Longer-term effects of ADAS use on driving performance of healthy older drivers and drivers diagnosed with Parkinson’s disease
Dotzauer, Mandy

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3.1 New developments, potential benefits, and problems

Older drivers make adjustments on the tactical level in order to be able to deal with traffic-relevant information from their surroundings. For example, older drivers travel at lower speeds (Becic et al., 2013; Shinar et al. 2005) to read traffic signs (Musselwhite & Haddad, 2010) or accept larger gaps when crossing intersections (Middleton et al., 2005). Considering this behavior outside of the general traffic context, we could conclude that older drivers engage in safe driving behavior as they apply compensatory strategies. Taking into account, other road users, this behavior might be perceived as traffic blocking by some, especially when other drivers do not see an obvious reason (e.g. a traffic jam) for traveling under the speed limit or not crossing in the case of exceptionally large gaps. Such compensatory behaviors might produce “inconvenient” pace differences, contributing to hazardous behaviors of other drivers. Hence, support that will limit engaging in “irritating” compensatory strategies is desirable.

Based on older drivers’ unique characteristics and crash profile, a system that supports older drivers maneuvering safely through traffic including passing through intersections by providing relevant traffic information is desirable. Such system detects and conveys traffic signs with respect to speed limits and priority regulation, monitors speed and time headway, warns drivers when speed is inappropriate and the gap to the lead vehicle too small, and gives advice on safe gaps to crossing traffic. Not only relevant traffic information is conveyed, drivers also receive immediate feedback on speed and time headway choices. Receiving information in advance serves two purposes. It takes away uncertainty because drivers know what to expect and can anticipate; it can thus compensate for decision making under time pressure. It also counters difficulties with divided attention because important information, for example, priority regulation at the upcoming intersection, is fed to the driver before reaching an intersection. In theory, giving older drivers information about speed limits, priority regulations, and approaching traffic in advance, can offset attentional capacity challenges and spare enough resources to fulfill the primary driving task.

Technology needed to realize provision of information involves C2C- and C2I-communication. Innovations for car-to-infrastructure communication have come from European projects and major car manufacturers (Weiß, 2011). An intersection assistant,
for example, is realizable using C2I-communication. One form of assistance involves communication between vehicles and traffic lights at signalized junctions. In such systems, cars communicate with traffic lights and, after appropriate filtering, the driver is informed about the status of the upcoming traffic light and receives speed recommendations that will ensure a “green wave” (Volkswagen, 2013; Bickerstaffe, 2012). Such intersection systems are intended for improving transport efficiency. But intersection assistants are also designed for safety purposes (Röglinger, 2011). Drivers are warned when they are about to run a red light (Volkswagen, 2013; Bickerstaffe, 2012) and some systems are even designed to intervene in such cases. Warnings are also given when a driver makes a hazardous turning maneuver (Bickerstaffe, 2012).

C2C-communication is also under investigation in order to bring intersection assistance forward. C2C-technology appears promising when designing for intersection assistance that is intended to inform drivers as they are on a colliding course with crossing traffic but also to advise drivers on safe crossing gaps. Ford is one car manufacturer that investigates this approach. They use cellular mobile telephony and WiFi to transmit data such as speed, status of brakes and indicators. If the transmitted data indicate a dangerous situation (e.g. approaching speed of another vehicle is too high), it will warn the driver (Ford, 2012).

Realizing assistance as described above involves very complex technology and an effective and efficient interplay of the components making up an assistance system. If one of the components involved does not work properly, the system may fail. Considering Ford’s approach to an intersection assistant which uses internet communications, the information would not be provided when the internet is not available. This is probably a more pronounced problem in rural areas than in urban areas and needs to be considered (Note: Response to system failure is a research area of its own).

Besides technological problems that can occur, a major concern is human-machine interaction (HMI). Even though ADAS are intended to improve safety, comfort, traffic efficiency, and the environment, hence facilitating driver performance (IHRA, 2010); research has also shown that with the introduction of automation, performance may deteriorate (Young & Stanton, 1997). One factor contributing to performance deterioration is mental workload. Additional information that is presented to the driver needs to be processed and this requires mental and/or visual resources. Because older
drivers already experience difficulties in more complex driving tasks, the additional information might increase mental workload because drivers also need to pay additional attention to what the system is doing. De Waard and colleagues (1999a) as well as Davidse and colleagues (2009) found that with the introduction of additional information, workload increased.

Another factor that influences ADAS use is trust in automation. In general, it has been observed that if the first experience with information provided proves to be trustworthy and useful (Dijksterhuis et al., 2012), drivers tend to start over-trusting ADAS resulting in reliance on and compliance with the advice given without confirming the accuracy of the information (Nilsson, 1995, Young & Stanton, 1997; De Waard et al., 1999b; Buld & Krüger, 2003; Rudin-Brown & Noy, 2002; Rajaonah et al., 2006). Little is known about older drivers and their trust in automation. Development of trust can go two ways. Older drivers are more reluctant to accept new technologies (Hancock & Parasuraman, 1992); therefore, it might be possible that they will reject the automation and do not trust it, which in turn leads to an underutilization, referred to as disuse by Parasuraman and Riley (1997). On the other hand, many older drivers are aware of their difficulties and impairments (Musselwhite & Haddad, 2010) as illustrated, for example, by self-imposed driving restrictions (Singh et al., 2007). Thus, they might trust the system more than their own abilities and start over-utilizing the system, relying on and complying with the advice given, a phenomenon referred to as misuse (Parasuraman & Riley, 1997).

Automation in the vehicle can also change how the driving task is perceived and what is demanded from the driver. This may lead to a change in driving behavior. Several studies (Rudin-Brown & Noy, 2002; Rudin-Brown & Parker, 2004; Rajaonah et al., 2006) have investigated the effect of different ADAS on driving behavior. When ADAS is added to the vehicle, drivers often display a behavior termed behavioral adaptation. ‘Behavioral adaptations are those behaviors which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change. Behavioral adaptations occur as road users respond to changes in the road transport system such that their personal needs are achieved as a result. They create a continuum of effects ranging from positive increase in safety to a decrease in safety’ (OECD, 1990, p. 23).
The concept of behavioral adaptation has been investigated thoroughly and many different models have been proposed (e.g. Cotter & Mogilka, 2007; Rudin-Brown & Parker, 2004; Rudin-Brown & Noy, 2002; Saad, 2007; Weller & Schlag, 2003) trying to explain the concept of behavioral adaptation. Each model individually does not capture the magnitude of behavioral adaptation or allow for comprehensive predictions of how ADAS will influence driving behavior and performance. As the Joint Conceptual Theoretical Framework (JCTF) of behavioral adaptation in response to ADAS in Figure 3.1 illustrates, a wide range of internal as well as external factors have been identified that are associated with behavioral adaptation. Processes of behavioral adaptation are influenced by, for example, the type of system studies, but also the HMI design, not to forget drivers’ characteristics as well as the context of use. The framework does not aim to establish interaction mechanism but rather tries to show the multifaceted nature of adaptation processes including behavioral changes as well as psychological processes (Wege et al., 2013). Developing and testing new ADAS also calls for being alert to intentional and/or unintentional changes as a response to ADAS use.

Figure 3.1: Joint Conceptual Theoretical Framework (JCTF) of behavioural adaptation in response to Advanced Driver Assistance Systems (Source: Wege et al., 2013).
Nonetheless, provision of information such as gap size information, speed and headway information, and priority regulation seems to be promising technologies supporting older drivers in negotiating traffic in general and intersections specifically. It might counter difficulties with decision making under time pressure and divided attention. As recent developments show, technology has progressed and such assistance is now realizable. When designing such systems, thorough research is needed so that intended safety benefits are not compromised by unforeseen behavioral adaptation, and that crucial flaws in design and function are identified before systems are introduced into the market.

3.2 Previous research

Systems, such as speed advisory systems, forward collision warning, or intersection assistants, are nowadays technically realizable. Except for intersection assistance, these systems have already been implemented in vehicles in one way or another. An extensive body of research with regard to driving performance, acceptance, and traffic safety can already be found for speed advisory systems. The effects of forward collision warning/safe gap advisory systems on traffic safety have also been studied (Mazureck & Hattem, 2006; Young et al., 2007, Merrikhpour et al., 2012). Intersection assistance has received increasing attention in recent years. In comparison to the other systems, intersection assistance is rather a novelty, so most of the research done so far deals with the technical realization and feasibility of such support system. Nonetheless, a few studies have been administered to test the effects of intersection support system on traffic safety (Staplin & Fisk, 1991; De Waard et al., 1999a; Lee at al., 1999; Hanowski et al., 1999; Caird et al., 2008, Becic et al., 2013). Traffic sign recognition is not a stand-alone system; it is usually coupled with other systems. For example, in newer versions of speed advisory systems, traffic sign recognition is incorporated (Paine et al., 2007; Vlassenroot et al., 2007; Warner & Åberg, 2008). Systems do not have to rely on digital maps anymore to provide information about speed limits and changes in speed, but cameras scan the road ahead for variable message signs (VMS) and the side of the road for traffic signs and convey the information to the driver (Mobileeye, 2014; Hella Aglaia, 2014). Traffic sign recognition may also come into play to improve the effectiveness and efficiency of intersection assistance as it can scan the road for traffic signs that indicate the priority regulation on the upcoming intersection (Mobileeye, 2014; Hella Aglaia, 2014). In the
following section, past research with regard to speed advisory systems, forward collision warning, and intersection assistance is described in more detail.

3.2.1 Intelligent speed adaptation

Intelligent speed adaptation (ISA) systems are in-vehicle devices that inform about speed, warn when speeding, discourage speeding, or prevent speeding (Brookhuis & De Waard, 1999). Those systems are categorized into four types depending on the degree of intervention: (1) informative/advisory, (2) warning/open caution, (3) intervening/supportive, and (4) mandatory/automatic. Informative/advisory speed systems display speed to inform and remind drivers of the speed limit and speed limit changes. Warning systems, also referred to as open caution systems, warn drivers when they exceed the speed limit. With those systems, it is the driver’s responsibility to act upon the warning and reduce speed again. Half-open systems (intervening/supportive speed systems) put upward pressure on the accelerator when drivers exceed the speed limit. The system can be overruled by putting extra pressure on the accelerator. The fourth kind of ISA is a mandatory/automatic system. It fully prevents speeding. Overruling the system is impossible (Morsink, et al., 2006).

As speed plays an important role in the context of traffic safety (Elvik et al., 2004; Aarts & Van Schagen, 2006), speed advisory system are aimed at facilitating speeds within the speed limit (i.e. preventing speeding). A large number of studies has been done to test the effectiveness of ISA (Brookhuis & De Waard, 1999; De Waard et al., 1999a; Várhelyi et al., 2004; Jamson, 2006; Warner & Åberg, 2008; Lai et al., 2010; Young et al., 2010). Even though, in terms of traffic safety, systems that prevent speeding are most effective, the acceptability of these systems is rather low compared to speed adaption systems that are less intervening (Goodwin et al., 2006). The majority of systems tested, in driving simulator studies as well as on-road tests, are informative, advisory, or intervening systems. In general, it was found that ISA decreases speed especially maximum speed and time spent speeding (Vlassenroot et al., 2007; Warner & Åberg, 2008). It was concluded that such systems add to overall traffic safety. On the other hand, most studies investigated young drivers and sometimes middle-aged drivers. The effect of ISA use on older drivers has only been investigated a few times (De Waard et al. 1999a; Guo et al. 2013).
De Waard and colleagues (1999a) investigated an ISA, in a driving simulator study, which informed drivers about speed violations. The information was presented by means of a head-up display (HUD). For the purpose of the study, the speed performance of 18 middle-aged drivers ($M = 37$ years) and nine older drivers ($M = 66$ years) was analyzed. With a repeated measure design, the effects of feedback on speed violations were investigated. Drivers completed a baseline trial followed by two trials with feedback and a last trial without feedback. A decrease in the number of offenses was observed from the baseline trial to both feedback trials. In the last trial (no feedback), middle-aged drivers’ number of speed violation was comparable to the number of offenses during baseline; whereas, older drivers showed a decrease in the number of offenses across all sessions. The time spent speeding also decreased over time. Here again, older drivers showed a decrease across all sessions. Middle-aged drivers, on the other hand, showed a decrease in time spent speeding when the system was active, but the amount increased again during the last trial (no feedback). Overall, middle-aged drivers adapted their behavior as long as the system was active, but fell back into old habits as soon as the system was inactive. In addition, even though effects on speed were found, middle-aged drivers disliked the system. Older drivers were rather pleased with the information provided.

A second study focusing on the speed performance of older drivers in response to ISA was only done recently (Guo et al., 2013) as a follow up of Gou et al. (2010). Guo and colleagues (2010) observed that older drivers experience particular problems with speed compliance in low-speed zones. Speeding was not a deliberate act but rather the result of cognitive impairment and overload in complex situations (Selander et al., 2011). Therefore, in a driving simulator study, the effects of ISA on speed in low-speed zones (50 km/h) were tested investigating the performance of 26 older drivers ($M = 71$ years) and 16 middle-aged drivers ($M = 47$ years). Using a repeated measure design, performance of trials without ISA, an informative ISA, a supportive ISA, and a mandatory ISA were compared. Older drivers showed less lane deviation when driving with the supportive system. Lane deviation was smallest for middle-aged drivers when using the supportive ISA, but differences between groups were not statistically significant. Drivers’ performance in terms of speed was best when equipped with the mandatory ISA. Middle-aged drivers’ mean speed was closer to the speed limit, but they also violated the speed limit more frequently than older drivers. The authors concluded
that ISA should be designed differently for different age groups in order to be effective (Guo et al., 2013).

Investigation of ISA revealed that younger drivers are more likely to deliberately exceed speed limits and systems most effective should discourage speeding. Feedback on legal speed limits only might not be sufficient. More promising are approaches that incorporate warnings when speed is violated but also incentives for compliance with legal speed limits (Mazureck & Hattem, 2006; Merrikhpour et al., 2012). Older drivers, on the other hand, seem to need information on current speed limits and changes in speed limits. Deliberately speeding is not a problem, but rather the extraction of relevant traffic signs in complex situations (Musselwhite & Haddad, 2010), which, in turn, leads to unintentional speeding. According to Emmerson and colleagues (2013), older drivers have a propensity to refrain from driving as soon as they receive a speeding citation.

### 3.2.2 Forward collision warning

Technology advances have evolved so quickly that forward collision warning has never really penetrated the market. It was more or less skipped and forward collision avoidance systems, which actively interfere with the driving task have been implemented as safety systems instead. So, in principle, forward collision warning functions the same way as safe gap advisory systems. Both systems monitor the distance to the car in front and when a driver is on a collision course, the system warns the driver. Systems give feedback, do not interfere with driving, and leave it up to the driver to act upon the warning (Bishop, 2005, pp.121-157). As mentioned earlier, older drivers show limitations in dynamic visual acuity and movement detection (Davidse, 2007). This might lead to misjudging gaps between themselves and the car in front. In addition, older drivers react slower to sudden hazard (Charlton et al., 2005; Caird et al., 2008; Horswill et al., 2008) and, in general, react slower to traffic information due to their decreased information processing speed (Salthouse, 1996). A vehicle, in front, suddenly reducing speed or stopping is a hazard that might not be reacted to in a timely manner even when the driver is not distracted. Lee et al. (2002) found that distracted and undistracted drivers benefitted from forward collision warning. But conclusions drawn are based on the performance of participants between the ages of 25 and 55 years. The effects of a forward collision warning system on the performance of older drivers are not well understood as research lacks a thorough
investigation of older drivers. The few results that exist with respect to headway control are also contradicting.

Andrews and Westerman (2012) investigated time headway performance of 22 drivers between the ages of 26 and 40 years ($M = 33$ years) and 22 older drivers aged 60 years and above ($M = 67$ years) in a simulated car-following task. They found that older drivers kept longer time headway than younger drivers. These results are in line with the general finding that older drivers keep larger gaps between themselves and others maintaining ample safety margins (Summala, 2005, 2007; Middleton et al., 2005; Strayer & Drews, 2004). On the other hand, Ni et al. (2010) found contradicting results. In a driving simulator study, car-following performance under simulated fog conditions was investigated. Performance of eight young ($M = 21$ years) and eight older ($M = 73$ years) drivers was compared. Drivers were instructed to keep a distance of 18 meters to the car in front. They found that with increases in fog density time headway of older drivers decreased. Time headway was smaller for older drivers than for younger drivers. They concluded that in safety critical situation such as dense fog, older drivers’ crash risk increases as safety margins decrease. Without the fog, time headway values were the opposite way for young and older drivers.

Other than these above mentioned studies, efforts have been made to test the effects of feedback and incentives on following distance. In the Dutch project BELONITOR, it was investigated whether online feedback and incentives would improve car following distance. Altogether, 62 participants ($M = 44$ years) who leased a car from a national leasing company could earn rewards when they kept a safe distance to the car in front. Their cars were equipped with the necessary sensors and cameras, which enabled continuously measuring distance to the car in front. When the distance to the car in front was too small, drivers received feedback. The study was comprised of three stages. During the first stage, participants drove four weeks without receiving feedback or rewards. During the second stage, participants received feedback and could earn points for safe driving. This phase lasted for 16 weeks. The third stage also lasted for four weeks alike the first one. Drivers did not receive feedback anymore and could not earn any points for safe driving anymore. Results showed that with the introduction of feedback and the reward system, drivers increased car-following distance. But in phase 3, drivers lapsed back into old habits (Mazureck & Hattem, 2006).
More recently, in Canada, the effects of rewards on safe driving habits were also tested (Merrikhpour et al., 2012). The experimental set-up was similar to the Dutch experiment. It was also subdivided into three stages, but stage 1 and 3 lasted for only two weeks and stage 2 for twelve weeks. Results revealed are in line with results of the Dutch study. While driving with feedback and the reward system, drivers showed an increase in following distance, but the positive behavioral change did not sustain. They even found that long-term use did not result in sustained benefits.

Young et al. (2007), on the other hand, found positive long-term effects on drivers’ following behavior. During an extensive field operational test within the Australian SafeCar project, 23 participants (29-59 years, $M = 44$ years) completed 16 500 km of driving. During that time, they received online feedback on their car-following distance. Unlike the other studies, drivers did not receive incentives for safe driving behavior. Nevertheless, results of the study revealed that drivers increased their mean gap time when receiving online feedback.

Here again, research on older drivers and collision warning is lacking. Even though results show that older drivers keep greater distances to the car in front compared with younger age groups, it is also well-known that older drivers need more time to react to sudden hazard making forward collision warning an attractive support system. Unlike young drivers, unsafe driving habits do not necessarily need to be broken and safe ones learned. Violations of safe following distance are not a general issue within the older driving population, but rather an exception to the rule, especially in too complex situations that require dividing attention and fast reaction. Therefore, forward collision warning might be utilized to detect sudden and unforeseen hazards, compensating for age-related slow information processing.

### 3.2.3 Intersection assistance

Analysis of crash statistics show that older drivers are more likely to be involved in at-fault crashes on intersections and as the literature proves, this fact has been known for decades (Rothe, 1990; Hakamies-Blomqvist, 1993; Preusser et al., 1998; Langham et al., 2002; Clarke et al., 2010). From an engineering standpoint, a lot has been done to develop intersection collision avoidance systems identifying requirements, investigating feasibility, and justifying intersection assistant system in terms of fuel efficiency, travel
time efficiency, but also in terms of safety. From a human factors/ psychological perspective little has been done to investigate whether such support is appropriate for older drivers. But as mentioned earlier intersection assistance might be a promising approach for helping older drivers to safely maneuver through intersections. Only few studies addressed this issue (Staplin & Fisk, 1991; De Waare et al., 1999a; Lee et al. 1999; Hanowski et al., 1999; Louma & Rämä, 2002; Caird et al., 2008; Ziefe et al., 2008; Davidse et al., 2009; Becic et al., 2013). As early as 1991, Staplin and Fisk investigated the effect of advanced left turn information on decision making performance in younger ($M = 37$ years) and older ($M = 71$ years) drivers in simulator studies. Traffic approached intersections either at a speed of 30 mph (48 km/h) or at a speed of 60 mph (96 km/h) and, according to the signal presentation, participants needed to decide whether to go on or stop. The signal presentation was either redundant or non-redundant. Younger and older drivers made more accurate decisions when advanced information was available. They also found that younger drivers better understood the information presented than older drivers and that redundant information was interpreted more accurately than non-redundant information.

In a driving simulator study, De Waare et al. (1999a) investigated the effects of warning about red-light running and stop sign violations on driving performance. Data of 18 middle-aged drivers ($M = 37$ years) and nine older drivers ($M = 66$ years) was analyzed. It was found that red-light running decreased with an activated warning system. The same was true for the number of stop sign violations: stopping behavior improved. Changes were observed for middle-aged and older drivers respectively, even though older drivers appreciated the information more than middle-aged drivers. However, an increase in workload, as a result of the additional information processing, was also noticed.

In a driving simulator study, Lee and colleagues (1999) examined in-vehicle messaging, presented either alone or in combination with traffic signs. The information was presented on the dashboard. They found that older drivers ($M = 74$ years) rated the quality of their own performance equally good as young drivers ($M = 22$ years). Nevertheless, data revealed that older drivers’ performance deteriorated in terms of crashes per hour, lane variability, and speed variability when interacting with the in-vehicle and roadway information. Overall, their performance was significantly poorer compared with young drivers.
Hanowski and colleagues (1999) tested signing, navigation, and warning in-vehicle information systems in an instrumented vehicle on a test track. In this study the information was also presented on the dashboard of the vehicle. A signal informed the driver about an event, such as a car entering the road ahead. The information was presented for 5 seconds. Even though young drivers (18-25 years) reacted faster to events than older drivers (65-75 years), when the information was present, both age groups benefited from advanced information.

Other studies have been performed that have focused on workload and acceptance rather than driving performance as a result of ADAS use. Luomo and Rämä (2002) investigated driver acceptance of traffic signs, which were presented in the vehicle to young (M = 20 years) and older (M = 68 years) drivers. Four different message conditions were tested: (1) visual sign, (2) visual sign and auditory message, (3) visual sign and auditory feedback based on driver behavior, and (4) visual sign in combination with complete instructions. Young and older drivers favored message type (1) the most. Complete instructions were rated the least desirable by both age groups. Participants thought that the given information increased the effects of traffic signs and, therefore, increased traffic safety.

In a driving simulator study, Caird and colleagues (2008) investigated whether in-vehicle advanced warning signs improved young (M = 21 years) and older (M = 69 years) drivers’ intersection performance, especially stopping performance at signal-controlled intersections. Information was presented in a head-up display. They found that, overall, young and older drivers were more likely to stop at the intersection when in-vehicle warnings were given, especially at traffic lights with a relatively short amber-onset. As a result of the presence of the warning, drivers adopted a slower intersection approach speed and removed their foot from the accelerator earlier. Older drivers took more time to perceive and process the information given compared with young drivers, but when the decision was made to stop, they compensated by faster response times (i.e. time in seconds from the foot leaving the accelerator and engaging the decelerator) and higher deceleration rates.

Ziefle and colleagues (2008) investigated driving performance and acceptance of an intersection assistant in a driving simulator experiment. Information about the priority regulation and the traffic density at the upcoming intersection was conveyed to the driver.
Results showed that, overall, older drivers ($M = 62$ years) drove slower through intersections, but their performance in lane tracking did not differ from younger drivers ($M = 27$ years). The driving performance (i.e. speed control and lane tracking) of the group that drove without ADAS was superior to the group that drove with ADAS, indicating that ADAS induced additional workload. Younger drivers were indifferent as to whether the intersection assistant was helpful; whereas, the majority of older drivers rated the intersection assistant as helpful. Despite a driving performance deterioration when the information was presented in the auditory mode (in comparison with the visual mode), older drivers preferred the auditory over the visual interface. Younger drivers did not have a preference for one interface over the other.

In a driving simulator study, Davidse and colleagues (2009) investigated the effect of advanced in-vehicle information on driving performance and workload of 40 drivers categorized according to their functional age: 10 functionally young (chronological age between 30 and 70 years, $M = 39$ years), 20 functionally middle-aged (chronological age between 32 and 71 years, $M = 43$ years), and 10 functionally old subjects (chronological age between 37 and 88, $M = 69$ years). Information about priority regulation, obstructed view on upcoming intersections, safe gaps, and one-way streets were presented to the driver. They concluded that the information conveyed was beneficial for intersection performance. Other traffic approaching the intersection needed less sharp decelerations to prevent collisions, so less hindrance was given to other drivers. Driving speed was lower when participants had to yield to the other traffic and also when they received information about an obstructed view at the upcoming intersection. Participants also made less route errors when they received information about a one-way street that they were not allowed to enter. The beneficial effects of messages on driving performance were similar for younger and older drivers. It was also found that ADAS use did not result in workload reduction. It was concluded that longer experience with ADAS needs to be studied in order to draw conclusion about workload over time.

Becic et al. (2013) tested a Cooperative Intersection Collision Avoidance System- Stop Sign Assist (CICAS- SSA) in a driving simulator. Originally, it was a stationary intersection assistance system (Preston et al. 2004), which was converted into an in-vehicle information system. The system did not warn drivers but presented information about gap sizes to crossing traffic. Crossing performance of 24 older drivers ($M = 62$ years) and 24 young drivers ($M = 22$ years) was assessed. Participants came from a minor
two-lane road and had to cross a four-lane divided highway. Results show, with the intersection assistance systems active, drivers tended to be more conservative. They waited longer before crossing and were more likely to reject non-critical gaps. For older drivers, it was also found that in the dual-task paradigm, they performed worse on the secondary task indicating increased workload.

Overall, the studies summarized above show that an intersection assistant has the potential to support older drivers when crossing intersections. Information given in advance might help drivers anticipating upcoming events and act upon them. An assistant might also help them to react earlier to unexpected events. Acceptance ratings indicate that such functions are appreciated by the driver. Workload measures suggest that systems induce additional demand. Nevertheless, conclusions are based on findings from short-term studies, so no conclusions with respect to what happens to driver performance and driver behavior over time can be drawn.

3.3 Drawbacks, unanswered questions, and the need for further research

ADAS such as speed advisory systems, forward collision warning, and intersection assistance have been investigated in the past and potential benefits on traffic and road safety have been identified. But this field of research is not exhausted, as often older drivers or even mildly impaired older drivers (e.g. drivers with an early-stage diagnosis of PD or AD) have not been considered as thoroughly as young and middle-aged drivers leaving many unanswered questions. As the population grows older and a higher number of active drivers will be 65 years and above in the near future, it is also important to identify strategies that will improve traffic safety of older drivers, also taking into account the great heterogeneity of this age group caused by differences in health and experience.

Even though, intelligent speed adaptation has received a great deal of attention in the past, most research focused on young and middle-aged drivers because speeding is often perceived as a deliberate act within those age groups. Speed is a major contributing factor to road traffic safety, and therefore, ISA has been investigated as it inherits great potential to discourage/prevent speeding. Efforts have been made and long-term field operational tests executed. It was found that ISA reduces speeding, but results are limited to young and middle-aged drivers. Older drivers were not included in those studies, so long-term
effects on their speed performance as a response to a speed advisory system are not well-understood and need to be investigated from a different angle. Research revealed different findings. On the one hand, older drivers are more likely to travel at a too slow pace due to their slower information perception and processing time; therefore, ISA systems could be used investigating whether speed increases when sufficient speed information is provided. On the other hand, older drivers tend to overlook traffic signs, especially in complex traffic situations; therefore, if they speed it might not be a deliberate act that needs to be inhibited but is rather the result of limitations in cognition. Systems that prevent speeding might not be the most suitable for older drivers but rather in-vehicle systems that present information about speed limits and changes in speed limits. In addition, making information about speed more salient (e.g. change of color of the speedometer) might be sufficient support.

Safe gap advisory/forward collision warning has also been investigated in the past, but technology has advanced so quickly that those systems were practically skipped and collision avoidance systems were implemented. Nonetheless, forward collision warning has great potential to improve road traffic safety as long-term field operational tests have shown. Feedback on following distance led to greater distances to the car in front. Incentives also encouraged drivers to keep larger gaps between themselves and the lead vehicle. Here again, most research has considered young and middle-aged drivers, but not older drivers. Even though it is well-known that older drivers, in general, keep greater time headways, they also react later to sudden hazard due to their slower information processing speed. Unlike young drivers, assistance with time headway control should not be viewed as a learning tool, which teaches older drivers to keep a safe distance. It should be viewed as a support system that attracts drivers’ attention before drivers themselves see the danger of a rear-end collision and act upon it in a more timely manner.

Results of studies investigating intersection performance show that intersection assistance improves driver performance and also that it is potentially beneficial for the older driver. All studies have one major drawback: the effects of the system on driver performance, driver behavior and/or workload were assessed in short-term studies. The overall findings were that even though older drivers benefitted from the system, they performed worse than younger drivers (Staplin & Fisk, 1991; Lee et al., 1999; Hanowski et al., 1999; Caird et al., 2008; Ziefle et al., 2008; Becic et al., 2013). Results of workload ratings also indicate that systems induce workload rather than reduce the mental effort (De Waard et
al., 1999a; Ziefle et al., 2008; Davidse et al., 2009; Becic et al., 2013) However, short-term studies do not provide an opportunity the older drivers to get acquainted with the system and the new environment. It is also well-established that older drivers are able to learn new and complex tasks, only at a slower pace than young drivers. Performance of older drivers is poorer than of younger drivers, especially in complex new situations, while in routine situations the difference between younger and older drivers is much smaller (Lowe & Rabbit, 1997). So, initial differences might diminish over longer periods when the new task is learned. Drawing conclusions on a single assessment might be erroneous. Differences in performance between young and old and the impact on safety should be investigated in longer-term studies as short-term studies cannot answer several important questions with respect to the overall benefit to road traffic safety. Longer-term exposure to ADAS might result in more positive effects for the older driver. Depending on the degree of impairment, ADAS might be beneficial for drivers with impaired executive functions. Showing mild impaired executive functioning means that more practice might be needed to show favorable effects. So most likely benefits of ADAS on performance might be reflected later in time and perceived mental effort might persist for a longer period of time.

Little is known about how ADAS use changes driving behavior over time and whether behavioral adaption is different for young and older drivers. Testing participants in a longer-term study and acquainting them with the system over numerous consecutive sessions may reveal whether the particular ADAS leads to further positive or negative effects. In this light, it is also important to study what happens when ADAS is taken away from the driver after a longer period of usage (i.e. whether carry-over effects can be observed). Trust and acceptance play an important role when it comes to the appropriate use of ADAS. Long-term studies allow changes in those ratings to be detected which, in turn, might lead to changes in ADAS use.

Another question that cannot be answered is whether intersection assistance is beneficial for all age groups. Often it is argued that whatever helps older drivers will also support young drivers. Such conclusions are also drawn on the basis of a single assessment and might only show that young drivers learn faster than older drivers and do not allow conclusions to be drawn about added safety benefits. Young drivers experience different problems in traffic than older drivers. Helping them to cross an intersection might be
inappropriate because it is well within their capacities to do so safely, and therefore, they might receive support that is not needed. This may lead to unsafe attention allocation if crossing an intersection becomes too easy so that young drivers allocate attention to other tasks not related to driving. On the other hand, implementing an intervening system that discourages/prevents speeding actively might be more beneficial for young drivers than for older drivers. A great amount of severe crashes in the young age group results from inappropriate and high speeds. Forward collision warning/safe gap advisory might be technologies that serve as tutoring systems for young drivers teaching them safe following distance or as systems that detect sudden hazards and enables older drivers to react faster to it. ADAS might add significantly to road traffic safety but might also need to be investigated from different angles for different age groups as each age group has its unique characteristics.

Because many questions cannot be answered from short-term studies, more extensive research is needed to assess the magnitude of ADAS use, the effectiveness and efficiency of different ADAS functions and driving performance and behavior, and in how far this kind of support is beneficial or detrimental for various age groups.

### 3.4 Experimental set-up

Because currently marketed ADAS are not necessarily designed to fit the needs of older drivers a more tailored ADAS was designed and tested in a longer-term driving simulator study. Successively, data of different groups were collected. In a first phase, data of 18 healthy older drivers between the age of 65 and 82 years were collected. Drivers were randomly assigned to either the control or treatment group and performance of those groups compared. In a second phase, 18 young drivers between the age of 20 and 25 years were recruited and the effects of ADAS tested and compared to healthy older drivers. Young drivers followed the same protocol as older drivers but completed only the first eight sessions of the experiment (see Figure 3.2). Here again, drivers were randomly assigned to a control and treatment group. For the last experiment, a group of drivers diagnosed with Parkinson’s disease between the age of 67 and 82 years was recruited and the effects of ADAS use on performance tested and compared to healthy older drivers, who received the same treatment.
The study was a mixed study design with 13 or 14 repeated measures depending on the manipulation. Within four weeks, groups completed twelve consecutive sessions in the driving simulator. Drivers assigned to the control group, completed all sessions without ADAS. Drivers of the treatment group completed sessions 1 and 7 without ADAS and the remaining ten sessions with ADAS. After the first 12 sessions, participants took a four week break and then return for the final assessment. Drivers of the control group completed one session after the break and drivers of the treatment group two sessions: one with ADAS and one without. The order of the final assessment was counterbalanced across subjects.

The virtual driving environment was comprised of a 25 km city drive. Route instructions on when to turn left and right were given visually and auditory through a navigation system. In order to avoid learning effects, four different routes comparable in length and events were used and counterbalanced across participants. Drivers encountered various driving tasks such as changes in priority regulation, variations in speed limits, and slower moving lead vehicles.

3.5 Proposed ADAS

A tailored ADAS, designed to fit the needs of older drivers, was proposed, implemented, and tested in a driver simulator study. The ADAS provided relevant traffic information in advance. In more detail, the support system consisted of four functions: (1) in-vehicle traffic sign display, (2) speed advisory, (3) intersection assistance, and (4) forward collision warning. All information was presented by means of a head up display (HUD).
Head up displays have been used in the field of aviation for decades and have recently been introduced into (top-segment) vehicles as well. For the presentation of relevant traffic information, a head-up display is more favorable than a display positioned in the center column or in a head-down display (HDD). An HDD or display in the center column of the vehicle forces drivers to glance into the vehicle in order to extract important traffic information. Therefore, drivers have to take their eyes off the road creating undesirable distraction potential (Green, 1999). This can lead to late detection of other road users, obstacles, and hazardous situations (Louma & Rämä, 2002). An HUD removes the necessity to look into the vehicle to extract relevant traffic information as this information is projected onto the road, in form of transparent icons, in front of the driver.

3.5.1 Traffic sign recognition

Traffic sign recognition has already been introduced into vehicles, but is mostly limited to recognizing speed limit signs. In vehicles, the side of the road is scanned by means of cameras. When a traffic sign is recognized, it is compared to signs saved in a database. When a match is found, the traffic sign is shown to the driver in the instrument panel or on an HUD. In principle, the same notion is used for the implemented traffic sign recognition function. The side of the road is scanned for traffic signs, compared to signs in the database, and if a match is found, conveyed to the driver.

Figure 3.3: Illustration of the in-vehicle traffic sign recognition. The side of the road is constantly scanned for traffic signs. In the vicinity of intersections, speed limit information is replaced with priority regulation information.
Figure 3.3 and 3.4 illustrate how traffic sign recognition is realized in the simulator. When a driver approaches an intersection and is within a distance 150 meters to the intersection, traffic signs with regard to priority regulation have priority over speed limit signs. The information about speed limits is exchanged for information about priority. After an intersection is crossed, drivers are immediately informed about the speed limit again. The information about the speed limit remains on the HUD until the next intersection is reached. When the distance to the intersections is less than 150 meters, the information in the HUD changes again showing the priority regulation traffic sign instead of the speed limit sign as this is more important at that point in time.

3.5.2 Speed advisory

In principle, speed advisory systems are coupled with traffic sign recognition. Speed limit signs are recognized. At the same time, traveling speed is monitored. When the system detects that a driver is speeding, the driver receives a warning. Warnings can range from visual to haptic warnings. The same approach is used for the implemented ADAS. Current speed is compared to posted speed limits and drivers receive visual warnings.

Figure 3.4 illustrates a situation in which the posted speed limit is 70 km/h. The driver complies with the speed limit, and therefore, the digital speedometer in the HUD is lit up in green. Figure 3.5 shows two examples of exceeding the speed limit. The figure on the left shows a driver who set his traveling speed to 78 km/h and, therefore, the speedometer is presented in amber. In the illustration on the right, speed is set to 84 km/h and the speedometer is lit up in red. The different colors serve as an indication for the degree of exceeding the speed limit. The speedometer changes from green to amber when the speed
limit is exceeded by more than 10%. Exceeding the speed limit even more and reaching a value that is greater than 15% results in the presentation of the speedometer in red. When speed is reduced again and a driver complies with the speed limit again, the speedometer changes back to green.

![Figure 3.5: Illustration of the implemented speed advisory system. Left: When speed is exceeded by more than 10% of the posted speed limit, the speedometer changes color from green to amber. Right: Exceeding the speed limit by more than 15% of the posted speed limit, the speedometer color changes to red.](image)

### 3.5.3 Intersection assistance

The intersection assistant detects surrounding traffic and provides information about approaching traffic at the upcoming intersection. The information about whether it is safe to cross the intersection is presented in form of a bar in front of the driver below the digital speedometer (see Figure 3.6). It is a three-stage system that dynamically changes from green to amber to red depending on the distance to crossing traffic and vice versa as traffic at intersections changes.

The priority regulation at the intersection and the traveling direction (as indicated by activation/deactivation of the indicator) of the driver are taken into account by the assistant system. Therefore, the intersection assistant also utilizes the traffic sign recognition function in order to determine the priority regulation at the intersection.

For example, a driver wants to turn right at the upcoming intersection, which is also implied by activation of the indicator. At the intersection, drivers need to yield to the crossing traffic. The assistant takes that information into account and disregards traffic approaching the intersection from the right. Advice on safe gaps is with respect to crossing traffic approaching the intersection from the left. When the gap between the
driver and the approaching car is greater than five seconds a green bar lights up indicating that it is safe to cross. Gaps between 2.5 and five seconds are classified as marginal indicated by an amber flag, and gap sizes smaller than 2.5 seconds are unsafe as conveyed by the red flag. In order to calculate gaps and give advice on whether to proceed through the intersection, the driver’s time-to-intersection (TTI) and time-to-collision (TTC) with crossing traffic are taken into account. TTI and TTC values are based on course, speed, and distance.

![Figure 3.6: Illustration of the implemented gap advice. The bar below the digital speedometer indicates whether the distance to the crossing traffic is safe.](image)

### 3.5.4 Collision warning

The so called 2-second-rule serves as a rule of thumb, in the Netherlands and many other European countries, to keep a safe following distance. Meaning that when following another car two seconds need to lie between a defined passing point of the first and the second car. With the help of the collision warning function, the distance between the driver and the car in front is constantly measured. Based on speed and distance between cars, time headway is calculated. When the distance becomes too small, and the time headway value falls below two seconds, an icon as seen in Figure 3.7 (left) will appear in the HUD advising the driver to increase the distance. When time headway is greater than two seconds again, the icon will disappear. But when the following distance gets even smaller and falls below one second, the driver will be warned that a collision is about to happen (see in Figure 3.7, right).
3.5.5 Overview of projected information

The table below provides a brief overview of the information selected to be presented in the HUD. Information about priority regulation was limited to right-of-way traffic sign, yield and stop sign. Speed limits in the virtual environment changed between 30 km/h, 50 km/h, and 70 km/h. Warnings on close following distance where presented in two different ways depending on how close drivers followed the lead vehicle. A three-stage system was used to provide information about gap sizes to crossing traffic.
Table 2.2: Overview of projected information/icons

<table>
<thead>
<tr>
<th>Icon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Traffic signs" /></td>
<td>Traffic signs with information about priority regulation are projected onto the HUD when an intersection is approached and drivers distance to the intersection is smaller than 150 meters.</td>
</tr>
<tr>
<td><img src="image2" alt="Speed limits" /></td>
<td>After an intersection is passed information about the legal speed limit is projected onto the HUD. This information remains in the HUD until the next intersection is approached.</td>
</tr>
<tr>
<td><img src="image3" alt="Headway" /></td>
<td>This icon appears in the HUD when time headway to the car in front drops below 2 seconds requesting drivers to increase their following distance.</td>
</tr>
<tr>
<td><img src="image4" alt="Collision" /></td>
<td>With this icon drivers are warned that a rear-end collision is about to happen. It lights up when the following distance becomes too small and time headway drops below 1 second.</td>
</tr>
<tr>
<td><img src="image5" alt="Crossing advice" /></td>
<td>These bars give advice on whether crossing an intersection is safe. If the gaps size to the crossing traffic is greater 5 seconds, the green flag will light up. If the gap to the crossing traffic is between 2.5 and 5 seconds, the amber bar indicates that crossing is critical. The red flag indicates that the distance to the crossing traffic is unsafe for crossing. Red lights up when the gap to crossing traffic is smaller than 2.5 seconds.</td>
</tr>
</tbody>
</table>