European Road Safety Observatory

Road Safety Thematic Report - Seniors

This document is part of a series of 20 thematic reports on road safety. The purpose is to give road safety practitioners an overview of the most important research questions and results on the topic in question. The level of detail is intermediate, with more detailed papers or reports suggested for further reading. Each report has a 1-page summary.

The topic "seniors" is also addressed in the "*Facts and Figures* - Seniors", presenting more detailed and up-to-date European data in addition to this qualitative analysis.

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Summary

Seniors in road traffic

This report considers seniors as those aged 65 years and over. Health conditions that reduce mobility and increase crash risk can occur at any age, but do so more frequently from 50 years on. The greatest increase in road risk is observed from 75 years on.

Although the current and future generations of older adults are more mobile than past generations, travel reduces with increasing age. The share of trips as a car driver also reduces, while the share of walking and riding as a passenger increases.

Seniors are most at risk in traffic as vulnerable road users (VRU). They form a high proportion of casualties as well as being at significantly greater risk per kilometre travelled. As car occupants, they are better protected than as VRU and the absolute number of casualties decreases with age. Nevertheless, their risk *per distance travelled* still increases. As drivers, seniors are a greater risk to themselves than to other road users.

This greater risk to seniors is due to three factors: *Vulnerability*: crashes are more likely to have serious consequences. This is the most important reason for the overrepresentation of seniors in crash statistics. *Reduced driving*: Drivers with a low mileage have a higher risk per kilometre (regardless of age) because of the higher proportion of kilometres driven in urban areas and a lack of routine; and *Fitness to drive*: on average seniors have a greater crash risk because of age-related, cognitive and physical limitations and because of the greater incidence of health conditions that increase the crash risk.

With respect to *crash-types*, all complex traffic situations, in particular intersections, tend to become more difficult to manage at an older age. For drivers and riders this applies in particular to turning left (turning right in case of left-hand traffic) and for pedestrians crossing at unsignalised locations.

Countermeasures

With respect to *infrastructure*, seniors particularly benefit from clear and predictable layout of intersections with ample time to react, as do other road users.

The *fitness* of older drivers must be monitored in a staged system of screening (self-test, advice from the primary care physician; reference to a specialist for a more thorough examination). A general age-based screening of all drivers is not deemed advisable.

Training can counter age-related problems in traffic and support seniors' compensation strategies. The effect of such training tends, however, to be mixed.

Passive safety measures such as smart seatbelts and cycle helmets are important for seniors to compensate for their physical vulnerability.

Advanced Driver Assistant Systems *(ADAS)* as well as In-Vehicle Information Systems *(IVIS)* can help to compensate for some age-related problems. In particular, forward collision warning/mitigation, navigation systems, and parking assistants have been favourably evaluated. Highly automated vehicles will affect the question of fitness to drive, but not necessarily resolve it.

1. Highlights

- More than 1 in 4 persons killed in traffic is 65 or older.
- 1 in 2 pedestrians or cyclists killed in a road traffic crash is 65 or older.
- As drivers, seniors are a greater risk to themselves than to others.

2. What is the problem?

We are continuously aging and the baby boomer generation, who are getting older, are healthier and more mobile than any other generation of seniors. The proportion of people aged 65 years or over in the total population (EU-27) has been projected to increase from 17.5% in 2010 to 29.5% in 2060 (Eurostat, 2013). Similarly, the number of people aged 80 years or over is expected to grow from 4.8% in 2011 to 12% in 2060. With larger absolute numbers and greater participation in traffic the number of senior road crash casualties is also rising (Facts and Figures Seniors; European Commission, 2021).

Most statistics define seniors as people aged 65 and over. However, it is not possible to draw a firm line here, because this group is very heterogeneous (Bell et al., 2013). Some studies consider 50 or 55 year-olds as seniors already, others only start with the age-group of 70 (Krarup, 2012). This practice reflects the fact that seniors form a very heterogeneous group. Some struggle with health problems and functional loss as early as 50 to 60 years, others are fit until high in their 80s (GOAL, 2013).

On average, the risk of being fatally or seriously injured increases from the age of 75 on. Between 65 and 74 years of age, the average risk is also increased, but less so (CONSOL, 2014). It is important to make a distinction between the risk that the elderly run themselves, and the risk that they pose to other road users. Older people are mainly at a greater risk of being (severely or fatally) injured in a road crash as compared to middle-aged road users. The probability that they cause a crash harming another road user is less increased (e.g., Davidse, 2007). Older road users' greater physical vulnerability and the changes associated with ageing form a challenge for policymakers to make the infrastructure 'foolproof', ensure this groups' fitness to drive or to cycle, and to promote technical solutions that can compensate for certain age-related problems (e.g., Karthaus & Falkenstein, 2016).

3. How do seniors participate in traffic?

With increasing age, seniors reduce the number and length of their trips. In particular, between the ages of 75 and 79 a drop in the number of trips is observed in many European countries (Bell et al., 2013). Although the distribution of transport modes varies between countries, typically the proportion of trips as a car driver decreases while the share of walking and riding as a passenger is increased (Bell et al., 2013). In countries where cycling is common, there is a strong increase in the use of pedelecs (electrically assisted bicycles) by older cyclists. In Germany, for example, 11% of all households consisting of seniors have at least one pedelec, and half of the distances covered by pedelecs are by persons of 60 years and above (Nobis & Kuhnimhof, 2018).

4. Seniors and road safety

The rising number of seniors in the population is reflected in the crash statistics. In 1992, in Europe 1 in 7 people (17%) who were killed in a road crash was 65 and older: whereas in 2018 it was more than 1 in 4 (29%). Seniors make up a large proportion of the pedestrians (50%) and cyclists (46%) killed in traffic. Accordingly, almost half (49%) of the senior fatalities in Europe (2018) was either a pedestrian or cyclist. In contrast, among middle-aged adults (35-64 years old) pedestrians and cyclists account for only a quarter of the fatalities. For more details see Facts and Figures Seniors (European Commission, 2021).

4.1. Crash risk

Compared to middle-aged adults, seniors – especially from 75 years on – have a greater risk of severe injury or even death in every mode of transport (Bell et al., 2013). For example, in Belgium, older (75+) car occupants carry a risk of dying in a road crash three times higher than for middle-aged occupants (45-64), and for older (75+) cyclists the risk is more than 5 times higher and for older (75+) pedestrians the risk is even 8 times higher than for a middle-aged pedestrian. Road users between the ages of 65 and 74 also have an increased risk, but here the increase is much smaller (Pelssers, 2020).

For motor-vehicle drivers, we can differentiate between two types of risk: sustaining injuries (or death) oneself due to a crash, or being involved in a crash where someone else is injured (a passenger or another party). Older drivers are at especially increased risk of dying or being seriously injured due to a crash, but less so to be involved in a crash in which someone else is hurt (Davidse, 2007; Dellinger et al., 2004; Tefft, 2008). Seniors are more at risk themselves than being a danger to others in traffic.

4.2. Causation factors

Increased risk for older road users can be ascribed to three factors:

- Frailty bias: older people are more vulnerable. A crash that would leave a younger person with relatively minor injuries can cause severe injuries in older persons (see paragraph 4.3. Frailty). Moreover, seniors have an increased likelihood of complications and even with fatal consequences. Accordingly, older road users are overrepresented in all crash statistics, in particular regarding severe injury and fatality (Langford et al., 2006).
- Reduced driving: older drivers travel less than younger people. Low mileage drivers have a higher risk per kilometre travelled (regardless of age) – particularly because of the type of road that is mostly used (more high-risk urban traffic, fewer low-risk motorways) but also because of the lack of routine (Langford et al., 2006).

- Fitness to drive: on average seniors are at greater risk of being involved in a crash because of age-related cognitive and physical limitations and because of the higher occurrence of diseases that increase crash risk (Charlton et al., 2010; Vaa, 2003).

4.3. Frailty

Older people's bones break more easily, broken tissue takes longer to heal, and complications are more likely – in particular in conjunction with possible existing health conditions. For this reason older road users are severely injured or even killed in crashes that would be less serious for younger people (Ang et al., 2017; Johannsen & Müller, 2013). The EC project SENIORS (Wisch et al., 2017) gives a good overview of injuries for senior road users:

- For *car occupants*, thorax injuries especially are more frequent and more severe in older occupants. For example, breaking three ribs or more is the most common injury type, with the risk being approximately 1.5 times greater for the 65+ age group compared with the 25-64 age group. These injuries are often caused by the seatbelt.
- For *cyclists*, most very severe injuries occur to head, thorax and lower extremities. Injuries to the upper extremity are common among injuries of moderate severity. Moreover, for users of pedelecs, the injury risk is greater for injuries to the head and the upper and lower extremities (Poos et al., 2017).
- In the case of *pedestrians*, the body regions most affected are similar to those for younger pedestrians, namely the lower extremities, the head, and the thorax. Also, senior pedestrians often suffer injuries to the upper extremities, although these are mostly of moderate severity.

4.4. Age-related changes

Older road users are less likely to exhibit risky behaviour. As drivers, they drive more slowly, keep a greater following distance, and are less likely to execute dangerous manoeuvres (such as risky overtaking). A number of functions required to drive a vehicle can however deteriorate with increasing age: sight, in particular peripheral sight and night vision; balance; agility; reaction time. Such deterioration does not affect everybody to the same extent at the same age and does not necessarily lead to reduced fitness to participate in traffic. Often these limitations are compensated for by choosing the place and time where one drives or rides and by a careful driving/riding style. Apart from the "normal" age-related symptoms, chronic diseases such as heart and arterial problems, dementia or arthritis become more frequent at an older age. While limitations related to just one illness can often be compensated for, the risk of crashes increases clearly with multiple diseases. Medicine that is taken because of these conditions can moreover cause drowsiness and inattentiveness and therefore also impair driving (Ramaekers, 2017). (See, e.g., Karthaus and Falkenstein (2016) for more details.)

4.5. Typical crashes

4.5.1. Pedestrians

When a pedestrian falls, this is not considered as a road crash if no vehicle is involved (UNECE, 2019). This is estimated to be the case with three out of four injured pedestrians treated in hospital. Consequently, these cases do not figure in any statistics on transport crashes. The causes of this type of crash are often found to be a poor (or poorly maintained) road surface (Methorst et al., 2017).

Analysis of Belgian crash figures from 2008 to 2012 (Martensen, 2014) has shown that out of the fatally injured pedestrians who collided with a (motor) vehicle, almost half (46%) were 65 years of age or older and almost a third (31%) were even older than 75 years. Seven out of 10 older pedestrians (75+) killed in traffic were crossing the road. In a literature review (Oxley et al., 2004) it was shown that older adults – especially those with reduced mobility – are less likely to use crossing facilities if this involves more walking. On unsignalled crossings, older pedestrians fail more often than younger ones to take their slower walking speed into account, especially in complex traffic environments. Moreover, they are more likely to look down to the ground to avoid falling and therefore fail to see other road users. Other causal factors include incorrectly judging the speed of the oncoming vehicle or not expecting the vehicle's manoeuvre (e.g. vehicles reversing or turning). Finally, pedestrians' reduced visibility plays an important role in crashes of all age-groups (Ewert, 2012; Oxley et al., 2004).

4.5.2. Cyclists

Among cyclists who were treated in hospital or the emergency rooms in the Netherlands, Austria, and Switzerland, approximately 10% had collided with a motor vehicle, whereas 90% had fallen or crashed with another non-motorized vehicle. The latter group is rarely reported to the police and is therefore almost invisible in crash statistics. It is however likely that the share of older cyclists in this group is particularly high (Methorst et al., 2016).

Older cyclists who were involved in a crash *without* a motor vehicle were studied in the Netherlands. Three types of crashes were identified, each with an approximately equal share (Boele-Vos et al., 2017):

(1) collided with another cyclist (mainly not so old cyclists, 50-70)
(2) bumped into an obstacle (all ages 50+)
(3) fell (e.g. due to a steering error or when stopping or turning) (mainly 70+).

In the Netherlands, helmets are rarely worn by cyclists – except for sports cycling (Achermann Stürmer et al., 2020). The older cyclists in the study above were no exception – only 6 out of 41 wore a helmet.

Older cyclists colliding *with* a motor vehicle are often turning left (right in countries with left-hand traffic) (Goldenbeld, 1992; Oxley et al., 2004).

Pedelecs (electrically assisted bicycles) are a new, attractive means of transport for senior citizens. In a naturalistic cycling study, it was found that seniors ride their pedelecs more slowly than middle-aged cyclists but faster than their peers on conventional bikes (Schleinitz et al., 2017). The crash-involvement risk when using a pedelec is subject to scientific debate. The risk is particularly great for older women. It is greater when they ride pedelecs as compared to conventional bicycles, while risks are greater than for younger cyclists (men & women) on either conventional bicycles or pedelecs. For older women involved in a crash with a pedelec, the injury risk is also greater than in crashes with a conventional bike, but not for older men where the tendency is even the other way around. Important crash causation factors are problems with balance and unfamiliarity with the pedelec (Fyhri et al., 2019; Schepers et al., 2020).

4.5.3. Car drivers

Intersections are challenging for all drivers because they require observation of several road users simultaneously, their speed to be assessed, and rapid decisions on how to respond. Some of these skills can deteriorate with ageing, which makes these situations particularly difficult for seniors. Accordingly, senior drivers have a higher percentage of crashes at intersections, in particular with turning left (or right in left-hand traffic countries). Senior drivers fail more often than middle-aged drivers to give priority to other road users and commit more driving errors such as crossing a red light or deviating from their lane (Fornells et al., 2017; Johannsen & Müller, 2013). In Denmark, an in-depth investigation of 32 crashes involving car drivers of 70 years or over found three types of crash, each taking up about one third of the sample (Krarup, 2012):

(1) The driver became ill and therefore incapacitated to drive. Denmark had at the time of the study a mandatory medical check-up for senior drivers and all drivers had passed the mandatory examination within the year preceding the crash. The investigator judged in two cases that there could have been doubts regarding the fitness to drive at the time of testing. For two other drivers, it was concluded that they should have realised before departure that their health condition was deteriorating.

(2) The driver should have given priority or had crossed a red light. In all cases the senior driver missed some vital information. Contributing factors were stress or anxiety on the senior’s part, exaggerated speed by the other party, and complexity of the infrastructure.

(3) The driver was innocently involved because of another road user’s error. There was nothing the senior could have done to prevent the crash.

5. Countermeasures

5.1. Infrastructure

Generally speaking, infrastructure that is good for seniors is good for everyone. Seniors particularly benefit from clear and predictable layout at intersections, but younger road users also benefit. Important aspects include (Davidse, 2007):

- Pedestrian islands between wide crossover intersections where pedestrians and cyclists can safely wait. With fewer lanes to cross and only one direction to check, the complexity of crossing is reduced.
- Good maintenance of pavement and cycle paths, reducing the risk of falling and the need to look down.
- Good visibility in the approach to an intersection, giving drivers time to anticipate.
- Joining roads at an angle of 90° so that looking back over the shoulder to see oncoming traffic can be avoided.
- Conflict-free traffic lights and separate lanes for left-turning traffic (right turning in case of left hand traffic).
- Clear traffic signs, installed well in advance (right-of-way rules, warnings, indication of lanes).
- Traffic signs and road markings with high contrast.
- Reduced speed.

For the benefit of walking and cycling seniors, road-crossings should have flattened curbs and all walking and cycling infrastructure should be well maintained so as to prevent potholes, slippery surfaces, protruding tiles, etc. that can cause falls or distract seniors from attending to other aspects of the traffic (Methorst et al., 2017).

5.2. Road-users

5.2.1. Fitness to drive

Due to the increased numbers and mobility of older drivers in most industrialised countries, there has been a growing concern to ensure the fitness of older drivers. General screening from a certain age seems intuitively the most obvious solution. However, this is not recommended (Grabowski et al., 2004; Langford et al., 2008; Siren & Haustein, 2015; Siren & Meng, 2012; Vlakveld & Davidse, 2011) because there are unfortunately no tests which provide a sound enough assessment of fitness to drive and which are feasible practically to apply to everyone from a certain age (Fastenmeier et al., 2015; Karthaus & Falkenstein, 2016). In practice, broad testing of all seniors (without any specific reason) has even proven to be counterproductive: seniors were found to have *more* traffic violations and crashes *after* they had passed the test than before (Mikkonen, 2014). This counterintuitive result is probably due to a boost in self-confidence among drivers with whom the test did not detect problems with driving ability. Of course, drivers can also be wrongly classified as unfit to drive. This could be a problem for road safety because older road users are typically more at risk when they walk or cycle instead of using the car (Hakamies-Blomqvist et al., 1996; Vlakveld & Davidse, 2011). Moreover, disqualification could mean for those affected a dramatic – and unnecessary -- reduction in social integration (Marottoli et al., 2000).

Advising against age-based screening does not mean that it is not necessary to pay attention to the fitness of drivers. A staged system of screening, starting with a simple self-test and /or a visit to the primary care physician, is an alternative to mass screening.

If the primary care physician doubts the patient's fitness to drive, (s)he can refer them to a specialist for a more thorough examination, which should be focused on maintaining mobility, e.g. by issuing a limited licence (e.g. day-time only), adjusting medication, or possibly adapting the vehicle (Helman et al., 2017).

5.2.2. Training

Refresher courses for older drivers are offered in many countries. These courses usually consist of a theoretical and often also a practical part (Marin-Lamellet & Haustein, 2015). Feedback drives, where the participants take a ride with an instructor and get feedback afterwards on how to improve their driving, are particularly popular. Their effectiveness is however not yet known.

No reductions in crash risk or improvements to driving performance have been demonstrated simply as a result of educational measures (e.g., awareness-raising with respect to age-related problems in driving; encouragement to minimise difficulties by avoiding certain situations like not driving at night or during rush-hours; refreshing the knowledge of traffic rules) (Fausto et al., 2021). While courses focusing on either education alone or on driving lessons alone could not be proven to be effective, the combination of the two has been shown to significantly improve driving performance (Fausto et al., 2021; Poschadel et al., 2012) and reduce crash risk (Ulleberg et al., 2012).

Another type of training focusses on functionalities that are reduced specifically in older adults, such as useful field of view, information processing speed, or physical agility. This kind of training often takes place in much longer courses (typically 4 to 12 sessions) and has been shown to also improve driving performance (Fausto et al., 2021).

Courses can also be aimed at encouraging walking, cycling, and the use of public transport. The drawback with existing courses is that they usually attract persons who have already adopted the desired behaviours, and the courses are less successful in increasing acceptance of other transport modes by car-reliant users (Marin-Lamellet & Haustein, 2015).

For cyclists, in particular for new users of pedelecs, courses to improve safe cycling have also been suggested (Fyhri et al., 2019; Schepers et al., 2020).

5.3. Vehicles

5.3.1. Passive protection systems

Seatbelts have an important protective function, but nevertheless they can also be the source of injuries (rib fractures) that can be very serious and even life-threatening for senior car occupants. To improve their protection, it is necessary to test vehicles and restraint systems with crash test dummies that reflect the frailty of senior car occupants. Since injury probability for seniors starts increasing at lower speeds, crash tests should also include a moderate speed condition (e.g. 35 km/h) to optimize research into protective measures for this target group. New restraint system concepts can greatly reduce the risk of serious thorax injury to older car occupants in frontal impacts. While benefits will also accrue for occupants of other ages, it has been estimated that new restraints would potentially save 800 to 1,200 lives and avert 6,500 to 10,500 serious injuries over ten years if implemented in all new cars in Europe (Thomas et al., 2018).

Bicycle helmets can reduce serious head injury by 48% (Høye, 2018), which would be important for senior cyclists who have a heightened risk of head injury – especially if they use a pedelec (Poos et al., 2017).

5.3.2. Assistance and information systems

We distinguish between advanced driver assistance systems (ADAS) and in-vehicle navigation systems (IVNS). According to (Davidse, 2007) ADAS and IVNS are useful for older motorists if they:

- draw the driver's attention to oncoming traffic;
- signal road users who are in the driver's blind spot;
- help the driver to focus his or her attention on the important aspects of traffic;
- provide advance information on the traffic situation.

In-vehicle navigation systems (IVNS)
Navigation systems are favourably evaluated, because they help drivers to focus on their driving rather than be distracted by searching for particular roads or streets (Eby et al., 2016; Young et al., 2017). They can however also be a source of distraction from driving (Emmerson et al., 2013). For senior drivers, the reference to landmarks (as icons or audio instructions) can improve the support in way finding (Edwards et al., 2016).

Possible extensions tailored to specific problems of senior drivers have been suggested: specially adapted route selection, e.g. avoid turning left – or right in case of right hand traffic (Schwarze et al., 2014); or displaying relevant information from the environment, e.g. signs or cyclists/pedestrians (Hoffmann et al., 2013). However, products "especially for the elderly" can be perceived as stigmatizing and might not therefore reach their intended user group (Braun et al., 2019).

Advanced Driving Assistance Systems (ADAS)
For advanced driving assistance systems, three questions need to be asked: (1) does it (if applied) prevent crashes? (2) is it used?, and (3) could drivers put too much trust in the system (overconfidence)?

Forward collision warning or mitigation can compensate for reduced vision and attention and slower execution of movements due to age. Since the systems work on the basis of radar (among other things) they can compensate for poor night vision. It is estimated that the number of crashes could be reduced by 20% if all vehicles (independent of driver age) were equipped with such a system. Forward collision warning systems are well received by seniors and do not cause overconfidence (Eby et al., 2016).

Intersection assistants can compensate for some seniors' problems by estimating speed and distance of oncoming vehicles and simultaneously monitoring different road users. However, the results of simulator studies are mixed. Some positive results were found, but other studies found no clear improvement in crossing behaviour, and even deterioration. There appeared to be overconfidence in the system in that participants did not check intersections as they had before using the assistant (Becic et al., 2018).

Behavioural adaptation can also be established for *blind-spot warnings*. Many seniors find it increasingly difficult to turn their head and check their blind-spot which therefore makes a blind-spot warning system welcome to them. Users report increased awareness of the vehicles around them and are seen to check their mirrors more frequently. However, they also make less use of their indicator lights and take fewer looks over their shoulder, which could be seen as overconfidence in the system (Eby et al., 2016).

Parking assistants do not only increase comfort and reduce stress levels, but also reduce some actual dangers such as running into a passing vehicle or pedestrian when backing out of a parking space (Eby et al., 2016).

Use of ADAS and INVS: senior drivers have as many driving assistance systems in their car as the middle-aged generation and are more concerned about safety: and yet older drivers see less value in ADAS and are less inclined to use assistants which remove their control of the vehicle. Promoting the use of ADAS and INVS would increase the safety of this group. Driving simulators appear to be a safe way of introducing senior citizens to assistance systems. Such hands-on learning appears more effective in promoting the use of such systems than verbal explanation (Bellet et al., 2018; Li et al., 2019).

5.3.3. Vehicle Automation

While great hope is placed on ADAS and INVS systems, vehicle automation that takes over the driving task (almost) completely from the driver is seen as even more promising. However, the degree of automation that can realistically be achieved within the next few decades is that of Highly Automated Vehicles (Level 3, SAE, 2016), and this will not resolve the problem of fitness to drive. When a take-over request from the vehicle occurs, one has to switch from passenger to driver and the mental flexibility required at that moment could be subject to age-related decline. Initial studies investigating the quality of take-over by senior drivers in a simulator (see the overview of Li et al., 2019) suggest that differences between senior and middle-aged drivers are rather small. Older drivers are more intensively engaged in their side activities, benefit more from longer advance warning of taking over, and in difficult situations braked or steered a little too hard. However, the differences were clearly smaller than those between middle-aged and young drivers. Therefore, there is probably no general problem for older drivers, but the participants in these studies were all healthy seniors who drive regularly. These findings are silent on the effect of certain health conditions on the ability to take over the wheel again. To conclude, there are health requirements that must be met for driving an automated vehicle, although they may not be the same as for conventional vehicles. Guidelines will therefore be needed in the foreseeable future for the fitness to drive highly automated vehicles which still require human involvement.

5.3.4. Bicycles for seniors

Because seniors - especially very old seniors - often have problems keeping their balance when stopping and setting off, bicycles for seniors have been developed that enable the riders to put their feet on the ground when slowing down and still pedal comfortably. For instance by automatically lowering the saddle when the bike slows or by moving the cranks slightly forward of the rider instead of underneath to reduce the saddle height (Dubbeldam et al., 2017).

Rear-view systems: a research group is experimenting with rear-view systems that give a warning when someone approaches from behind. Two experiments with a bicycle simulator showed that comfort and safety improved when turning left (in right-hand traffic), which is a difficult manoeuvre for older cyclists (Engbers et al., 2018).

6. Further reading

Davidse, R. J. (2007). *Assisting the older driver: intersection design and in-car devices to improve the safety of the older driver*. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV. swov.nl/sites/default/files/publicaties/dissertatie/ragnhild_davidse.pdf

Karthaus, M., & Falkenstein, M. (2016). Functional changes and driving performance in older drivers: Assessment and interventions. In *Geriatrics (Switzerland)* (Vol. 1, Issue 2). MDPI Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/geriatrics1020012

Eby, D. W., Molnar, L. J., Zhang, L., St. Louis, R. M., Zanier, N., Kostyniuk, L. P., & Stanciu, S. (2016). Use, perceptions, and benefits of automotive technologies among aging drivers. *Injury Epidemiology*, *3*(1). https://doi.org/10.1186/s40621-016-0093-4

Li, S., Blythe, P., Guo, W., & Namdeo, A. (2019). Investigation of older drivers' requirements of the human-machine interaction in highly automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *62*, 546–563. https://doi.org/10.1016/j.trf.2019.02.009.

References

Achermann Stürmer, Y., Berbatovci, H., & Butler, I. (2020). *Cyclists. ESRA2 Thematic report Nr. 11. ESRA project (E-Survey of Road users' Attitudes)*. Swiss Council for Accident Prevention. esranet.eu/storage/minisites/esra2018thematicreportno11cyclists.pdf

Ang, B. H., Chen, W. S., & Lee, S. W. H. (2017). Global burden of road traffic accidents in older adults: A systematic review and meta-regression analysis. *Archives of Gerontology and Geriatrics*, *72*, 32–38. https://doi.org/10.1016/j.archger.2017.05.004

Becic, E., Edwards, C. J., Manser, M. P., & Donath, M. (2018). Aging and the use of an in-vehicle intersection crossing assist system: An on-road study. *Transportation Research Part F: Traffic Psychology and Behaviour*, *56*, 113–122. https://doi.org/10.1016/j.trf.2018.03.032

Bell, D., Pokriefke, E., Risser, R., Biler, S., Šenk, P., Parkes, A., Stannard, J., Armoogum, J., Marin Lamellet, C., Gabaude, C., Loupe Madre, J., Alauzet, A., Monterde i Bort, H., & Henriksson, P. (2013). *Mobility Patterns in the Ageing Populations. Deliverable WP2 of* *the EC FP7 Project CONSOL*.

Bellet, T., Paris, J. C., & Marin-Lamellet, C. (2018). Difficulties experienced by older drivers during their regular driving and their expectations towards Advanced Driving Aid Systems and vehicle automation. *Transportation Research Part F: Traffic Psychology and Behaviour*, *52*, 138–163. https://doi.org/10.1016/j.trf.2017.11.014

Boele-Vos, M. J., Van Duijvenvoorde, K., Doumen, M. J. A., Duivenvoorden, C. W. A. E., Louwerse, W. J. R., & Davidse, R. J. (2017). Crashes involving cyclists aged 50 and over in the Netherlands: An in-depth study. *Accident Analysis and Prevention*, *105*, 4–10. https://doi.org/10.1016/j.aap.2016.07.016

Braun, H., Gärtner, M., Trösterer, S., Akkermans, L. E. M., Seinen, M., Meschtscherjakov, A., & Tscheligi, M. (2019). Advanced driver assistance systems for aging drivers. *Proceedings - 11th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2019*, 123–133. https://doi.org/10.1145/3342197.3344517

Charlton, J. L., Koppel, S., Odelll, M., Devlin, A., & Langford, J. (2010). *Influence of chronic illness on crash involvement of motor vehicle drivers*. Monash University, Accident Research Centre.

CONSOL (2014). CONcerns & SOLutions - Road Safety in the Ageing Societies. Synthesis & Recommendations. Deliverable 6 of the EC FP6 project CON-SOL. https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/projects_sources/consol_synthesis_recommendations.pdf

Davidse, R. J. (2007). *Assisting the older driver : intersection design and in-car devices to improve the safety of the older driver*. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV.

Dellinger, A. M., Kresnow, M. J., White, D. D., & Sehgal, M. (2004). Risk to self versus risk to others: How do older drivers compare to others on the road? *American Journal of Preventive Medicine*, *26*(3), 217–221. https://doi.org/10.1016/j.amepre.2003.10.021

Dubbeldam, R., Baten, C., Buurke, J. H., & Rietman, J. S. (2017). SOFIE, a bicycle that supports older cyclists? *Accident Analysis and Prevention*, *105*, 117–123. https://doi.org/10.1016/j.aap.2016.09.006

Eby, D. W., Molnar, L. J., Zhang, L., St. Louis, R. M., Zanier, N., Kostyniuk, L. P., & Stanciu, S. (2016). Use, perceptions, and benefits of automotive technologies among aging drivers. *Injury Epidemiology*, *3*(1). https://doi.org/10.1186/s40621-016-0093-4

Edwards, S. J., Emmerson, C., Namdeo, A., Blythe, P. T., & Guo, W. (2016). Optimising landmark-based route guidance for older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *43*, 225–237. https://doi.org/10.1016/j.trf.2016.10.017

Emmerson, C., Guo, W., Blythe, P., Namdeo, A., & Edwards, S. (2013). Fork in the road: In-vehicle navigation systems and older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour*, *21*, 173–180. https://doi.org/10.1016/j.trf.2013.09.013

Engbers, C., Dubbeldam, R., Brusse-Keizer, M. G. J., Buurke, J. H., de Waard, D., &

Rietman, J. S. (2018). Characteristics of older cyclists (65+) and factors associated with self-reported cycling accidents in the Netherlands. *Transportation Research Part F: Traffic Psychology and Behaviour*, *56*, 522–530. https://doi.org/10.1016/j.trf.2018.05.020

European Commission (2020) Facts and Figures - Seniors. European Road Safety Observatory. Brussels, European Commission, Directorate General for Transport.

Ewert, U. (2012). *Senioren als Fussgänger. Bfu-Faktenblatt Nr.08*. bfu – Beratungsstelle für Unfallverhütung.

Fastenmeier, W., Gstalter, H., Rompe, K., & Risser, R. (2015). Selektion oder Befähigung: Wie kann die Mobilität älterer Fahrer aufrechterhalten werden? Stellungnahme des Vorstandes der Deutschen Gesellschaft für Verkehrspsychologie e.V. *Zeitschrift Für Verkehrssicherheit*, *61*(1), 33–42.

Fausto, B. A., Adorno Maldonado, P. F., Ross, L. A., Lavallière, M., & Edwards, J. D. (2021). A systematic review and meta-analysis of older driver interventions. *Accident Analysis and Prevention*, *149*(April 2020). https://doi.org/10.1016/j.aap.2020.105852

Fornells, A., Parera, N., Ferrer, A., & Fiorentino, A. (2017). Senior Drivers, Bicyclists and Pedestrian Behavior Related with Traffic Accidents and Injuries. *SAE Technical Papers*, *2017-March*(March). https://doi.org/10.4271/2017-01-1397

Fyhri, A., Johansson, O., & Bjørnskau, T. (2019). Gender differences in accident risk with e-bikes—Survey data from Norway. *Accident Analysis and Prevention*, *132*(March), 105248. https://doi.org/10.1016/j.aap.2019.07.024

GOAL. (2013). *GOAL Transport Needs for an Ageing Society. Action Plan*. https://trimis.ec.europa.eu/sites/default/files/project/documents/20140115_095617_32515_Action_Plan__Transport_Needs_of_an_Aging_Society.pdf

Goldenbeld, C. (1992). *Ongevallen van oudere fietsers in 1991. R-92-71*. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV).

Grabowski, D. C., Campbell, C. M., & Morrisey, M. A. (2004). *Elderly Licensure Laws and Motor Vehicle Fatalities*. http://jamanetwork.com/pdfaccess.ashx?url=/data/journals/jama/4932/

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), 650–653. https://doi.org/10.1111/j.1532-5415.1996.tb01826.x

Helman, S., Vlakveld, W., Fildes, B., Oxley, J., Fernández-medina, K., & Weekley, J. (2017). *Study on driver training, testing and medical fitness*. European Commission, DG MOVE.

Hoffmann, H., Wipking, C., Blanke, L., & Falkenstein, Mi. (2013). *Experimentelle Untersuchung zur Unterstützung der Entwicklung von Fahrerassistenzsystemen für ältere Kraftfahrer*. Bundesanstalt für Straßenwesen (BASt).

Holte, H. (2018). *Seniorinnen und Senioren im Straßenverkehr - Bedarfsanalysen im Kontext von Lebenslagen, Lebensstilen und verkehrssicherheitsrelevanten Erwartungen*.

Bundesanstalt für Straßenwesen (BASt).

Hoye, A. (2018). Bicycle helmets – To wear or not to wear? A meta-analyses of the effects of bicycle helmets on injuries. *Accident Analysis and Prevention*, *117*(December 2017), 85–97. https://doi.org/10.1016/j.aap.2018.03.026

Johannsen, H., & Müller, G. (2013). Accident and injury risks of elderly car occupants. *Enhanced Safety of Vehicles (ESV)*, 1–10.

Karthaus, M., & Falkenstein, M. (2016). Functional changes and driving performance in older drivers: Assessment and interventions. In *Geriatrics (Switzerland)* (Vol. 1, Issue 2). MDPI Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/geriatrics1020012

Krarup, N. (2012). *Ulykker med aeldre bilister. Temarapport 9*. HVU, Havarikommissionen for Vejtrafikulykker.

Langford, J., Bohensky, M., Koppel, S., & Newstead, S. (2008). Do age-based mandatory assessments reduce older drivers' risk to other road users? *Accident Analysis and Prevention*, *40*(6), 1913–1918. https://doi.org/10.1016/j.aap.2008.08.010

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*, *38*(3), 574–578. https://doi.org/10.1016/j.aap.2005.12.002

Li, S., Blythe, P., Guo, W., & Namdeo, A. (2019). Investigation of older drivers' requirements of the human-machine interaction in highly automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *62*, 546–563. https://doi.org/10.1016/j.trf.2019.02.009

Marin-Lamellet, C., & Haustein, S. (2015). Managing the safe mobility of older road users: How to cope with their diversity? *Journal of Transport and Health*, *2*(1), 22–31. https://doi.org/10.1016/j.jth.2014.07.006

Marottoli, R. A., de Leon, C. F. M., Glass, T. A., Williams, C. S., Cooney, L. M., & Berkman, L. F. (2000). Consequences of Driving Cessation: Decreased Out-of-Home Activity Levels. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *55*(6), S334–S340. https://doi.org/10.1093/geronb/55.6.s334

Martensen, H. (2014). *Senioren in het verkeer. Mobiliteit en verkeersveiligheid van oudere weggebruikers*. Vias institute – Kenniscentrum Verkeersveiligheid.

Methorst, R., Eenink, R., Cardoso, J., MacHata, K., & Malasek, J. (2016). Single Unprotected Road User Crashes: Europe we have a Problem! *Transportation Research Procedia*, *14*, 2297–2305. https://doi.org/10.1016/j.trpro.2016.05.246

Methorst, R., Schepers, P., Christie, N., Dijst, M., Risser, R., Sauter, D., & van Wee, B. (2017). 'Pedestrian falls' as necessary addition to the current definition of traffic crashes for improved public health policies. *Journal of Transport and Health*, *6*, 10–12. https://doi.org/10.1016/j.jth.2017.02.005

Mikkonen, V. (2014). Ajokortin uusintaan liittyvien ikäkausitarkastusten vaikutus liikennemenestykseen. In *Trafi Research Report* (Issue 02/2014). https://arkisto.trafi.fi/filebank/a/1394024746/d14a9dd33fc059d7bfde272b04cd2fab

/14340-Trafin_tutkimuksia_02-2014_-_Ikakausitarkastusten_vaikutus_liikennemenestykseen.pdf

Nobis, C., & Kuhnimhof, T. (2018). *Mobilität in Deutschland – MiD Ergebnisbericht. Studie von infas, DLR, IVT und infas 306 im Auftrag des Bundesministers für Verkehr und digitale Infrastruktur (FE-Nr. 70.904/15).* www.mobilitaet-in-deutschland.de

Oxley, J., Corben, B., Fildes, B., O'HARE, M., & Rothengatter, T. (2004). Older Vulnerable Road Users: Measures To Reduce Crash and Injury Risk. Report No. 218. *Report*.

Pelssers, B. (2020). *Hoe verplaatsen we ons het veiligst? – Onderzoek naar de wijze waarop we ons verplaatsen en verkeersveiligheid*. Vias institute – Kenniscentrum Verkeersveiligheid.

Poos, H. P. A. M. J., Lefarth, T. L., Harbers, J. S., Wendt, K. W., El Moumni, M., & Reininga, I. H. F. (2017). E-bikers raken vaker ernstig gewond na fietsongeval: Resultaten uit de Groningse fietsongevallendata base. *Nederlands Tijdschrift Voor Geneeskunde*, *161*(20), 1–7.

Poschadel, S., Boenke, D., Blöbaum, A., & Rabczinski, S. (2012). *Ältere Autofahrer: Erhalt, Verbesserung und Verlängerung der Fahrkompetenz durch Training. Mobilität im Alter, Band 06*. TÜV Rheinland.

Ramaekers, J. G. (2017). Drugs and Driving Research in Medicinal Drug Development. *Trends in Pharmacological Sciences*, *38*(4), 319–321. https://doi.org/10.1016/j.tips.2017.01.006

SAE. (2016). *J3016™ Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*.

Schepers, P., de Geus, B., van Cauwenberg, J., Ampe, T., & Engbers, C. (2020). The perception of bicycle crashes with and without motor vehicles: Which crash types do older and middle-aged cyclists fear most? *Transportation Research Part F: Traffic Psychology and Behaviour*, *71*, 157–167. https://doi.org/10.1016/j.trf.2020.03.021

Schepers, Paul, Klein Wolt, K., Helbich, M., & Fishman, E. (2020). Safety of e-bikes compared to conventional bicycles: What role does cyclists' health condition play? *Journal of Transport and Health*, *19*(December 2019), 100961. https://doi.org/10.1016/j.jth.2020.100961

Schleinitz, K., Petzoldt, T., Franke-Bartholdt, L., Krems, J., & Gehlert, T. (2017). The German Naturalistic Cycling Study – Comparing cycling speed of riders of different e-bikes and conventional bicycles. *Safety Science*, *92*, 290–297. https://doi.org/10.1016/j.ssci.2015.07.027

Schwarze, A., Ehrenpfordt, I., & Eggert, F. (2014). Workload of younger and elderly drivers in different infrastructural situations. *Transportation Research Part F: Traffic Psychology and Behaviour*, *26*(PART A), 102–115. https://doi.org/10.1016/j.trf.2014.06.017

Siren, A., & Haustein, S. (2015). Driving licences and medical screening in old age: Review of literature and European licensing policies. *Journal of Transport and Health*, *2*(1), 68–78. https://doi.org/10.1016/j.jth.2014.09.003

Siren, A., & Meng, A. (2012). Cognitive screening of older drivers does not produce safety benefits. *Accident Analysis and Prevention*, *45*, 634–638. https://doi.org/10.1016/j.aap.2011.09.032

Tefft, B. C. (2008). Risks older drivers pose to themselves and to other road users. *Journal of Safety Research*, *39*(6), 577–582. https://doi.org/10.1016/j.jsr.2008.10.002

Thomas, A., Hynd, D., Kent, J., Appleby, J., & Zander, O. (2018). *Benefit analysis SENIORS project. Deliverable 4.3 of the EC H2020 project SENIORS*.

Ulleberg, P., Bjornskau, T., & Fostervold, K. . (2012). Don't wait until it's too late: Evaluation of a refresher course for older drivers. *Presentations at the 5th ICTTP, Groningen (NL).*

UNECE. (2019). Glossary for Transport Statistics 2019 5th edition. In *Glossary for Transport Statistics 2019 5th edition*. https://doi.org/10.1787/505b670b-en

Vaa, T. (2003). *Impairments, diseases, age and their relative risks of accident involvement : results from meta-analysis*. Institute of Transport Economics.

Vlakveld, W., & Davidse, R. (2011). *Effect van de verhoging van de keuringsleeftijd op de verkeersveiligheid. R-2011-6*. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV).

Wisch, M., Vukovic, E., Schäfer, R., Hynd, D., Barrow, A., Khatry, R., Fiorentino, A., Fornells, A., Pradeep, P., & Lübbe, N. (2017). *Road traffic accidents involving the elderly and obese people in Europe incl. investigation of the risk of injury and disabilities. Deliverable 1.2 of EC H2020 project SENIORS*.

Young, K. L., Koppel, S., & Charlton, J. L. (2017). Toward best practice in Human Machine Interface design for older drivers: A review of current design guidelines. *Accident Analysis and Prevention*, *106*, 460–467. https://doi.org/10.1016/j.aap.2016.06.010

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