risky or at risk?**

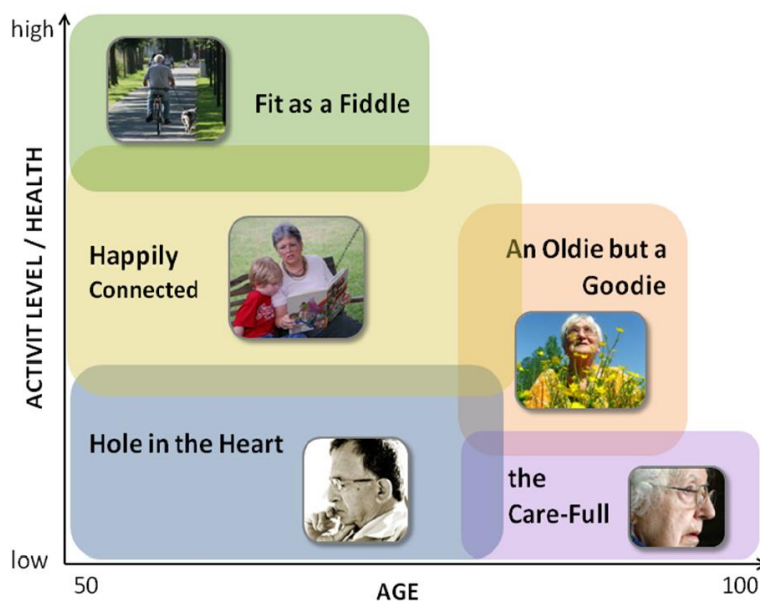
Older drivers are often characterized as a group that has a high fatality rate in traffic. This high fatality rate can be caused both by increased crash involvement and by increased injury severity. However, older drivers – that is those aged 75 and above – are very diverse, in their driving skills as well as in their physical and mental abilities. One thing that they do have in common is their

lower annual mileage. The latter may influence their crash rate, since drivers travelling fewer kilometres have increased crash rates per kilometre compared to those driving more kilometres. In addition, they generally drive less 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. This is reflected in the crash types that are common among older drivers. Older drivers are over-represented in crashes at intersections, where typically the older driver turns against oncoming traffic with right of way on the main road.

## 2.1 Older adult drivers: drivers aged 75 and above

In general, the age-group referred to as older adult drivers is the one of 75 years and above. Previously, it was those aged 65 years and above. The reason for this shift in age-group is that older people are becoming more vital. Today's 75 year-olds are as vital as 65 year-olds were in the past and this is reflected in their fatality rate. Nevertheless, using rigid age boundaries does not take into consideration the fact that ageing is a process that does not start at the same age for each and every individual, nor progresses at the same pace. There can be large differences in driving skills between people of the same age, as well as in their physical and mental abilities. Some 85 year-olds may well be in better shape than some 40 year-olds. This is nicely illustrated by the profiles which were identified in the European GOAL-project (see Figure 2). The youngest group of older people is usually "Fit as a Fiddle" – having excellent physical and mental health and driving a lot – but some of them suffer from pain and illness and are severely limited in activities. The latter group, which is characterized as "Hole in the Heart", prefers the car for their trips, but the number and distance of their trips is reduced. Similarly, the oldest group also consists of both relatively fit and active people "An Oldie but a Goodie" and people who suffer from severe physical and mental diseases. The latter "Care-Full" do not leave their homes very often (Millonig et al., 2013; GOAL, 2013).

**Figure 2: Age and activity level of the identified groups of older people.**



Source: Gorris et al., 2013

## 2.2 High fatality rate: more crashes or more severe injuries?

Older drivers have a relatively high fatality rate. Data from the Netherlands illustrates this: taking distance travelled into account, the fatality rate for car drivers and passengers is seven times higher for those aged 75 years and older than for the average for all ages. The fatality rate of the 65 to 74-year-olds age-group is much lower. However, other means of independent transport are not safer. The fatality rate is particularly high for older cyclists. This rate is about 11 times higher for cyclists aged 75 years and older than for 'the average for all ages'. Compared with the fit group of 30 to 49-year-olds, the difference is even larger (see Table 1).

**Table 1: Fatality rate: traffic fatalities per billion kilometres travelled, by age and mode of transport, Netherlands (2011-2014)**

	Pedestrians	Cyclists	Car occupants
<b>30 – 49</b>	7,1	5,1	1,0
<b>65 – 74</b>	10,7	21,9	1,5
<b>75+</b>	90,2	146,3	10,0
<b>All ages</b>	11,1	12,7	1,4

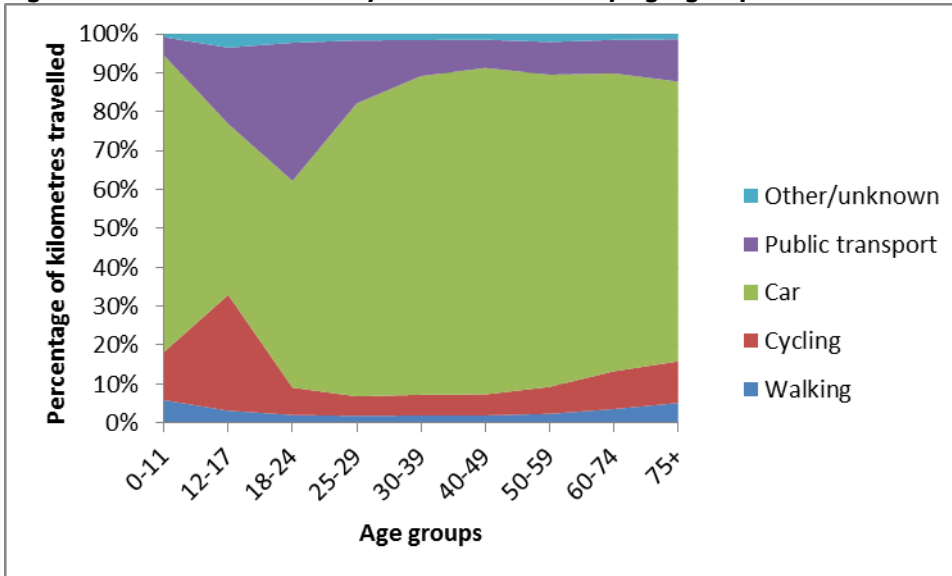
Source: Ministry of Infrastructure and the Environment, Statistics Netherlands

Unfortunately, cross-national comparisons at this level of detail (fatality rate by age and mode of transport) are not possible. The international databases that contain crash data of several European countries do not include data on fatalities per means of transport per age-group. Cross-national comparisons of the number of fatalities and of fatality rates for all road users aged 65 years and above (regardless of means of transport) can be found in [ERSO Traffic Safety Basic Facts 2017: The Elderly \(Aged >64\)](#).

The mobility patterns of older people are fairly comparable to those of younger persons. In all age-groups between 30 and 59, about 80% of all kilometres are travelled by car. After the age of 60, the percentage gradually reduces to 70%. In the Netherlands (2011-2014), there is a shift to walking (total of 5% for people aged 75 and above), cycling (total of 11%) and public transport (total of 11%; See Figure 3).



**Figure 3: Distance travelled by different modes by age-group in the Netherlands, 2011-2014**



Source: Statistics Netherlands, Ministry of Infrastructure and the Environment

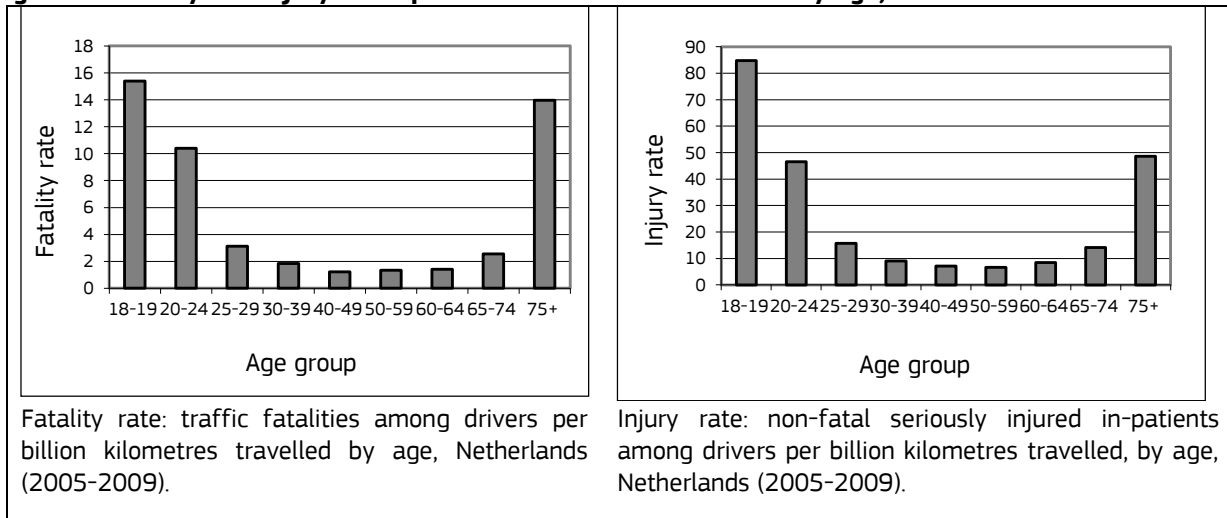
Note, however, that the occurrence of a traffic conflict or crash is also dependent on the possibility of meeting other traffic (traffic density and segregation of traffic modes) and on time spent in traffic. The value of the latter type of exposure varies greatly depending on the transport mode chosen to travel a certain amount of kilometres. Unfortunately, there are no recent national or European data available to illustrate the effects of the abovementioned factors on fatality rate per transport mode and/or age.

High fatality rates can be caused either by higher crash rates or by greater physical vulnerability. The vulnerability of a group of road users is reflected in the difference between their fatality rate and injury rate, but also in their fatality ratio: the percentage of fatalities in the total number of casualties.

### 2.2.1 Fatality rate versus injury rate for different age-groups

Older drivers have the second highest fatality rate. Only the youngest group of drivers (18- and 19-year olds) has a higher fatality rate. The left side of Figure 3 shows the well-known U-shape: fatality rates of the young drivers are high, after which the rate declines to a minimum for drivers of the age of 40-60 years. Then it increases again, to a maximum for those aged 75 and older. The injury rates in Figure 4 (right side) also show a U-shape but they level off at the oldest age group. Whereas young drivers (18-24 years old) have a relatively high injury rate as well as a high fatality rate, the injury rate for older drivers is much lower than their fatality rate.

**Figure 4: Fatality and injury rates per billion kilometres travelled by age, Netherlands 2005-2009**



Source: Ministry of Infrastructure and the Environment, Statistics Netherlands

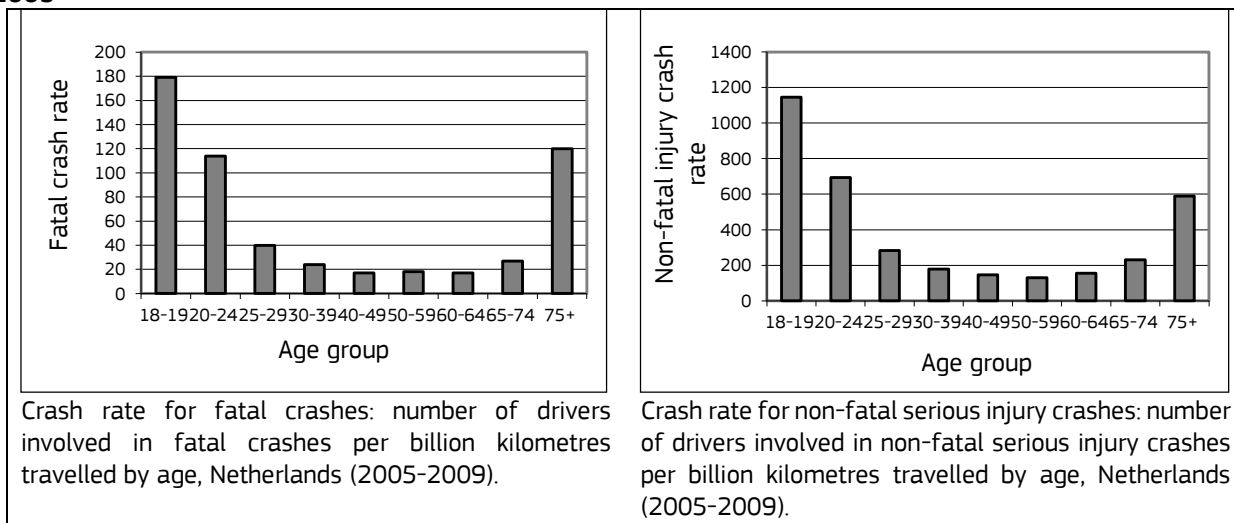
To explain this difference between young and older drivers, data is needed on the two underlying aspects of both rates: crash involvement and physical vulnerability. Crash involvement indicates how often a particular group of road users is involved in a crash (of a particular severity), without giving insight in the injury of the group of road users concerned (see Section 2.2.2). Physical vulnerability indicates the average injury severity of a particular group of road users (see Section 2.2.3).

### 2.2.2 Crash rate of older drivers in comparison with other age-groups

A comparison of the *crash rates* for fatal and non-fatal serious injury crashes for different age-groups shows that the youngest group of drivers is much more often involved in these types of crashes than other age-groups (see Figure 5). The group of drivers aged 75 and above has the second and third highest crash rate for fatal and non-fatal injury crashes respectively. However, the difference between the fatal crash rate for the youngest and that for the oldest group is much larger than the difference between their fatality rates. Therefore, it seems that the fatality rate of young drivers is influenced more by their crash involvement than is the case for those aged 75 and above. The high fatality rate of the latter age-group is probably determined to a larger extent by their physical vulnerability.

A confounding factor in the relationship between crash involvement and fatality rate is crash type. Some age-groups may have crashes that typically have greater impact, such as running off the road or crashes while driving at a higher speed. Driver behaviour also plays a role here. Older people, on average, drink and drive less often than younger adults and generally obey the traffic rules more often (Brouwer et al., 1988; Hakamies-Blomqvist, 1994a).

**Figure 5: Fatal and serious injury crash rates per billion kilometres travelled by age, Netherlands 2005-2009**

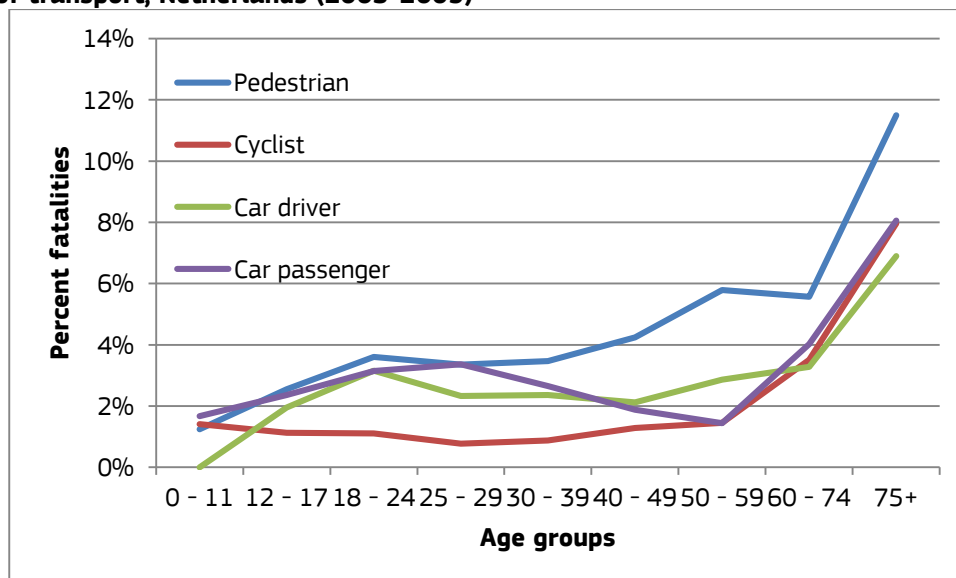


Source: Ministry of Infrastructure and the Environment, Statistics Netherlands

### 2.2.3 Fatality ratio of older drivers in comparison with other age-groups

Fragility can be expressed as the number of fatalities per 100 injured victims or as the percentage of fatalities in the total number of casualties. The latter is called the fatality ratio (Mitchell, 2000). This ratio increases with age and is higher for unprotected road users such as pedestrians (see Figure 6 and Section 3.3 on Physical vulnerability).

**Figure 6: Fatality ratio: percentage of all injuries reported by police that are fatal, by age and means of transport, Netherlands (2005-2009)**



Source: Ministry of Infrastructure and the Environment

## 2.3 Common crash types among older drivers

Various crash studies and surveys have shown that older drivers are over-represented in crashes at intersections, where older drivers typically turn against oncoming traffic with right of way on the main road (Hakamies-Blomqvist, 1993, 1994b; Zhang et al., 1998; McGwin & Brown, 1999; Davidse, 2000; OECD, 2001). In general, intersections represent complicated traffic situations

which involve time pressure and the necessity of dividing attention between various sub-tasks (Brouwer & Ponds, 1994). Negotiating an intersection represents a “testing of the limits” type of task, since it combines a host of age-sensitive functions while simultaneously limiting the usefulness of normal safe driving strategies. Therefore, it seems plausible that the individual’s increased risk is related to the combined deterioration of a number of relevant perceptual and cognitive functions rather than to the deterioration of single functions (OECD, 2001).

Older drivers are under-represented in crashes involving loss of control, speeding, risky overtaking or driving under the influence of alcohol (Hakamies-Blomqvist, 1993, 1994b, 2003; McGwin & Brown, 1999; OECD 2001). This suggests that they are more aware of the risks associated with speeding and drinking and driving, and are more willing to avoid these kinds of risk-taking behaviour (see also Section 3.2 on Behavioural adaptation).

## 2.4 Role of annual mileage

Older drivers typically drive a shorter distance per trip and hence have lower annual accumulated driving distances. 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 (Hakamies-Blomqvist, Raitanen & O’Neill, 2002; Fontaine, 2003; Holte, 2005; Langford, Methorst & Hakamies-Blomqvist, 2006). They all found that when driver groups were matched for annual mileage, age-related increases in crash rates per kilometre travelled 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 is the case 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, the safest types of roads, and tend to drive on streets with intersections, which are, by their very nature, less safe and where more crashes occur (Janke, 1991). Hence, older drivers’ risk estimates based on injuries or fatalities per distance driven will be overestimated when compared to those of younger drivers with higher annual mileage on safer roads (OECD, 2001).

## 3 Functional limitations and physical vulnerability

The road safety of older road users is to a large extent determined by functional limitations and physical vulnerability. Both factors contribute to the relatively high fatality rate as a result of crashes among older road users. Functional limitations can increase crash risk, whereas a higher physical vulnerability increases injury severity. Functional limitations and age-related disorders do not automatically lead to unsafe traffic behaviour. Other characteristics of older road users can prevent safety problems. Among these are the insight into one’s own limitations, driving experience, and compensation behaviour such as driving when the roads are less busy or when it is daytime and dry.

## 3.1 Functional limitations, diseases and medication

As people age, functional limitations and disorders occur that can increase the crash rate of road users. This is particularly the case in the decline of motor functions such as muscle strength, finely-tuned coordination and the ability to adapt to sudden changes in bodily position. There are few indications that a decline in visual and cognitive functions, as part of normal ageing, has road safety consequences. Only in the case of severe sensory, perceptual, and cognitive limitations does the relation between functional limitations and crash involvement become evident (Brouwer & Davidse, 2002). Examples are eye disorders such as cataract, macular degeneration, and glaucoma and diseases like dementia, stroke, and diabetes. In considering whether to advise the restriction or suspension of driving licences or for prescriptions, the end functional capacity is the main concern, rather than individual sources of functional loss. The main issue is the severity of impact of all combined effects, and importantly, one needs to consider how much compensatory potential the older driver may have, to compensate for a particular deficit (Holland, Handley & Feetam, 2003). The relative risks of being involved in crashes due to a medical condition like diabetes or a vision impairment have been calculated in the EU-project IMMORTAL (Vaa, 2003). The results of these calculations are shown in Table 2. The significance of these health impairments for the total number of crashes depends on their prevalence in the population (Elvik, Høy, Vaa, & Sørensen, 2009; Vlakveld & Davidse, 2011). Descriptions and prevalence of the medical conditions mentioned in Table 2 can be found in the next sections on age-related functional limitations, age-related disorders and medication.

**Table 2: Relative risks of selected medical conditions.**

Medical condition	Relative risk*	95% Confidence Interval	Number of results
Vision impairment (all types)	1,09**	(1,04; 1,15)	79
- Field of vision	0,90	(0,69; 1,17)	4
- Progressive eye diseases	0,86	(0,50; 1,49)	4
- Binocular visual acuity	1,13**	(1,05; 1,22)	39
Hearing impairment	1,19**	(1,02; 1,40)	5
Arthritis/Locomotor disability	1,17**	(1,00; 1,36)	12
Cardiovascular diseases (all types)	1,23**	(1,09; 1,38)	48
- (Serious) arrhythmia	1,27**	(1,09; 1,47)	14
- Abnormal arterial blood pressure	1,03	(0,86; 1,22)	8
- Suffering from angina	1,52**	(1,10; 2,09)	3
- Myocardial infarction	1,09	(0,62; 1,92)	2
Diabetes mellitus	1,56**	(1,31; 1,86)	25
Neurological diseases (all types)	1,75**	(1,61; 1,89)	22
- Diseases affecting central nervous system (e.g. stroke, Parkinson's disease)	1,35**	(1,08; 1,67)	11
- Epilepsy/other seizures	1,84**	(1,68; 2,02)	8
Mental disorders (all types)	1,72**	(1,48; 1,99)	33
- Dementia	1,45**	(1,14; 1,84)	18

Alcoholism	2,00**	(1,89; 2,12)	3
Drugs and medicines	1,58**	(1,45; 1,73)	68
Renal disorders	0,87	(0,54; 1,34)	3
Weighted average across all main groups	1,33**	(1,28; 1,37)	298
* A relative risk of 1,09 means that drivers with the mentioned medical condition have a 9% higher crash rate than drivers without any medical condition.			
** The relative risk is statistically significant at a level of $\alpha < 0.05$			

Source: Vaa, 2003

### 3.1.1 Age-related functional limitations and their relevance to road safety

As drivers age, information processing capacities generally decline. However, individual differences are large, not only in terms of the chronological age at which the ageing process manifests itself, but also in terms of the pace at which the ageing process continues. Several traffic-related studies have given an overview of the specific sensory, cognitive, and motor skills that deteriorate with age (Holland, 2001; Maycock, 1997; Sivak et al., 1995). The most important functional changes that accompany normal ageing relate to:

- Visual and perceptual abilities
- Cognitive abilities
- Physical abilities

#### Decline in vision and perceptual abilities

The visual functions which decrease as people age are: visual acuity, peripheral vision, visual acuity in poor light and sensitivity to glare, contrast sensitivity, detection of movement, and colour vision (Shinar & Schieber, 1991; Klein, 1991; Sivak, 1995; Holland, 2001).

Decreases in visual acuity (the ability to see details) generally accelerate after the age of 50 (Corso, 1971). The decrease of visual acuity often occurs so slowly, that people do not notice their visual acuity becoming worse and people therefore often overestimate their visual powers. In many cases, the visual acuity of drivers is below the legal standard, without their knowing it. Good visual acuity is not only important for the perception of traffic signs and signals, but also for long-distance sight that is specifically needed for overtaking on secondary roads (Groot, 1999).

The visual field determines to what extent objects and events situated outside the fixation point are perceptible. Adequate peripheral vision is one of the most important prerequisites for safe driving. The driver has to see cars in adjacent lanes when making a lane change, to keep the car centered in its lane; to see a pedestrian leaving the pavement or to see another car approaching an intersection. Defects in peripheral vision typically occur in patients with glaucoma (increased eye pressure), macular degeneration, diabetes, and after stroke or other cerebral diseases (Groot, 1999). These diseases are found more often amongst older drivers.

Functional impairments relevant for driving in the dark are 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, Sivak & Egan, 1983). A consequence of reduced retinal illumination is that sources must be of higher intensity to be seen at night (Olson, Sivak & Egan, 1983). However, older adults' increased vulnerability to disability glare makes it important to assure that lighting is appropriately directed (Kline & Scialfa, 1997): 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). Cataract is one of the main causes of sensitivity to glare among older people (Groot, 1999).

As far as contrast sensitivity is concerned, older adults have more trouble discerning small details and this becomes worse at low illumination levels. 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 (Shinar & Schieber, 1991; Holland, 2001).

The age-related changes in colour vision relevant to driving also concern contrast. Older adults have problems discriminating between blue, blue-green and violet: not important colours for the perception of traffic signs and signals. However, older adults also have problems discriminating between colours that are very much alike. Therefore, the differences between colours used in displays of Intelligent Transportation Systems should be as pronounced as possible (Holland, 2001).

Detection of movement decreases with increasing age. This is as a result of age-related changes to neural mechanisms and a less smooth movement of the oculomotor system which results from the ageing process. Obviously, the ability to detect movement is very important for safe driving, not only to detect vehicles approaching from the side and to estimate their speed, but also to detect changes in the speed of the vehicles ahead, i.e. stopping, slowing down, speeding up, and reversing (Shinar & Schieber, 1991; Holland, 2001).

## Declines in cognitive abilities

Age-related decreases in sensory abilities such as vision have an impact on the input the driver receives from other road users and the infrastructure. To select the appropriate information, interpret it and make decisions which must then be translated into an appropriate driving action, one needs perceptual and cognitive processes. Some of these processes decline as people grow older, including the ability to maintain attention over longer periods of time, the ability to separate important from unimportant information (selective attention), the ability to share attention between various tasks (divided attention), short-term memory and information-processing speed (Maycock, 1997).

Speed of processing information is often crucial to making safe decisions in driving. Fundamental to this aspect of the driving task is the time taken by a driver to respond to the demands placed upon him or her by the traffic environment (often referred to as the '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 increase when drivers have to make decisions in complex situations (Quimby & Watts, 1981).

## Physical changes

Physical abilities 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). The crash risk associated with diseases such as arthritis can be found in the Table 2 (Vaa, 2003).

### **3.1.2 Age-related disorders that can restrict fitness to drive**

A number of diseases and disorders are found to be related to crash proneness. These are: eye disorders, dementia, Parkinson's disease, stroke, cardiovascular diseases and diabetes. These diseases and disorders can occur at all ages, but they are more common among older adults. Comorbidity, which means having more than one disease, is also more common among older adults. Specific crash risks associated with age-related disorders can be found in Table 2 (Vaa, 2003). It should be noted, however, that increased risks can also be caused by the medications that are being taken because of one or more disorders. The next sections provide a brief outline of the influence of chronic illness on crash involvement of drivers. A comprehensive overview can be found in Charlton et al. (2010).

#### 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). The crash risks associated with eye disorders can be found in Table 2 (Vaa, 2003). 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 see cars. 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 causes difficulties seeing 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.

#### Dementia

Dementia is a syndrome that is characterized by a progressive decline of cognitive functions as a result of brain damage or illness. The most common illness which leads to this syndrome is Alzheimer's disease, accounting for approximately half of all dementia cases. Alzheimer's disease is characterized by impairments in memory and at least one other cognitive domain, such as attention or judgement. The exact impairments depend on the areas of the brain that are affected.

Dementia often involves a poor understanding 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. 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 et al., 1999). The mere diagnosis of dementia is not 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, 1997). The crash risk associated with dementia can be found in Table 2 (Vaa, 2003). Estimates of the prevalence of dementia in the total group of people over 65 years of age vary from 5% to 15%. Prevalence increases markedly with age, with European estimates of 0,4-1,0% for people aged 60-64 to 42,3-55,8% for people aged 95 and above (Oxley et al., 2010).

## 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 people 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%.

Both the movement and cognitive effects of Parkinson's disease have potentially important implications for the patient as a driver. However, as in other chronic diseases, the level of function is a more important criterion for fitness to drive than the diagnosis of Parkinson's disease itself. Most people with severe Parkinson's disease give up driving (Holland, Handley & Feetam, 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 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). The crash risk associated with Parkinson's' disease can be found in Table 2 (Vaa, 2003).

## 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. Driving after a stroke is problematic if there are cognitive changes, even assuming that the patient is rehabilitated enough to manage the driving task. Many people do not resume driving after a stroke. Those who stop driving are generally older and/or have other sources of impairment or disability in addition to the effects of their stroke (Holland, Handley & Feetam, 2003). Little research has been done into the effects of a 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 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-sided 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). The crash risk associated with a stroke can be found in Table 2 (Vaa, 2003).

## 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 distinguished these different conditions have indicated that only cardiac arrhythmias and angina pectoris increase crash risk. Actual heart attacks are only responsible for a small part of the total relationship of cardiovascular illness with driving risk (Holland, Handley & Feetam, 2003). The crash risks associated with cardiovascular diseases can be found in Table 2 (Vaa, 2003).

## 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 possibilities for diabetic patients to monitor 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 diminished. 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). The crash risk associated with diabetes can be found in Table 2 (Vaa, 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.

## Comorbidity (more than one disease)

Many older adults suffer from more than one disease. In a study by Holte and 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 ability 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.

### 3.1.3 Medication

Regardless of the age of the patient, there is consensus on medications that present a risk to drivers. These are, among others, benzodiazepines, tricyclic and second generation antidepressants, painkillers that act on the peripheral and central nervous system (analgesics), and first generation antihistamines. Older patients, however, are likely to exhibit altered sensitivity to medication, and this should be taken into account when prescribing. This change usually involves an increased effect, including side-effects and adverse reactions, and the duration of action of a drug may be significantly prolonged. Since many older adults suffer from more than one disease, older patients are also more likely to be prescribed multiple medication (polypharmacy). The wider variety of medications 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 (Holland, Handley & Feetam, 2003).

In evaluating the possible impact of a medication on driving, it is important to remember 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 increase any deterioration in driving ability caused by the illness, or it could even act to reduce the risk to the patient caused by the illness. The issue is not whether the specific drug has an effect on driving performance, but rather, whether the individuals are capable of functioning safely in their environment (Holland, Handley & Feetam, 2003).

## 3.2 Behavioural adaptation

Functional limitations and age-related disorders do not automatically lead to unsafe traffic behaviour. But other characteristics of older road users can prevent safety problems. They include insight into one's limitations, long driving experience, and compensatory behaviour. There are various reasons why older people have more opportunities to compensate. Firstly, they often have more freedom in choosing when to travel. Various studies have shown that older people more often choose to drive during daytime and dry weather (e.g., Davidse & Hoekstra, 2010; Henrikson, Levin, Willstrand & Peters, 2014). In the second place older people on average have a great deal of driving experience. The traffic insights they have acquired may give them the ability to anticipate possible problematic situations. In the third place, the diminishing desire for excitement and sensation when getting older possibly plays a role. In line with this, older people, on average, drink and drive less often than younger adults and generally obey the traffic rules more frequently (Brouwer, Rothengatter & Van Woffelaar, 1988; Hakamies-Blomqvist 1994a).

With regard to compensation for functional limitations, Jansen et al. (2001) identified four different compensation styles among older drivers which account for 84% of their study participants (the compensation styles of the remaining 16% could not be identified):

- Functional compensation (23,4%): people are aware of their deficits and report adequate changes of driving behaviour.
- Dysfunctional compensation (5,5%): people are aware of their deficits, but do not report adequate changes of driving behaviour.
- Preventive behaviour (24,9%): people are not aware of their deficits, but they report adequate changes of driving behaviour.
- Missing compensation (30%): people are not aware of their deficits, and they do not report adequate changes of driving behaviour.

## **Possibilities for compensatory behaviour**

According to the hierarchic structure of the driving task proposed by Michon (1971; 1985), there are three levels of skill and control: strategic, tactical and operational. Possibilities for compensatory behaviour are offered especially at the higher levels of control. At these higher levels (strategic and tactical), there is hardly any pressure of time, giving the driver enough time to make the right decisions. Examples of the kind of decisions that are made at the strategic level are “when and how to drive to a certain destination”. At the tactical level, decisions are made on the distance that should be kept from the vehicle in front, and whether or not to overtake. At the operational level, only milliseconds are available for decisions on braking and steering. By deciding on a longer headway from the vehicle in front (at the tactical level), there will be more time to react and operate. Similarly, by reducing speed at the approach of an intersection, there will be more time to respond to the information given by the traffic environment.

## **3.3 Physical vulnerability**

Older adults are more vulnerable than younger adults: their injuries will be more severe given the same impact. With the same impact force, the fatality rate is approximately three times higher for a 75 year old motor vehicle occupant than for an 18 year old (Evans, 1991, 2001). Physical vulnerability has the severest consequences during 'unprotected' journeys such as walking and cycling. This physical vulnerability is a less important factor for car drivers, but it still has an influence on injury severity. Physical vulnerability is mainly caused by age-related disorders such as osteoporosis (Mackay, 1988).

## **4 Factors influencing the future number of fatalities among older drivers**

Various factors can lead to an increase or reduction of the current number of fatalities among older drivers. These factors can be divided into autonomous factors and road safety measures. Examples of autonomous factors are the age composition of the population, the number of driving licence holders, and mobility. If these factors change in the course of time, they will influence the future number of fatalities among older drivers. Road safety measures can be taken to reduce the fatality rate of older drivers in the future (see Section 5).

Another factor that might 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 sub-groups 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).

### **4.1 Population**

In most European countries, the number of older people has increased over the last decades. This increase will intensify in the next 20 years. Currently, 16% of the European population is aged 65 years or above, and 4% is aged 80 years and above. These percentages will increase

up to 25% and 8% respectively in 2040 (Lanzieri, 2011). The percentage of people having difficulties in traffic due to functional limitations is clearly larger among the older group (80 and above) than among the younger group (65–79 years). This not only applies to older pedestrians and cyclists, but also to older drivers. As the group of older people becomes increasingly large, road safety policy will need to focus more on the safety needs of this group of road users.

## 4.2 Driving licences

In Europe, the percentage of licenced drivers in the group of drivers between the age of 65 and 74 years used to vary from 71 to 93% for men and from 7 to 46% for women (OECD, 2001). These groups of drivers represent the older drivers of today, those aged 75 years and above. For example, data from the 2014 travel survey of the Netherlands show that 80% of men and 40% of women aged 75 years and above had a driving licence, whereas the rates for those aged between 65 and 74 years are now as high as 94% for men and 73% for women. Licence rates for women, in particular, have increased. Translating the licence rates for even younger age-groups to the future, and combining them with population data will provide estimates of the percentage of drivers aged 65 years and above in 2030. These figures show that in 2030, a quarter of all drivers will be aged 65 and above (see Table 3).

**Table 3: Percentage increase in licensed drivers to 2030 for selected countries**

Country	Percentage of total number of licensed drivers aged 65+ in 2000	Percentage of total number of licensed drivers aged 65+ in 2030	Percentage increase in licensed drivers aged 65+
Finland	14,9%	26,7%	79%
France	16,1%	25,8%	60%
Netherlands	13,7%	26,5%	93%
Norway	15,3%	23,5%	53%
Spain	16,8%	26,1%	55%
Sweden	17,2%	24,1%	40%
United Kingdom	15,7%	23,5%	49%

Source: OECD, 2001

## 4.3 Mileage

Expectations are that tomorrow's older driver will continue to drive longer and for larger distances than earlier cohorts, partly because they have better access to cars. In England, Sweden and Norway, the number of trips taken daily by older people (as well as by other age-groups) remained reasonably constant between 1985 and 2000, but the daily distance travelled increased (OECD, 2001). In the United States, the number and length of trips have increased for people over 65 years of age, with faster growth for older people than for other age-groups (Rosenbloom, 2000). Much of the increase in travel distance among older groups can be attributed to better access to a car. The car is becoming more dominant as a transport mode for older people, but there are differences among countries, especially between Europe and the United States. In Europe, walking is still an important transport mode for older people, with 30-

50% of older people's trips made on foot. However, car use seems to be replacing walking and to a lesser extent, public transport (OECD, 2001), although there are differences between and even within countries, possibly influenced by town planning and access to cars and public transport (Mollenkopf et al., 2004; Bell et al., 2010). Differences are also observable between the young old and older old age-groups, with the younger age-groups using cars more frequently (Bell et al., 2010). Since there will be more older females with a driving licence in future, gender differences in car use among older people today may be reduced by 2030 (OECD, 2001), although several studies indicate that older men and women seem to have different motives for driving (Siren & Haustein, 2013).

## 4.4 Expectations of the future number of crashes and fatalities

Using population figures, data relating to the number of licensed drivers, data on the annual mileages they drive, and crash data, Maycock (2001) has forecast the number of fatalities and serious injuries among UK older driver groups for the period 1998-2022. The results of the forecasts show that during this period the number of fatal and serious casualties among older male drivers will decline, whereas the number of fatal and serious casualties among older female drivers will increase (see Table 4). The yearly rates of decline and increase differ by age-group: the older the age-group, the smaller the decline for male drivers and the larger the increase for female drivers. The increase of fatalities and serious injuries among older female drivers is caused by the expected future growth in the number of drivers in this group (see Section 4.2). These forecasts show that the number of casualties among older drivers will decrease less than the number of casualties among younger drivers, leading to a larger share of casualties among older drivers. The same trend was predicted for the Netherlands by Davidse (2000, 2007).

**Table 4: Predicted yearly rates of increase or decrease of the number of fatal and serious casualties in the period 1998-2022 in the UK**

	Male drivers	Female drivers
60-64	-3,5%	-2,0%
65-69	-4,0%	-1,8%
70-74	-3,1%	-0,8%
75-79	-2,9%	0,0%
80-84	-2,1%	0,9%
85-89	-1,6%	2,2%
90+	-0,8%	4,2%

Source: Maycock, 2001

## 5 Improving older driver safety

The road safety of older road users is to a large extent determined by two factors: functional limitations and physical vulnerability. Both factors contribute to the relatively high fatality rate among older road users as a result of crashes. Functional limitations can increase crash risk, whereas a higher physical vulnerability increases injury severity. Taking into account these

causes of the high fatality rate among older drivers, a package of measures to reduce their fatality rate should include measures that are aimed at reducing injury severity as well as their crash involvement. Examples of measures aimed at reducing crash involvement are: infrastructural measures, driver assistance systems and providing education and training (Maycock, 1997; Hakamies-Blomqvist, Sirén & Davidse, 2004; Davidse, 2007). In the case of a progressive decline of functions, training and adaptations of the infrastructure and the vehicle can no longer compensate for reduced fitness to drive. Therefore, a procedure is needed that will lead to a timely cessation of the driving career. The availability of alternative means of transport will alleviate the pain of giving up driving (see Chapter 6). To sum up, to ensure the older adult's safety, a package of measures should be composed that includes all of the elements listed below:

- Infrastructural measures
- Advanced Driver Assistance Systems (ADAS)
- Vehicle design and vehicle safety
- Education and training
- Arguably assessing the fitness to drive

## 5.1 Infrastructural measures

An infrastructure that takes into account the functional limitations that accompany ageing can contribute to a reduction of the crash involvement of older people and is a key element of the recommended *Safe System* approach. This involves providing the older driver with enough time to observe, decide and act either by providing more time, or by making the driving task easier. Examples of infrastructural elements that provide enough time are long acceleration lanes on motorways and large stopping sight distances at intersections. Examples of infrastructural elements that make it easier to observe, decide and act, are an increased letter-height and retro-reflectivity of street name signs, and a higher contrast between pavement markings and the carriageway. Based on problems that older drivers encounter in traffic (see Box below), infrastructural measures should focus on (Staplin et al., 2001):

- Intersection design
- Road signs and markings
- Traffic lights and fixed lighting
- Exits and entries of motorways

## **Which infrastructural elements create problems for older adult drivers?**

With respect to infrastructural measures that might be able to improve the safety of older adult drivers, it is interesting to know what the older adults themselves indicate to be a problem. Benekohal et al. (1992) posed this question to a group of older adult drivers in the USA. Topics mentioned most were:

- Reading street signs in town
- Driving across an intersection
- Finding the beginning of a left-turn lane at an intersection
- Making a left turn at an intersection
- Following pavement markings and
- Responding to traffic signals.

The same group of researchers also gathered information about the highway features that become important to drivers as they age:

- Lighting at intersections;
- Pavement markings at intersections;
- Number of left-turn lanes at an intersection;
- Width of travel lanes;
- Concrete lane guides (raised channelisation) for turns at intersections; and
- Size of traffic signals at intersections.

Mesken (2002) posed similar questions to older adult drivers in the Netherlands. Traffic situations 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 and
- Driving round a roundabout which has more than one lane.

## **The Older Driver Highway Design Handbook**

The 'Older Driver Highway Design Handbook' by Staplin, Lococo and Byington (1998), and its second edition 'Highway Design Handbook for Older Drivers and Pedestrians' (Staplin, Lococo, Byington & Harkey, 2001) can be regarded as important reference books on the subject of road design elements that take the older adult driver into account. These two handbooks contain recommendations regarding the design of highways including the references on which these recommendations were based. A major advantage of these handbooks is that all recommendations have been presented to engineers with the request to check whether these recommendations would contribute to a solution of existing problems of older adult drivers, and whether they would apply these recommendations to their own roads. Feedback from the engineers has been incorporated in the handbooks.

Since the infrastructure in the United States is rather different than in Europe, it would not be wise just to copy all proposed measures. Therefore, Davidse (2002) thoroughly screened all recommendations with the help of Dutch engineers on the possibility and desirability to translate them to the European situation. In her report, only those recommendations were included that were judged to be suitable for the European situation and that were related to intersections and interchanges. Where possible, these recommendations were complemented with the results of studies that were not included in the reference list of the American handbooks. An English translation of the report is included in Hakamies-Blomqvist et al. (2004).

### **5.1.1 Intersection design**

Several studies have revealed that crashes at intersections are over-represented among crashes involving at-fault drivers of 75 years and older (Hakamies-Blomqvist, 1993, 1994b, Zhang, 1988; McGwin & Brown, 1999; Davidse, 2000, 2007). Negotiating intersections requires complex judgements of speed and distance under pressure of time. Older adults generally have more



trouble in meeting these requirements than do younger drivers. Functional limitations that are particularly related to these problems are an increased perception-reaction time and a decline in the ability to discriminate between relevant and irrelevant information. Besides this, a decrease in both visual acuity and mid-peripheral vision plays an important role in safely negotiating an intersection. Mid-peripheral vision is important to allow the sighting of a pedestrian getting ready to cross the street or to enable the driver to see another car approaching the intersection. Infrastructural measures that are important in this respect are:

- providing a good and early view on the intersection;
- assistance in making a left turn; and
- roundabouts.

## View of the intersection

At the approach of an intersection, the view of other traffic approaching it 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 obtain an overview of the intersection and to notice other road users. Road users can compensate for these difficulties by minor changes to the position of their head. But since older adult road users generally have restricted head and neck mobility, they will experience more problems with intersections where streets meet at a reduced angle. Therefore, a right-angled junction is important for older adult road users. A secondary benefit of a right-angled junction is that it keeps the intersection area as small as possible, thereby reducing the chance of a crash.

Apart from the fact that older adult road users have more problems viewing the intersection because of restricted mobility of the head and neck, they also need more time to react (reduced perception-reaction time). A restricted view on 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 on the intersection, leaves the driver little time to survey the intersection and little time to react. The resulting pressure of time causes more problems for older adult drivers than for younger drivers. Therefore, a restricted sight distance or stopping sight distance has more adverse consequences for older adult drivers than for younger drivers. This problem can be addressed by using a longer perception-reaction time when calculating the required sight triangle and the stopping sight distance, with a minimum of 2,5 seconds. A reduction of vehicle speeds at intersections is also helpful. This can be achieved by, for example, raising the intersection or replacing an intersection with a roundabout.

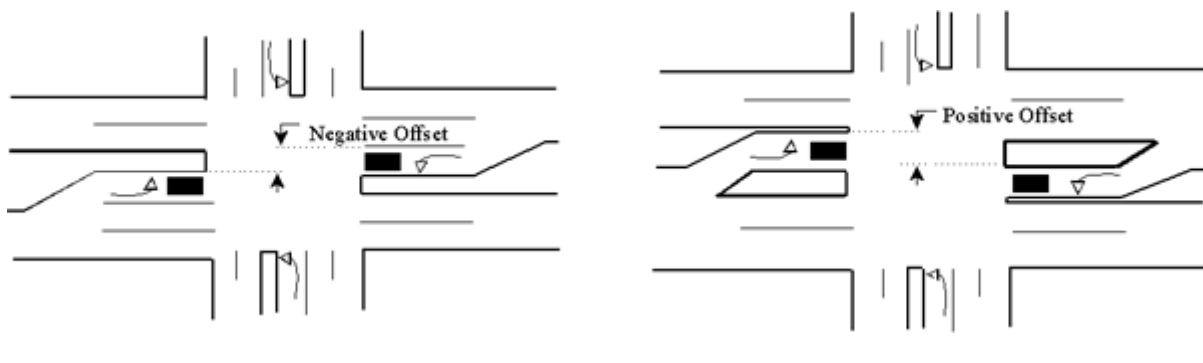
## Assistance in making a left turn

As mentioned previously, older drivers are over-represented in crashes while turning left. These crashes often occur because drivers do not give way to traffic going straight ahead: they either estimate the speed of the approaching vehicle incorrectly, or have not seen it. These factors combine with the various functional limitations that accompany ageing, such as a decrease in depth and motion perception (necessary to determine speed and distance of approaching traffic) and a decline in divided and selective attention (the ability to share attention between various tasks and to separate important from unimportant information respectively). For intersections with traffic lights, errors in giving way and any resulting crashes can be prevented by a conflict free regulation: traffic that can collide does not get a green light simultaneously (for example, separate phases for traffic travelling straight on and traffic turning left). In such a case, road users never have to decide on whether it is safe to turn left.

Intersections without traffic lights need to be designed to allow drivers to have an uninterrupted view of the traffic they must cross. Amongst other considerations, this means that two roads should preferably cross at right angles, that bushes and buildings do not obstruct the view, and also that drivers do not block each other's view (e.g. cars in the opposite left-turn lane waiting to turn left restricting the driver's view of oncoming traffic in the through lanes). This last situation can be prevented by offsetting the position of opposite left-turn lanes such that drivers facing each other do not obstruct each other's view (Staplin et al., 2001).

### Positive offset of left-turn lanes

Opposite left-turn lanes and traffic using these can restrict the left-turning driver's view of oncoming traffic in the through lanes. The level of restricted view depends on how the opposite left-turn lanes are aligned with respect to each other, as well as the type/size of vehicle 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. The difference between a negative offset of opposite left-turn lanes, which provides the worst sight on other traffic, and a positive offset, which provides the greatest sight distance, is shown below:



Source: Staplin et al., 2001

### Roundabouts

Modern roundabouts have all the required qualities to compensate for the functional limitations of older drivers: 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 on the intersection is not restricted by small angles between intersecting streets (Staplin et al., 2001; Davidse, 2000). For this reason, roundabouts are highly relevant for solving the problems that the older adult driver encounters when crossing intersections. All the more so, because roundabouts not only reduce crash numbers, but also, as a result of lower speeds, crash severity which is especially beneficial to improving the safety of older drivers.

At the same time, there are several problems which need to be borne in mind. Firstly, roundabouts are relatively new to motorists in some countries and older adults are at a disadvantage in responding to novel, unexpected stimuli (Staplin et al., 2001; Davidse, 2000). This may even lead to older drivers avoiding roundabouts. Simms (1992) reports avoidance of roundabouts by drivers over 70 years old (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) made 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 older drivers seem to prefer single-lane roundabouts.

In general, right-angle connections are more effective in reducing driving speed and provide a better view of roundabout traffic for drivers that are about to enter the roundabout, than tangential connections (Brouwer, Herland & Van der Horst, 2000). Bearing in mind the additional problems of restricted head and neck mobility of many older drivers, it is recommended that right-angle connections to the roundabout are used. Another design element of roundabouts that is related to the traffic view is the distance between the roundabout and cyclist and/or pedestrian crossings. A driver leaving the roundabout needs to have a good view of crossing cyclists and pedestrians who have right-of-way and thus should be at a right angle with the cyclist/pedestrian crossing. This angle can only be obtained when the crossing is placed at approximately one length of a car from the circulation area (Linderholm, 1996, cited in Brouwer, Herland & Van der Horst; CROW, 1998, 2002).

## **5.1.2 Road signs and markings**

As people age, visual functions decline and people have more difficulty in dividing attention between, for example, different aspects of the road scene. This makes it more difficult to detect traffic signs and obstacles, and hence to understand the traffic situation at hand. 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.

### Street name signing

The legibility of street name signs is important to minimise the time and effort needed to read the street name. One can imagine the kind of danger that could result from a driver who is distracted from the basic driving task for a longer period of time or from a driver who suddenly brakes on approaching a street name sign (Taoka, 1991; Malfetti & Winter, 1987). The main factors that influence the legibility of street name signs are: contrast, luminance, font, letter height, letter width and inter-letter and inter-word spacing. These factors increase in importance as a road user's eyesight deteriorates. Older drivers, given 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. This can be accomplished by raising the requirements for letter size and the retro-reflectivity of street name signs. The 'Older Driver Highway Design Handbook' recommends a minimum letter-height of 150 mm for use on post-mounted street name signs on all roads where the speed limit exceeds 40 km/h.

Since older adult drivers need more time to act (e.g. turning into a street) after having received directional information (e.g. a street name), the placement of street name signs is also important. Older drivers need sufficient time to prepare and execute their actions and good visibility and prior notification can provide the driver with some extra time to act. Accordingly, street name signs post-mounted along the side of the road and advance street name signs which improve the visibility of street name signs on major roads and grade-separated junctions are helpful. Furthermore, the use of retro-reflective sheeting to provide increased sign conspicuity and legibility is recommended. When different street names are used for different directions of travel on a crossroad, the names on intersection street name signs should be separated and accompanied by directional arrows.

## Lane-use control signs

The increased perception-reaction time of older adult drivers (which is responsible for the 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. The use of overhead lane-use control signs in advance of the intersection as a supplement to pavement markings is therefore recommended. Drivers need to be able to read these signs at least 5 seconds in advance of the intersection (at operating speed; 50 meters at 36 km/h), regardless of the specific lighting, channelisation or delineation treatments implemented at the intersection (Staplin, Lococo & Byington, 1998).

## “One-way”and “Yield” signs

Older drivers need to be informed about the obligatory direction of travel and right-of-way as early as possible. Research in the United States and The Netherlands has shown that older adult drivers are over-represented in wrong-way movements (Crowley & Seguin, 1986; Blokpoel & De Niet, 2000). This over-representation can be explained by older drivers’ reduced peripheral vision and their decreased selective attention (the ability to ignore irrelevant information and to discriminate between relevant and irrelevant information). To compensate for these deficits, the most relevant information needs to be signalled in a direct manner to ensure that it receives a high priority for processing in situations where there is a great deal of complexity. 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. To prevent wrong-way driving these recommendations are particularly relevant for signs indicating one-way roads and ‘no entry’. However, the same recommendations apply to traffic signs indicating stop-and yield-controlled intersections, since crashes resulting from failure to yield are also over-represented among crashes involving at-fault drivers of the age of 75 and older (Aizenberg & McKenzie, 1997; Zhang, 1988; Davidse, 2000). Moreover, Council and Zegeer (1992; cited in Staplin, Lococo & Byington, 1998) found that both drivers aged 65-74 years old and drivers aged 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 markings and delineation of raised channelisation

Road markings help the driver to maintain the correct lane position and provide a preview of the course of the road ahead. Given 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 to have enough time to act upon them. The same applies to the delineation of discontinuities, such as curbs of traffic islands and medians. Older adults report difficulties in seeing these, resulting in a possibility of running over them (Staplin, Lococo & Sim, 1990; Benekohal et al., 1992; Staplin et al., 1997).

Studies in the United States have indicated that driver performance in general – measured by the probability of exceeding lane limits – was optimized when the perceived brightness contrast between pavement markings and the carriageway was 2.0 (Blackwell & Taylor, 1969; Allen, O’Hanlon & McRuer, 1977). This indicates that pavement markings need to be at least three times as bright as the carriageway. However, these studies were not specifically focused on 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, Lococo and Byington (1998) 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 a minimum in-service contrast level of 2.0 is deemed to be sufficient.

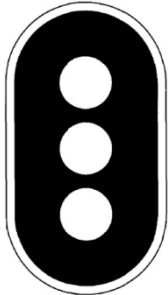
### 5.1.3 Traffic lights and fixed lighting

The visual limitations of older adults also need to be taken into account in the design of traffic signals and fixed lighting. Here, the older driver's need for increased levels of luminance and contrast should be weighed against their sensitivity to glare.

#### Traffic signals

Backplates can provide more contrast between the traffic light and its direct surroundings without increasing the risk of glare and are a good alternative to increased intensity of light. Guidelines recommend that backplates (see Figure 7) should only be omitted where the plate would be too close to the carriageway (CROW, 1996; Regeling Verkeerslichten, 1997). Glare can be further reduced by reducing the intensity of traffic signals during darkness, except when this is unnecessary or undesirable because of the (fixed) lighting of the surroundings (Regeling Verkeerslichten, 1997).

**Figure 7: Backplate for a traffic light**



#### Fixed lighting

Lighting is more important for older adults than for the average road user. Both 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 (Olson, 1993). Furthermore, timely warnings of unexpected situations and changes in lane configuration and lane width are helpful to older adults given their increased perception-reaction time and can be achieved by lighting these areas. Wherever feasible, fixed lighting installations are recommended (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 (Staplin et al., 2001).

### 5.1.4 Exits and entries of motorways

Both intersections, at-grade and grade-separated interchanges, pose problems for older adult drivers. A study by Staplin and Lyles (1991) showed that drivers over 75 are over-represented as the driver at fault in merging and weaving crashes near interchange ramps. Age differences in interchange crashes and violations may be understood in terms of driving task demands and

age-related diminished driver capabilities (Staplin, Lococo & Byington, 1998). Merging and weaving on interchanges involves the processing of a large amount of information in a short period of time and at high speeds, while maintaining or modifying position within the traffic stream. Under these circumstances, several functional limitations of older adult drivers come into play including a slower processing of information, reduced visual acuity and peripheral vision, and reduced flexibility of head and neck. When merging and weaving take place in the dark or under bad lighting conditions, poor night vision and increased sensitivity to glare are also involved.

During focus group discussions that were held as part of a study by Lerner and Ratté (1991), older adult drivers indicated that interchanges could be improved by eliminating weaving sections and short merge areas; and improving exit signing by better graphics and more information on upcoming exits.

Specific measures that apply to these and other road design elements of interchanges relate to:

- exit signing;
- design of acceleration and deceleration lanes;
- fixed lighting at interchanges; and
- prevention of wrong-way manoeuvres.

## Exit signing

The usefulness of directional information is determined by its legibility and the time available to act upon the information. Older adult drivers, given 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. This can be accomplished by raising the requirements for letter size and retro-reflectivity of direction signs. Research has shown that the US standard for the height of capital letters (the “legibility index” of 50 ft/inch (6,2 metre per 10 mm letter height); also used in e.g. the Netherlands) is insufficient for the visual ability of 30 to 40% of drivers who are 65-74 years old, even under favourable contrast conditions (Transportation Research Board, 1988). Based on research by Olson & Bernstein (1979) and Olson, Sivak & Egan (1983) the ‘Older Driver Highway Design Handbook’ recommends the raising of the legibility standard to one that assumes that a 10-mm tall letter is legible at 4 metres. The time available to act on directional information can be prolonged by multiple use of advance signing on exits and on lane configuration. This is particularly important for older drivers who have an increased perception-reaction time.

## Design elements for acceleration and deceleration lanes

Merging poses high demands on several visual, information processing, and physical abilities; abilities that decline with age. In addition, the act of merging has to be performed under pressure of time, since the end of the acceleration lane restricts the possibility to merge. Older drivers’ difficulties in merging, at worst resulting in a crash, illustrate the extra time needed to merge. Therefore, a vital measure for improving the safety of merging by older drivers is the length of the acceleration lane. In a survey of drivers aged 65 and older, 49% reported that the length of motorway entry lanes was a highway feature that was more important to them now than 10 years previously (Benekahal et al., 1992; Staplin, Lococo & Byington, 1998). No research is available on the minimal length of acceleration lanes necessary to accommodate older drivers, and general guidelines on acceleration lane lengths differ between countries. For example, the Dutch guidelines prescribe longer lane lengths (350 m) than those recommended in the ‘Older

Driver Highway Design Handbook' (based on US guidelines; AASHTO (1984). However, the longer the acceleration lane, the better. In addition, a parallel design should be used for entrance ramps to enable the driver to obtain full view of following traffic (instead of a taper design, which does not have a separate acceleration lane and leads the driver directly onto the traffic lane; Staplin, Lococo & Byington, 1998).

As far as deceleration lanes are concerned, good sight is needed of the following curve. The acquired information gives the driver the opportunity to assess the required vehicle control actions (braking, steering). The visibility of the curve can be improved by post-mounted delineators and chevrons (Staplin, Lococo & Byington, 1998).

### Fixed lighting at interchanges

Lighting is more important for older adults than for the average road user (see Section 5.1.3 on Fixed lighting). On motorways fixed lighting should be implemented at exits and entries. The 'Older Driver Highway Design Handbook' recommends complete interchange lighting, but where this is not feasible, a partial interchange lighting system comprised of two high-mast installations per ramp is recommended, with one fixture located on the inner ramp curve near the gore, and one fixture located on the outer curve of the ramp, midway through the controlling curvature (Staplin, Lococo & Byington, 1998). In the case of a partial interchange lighting system, Dutch design guidelines recommend additionally illuminating a part of the carriageway (AVV, 1993).

For evidence on the need of motorway lighting by older drivers, Staplin et al. (2001) refer to the results of a survey by Knoblauch, Nitzburg and Seifert (1997): 70% of the older drivers in the ages of 50 to 97 indicated that more lighting is needed on motorways, especially on interchanges, construction zones and toll plazas.

### Design elements to prevent wrong-way manoeuvres

The most important cause of wrong-way driving among older drivers is using the exit as an entry. Measures to address this problem mainly focus on making the entry more conspicuous. Compliance with the existing specifications for the signing and visibility of entries, and maintenance of markings are amongst the most important measures to be taken to prevent wrong-way driving. The location of warning signs is also important. For example, the "Do not enter/go back" signs used in the Netherlands to warn drivers against entering an exit (see Figure 8), which are located in the median between the exit and entry on half cloverleaf junctions, are often also visible when driving into the entry. As a result, drivers are used to seeing them and learn to ignore them which can reduce the effectiveness of signs and even lead to their having an adverse effect. For this reason, it is recommended that the signs should be placed or shielded in such a way that they cannot be seen and do not appear to be intended for traffic on the entry.

**Figure 8: "Do not enter/go back" signs used in the Netherlands**



Wrong-way arrow pavement markings near the terminus on all exit ramps, accompanied by red raised-pavement markers facing wrong-way traffic are also recommended. Where adjacent entrance and exit ramps intersect with a crossroad, the use of a median separator is recommended, with the nose of the separator delineated with reflecting paint and extending as close to the crossroad as is practical without obstructing the turning path of vehicles. In addition, it is recommended that the 'obligatory direction of travel' sign is posted on the median separator nose (De Niet & Blokpoel, 2000; Staplin, Lococo & Byington, 1998).

### **Incidence of wrong-way driving**

Crashes following wrong-way driving account for only a very small part ( $\pm 1\%$ ) of the total number of crashes on motorways. This applies to all age-groups, but with considerable differences between the age-groups. Dutch figures show that the percentage of wrong-way drivers among drivers involved in a crash increases above the age of 55, with drivers of 70 years and older having the highest percentage (0,65% compared to an average of 0,06%). Looking at the wrong-way manoeuvres that led to a fatality or a serious injury, one third of the wrong-way drivers was aged 70 years or older (Blokpoel & De Niet, 2000). Staplin et al. (2001) report similar findings in studies by Tamburri & Theobald (1965) and Lew (1971): both studies showed that drivers above the age of 70 experienced the most wrong-way incidents and crashes.

An analysis of the official police reports of crashes in the Netherlands that were caused by wrong-way drivers showed that about half of the wrong-way manoeuvres that led to a crash, started on the exit road (De Niet & Blokpoel, 2000). These wrong-way manoeuvres occurred predominantly during darkness and involved older drivers (age 55 and older). Drivers wanted to enter the entry road to the motorway correctly but turned left onto the exit road too soon. De Niet & Blokpoel (2000) also did some supplementary research to find out to what degree road design could have played a role in wrong-way driving. To this end, they visited locations where drivers started wrong-way manoeuvres. It turned out that these locations could have encouraged turning off prematurely by (1) a conspicuous exit and poor view of the entry, leading the driver to the exit road; (2) worn-out markings and misplaced or missing signs making it difficult to know what is permitted; and/or (3) a curve of the subordinate road onto the exit that is not tight enough to hinder a premature turn-off.

The combination of the earlier mentioned age-related functional limitations of the older adult and several characteristics of the above-mentioned locations make older adults more vulnerable to difficulties when entering the motorway. For example, older drivers need a higher contrast between pavement markings and carriageway to be able to see the markings and still have enough time to act upon them. Furthermore, the decreased ability to discriminate between relevant and irrelevant information and to ignore irrelevant information raise the importance of making the entry more conspicuous than the exit. This not only explains the overrepresentation of older adult drivers among wrong-way drivers, but it also shows that measures to prevent wrong-way driving are particularly important for the safety of older adult drivers.

## **5.2 Advanced Driver Assistance Systems (ADAS)**

Advanced Driver Assistance Systems (ADAS) provide personal assistance in a road environment that does not always take into account the possibilities and limitations of the older driver. An



analysis of the strengths and weaknesses of the older driver has shown that the most important need for support stems from the difficulties that older drivers have to (Davidse, 2007):

- judge whether fellow road users are approaching the same intersection and at what speed;
- notice other road users while merging and changing lanes;
- notice traffic signs and signals;
- react quickly in a complex traffic situation.

These difficulties stem from functional limitations such as a decrease in motion perception, peripheral vision, flexibility of head and neck, selective attention, and speed of processing information and decision making. ADAS can compensate for these limitations and contribute to a reduction of the crash involvement of older drivers if they have one or more of the following functionalities (Davidse, 2006, 2007).

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

Examples of ADAS systems which have these functionalities are collision warning systems aimed at intersections and in-vehicle signing systems (see Section 5.2.1). ADAS can also improve the mobility of the older driver, or reduce injury severity. Examples of those systems are vision enhancement systems, navigation systems and mayday systems (see Section 5.2.2).

Using ADAS to improve the safety or mobility of the driver involves more than making sure that the supported sub-task is carried out safely. It also requires that the support provided does not have any negative effects on the other elements of the driving task. Examples of negative side effects are increased task load due to a bad design of the human machine interface, and the effects of behavioural adaptation (see Section 5.2.4).

## 5.2.1 ADAS for crash avoidance

Several studies have mentioned the potential for ADAS to provide tailored assistance for older drivers (Mitchell & Suen, 1997; Shaheen & Niemeier, 2001; Färber, 2000). ADAS have potential to compensate for limitations in motion perception, peripheral vision, selective attention and decreased speed of processing information and decision-making (Mitchell & Suen, 1997). The ADAS with the most potential for crash avoidance are summarized in Table 5 below.

**Table 5: Desired functionalities for older drivers and ADAS that appear to offer them**

Functionality	ADAS
Draw attention to approaching traffic	<ul style="list-style-type: none"> <li>• Collision warning systems aimed at intersections</li> <li>• Automated lane changing and merging systems</li> </ul>
Signal road users located in the driver's blind spot	<ul style="list-style-type: none"> <li>• Automated lane changing and merging systems</li> <li>• Blind spot and obstacle detection systems</li> </ul>
Assist the driver in directing his attention to relevant information	<ul style="list-style-type: none"> <li>• In-vehicle signing systems</li> <li>• Special intelligent cruise control</li> </ul>
Provide prior knowledge on the next traffic situation	<ul style="list-style-type: none"> <li>• Systems that give information on the characteristics of complex intersections the driver is about to cross</li> </ul>

Source: Davidse, 2007, adapted from Mitchell and Suen (1997)

Many of these systems are still being developed and little research has been done on the effects on driver behaviour. If research on the effects on driver behaviour has been carried out, drivers involved were generally young. As a result, little can be said on whether these systems – when available – will actually be used by older drivers and will produce road safety benefits (Davidse, 2006, 2007). Fortunately, in the past decade the development of ADAS for older drivers receives growing attention from both car industry and research (see for example Davidse et al., 2009; Pereira, Bruyas & Simoes, 2010; Gelau, Sirek & Dahmen-Zimmer, 2011; Dotzauer, Caljouw, De Waard & Brouwer, 2013; Reimer, Mehler & Coughlin, 2016).

### **5.2.2 ADAS for enhanced mobility and lower injury severity**

Systems that could enhance the mobility of older drivers, or that could lower their injury severity, are:

- night-vision enhancement systems,
- navigation systems, and
- mayday systems.

These systems seem to be helpful for drivers who have difficulties driving in the dark or driving in an unfamiliar area, and for those who have subjective feelings of insecurity respectively (Mitchell & Suen, 1997; Fildes & Charlton, 2005). Hence, these systems are particularly suitable to enhance the mobility of older people.

Mayday systems can also reduce the time to medical treatment, thereby reducing injury severity. Usage of the other two systems may also lead to a reduction of the crash rate of older drivers by compensating for impaired night-time visual acuity and by preventing search behaviour respectively. Whether this reduction in crash rate will also lead to a reduction in the number of victims is dependent on the magnitude of the reduction in crash rate. The latter reduction should be larger than the increase in mobility due to system usage (see also Section 3.2 on Behavioural adaptation).

### **5.2.3 User acceptance**

Several studies have shown that older drivers are to a large extent willing to consider using and buying ADAS that meet an existing need, such as reversing aids, and collision warning systems that are aimed at the prevention of crashes on intersections (Oxley & Mitchell, 1995; Viborg, 1999; Bjelkemyr, Dukic, Owens, Falkmer & Lee, 2013). Furthermore, older drivers are also willing to accept systems that (partly) take over vehicle control (like automatic speed or distance adjustment) or that give feedback messages (Viborg, 1999). These results indicate that older drivers will also accept ADAS as a means to improve their safety. Whether the introduction of one of those systems will actually result in a reduction of the number of crashes will also be dependent on the design of that particular system.

### **5.2.4 Pre-conditions for safe use of ADAS by older drivers**

Knowing which types of ADAS have the most potential to improve the safety of older drivers is not enough to actually improve their safety. Besides the fact that the user will have to accept, buy, use and trust the system, the driver should also be able to understand the information the ADAS sends to him (via a display or by 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. The support provided by the system(s) should not have any negative safety consequences. These preconditions can be met by:

- complying with the guidelines for human machine interfaces,
- making sure that ADAS work together, and
- being aware of the effects of behavioural adaptation.

## 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 (Oxley, 1996). There are several reports available which describe the current guidelines (see Green, 2001a for an overview). Caird, Chugh, Wilcox and Dewar (1998) have summarized these guidelines and in addition included a section on guidelines for older drivers. The design guidelines for older drivers are summarized in Table 6, along with the functional limitations of older adults which they take into account.

**Table 6: Functional limitations and relevant design principles**

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
Diminished low-light vision	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 1.500-2.500 Hz range
Depth perception	Where depth perception is important, provide non-physical cues, such as relative size, interposition, linear position and texture gradient
Selective attention	Enhance the conspicuity 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

Source: Davidse, 2007; based on Caird et al. (1998) and Gardner-Bonneau & Gosbee (1997)

Whereas the guidelines in this table have all been selected based on the older adult's functional limitations, it should be kept in mind that designers can also take advantage of the experience that older drivers have. This can be accomplished by using familiar 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).

Older drivers should not only be kept in mind during the design phase, but also afterwards. ADAS should be evaluated using both younger and older drivers. The latter experience considerably

more difficulty in completing telematic 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 do so as well.

## ADAS should work together

When car owners install or manufacturers equip more than one ADAS in a vehicle, the presence of several displays may introduce new problems. Each display will attract the attention of the driver. Older drivers will suffer the most since age differences become more evident as tasks are becoming more complex. This will result in longer reaction times (see for example McDowd & Craik, 1988). Messages sent simultaneously from different ADAS will increase the pressure on the driver even further. In effect, the presence of several, independently functioning systems increases the task load which is the opposite aim of ADAS in lowering the task load.

Co-ordination between the installed ADAS may overcome these difficulties (ETSC, 1999). In addition, it can also prevent systems from sending conflicting instructions or, even worse, carrying out conflicting actions. The coordination between systems can be implemented in several ways. Heijer et al. (2001) suggested that one ADAS should be able to support the driver in a set of problematic situations instead of separate ADAS each supporting 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 (Vonk, Van Arem & Hoedemaeker, 2002; Färber & Färber, 2003; Piechulla, 2003; Wheatley & Hurwitz, 2001).

## Behavioural adaptation

The phenomenon of behavioural adaptation implies that people in many cases adapt behaviour to some of the improvements of a system by taking more chances (see Dragutinovic, Brookhuis, Hagenzieker & 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 as risk compensation and risk homeostasis (Wilde 1982). A form of behavioural adaptation that could arise among older drivers, is the withdrawal of compensatory 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 (Hakamies-Blomqvist, 1994a; Aizenberg & McKenzie, 1997; Zhang et al., 1998; McGwin & Brown, 1999). When the large-scale introduction of night vision enhancement systems makes older adults drive at night again, this will increase their mobility and improve their quality of life. However, it remains to be seen whether the use of night vision enhancement systems will provide similar risk compensation for impaired night-time visual acuity to the older driver's compensation strategy of not driving at night (Caird et al., 1998; Smiley, 2000).

## **5.3 Vehicle design and vehicle safety**

Measures which relate to the vehicle are aimed at improving the physical access to the car, at making it easier to operate the vehicle, or at improving the safety of the occupants. The first two types of measure primarily relate to vehicle design, the latter to vehicle safety.

## 5.3.1 Vehicle design

Age-related muscular-skeletal impairments such as osteoarthritis, rheumatoid arthritis and decreasing strength may all affect the range of motion of limbs, making it more difficult to enter and exit vehicles and to reach driving controls or handle the steering wheel. To facilitate older people's entry and exit of a car, door frame height, width of door opening, doorsill height and seat height should have the right dimensions (see Table 7).

**Table 7: Recommended car access dimensions**

Car part	Recommended dimension (cm)
Door frame height above ground	133-138
Width of door opening	80-100
Seat height above ground	50-60, 50 optimum
Doorsill height	36-40
Doorsill to car floor	4-9, 6 optimum
Seat front edge	35-45
Door opening angle	70, 90 when assistance needed

Source: Institute of Consumer Ergonomics, 1985; Petzäll, 1991, cited in OECD, 2001

In addition, handles on the doorframe can help during entry and exit of the car. Equipment that can make it easier to operate the vehicle are power steering, automatic transmission, and wide-angle and planar rear-view mirrors to support drivers suffering from impaired field of vision or restricted head movements (OECD, 2001). Finally, Advanced Driver Assistance Systems (ADAS) such as in-vehicle signing systems and night-vision enhancement systems can also compensate for functional limitations (see Section 5.2).

## 5.3.2 Vehicle safety

Older adults are more vulnerable than younger adults: their injuries will be more severe given an identical collision impact. Given the estimated increase in the number of older drivers into the future, improved crashworthiness of vehicles is very important. However, currently, crash-test dummies and models are based on averagely fit people. Test dummies capable of modelling the effects on an older occupant are needed to be able to take into account older occupants' frailty when testing and improving vehicle safety (OECD, 2001).

In addition, occupant protection can be enhanced by the further development of seat belts and airbags, particularly through force-limiting features. In their current state of development, seat belts are beneficial to older occupants. However, in some circumstances, they may also contribute to the incidence of injuries. Recent developments suggest that this drawback is well on its way to being resolved, by the use of a 'force limiting feature', which controls the maximum restraining force exerted by the shoulder belt. Other technological advances that are likely to be especially relevant for the protection of older occupants include (Pike, 1989; cited in OECD, 2001):

- Intelligent restraint systems, capable of adjusting for lighter, older occupants;
- Dual-stage airbags to minimise aggressive airbag contacts in moderate crashes;
- Active head restraints to minimise soft tissue injury and whiplash injuries to the neck;

- Side airbags to protect the head and chest in side collisions, such as crashes when turning left in which older drivers are overrepresented.

## 5.4 Education/training

Formal education and training are important ways to inform older drivers of the physical and cognitive changes experienced as part of the ageing process, on the implications of ceasing to drive and on the choice of safer vehicles. In addition, other people with a particular interest in the safety and mobility of older people, such as doctors, family, vehicle manufacturers, highway engineers, but also other drivers who share the road with older drivers should be informed of the difficulties experienced by older drivers in traffic. The latter could even involve this topic being included in the curriculum for obtaining a driver's licence. The next two sections focus on educational programmes and training programmes for the older driver:

### 5.4.1 Informing the older driver

Older drivers need information on the physical and cognitive changes that accompany ageing, and on the implications of ceasing to drive. In particular, it is important to inform older drivers of:

- The potential for declining sensory and cognitive abilities, difficulties that may arise in traffic as a result of these declining abilities, and how to modify driving strategies to avoid these difficulties. Recognition by the individual driver is the essential first step in effective remedial action. At the same time, information must be available to provide reassurance that with care and planning, drivers can continue to drive safely well into old age.
  - Vehicle equipment and ADAS which are available to make driving easier.
  - Increased vulnerability, and the importance of using protection devices.
  - Influence of age-related illnesses and prescribed medication on driving abilities.
  - Information about the procedure to be followed to extend the driving licence.
  - Possible decision to no longer drive a car: making this debatable, and discussing the roles that relatives and family doctor can play.
  - How and where to seek and access mobility alternatives to the car.
- (Maycock, 1997; OECD, 2001).

The above information can be disseminated in special meetings organized by traffic safety organizations or by senior citizens' leagues, or it can be published in leaflets to be distributed in buildings frequented by older people. One specific occasion for distributing leaflets would be the medical examination that is required in many European countries to renew the driving licence. Examples of leaflets are:

- Drive on! Advice for older drivers, a leaflet by the Department for Transport of the UK.
- Seniors in traffic, a brochure in Dutch and French by the Belgian Institute for Road Safety.
- Driving for all ages, a brochure by the Finnish National Transport Authority.

A useful discussion on how the public and private sectors can influence older drivers' self-regulation was published by the British Royal Automobile Club Foundation (Berry, 2011).

### 5.4.2 Training the older driver

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. In addition,

attention can be paid to difficult traffic situations in the neighbourhood and new traffic rules. The programme can be supplemented with a practical training module or assessment drive. Examples of training programmes are the German programme called ‘Ältere aktive Kraftfahrer’ and the BROEM-drives that are organised in the Netherlands (see Box). Some other examples can be found in the list of “good practices” to manage older people’s safe mobility that were identified by the European CONSOL project (Marin-Lamellet et al., 2013; Marin-Lamellet & Hausteijn, 2014): the Norwegian Bilfører 65+ (Ulleberg et al., 2012) and the Swiss “Älter – Aber Sicher! Wissenwertes für Senioren am Steuer” (Lang et al., 2013).

### Examples of training programmes

The German programme ‘**Ältere aktive Kraftfahrer**’ consists of four successive seminars that are run in the style of a workshop. Participants are encouraged to examine their own behaviour and driving habits behind the wheel, by discussion and the sharing of experiences. The courses offer older drivers the opportunity of keeping up to date with the latest driving regulations and of resolving individual problems which may have arisen from their own driving experiences.

The Dutch **BROEM** is a voluntary assessment drive for drivers over 50 years of age; it is not a driving test. The BROEM drive includes assessment of driving style, eyesight and response times, and provides a refresher course on traffic rules. The drive is supplemented by a reference book which includes information on the effects of age on driving and gives helpful advice to older drivers. After the drive, the participant is given a report indicating his strengths and weaknesses, with suggestions for improvement.

## 5.5 Assessing fitness to drive

The assessment of an older person’s fitness to drive can take place both as part of renewal of the driving licence at a specified age and when a health problem has been identified.

### 5.5.1 Licensing procedures for older drivers

Practice in European countries on the licensing of older drivers varies. Some countries require renewal of the driving licence at a certain age, whereas others do not. Those countries that do, often require some sort of medical examination (See Box on licensing procedures). Increasingly, researchers recognise that age-based mandatory assessment programmes targeting older drivers are unlikely to produce safety benefits and may have counter-productive results. One of the few evaluations of existing driver testing programmes compared Finnish and Swedish licensing practices (Hakamies-Blomqvist et al., 1996). Finland requires regular medical check-ups in conjunction with licence renewal starting at age 70, whereas Sweden has no such age-related control. A comparison of Finland and Sweden showed no apparent reduction in crashes as a result of the Finnish programme. However, Finland had a higher rate of fatalities among unprotected older road users than Sweden, arguably the result of an increase in the number of older pedestrians who had lost their driving licence. An Australian study reached a similar conclusion. Although the state of Victoria has no age-related licensing controls, its crash statistics for older drivers are no worse than those of other states with established testing programmes (Torpey, 1986).

Given the variation in older-driver licensing programmes in European countries, it is understandable that evidence relating to the effectiveness of age-related controls is inconclusive. However, one outcome is clear: many drivers (especially women) voluntarily stop

driving rather than undergo a medical examination or a driving test (Levy, 1995; Hakamies-Blomqvist & Wahlstrom, 1998). Some give up their licences for health reasons or owing to difficulties in driving, although it remains to be established whether these factors are severe enough to warrant cessation of driving (OECD, 2001).

## Licensing procedures in selected European countries

Practice in European countries governing the licensing of older drivers varies. The results of an OECD survey show some of the differences in medical requirements for licence renewal. In addition to the medical requirements for renewal of the driving licence, some countries also require older drivers to pass driving tests.

Country	Renewal procedure	Renewal interval	Medical requirements for renewal
Austria	No	No renewal required	None
Belgium	No	No renewal required	None
Bulgaria	No	No renewal required	None
Cyprus	Yes	First assessment at age 70	Yes
Czech republic	Yes	First assessment at age 60, and then at age 65, 68 and at ages 70+ every 2 years	Examination by general practitioner
Denmark	Yes	At age 70, issued for four years At age 71, issued for three years At ages 72-79, issued for two years At ages 80+, issued for one year If ill, shorter terms possible.	Doctor's certificate required
Estonia	Yes	Ten-year renewal up to age 65 Five-year renewal after age 65	Examination by general practitioner
Finland	Yes	At age 45, renewal every fifteen years (administrative renewal) As of age 70, every five years (with medical check)	GP examination. Doctor's certificate required
France	No	No renewal required	None
Germany	No	Renewal not determined by age	None
Greece	Yes	First assessment at age 65, and then every three years.	Assessment by two physicians: 1) a pathologist, cardiologist or pneumologist 2) an ophthalmologist
Hungary	Yes	Ten-year renewal up to age 40 Five-year renewal at ages 40-59 Three-year renewal at ages 60-69 Two-year renewal at ages 70+	Examination by general practitioner
Ireland	Yes	One-, three- or ten-year renewal up to age 60 (optional). Three-year renewal up to age 70 First assessment at age 70, then every 1 to 3 years depending on medical situation.	At 70, a certificate of medical fitness is required Assessment by a doctor, usually a general practitioner



# Older Drivers

Italy	Yes	Ten-year renewal up to age 50 First assessment at age 50 Five-year renewal after age 50 Three-year renewal after age 70	Examination by general practitioner
Latvia	Yes	Ten-year renewal up to age 60 Three-year renewal after age 60	Examination by general practitioner
Lithuania	Yes	Ten-year renewal up to age 55 Five-year renewal after age 60 Two-year renewal after age 70 One-year renewal after age 80	Examination by general practitioner (if necessary psychiatrist)
Luxemburg	Yes	First assessment at age 60 Next assessment at age 70 Three-year renewal up to age 80 One-year renewal after age 80	Examination by general practitioner
Malta	Yes	First assessment at age 70, then every five years.	Not specified
Netherlands	Yes	First assessment at age 75 (between 74 and 79 depending on the exact age at which the driver got the first driver licence). Five-year renewal (or every 1 to 3 years depending on medical situation)	Assessment by general practitioner (not family doctor). Standard set of medical tests.
Poland	No	No renewal required	None
Portugal	Yes	At age 50, 60, 65, 70, and after age 70 every two years	Examination by general practitioner (psychological assessment optional).
Romania	Yes	Every ten years	Psychological and medical examination. Assessment in private or state clinics.
Slovakia	Yes	First assessment at age 65 Two-year renewal	Psychological and medical examination.
Slovenia	Yes	First assessment at age 70 Ten-year renewal	Medical certificate on physical and mental fitness to drive.
Spain	Yes	At obtainment of each new licence, or when one expires, with different periods depending on age/ health status. Ten-year renewal up to age 65 Five-year renewal after age 65	Psychological and medical examination.
Sweden	Yes	Every ten years (administrative renewal)	No medical requirements

United Kingdom	Yes	From age 70, mandatory renewal for three-year periods	Confirmation required at age 70 that no medical disability is present, thereafter every three years drivers must satisfactorily complete a self-certification checklist on medical conditions to renew their licence. Drivers reporting a disability or medical conditions may be required to undergo a fitness to drive assessment in a mobility centre.
----------------	-----	---	---

Source: OECD, 2001; Siren et al., 2013

### 5.5.2 Consultation of doctors

When a health problem has been identified, the question of whether to continue driving depends not on a medical diagnosis, but on the functional consequences of the illness. Moreover, a given condition may affect an individual's fitness to drive in different ways and to varying degrees (OECD, 2001; Holland, Handley & Feetam, 2003).

Although medical assessment seldom provides sufficient grounds for an absolute assessment of driving ability, it does play a role when there are genuine reasons to question older drivers' functional capabilities. Physicians, especially those working in primary care, represent an important first contact and information source and are in a position to make judgements and give advice to the patient about fitness to drive. In addition to assessing specific conditions and disabilities, physicians also need to advise on the effects of any prescribed drugs on driving (OECD, 2001).

## 6 Safety versus mobility and quality of life

A licensing procedure that results in people losing their driving licence when they can still drive a car safely is undesirable for a variety of reasons. Firstly, the fatality rate for older cyclists and pedestrians is many times greater than for older drivers. Consequently, they are safer in a car. In addition, older people will often have already stopped cycling, partly because of loss of balance. Saying farewell to their car often is also a farewell to part of their social lives. This can have negative consequences for the well-being of the individual, but also for society as a whole (e.g. the extra costs of door-to-door community transport). At the same time older people who still drive do not pose a disproportional danger to other road users. They are more often severely injured themselves (killed or hospitalized) in a collision with a younger motorist than that they, as a motorist, cause severe injury to a younger road user (OECD, 2001; SWOV, 2012).

When safe mobility as a car driver is indeed no longer possible, alternative means of transport should be made available to ensure the mobility of older people. Many countries do this. Examples of alternative means of transport are: conventional public transport services, bus service routes, taxis, and dial-a-ride service 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.

## 6.1 The importance of the private car

Driving a car is important for people in general because it provides status and the opportunity for personal control and independence (Ellaway et al., 2003; Steg, 2003). In sparsely populated areas, owning a car is even more important, since it provides the only opportunity for travelling long distances due to a lack of public transport. For older people, having 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 (Rabbitt, Carmichael, Jones & Holland, 1996; Jansen et al., 2001). The same drivers expressed anxiety about the poor quality of public transport services. This anxiety seemed to be based on reality because 50% of those respondents who already had given up driving felt public transport to be, at least in some measure, inadequate (Rabbitt, Carmichael, Jones & Holland, 1996).

Before older people stop driving, they usually reduce how much they drive and limit their driving to local journeys in familiar areas and under easy driving conditions. The better the provision of alternative means of mobility, the more likely a driver is to start using them for journeys, long before ceasing to drive. This makes it easier to remain mobile after ceasing to drive. The lack of attractive and feasible transport alternatives to the private automobile, coupled with land-use patterns that make walking difficult or impossible, contributes to the problems experienced by people who have to stop driving, notably in North America.

However, similar problems occur in Europe for older people living in suburbs and rural locations, as they increasingly do. In Great Britain, older drivers appear to be more likely to stop driving if they live in urban areas where walking, buses and taxis offer realistic mobility alternatives (OECD, 2001). The ability to go everywhere and do everything without a car is also mentioned in surveys on reasons for driving less. However, the most important factors for ceasing to drive seem to be safety, health, and finance (Rabbitt, Carmichael, Jones & Holland, 1996; Jansen et al., 2001). Men more often give up driving because of bad health. Women tend to retire from the wheel earlier and for less pressing reasons, such as driving seldom (Hakamies-Blomqvist & Wahlstrom, 1998; Hakamies, Sirén & Davidse, 2003; Jansen et al., 2001).

## 6.2 The effects of giving up driving

Stopping driving is likely to reduce mobility and negatively affect the quality of life. The consequences have been described to be mostly negative (for an overview see Harrison & Ragland, 2003; Hakamies, Sirén & Davidse, 2003). Stopping driving has been found to reduce the number of out-of-home activities (Marottoli et al., 2000) and to be related to increased depression (Fonda, Wallace & Herzog, 2001). It has also been argued that giving up driving has a negative impact on an older person's identity, his feeling of independence, and his 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 has been a large part of their adult life and was closely identified with their perceived roles in family and society. Having ceased driving, most people dislike asking for rides. To keep their dignity, people often insist that they provide some reciprocal service (cooking a meal, babysitting) or gift in return for the ride (Burkhardt, 1999; Carp, 1988).

## 6.3 Alternative means of transport

The availability of means of transport other than the car is one of the most important ways to maintain older people's mobility. Such options allow older people to travel. Viable transport options need to provide opportunities for spontaneous travel and flexibility in modal choice in order to enable older users to reach the desired destinations. Such options need to ensure that the entire travel chain is suitable for older people, taking account of older people's capabilities and limitations and be affordable and accessible (OECD, 2001).

Alternatives to the car are often provided by community transport and para-transit (Dial-a-Ride) services. These can be useful, although a drawback of these services is that they often require advance booking. They rarely permit spontaneous travel of the kind that is possible by car or on foot. Powered wheelchairs, scooters and golf carts constitute another class of mobility alternative that does not require a driving licence. These vehicles allow for spontaneous travel and are being used for journeys of up to about 4 km which are made under favourable weather conditions (OECD, 2001). 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. These services include:

- Conventional public transport services, which are accessible to passengers in wheelchairs, wherever possible.
- Bus service routes using small vehicles that pick up and discharge passengers close to origin and destination. This service is particularly appropriate for areas where demand is low (e.g. in rural areas).
- Conventional taxis, often with user-side subsidies in order to reduce the fare
- Dial-a-Ride service for door-to-door travel for passengers who require assistance and/or who use a wheelchair that cannot be accommodated by a taxi or accessible bus
- Accessible pedestrian infrastructure to allow access to all transport services and to make journeys wholly on foot or by (powered) wheelchair or mobility scooter.

## References

AASHTO (1984) A policy on geometric design of highways and streets. American Association of State Highway and Transportation Officials, Washington DC.

Adviesdienst Verkeer en Vervoer (1993) Richtlijnen voor het ontwerpen van autosnelwegen (ROA). Hoofdstuk IV: knooppunten en aansluitingen. Directoraat-generaal Rijkswaterstaat, Adviesdienst Verkeer en Vervoer, Rotterdam.

Aizenberg, R. & McKenzie, D.M. (1997) Teen and senior drivers. CAL-DMV-RSS-97-168. California Department of Motor Vehicles CAL-DMV, Sacramento, CA.

Allen, R.W., O'Hanlon, J.F., & McRuer, D.T. (1977) Driver's visibility requirements for roadway delineation, Vol. I: Effects of contrast and configuration on driver performance and behaviour. FHWA-RD-77-165. Federal Highway Administration, Washington DC.

Bell, D., Füssl, E., Ausserer, K., Risser, R., Wunsch, D., Braguti, I., Oberlader, M., Friedwagner, A. (2010) Scenarios of the future mobility of elderly people. Life transition points and their impact on everyday mobility of elderly people; future mobility developments and necessary support measures with special regard to retirement and loss of partner. Final project report, ERA NET TRANSPORT, ENT14 Keep Moving. Austrian Federal Ministry for Transport, Innovation and Technology, Vienna.

Benekohal, R.F., Resende, P., Shim, E., Michaels, R.M. & Weeks, B. (1992) Highway operations problems of elderly drivers in Illinois. FHWA-IL-023. Illinois Department of Transportation, Springfield, Illinois.

Berry, C. (2011) Can older drivers be nudged? How the public and private sectors can influence older drivers' self-regulation. RAC Foundation, London.

Bjelkemyr, A., Dukic, T., Owens, R., Falkmer, T. & Lee, H.C. (2013) Support systems designed for older drivers to achieve safe and comfortable driving. Journal of Transportation Technologies, 3, pp. 233-240.

Blackwell, H.R. & Taylor, J.H. (1969) Survey of laboratory studies of visual detection. NATO seminar on detection, recognition, and identification of line-of-sight targets. Den Haag.

Blokpoel, A. & De Niet, M. (2000) Spookrijders en frontale botsingen op autosnelwegen [Wrong-way drivers and head-on collisions on motorways; number and development of their threat to road safety, in the period up to 1998]. R-2000-16. SWOV, Leidschendam.

Bonnel, W. (1999) Giving up the car: Older women's losses and experiences. Journal of Psychosocial Nursing and mental Health Services, 37, pp. 10-15.

Brouwer, R.F.T., Herland, L. & Van der Horst, A.R.A. (2000) Sustainable safe design of roundabouts. TNO-report TM-00-D002. TNO Human Factors TM, Soesterberg

Brouwer, W.H. & Davidse, R.J. (2002) Oudere verkeersdeelnemers [Elderly drivers]. In: J.J.F. Schroots (Ed.), *Handboek Psychologie van de Volwassen Ontwikkeling & Veroudering*. Van Gorcum, Assen, pp. 505-531.

Brouwer, W.H. & Ponds, R.W.H.M. (1994) Driving competence in older persons. *Disability & Rehabilitation*, 16(3), pp. 149-161.

Brouwer, W.H., Rothengatter, J.A. & Wolffelaar, P.C. van (1988) Compensatory potential in elderly drivers. In: T. Rothengatter & R. de Bruin (red.), *Road User Behaviour: Theory and Research* (p. 296-301). Assen: Van Gorcum.

Burkhardt, J.E. (1999) Mobility changes: Their nature, effects, and meaning for elders who reduce or cease driving. *Transportation Research Record: Journal of the Transportation Research Board*, 1671, pp.11-18.

Burkhardt, J.E., Berger, A.M. & McGavock, A.T. (1996) The mobility consequences of the reduction or cessation of driving by older women. In: *Proceedings of the second national conference on women's travel issues, October 23-26, Baltimore, Maryland*. U.S. Department of Transportation, Washington DC.

Caird, J.K., Chugh, J.S., Wilcox, S. & Dewar, R.E. (1998) A design guideline and evaluation framework to determine the relative safety of in-vehicle intelligent transportation systems for older drivers. TP 13349E. Transport Canada, Transportation Development Centre TDC, Montreal, Quebec.

Carp, F.M. (1988) Significance of mobility for the well-being of the elderly. In: *Transportation in an aging society: improving mobility and safety for older persons*. Volume 2: technical papers. Special Report No. 218. National Research Council NRC, Transportation Research Board TRB / National Academy Press, Washington, DC.

Charlton, J., Koppel, S., Odell, M., Devlin, A., Langford, J., O'Hare, M., Kopinathan, C. Andrea, D., Smith, G., Khodr, B., Edquist, J., Muir, C. & Scully, M. (2010) *Influence of Chronic Illness on Crash Involvement of Motor Vehicle Drivers: 2nd Edition*. Report No. 300. Monash University Accident Research Centre, Melbourne.

Corso, J.F. (1971) Sensory processes and age effects in normal adults. *Journal of Gerontology*, 26, p. 90-105.

CROW (1996) *Aanbevelingen voor verkeersvoorzieningen binnen de bebouwde kom (ASVV)*. CROW-publicatie 110. CROW, Ede.

CROW (1998) *Eenheid in rotondes*. CROW-publicatie 126. CROW, Ede.

CROW (2002) *Fietsoversteken op rotondes; Supplement bij publicatie 126 'Eenheid in rotondes'*. CROW-publicatie 126a. CROW, Ede.

Crowley, K.W. & Seguin, E.L. (1986) *Wrong way traffic control at intersections*. FHWA-RD-86-116. Department of Transportation, Federal Highway Administration, Washington DC.

Davidse, R.J. (2000) Ouderen achter het stuur [Older drivers at the wheel]. D-2000-5. SWOV Institute for Road Safety Research, Leidschendam.

Davidse, R.J. (2006) Older drivers and ADAS - Which systems improve road safety? IATSS Research, 30(1), pp. 6-20.

Davidse, R.J. (2007) Assisting the older driver; Intersection design and in-car devices to improve the safety of the older driver. PhD thesis University of Groningen. SWOV Institute for Road Safety Research, Leidschendam.

Davidse R.J., Hagenzieker, M.P., Van Wolffelaar, P.C. & Brouwer, W.H. (2009) Effects of in-car support on mental workload and driving performance of older drivers. Human Factors, 51(4), pp. 463-476.

Davidse, R.J. & Hoekstra, A.T. (2010) Evaluatie van de BROEM-cursus nieuwe Stijl: Een vragenlijststudie onder oudere automobilisten [Evaluation of the new style BROEM course; A survey among older drivers].R-2010-6. SWOV Institute for Road Safety Research, Leidschendam.

Dotzauer, M., Caljouw, S.R., Waard, D. de, & Brouwer, W.H. (2013) Intersection assistance: A safe solution for older drivers? Accident Analysis and Prevention, 59, pp. 522-528.

Dragutinovic, N., Brookhuis, K.A., Hagenzieker, M.P. & Marchau, V.A.W.J. (2005) Behavioural effects of Advanced Cruise Control use – a meta-analytic approach. European Journal of Transport and Infrastructure Research, 5(4), pp. 267-280.

ECMT (2000) Transport and ageing of the population: report of the hundred and twelfth Round Table on Transport Economics held in Paris, on 19-20 November 1998. European Conference of Ministers of Transport ECMT / CEMT, Economic Research Centre, Paris.

Eisenhandler, S.A. (1990) The asphalt identikit: Old age and the driver's license. International Journal of Aging and Human Development, 30(1), pp. 1-14.

Ellaway, A., Macintyre, S., Hiscock, R. & Kearns, A. (2003) In the driving seat: psychosocial benefits from private motor vehicle transport compared to public transport. Transportation Research Part F: Traffic Psychology and Behaviour 6(3), pp. 217-23.

Elvik, R., Høy, A., Vaa, T. & Sørensen, M. (eds) (2009) The handbook of road safety measures. 2nd edition. Emerald Group, Bingley, United Kingdom.

ETSC (1999) Intelligent Transportation Systems and road safety. European Transport Safety Council ETSC, Brussels

Evans, L. (1991) Traffic safety and the driver. Van Nostrand Reinhard, New York

Evans, L. (2001) Age and fatality risk from similar severity impacts. Journal of Traffic Medicine, 29 (1-2), 10-19

Färber, B. & Färber, B. (2003) Auswirkungen neuer Informationstechnologien auf das Fahrerverhalten. Berichte der Bundesanstalt für Straßenwesen. Mensch und Sicherheit (Heft M149).

Färber, B. (2000) Neue Fahrzeugtechnologien zur Unterstützung der Mobilität Älterer. Zeitschrift für Gerontologie und Geriatrie 33, p. 178-185.

Fildes, B. & Charlton, J. (2005) Older drivers and possibilities for injury avoidance. Berichte der Bundesanstalt fuer Strassenwesen. Unterreihe Fahrzeugtechnik (55), pp. 225-34

Flade, A., Limbourg, M. & Schlag, B. (Eds.) (2001) Mobilität älterer Menschen. Leske + Budrich, Opladen.

Fonda, S. J., Wallace, R.B. & Herzog, A.R. (2001) Changes in driving patterns and worsening depressive symptoms among older adults. Journals of Gerontology Series B: Psychological Sciences and Social Sciences 56(6), pp. S343-S351.

Fontaine, H. (2003) Âge des conucteurs de voiture et accidents de la route – Quel risque pour les seniors? [Driver age and road traffic accidents – What is the risk for seniors?] Recherche Transports Sécurité, 79, pp. 107-120.

Gardner-Bonneau, D. & Gosbee, J. (1997) Health care and rehabilitation. In: Fisk, A.D. and Rogers, W.A. (Eds.), Handbook of human factors and the older adult. Academic Press Inc., San Diego, pp.231-255.

Gelau, Ch., Sirek, J. & Dahmen-Zimmer, K. (2011) Effects of time pressure on left-turn decisions of elderly drivers in a fixed-base drining simulator. Transportation Research Part F, 14, pp. 76-86.

GOAL Transport needs for an ageing society (2013) Action plan. Collaborative Project FP7- TPT-2011-RTD-1. Retrieved from [www.GOAL-project.eu](http://www.GOAL-project.eu)

Green, P. (2001a) Variations in task performance between younger and older drivers: UMTRI research on telematics. Paper presented at the Association for the Advancement of Automotive Medicine Conference on Aging and Driving, February 19-20, 2001, Southfield, Michigan, Southfield, Michigan.

Green, P. (2001b) Synopsis of driver interface standards and guidelines for telematics as of mid-2001. Technical Report UMTRI-2001-23. University of Michigan Transportation Research Institute, Ann Arbor, MI.

Groot, H.A.M. (ed.) (1999) Impaired vision and accident risks. Commission Internationale des Examens de Conduite Automobile CIECA, Brussels.

Hakamies-Blomqvist, L. & Wahlstrom, B. (1998) Why do older drivers give up driving? Accident Analysis and Prevention, 30(3), pp. 305-312.



Hakamies-Blomqvist, L. (1993) Fatal accidents of older drivers. *Accident Analysis and Prevention*, 25(1), pp. 19-27.

Hakamies-Blomqvist, L. (1994a) Compensation in older drivers as reflected in their fatal accidents. *Accident Analysis and Prevention*, 26(1), pp. 107-112.

Hakamies-Blomqvist, L. (1994b) Accident characteristics of older drivers: Can findings based on fatal accidents be generalized? *Journal of Traffic Medicine*, 22(1), pp. 19-25.

Hakamies-Blomqvist, L. (2003) Ageing Europe: the challenges and opportunities for transport safety: the fifth European Transport Safety Lecture, Brussels, 22nd January 2003. European Transport Safety Council ETSC, Brussels.

Hakamies-Blomqvist, L., Johansson, K. & Lundberg, C. (1996) Medical screening of older drivers as a traffic safety measure: a comparative Finnish-Swedish evaluation study. *Journal of the American Geriatrics Society*, 44(6), pp. 650-653.

Hakamies-Blomqvist, L., Raitanen, T. & O'Neill, D. (2002) Driver ageing does not cause higher accident rates per km. *Transportation Research Part F: Traffic Psychology and Behaviour*, 5(4), pp.271-274.

Hakamies-Blomqvist, L., Sirén, A. & Davidse, R.J. (2004) Older drivers – a review. VTI report 497A. Swedish National Road and Transport Research Institute VTI, Linköping.

Harris, M.I., Hadden, W.C., Knowler, W.C. & Bennett, P.H. (1987) Prevalence of diabetes and impaired glucose tolerance and plasma glucose levels in the U.S. population aged 20-74 yr. *Diabetes*, 36, pp. 523-534.

Harrison, A. & Ragland, D.R. (2003) Consequences of driving reduction or cessation for older adults. *Transportation Research Record* (1843), p. 96-104.

Heijer, T. et al. (2001) Action for Advanced Drivers Assistance and Vehicle Control System Implementation, Standardisation, Optimum Use of the Road Network and Safety. ADVISORS Deliverable D1/2.1 v1: Problem identification, user needs and inventory of ADAS (Advanced Driver Assistance Systems): Final report. Contract No. DGTREN GRD1 2000-10047. Commission of the European Communities, Directorate-General for Energy and Transport, Brussels.

Henrikson, P., Levin, L., Tania Willstrand, T. & Peters, B. (2014) Challenging situations, self-reported driving habits and capacity among older drivers (70+) in Sweden. VTI notat 9A-2014. VTI, Linköping.

Holland, C., Handley, S. & Feetam, C. (2003) Older drivers, illness and medication. Road Safety Research Report No. 39. Department for Transport, London.

Holland, C.A. (2001) Older drivers: a review. Road safety research report No. 25. Department for Transport, Local Government and the Regions (DTLR), London.

Holte, H. & Albrecht, M. (2004) Verkehrsteilnahme und -erleben im Strassenverkehr bei Krankheit und Medikamenteneinnahme. Berichte der Bundesanstalt für Strassenwesen, Mensch und Sicherheit, Heft M 162. Wirtschaftsverlag NW, Bremerhaven.

Holte, H. (2005) Sind Alter und Krankheit ein Sicherheitsproblem? Vortrag auf dem Internationalen Symposium „65plus mit Auto mobil? Mobilitätsprobleme von SeniorInnen und verkehrspsychologische Lösungsansätze“ in Salzburg, 28./29. April.

Janke, M.K. (1991) Accidents, mileage and the exaggeration of risk. Accident Analysis and Prevention, 23(2/3), pp. 183-188.

Jansen, E., Holte, H., Jung, C., Kahmann, V., Moritz, K., Rietz, C., Rudinger, G. & Weidemann, C. (2001) Ältere Menschen im künftigen Sicherheitssystem Strasse/Fahrzeug/Mensch. Berichte der Bundesanstalt für Strassenwesen, Mensch und Sicherheit, Heft M134. Wirtschaftsverlag NW, Bremerhaven

Kasznik, A.W. (1986) Parkinson's Disease. In: Maddox, G. (Ed.), The Encyclopedia of Aging. Springer, New York.

Klein, R. (1991) Age-related eye disease, visual impairment, and driving in the elderly. In: Human Factors, 33(5), pp. 521-525.

Kline, D.W. & Scialfa, C.T. (1997) Sensory and perceptual functioning: Basic research and human factors implications. In: A.D. Fisk, & W.A. Rogers (Eds.), Handbook of human factors and the older adult (p. 27-54). Academic Press, San Diego.

Kuhlman, K.A. (1993) Cervical range of motion in the elderly. Archives of Physical Medicine and Rehabilitation (74)10, p. 1071-1079.

Lang, B., Parkes, A. & Fernandez Medina, K. (2013) Driving choices for the older motorist; The role of self-assessment tools. RAC Foundation, London.

Langford, J., Methorst, R. & Hakamies-Blomqvist, L. (2006) Older drivers do not have a high crash risk – A replication of low mileage bias. Accident Analysis and Prevention, 28(3), pp. 574-578.

Lanzieri, G. (2011) The greying of the baby boomers; A century-long view of ageing in European populations. Eurostat Statistics in focus. European Union, Brussels.

Lerner, N.D. & Ratté, D.J. (1991) Problems in freeway use as seen by older drivers. Transportation Research Record 1325.

Levy, D.T. (1995) The relationship of age and state licence renewal policies to driving licensure rates. Accident Analysis and Prevention, 27(4), pp. 461-467

Lundberg, C. et al. (1997) Dementia and driving: an attempt at consensus. Alzheimer Disease and Associated Disorders, 11(1), pp. 28-37.

Mackay, M. (1988) Crash protection for older persons. In: Transportation in an aging society: improving mobility and safety for older persons. Volume 2: technical papers. Special Report 218.

Transportation Research Board TRB National Research Council NRC/National Academy Press Washington, DC.

Malfetti, J.L. & Winter, D.J. (1987) Safe and unsafe performance of older drivers: A descriptive study. American Automobile Association, Foundation for Traffic Safety, Falls Church, VA.

Marin-Lamellet, C., Haustein, S., Pokriefke, E., Monterde i Bort, H. & Strnadova, Z. (2013) Case analyses of practices aimed at managing the safety of senior road users. CONSOL Work package 5.2 Report. Retrieved from [www.consolproject.eu](http://www.consolproject.eu)

Marin-Lamellet, C. & Haustein, S. (2014) Managing the safe mobility of older road users: How to cope with their diversity? *Journal of Transport & Health*, 2(1), pp. 22-31.

Marottoli, R.A., Mendes de Leon, C.F., Glass, T.A., Williams, C.S., Cooney Jr., L.M. & Berkman, L.F. (2000) Consequences of driving cessation: decreased out-of-home activity levels. *Journals of Gerontology Series B - Psychological Sciences and Social Sciences* 55(6), pp. S334-S340.

Marottoli, R.A., Mendes de Leon, C.F., Glass, T.A., Williams, C.S., Cooney Jr., L.M., Berkman, L.F. & Tinetti, M.E. (1997) Driving cessation and increased depressive symptoms: prospective evidence from the New Haven Established Populations for Epidemiologic Studies of the Elderly EPESE. *Journal of American Geriatric Society* 45(2), pp. 202-206

Maycock, G. (1997) The safety of older car drivers in the European Union. European Road Safety Federation ERSF/ AA Foundation for Road Safety Research, Brussels/Basingstoke

Maycock, G. (2001) Forecasting older driver accidents and casualties. Road Safety Research Report No. 23. Department of the Environment, Transport and the Regions DETR, London.

McDowd, J.M. & Craik, F.I.M. (1988) Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance*, 14(2), pp.267-280.

McGwin Jr., G. & Brown, D.B. (1999) Characteristics of traffic crashes among young, middle-aged, and older drivers. *Accident Analysis and Prevention*, 31(3), pp.181-198.

Mesken, J. (2002) Kennisleemten en -behoeften van oudere verkeersdeelnemers in Drenthe; Verslag van een vragenlijstonderzoek [Knowledge gaps and needs among elderly road users in Drenthe; A questionnaire study]. R-2002-18. SWOV, Leidschendam.

Michon, J.A. (1971) *Psychonomie onderweg*. Wolters-Noordhoff, Groningen.

Michon, J.A. (1985) A critical view of driver behavior models: What do we know, what should we do? In: Evans, L. & Schwing R.C., (Eds.). *Human behavior and traffic safety*. New York: Plenum Press, pp. 485-524.

Millonig, A. et al. (2013) Profiles of older people. Growing Older, staying mobile: Transport needs for an ageing society GOAL Deliverable 2.1: Final report. Collaborative Project FP7- TPT-2011-RTD-1. Retrieved from [www.GOAL-project.eu](http://www.GOAL-project.eu)

Mitchell, C. G. B. & Suen, S. L. (1997) ITS impact on elderly drivers. In: Proceedings of the 13th International Road Federation IRF World Meeting, Toronto, Ontario, Canada, June 16 to 20, 1997, Toronto.

Mitchell, C.G.B. (2000) Some implications for road safety of an ageing population. Transport trends. Department of the Environment, Transport and the Regions, the Stationary Office, London, pp. 26-34.

Mollenkopf, H., Marcellini, Ruoppila, I. & Tacken, M. (2004) Ageing and outdoor mobility; A European study. IOS Press, Amsterdam.

Niet, M. de & Blokpoel, A. (2000) Tegen de stroom in: Beschrijvend onderzoek naar spookrijden op autosnelwegen; Achtergronden, oorzaken, aansprakelijkheden en maatregelen [Heading in the wrong direction; Descriptive research on wrong-way driving on Dutch motorways: background, causes, liability and measure]. D-2000-6. SWOV, Leidschendam.

OECD (2001) Ageing and transport; Mobility needs and safety issues. Organisation for Economic Co-operation and Development OECD, Paris.

OECD (2004) New transport technology for older people; Summary and Conclusions of the Symposium on Human Factors of Transport Technology for Older Persons, held on 23-24 September 2003, Cambridge, Massachusetts. Organisation for Economic Co-operation and Development OECD, Paris.

Olson, P.L. & Bernstein, A. (1979) The nighttime legibility of highway signs as a function of their luminance characteristics. Human Factors 21, p. 145- 160

Olson, P.L. & Sivak, M. (1986) Perception-response time to unexpected roadway hazards. Human Factors 28 (1), p. 96-99.

Olson, P.L. (1993) Vision and perception. In: B. Peacock & W. Karwowski (Eds.). Automotive ergonomics (p. 161-183). Taylor & Francis, London.

Olson, P.L., Sivak, M & Egan, J.C. (1983) Variables influencing the nighttime legibility of highway signs. UMTRI-83-36. University of Michigan Transportation Institute, Ann Arbor.

Oxley, P. R. & Mitchell, C. G. B. (1995) Final report on elderly and disabled drivers information telematics. Dedicated Road Infrastructure for Vehicle Safety in Europe DRIVE II Project V2031 Elderly and Disabled Drivers Information Telematics EDDIT, Deliverable type P. R & D Programme Telematics System in the Area of Transport (DRIVE II), Commission of The European Communities CEC, Directorate General XIII Telecommunications, Information Industries and Innovation, Brussels.

Oxley, P.R. (1996) Elderly drivers and safety when using IT systems. IATSS Research 20(1), pp. 102-110.

- Peel, N., Westermoreland, J. & Steinberg, M. (2002) Transport safety for older people: A study of their experiences, perceptions and management needs. *Injury Control and Safety Promotion*, 9, pp. 19-24.
- Pereira, M., Bruyas, M.-P. & Simoes, A. (2010) Are elderly drivers more at risk when interacting with more than one in-vehicle system simultaneously? *Le Travail Humain*, 73(1), pp.53-73.
- Piechulla, W., Mayser, C., Gehrke, H. & König, W. (2003) Reducing drivers' mental workload by means of an adaptive man-machine interface. *Transportation Research Part F: Traffic Psychology and Behaviour*, 6(4), pp. 233-248.
- Quimby, A.R. & Watts, G.R. (1981) Human factors and driving performance. Transport Research Laboratory Report LR 1004. TRL, Crowthorne, Berkshire, England.
- Rabbitt, P., Carmichael, A., Jones, S. & Holland, C. (1996) When and why older drivers give up driving. AA Foundation for Road Safety Research, Basingstoke, Hampshire.
- Regan, M., Oxley, J., Godley, S. & Tingvall, C. (2001) Intelligent Transport Systems: Safety and Human Factors issues. Report No. 01/01. Royal Automobile Club of Victoria (RACV) Ltd., Noble Park, Victoria.
- Regeling verkeerslichten. (1997) *Staatscourant* no. 245, p. 14-15.
- Reimer, B., Mehler, B. & Coughlin, J.F. (2016) Reductions in self-reported stress and anticipatory heart rate with the use of a semi-automated parallel parking system. *Applied Ergonomics*, 52, pp. 120-127.
- Rosenbloom, S. (2000) ECMT Report on transport ageing of the population. Note on policy issues. CEMT/CS/TPH (2000)5.
- Schaie, K.W. & Pietrucha, M. (Eds.) (2000) Mobility and transportation in the elderly. *Societal Impact on Aging Series*. Springer Publishing Company, New York.
- Shaheen, S.A. & Niemeier, D.A. (2001) Integrating vehicle design and human factors: minimizing elderly driving constraints. *Transportation Research Part C: Emerging Technologies* 9(3), p. 155-174.
- Shinar, D. & Schieber, F. (1991) Visual requirements for safety and mobility of older drivers. *Human Factors* 33(5), pp. 507-519.
- Simms, B. (1992) Driving after a stroke. TRL Contractor Report 276.
- Siren, A. & Haustein, S. (2013) Baby boomers' mobility patterns and preferences; What are the implications for future transport? *Transport policy*, 29, pp. 136-144.
- Siren, A. et al., (2013) Driver licensing legislation. CONSOL Work package 5.1 Report. Retrieved from [www.consolproject.eu](http://www.consolproject.eu).

Sivak, M., Campbell, K.L., Schneider, L.W., Sprague, J.K., Streff, F.M. & Waller, P.F. (1995) The safety and mobility of older drivers: what we know and promising research issues. *UMTRI Research Review* 26(1), p. 1-21.

Smiley, A. (2000) Behavioral adaptation, safety, and Intelligent Transportation Systems. *Transportation Research Record*, 1724, pp.47-51.

Staplin, L. & Lyles, R.W. (1991) Age differences in motion perception and specific traffic maneuver problems. *Transportation Research Record*, 1325.

Staplin, L., Harkey, D., Lococo, K., & Tarawneh, M. (1997) Intersection geometric design and operational guidelines for older drivers and pedestrians. Volume I: Final report. FHWA-RD-96-132. Federal Highway Administration, Washington, DC.

Staplin, L., Lococo, K. & Byington, S. (1998) Older Driver Highway Design Handbook. FHWA-RD-97-135. Department of Transportation, Federal Highway Administration, Washington, DC.

Staplin, L., Lococo, K. & Sim, J. (1990) Traffic control design elements for accommodating drivers with diminished capacity. FHWA-RD-90-055. Federal Highway Administration, Washington DC.

Staplin, L., Lococo, K. H., Stewart, J. & Decina, L.E. (1999) Safe mobility for older people notebook. DOT HS 808 853. National Highway Traffic Safety Administration NHTSA, US Department of Transportation, Washington.

Staplin, L., Lococo, K., Byington, S. & Harkey, D.L. (2001) Highway design handbook for older drivers and pedestrians. FHWA-RD-01-103. U.S. Department of Transportation DOT, Federal Highway Administration FHWA, Turner-Fairbank Highway Research Center Research and Development RD, McLean, VA.

Steg, L. (2003) Can public transport compete with the private car? *IATSS Research* 27(2), pp. 27-35.

SWOV (2012) The elderly in traffic. SWOV Fact sheet. SWOV Institute for Road Safety Research, Leidschendam.

Tacken, M. & Lamoën, E. van (2005) Transport behaviour and realised journeys and trips. In: Mollenkopf, H., Marcellini, F., Ruoppila, I., Széman, Z., & Tacken, M. (Eds.), *Enhancing mobility in later life: personal coping, environmental resources and technical support: the out-of-home mobility of older adults in urban and rural regions of five European countries*. Assistive Technology Research Series, Volume 17, IOS Press, Amsterdam.

Taaka, G.T. (1991) Distribution of driver spare glance durations. *Transportation Research Record* 1318.

Torpey, S.E. (1986) Licence re-testing of older drivers. Road Traffic Authority. Hawthorn, Melbourne.

Transportation Research Board (1988) Transportation in an aging society. Special Report 218, Volume 1 & 2. Transportation Research Board, Washington DC.

Vaa, T. (2003) Impairments, diseases, age and their relative risks of accident involvement: Results from meta-analysis. IMMORTAL Deliverable R1.1.

Viborg, N. (1999) Older and younger drivers' attitudes toward in-car ITS; A questionnaire survey. Bulletin 181. Department of Technology and Society, Lund Institute of Technology, Lund, Sweden.

Vlakveld, W.P. & Davidse, R.J. (2011) Effect van de verhoging van de keuringsleeftijd op de verkeersveiligheid [Road safety effects of raising the minimum age from 70 to 75 for the medical examination for driving licences A and B]. R-2011-6. SWOV Institute for Road Safety Research, Leidschendam.

Vonk, T., Van Arem, B. & Hoedemaeker, M. (2002) Cooperative driving in an intelligent vehicle environment (co-drive). In: Proceedings of the 9th World Congress on Intelligent Transport Systems ITS, Chicago, Illinois, October 14-17 2002. ITS America, Washington DC.

Waard, D. de, Hulst, M. van der & Brookhuis, K. A. (1999) Elderly and young drivers' reaction to an in-car enforcement and tutoring system. Applied Ergonomics 30(2), p. 147-158.

Waller, J.A. (1992) Research and other issues concerning effects of medical conditions on elderly drivers. Human Factors, 34(1), pp. 3-15.

Wheatley, D.J. & Hurwitz, J.B. (2001) The use of a multi-modal interface to integrate in-vehicle information presentation. In: Proceedings of the first international driving symposium on human factors in driver assessment, training and vehicle design held in Aspen, Colorado, 14-17 August 2001, University of Iowa, Iowa City, pp.93-97.

Wilde, G.J.S. (1982) The theory of risk homeostasis: Implications for safety and health. Risk Analysis, 2(4): pp. 209-225.

Zhang, J., Fraser, S., Lindsay, J., Clarke, K. & Mao, Y. (1998) Age-specific patterns of factors related to fatal motor vehicle traffic crashes: focus on young and elderly people. Public Health, 112(5), pp.289-295.

## Notes

### 1. Country abbreviations

	Belgium	BE		Italy	IT		Romania	RO
	Bulgaria	BG		Cyprus	CY		Slovenia	SI
	Czech Republic	CZ		Latvia	LV		Slovakia	SK
	Denmark	DK		Lithuania	LT		Finland	FI
	Germany	DE		Luxembourg	LU		Sweden	SE
	Estonia	EE		Hungary	HU		United Kingdom	UK
	Ireland	IE		Malta	MT			
	Greece	EL		Netherlands	NL		Iceland	IS
	Spain	ES		Austria	AT		Liechtenstein	LI
	France	FR		Poland	PL		Norway	NO
	Croatia	HR		Portugal	PT		Switzerland	CH

2. This 2018 edition of Traffic Safety Synthesis on Older Drivers updates the previous versions produced within the EU co-funded research projects [SafetyNet](#) (2008) and [DaCoTA](#) (2012). This Synthesis on Older Drivers was originally written in 2008 and then updated in 2012 and in 2015 by Ragnhild Davidse, [SWOV](#).

3. All Traffic Safety Syntheses of the European Road Safety Observatory have been peer reviewed by the Scientific Editorial Board composed by: George Yannis, NTUA (chair), Robert Bauer, KFV, Christophe Nicodème, ERF, Klaus Machata, KFV, Eleonora Papadimitriou, NTUA, Pete Thomas, Un.Loughborough.

### 4. Disclaimer

This report has been produced by the National Technical University of Athens ([NTUA](#)), the Austrian Road Safety Board ([KFV](#)) and the European Union Road Federation ([ERF](#)) under a contract with the [European Commission](#). Whilst every effort has been made to ensure that the matter presented in this report is relevant, accurate and up-to-date, the Partners cannot accept any liability for any error or omission, or reliance on part or all of the content in another context.

Any information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use that may be made of the information contained therein.

### 5. Please refer to this Report as follows:

*European Commission, Older Drivers, European Commission, Directorate General for Transport, February 2018.*





[www.erso.eu](http://www.erso.eu)