Longer-term effects of ADAS use on driving performance of healthy older drivers and drivers diagnosed with Parkinson’s disease
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The aim of the studies was to gain more insight in the effects of ADAS use on driving performance of young and older drivers and drivers diagnosed with Parkinson’s disease. As currently marketed ADAS are not necessarily designed to accommodate the needs of older drivers an ADAS was proposed more suitable to the unique characteristics of older drivers. Drivers received information about traffic signs, particularly priority regulations and speed limits, and about gap sizes to crossing traffic in intersections. They were also warned when they exceeded the speed limit too excessively or followed another car too closely. Also longer-term effects of the ADAS on acceptance and trust as well as driving performance and behavior were investigated in a driving simulator.

In a consecutive manner, data for different groups of interests were collected. In the first phase, data of 18 older healthy drivers between the ages of 65 and 82 years were collected over a period of two months. In a second phase, 18 young inexperienced drivers between the ages of 20 and 25 years were recruited. For young drivers, data collection was limited to the first eight sessions of the experiment due to time constraints but also to minimize chances of drop-outs. Data was collected over a period of three weeks. Because little is known about the effects of ADAS use on driving performance of patient groups, nine drivers diagnosed with Parkinson’s disease (PD) between the ages of 68 and 82 were recruited and data of 14 consecutive sessions collected. In the end, data of 45 participants in 513 sessions of approximately one hour each were collected. In sum: three treatment groups were created, one consisted of healthy older drivers, one of young inexperienced drivers, and a third one of drivers diagnosed with PD, and one control group of nine older and nine young drivers who completed all sessions without ADAS.

Changes in driving performance and subjective ratings in response to ADAS use were investigated with respect to effects of short-term and longer-term practice, but also with respect to ADAS removal after completing several consecutive sessions with ADAS. Of interest were within-group changes over time but also differences between groups, especially differences between age groups, control and treatment groups, and healthy older drivers and drivers diagnosed with PD. Subjective ratings, performance on intersections, and speed and headway control (for a detailed description of dependent measures see Table 8.1) were used to assess driving behavior and performance over time. In the following sections results obtained during the studies for healthy older drivers, drivers diagnosed with...
PD and young inexperienced will be discussed drivers aiming to provide a comprehensive overview of the results.

Table 8.1: List and summary of dependent measures used in the previous studies.

<table>
<thead>
<tr>
<th>Subjective Ratings</th>
<th>SHAPE Automation Trust Index (SATI, Dehn, 2008): rating trust in the system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trust</td>
<td>six items with regard to reliability, accuracy, understandability, confidence, liking, and robustness were answered utilizing a 7-point Likert scale ranging from 0 (never) to 6 (always)</td>
</tr>
<tr>
<td></td>
<td>completed by treatment groups after each session that was done with ADAS</td>
</tr>
<tr>
<td>Acceptance</td>
<td>Acceptance scale (Van der Laan, 1997): rating acceptance of the separate functions (traffic sign recognition, speed advice, gap advice, collision warning)</td>
</tr>
<tr>
<td></td>
<td>2 dimensions: usefulness and satisfaction (altogether 9 items) were rated on a 5-point Likert scale</td>
</tr>
<tr>
<td></td>
<td>completed by treatment groups after each session that was done with ADAS</td>
</tr>
<tr>
<td>Workload</td>
<td>Rating Scale Mental Effort (RSME, Van Zijlstra, 1993): indicating how demanding a session was experienced</td>
</tr>
<tr>
<td></td>
<td>one dimensional scale ranging from 0 -150</td>
</tr>
<tr>
<td></td>
<td>completed by all groups after each session</td>
</tr>
</tbody>
</table>

Performance on intersection*

*Intersections at which participants had another car in front of them were excluded from analyses, as behaviour may have been affected or restricted by that lead vehicle

<table>
<thead>
<tr>
<th>Intersection time</th>
<th>average sum of waiting time (velocity = 0 km/h) and crossing time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>calculated for intersections with a speed limit of 30 km/h and a priority regulation of yield-to-the-right</td>
</tr>
<tr>
<td></td>
<td>8 intersections with obstructed view (bushes along the road) and 8 intersections with clear view into the intersection</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>average of maximum speed values of intersection crossings</td>
</tr>
<tr>
<td></td>
<td>recorded for intersections with and without view obstruction separately</td>
</tr>
<tr>
<td></td>
<td>measured 12 meters before the intersection midpoint and 12 meters after</td>
</tr>
<tr>
<td>Percentage of stops</td>
<td>number of stops before crossing an intersection in percent</td>
</tr>
<tr>
<td></td>
<td>a stop was defined as approach speed between 0 and 1 km/h within the 12 meters to the intersection midpoint</td>
</tr>
<tr>
<td></td>
<td>stops were recorded separately for intersections with and without obstructed view, eight stops per session and intersection type was maximally possible</td>
</tr>
<tr>
<td>Collisions</td>
<td>recorded for each group throughout the experiment</td>
</tr>
<tr>
<td></td>
<td>categorized into intersection crashes and other crashes as well as driver being at-fault or not at-fault</td>
</tr>
<tr>
<td>Absolute minimum TTC</td>
<td>one value out of a maximum of eight minimum TTC values per intersection type</td>
</tr>
<tr>
<td></td>
<td>extracted TTC values were limited to data of participants entering and...</td>
</tr>
</tbody>
</table>
Percentage of critical crossings

= number of crossing with a TTC to crossing traffic smaller than one second in percent

- out of possible eight crossing per intersection type

Gaze behavior

= the percentage of gaze that falls within the area of the road center (PRC, Victor et al., 2005)

- gaze data analyzed included the gaze behavior for approaching the intersection (approximately 160 meters) and crossing the intersection (approximately 24 meters).
- videos were coded using ELAN, a tool used to annotate videos (Max Planck Institute for Psycholinguistics, 2013; Lausberg & Sloetjes, 2009)
- gaze was coded as center, left, right, or other.
- value of PRC was the cumulative time of fixation in the center over the total time

Speed and headway control

Maximum speed

= highest speed within predefined sections with posted speed limits of either 50 km/h or 70 km/h

- each section was of approximately 2000 meters
- no cars in front of the participants

Percentage of driving time spent speeding

= “total driving time of exceeding the speed limit” by “total driving time needed to complete sections”

- speeding was defined as traveling at a speed 10% greater than the posted speed limit within the same predefined sections

Minimum time headway

= smallest following distance in car-following task

- THW values extracted for sections with a speed limit of 50 km/h and a vehicle with varying speed in front of the participant
- approximate length: 2000 meters

8.1 Healthy older drivers

8.1.1 Performance in intersections

In healthy older drivers, usefulness and satisfaction ratings of the gap advice system were rather low. Mean ratings did not differ significantly from a neutral rating of zero. Results of acceptance ratings alone, suggest that the advice provided was not accepted. At the same time, changes in objective driving parameters were noticed, which are in contrast with this suggestion. It was observed that drivers of the treatment group decreased their intersection
time (i.e. the average sum of wait and cross time). Because cross time can only vary so much, changes in intersection time are mainly the result of changes in waiting in the intersection before crossing. This coincides with the observed decrease in percentage of stops before crossing. Because those changes were not observed for drivers of the control group (see Chapter 4), changes in performance might be the result of ADAS use. Results of the gaze analysis support this assumption. Drivers of the treatment group spent significantly more time looking at the road center than drivers of the control group. They retrieved relevant information about crossing traffic from the HUD instead of looking left and right in the intersection. This behavior might jeopardize traffic safety in a direct way but also in an indirect way. A system failure or inaccurate presentation of information should be an exception to the rule, but when such an event takes place reliance on the presented information might turn out to be fatal, a phenomenon referred to as overreliance (see Parasuraman & Riley, 1997). More direct consequences of overreliance on the information might be an increase in the number of critical crossings and very small TTC values to crossing traffic which in turn put drivers at risk. Time-to-collision data reveal that drivers of the control group made more conservative crossing decisions than drivers of the treatment group as reflected in greater TTC values, fewer critical crossing, and more safe crossing (according to van der Horst (1991) a TTC value to crossing traffic greater than 1.5 seconds is considered safe). One would assume that making more conservative decisions leads to safer driving performance. According to our data, this is not necessarily true. Using the number of collisions as the most crucial safety indicator, drivers of the control group were not as safe as drivers of the treatment group. Control group drivers caused three crashes in intersections; whereas, treatment group drivers did not cause any crashes. Another difference between groups was also seen in maximum speed. Differences in maximum speed between the control group and the treatment group were not found, but medium effects (Chapter 4) were revealed. Treatment group’s maximum speed in intersection was higher. It leads to the speculation that higher speeds might have made the difference when it came to collision avoidance: a strategy to compensate for critical crossing decisions.

At the midpoint of the twelve consecutive sessions, the treatment group completed a session without ADAS. At this point, five consecutive sessions with ADAS were already completed. Overall, healthy older drivers’ performance did not appear to be affected by the removal of the ADAS. No changes could be recorded for any of the driving performance parameters, but the gaze behavior of the treatment group was different from the control
group as well as young inexperienced drivers, and drivers diagnosed with PD (see Appendix B) in session 7. Gaze allocation between older drivers of the treatment group and the control group differed significantly in session 7 (Chapter 4): an alarming change. It was observed that drivers’ attention allocation in session 7 (session without ADAS) to the road center (PRC) was higher than the PRC of the control group and higher than their PRC in session 1 (baseline session). This might be a negative carry-over effect, having difficulty with suppressing the new learned behavior. In addition, removal of ADAS also did not result in an increase of intersection time. In session 7, drivers were as quick in crossing intersections as in other sessions with ADAS. We cannot state with certainty that the reduced glances to the left and right and short intersection time indicate greater risk. It might be the case that during sessions with ADAS, drivers learned to retrieve information from the surrounding more effectively and efficiently.

8.1.2 Speed and headway control

Acceptance ratings of the traffic sign recognition function and the speed advisory function indicate that healthy older drivers appreciate that type of support. Their average usefulness and satisfaction ratings differed positively from a neutral rating of zero (see Appendix A). In sections with posted speed limits of 50 km/h, the effectiveness of speed advisory and traffic sign recognition is in question. Drivers of the treatment group had a significantly higher maximum speed and spent more time speeding than the control group. Selander and colleagues (2011) found that older drivers tend to speed in low speed zones, but rather than being a deliberate act, it is the result of cognitive impairment and overload in complex situations. So, one possibility could be that ADAS induced workload creating a complex and cognitively demanding traffic situation. Based on workload ratings, this is not a likely explanation. An alternative explanation that speed advice makes the driving task easier might be more likely. Having the additional information presented in the HUD might free resources to the extent that the driving task at hand becomes too easy and drivers start traveling faster and exceeding the speed limit to reach an optimal level of workload again. As these effects on speed were only found for sections with a speed limit of 50 km/h and not for 70 km/h, there might be a ceiling effect to such behavior and traveling 70 km/h might already require all available resources again preventing excessively exceeding the speed limit in higher-speed zones.
Results of the car-following task in sections with a speed limit of 50 km/h also support the assumption that the task at hand was quite easy. Despite the fact that older drivers of the treatment group did not welcome the collision warning function (see Appendix A) and might have ignored warnings, following distance also closely relates to workload (Lewis-Evans et al., 2010). Drivers of the treatment group settled for shorter following distances than drivers of the control group. The close following distance might again serve as an indication of low cognitive demand. Workload ratings confirm the assumption of not perceiving the task as demanding.

8.2 Drivers diagnosed with Parkinson’s disease

8.2.1 Performance in intersections

Drivers diagnosed with PD were very positive about the gap advice function as indicated by their usefulness and satisfaction ratings (see Appendix A). Their ratings differed significantly from the test value of zero (indicating neither acceptance nor rejection). Driving performance parameters revealed that drivers diagnosed with PD decreased their intersection time. Unlike healthy older drivers, drivers diagnosed with PD decreased their intersection time, but not their percentage of stops before crossing an intersection. Lower intersection times are mainly due to shorter wait times before crossing. It appears that drivers became less hesitant and more confident over time accepting gaps earlier. An analysis of gaze data (see Appendix B) also suggests that drivers diagnosed with PD used the information about crossing traffic presented in the HUD to make a decision on crossing. In sessions completed with ADAS, the percentage of gazes that fell onto the road center was higher compared with the baseline session and session 7 (without ADAS). But unlike healthy older drivers, the allocation of attention in session 7 did not differ from the baseline session (as it was also observed in young drivers). In addition, the overall allocation of gaze to the road center was significantly lower for drivers diagnosed with PD compared with healthy older drivers of the treatment group.

In contrast to healthy older drivers of the treatment group, maximum speed in intersections did not increase in the PD group. It might be that, overall, drivers diagnosed with PD made safe crossing decisions based on the advice received. As it was for healthy drivers of the control group, drivers diagnosed with PD made more conservative crossing decisions than healthy older drivers of the treatment group. Their minimum TTC value to crossing traffic
was greater and the number of critical crossings smaller. Nonetheless, drivers diagnosed with PD caused four crashes in intersections. According to the data, drivers diagnosed with PD engaged less frequently in safety-critical maneuvers, but when a critical situation occurred they might have not been able to react in a timely manner and apply a corrective plan of action. Their cognitive and motor impairments might have contributed to the crashes. In addition to impairments in executive functioning (Ranchet et al., 2013), motor impairments such as akinesia, hypokinesia, and bradykinesia are characteristic symptoms of Parkinson’s disease (Marsden, 1989; Richard et al., 2004). Because of these impairments, it is often difficult to stop or adjust an ongoing movement. The gap advice lit up green when it was safe to cross an intersection. This concept is known from the traffic light. When a traffic light turns green, it signalizes drivers to go. This action is than initiated and executed. In our case, drivers might have seen the green light which in turn triggered and initiated their action plan of crossing the intersection. As a sudden hazard occurred, while executing their action plan of crossing an intersection, they might have seen the change in the current traffic situation, but because of difficulties of inhibiting one behavior, initiating and executing another plan of action, it might have not been realizable within the given time frame to apply an corrective movement such as braking or accelerating quickly.

8.2.2 Speed and headway control

Besides the gap advice, drivers diagnosed with PD were also very pleased with the speed advisory function and the traffic sign recognition function (see Appendix A). Speed information such as average speed, maximum speed, and time spent speeding was used to assess the effect of presenting information on driving performance. Two changes were observed for drivers diagnosed with PD. The desirable change observed was an increase in average speed. Musselwhite and Haddad (2010) found that older drivers tend to drive under the speed limit in order to seek relevant information such as speed limit signs. Lower traveling speed gives drivers more time to perceive and process information. Information about speed limits and current speed might have provided drivers with the opportunity to concentrate more on the driving task because they did not need to scan the environment for speed limit signs and also did not need to monitor their current speed too closely. An undesirable change observed was an increase in time spent speeding. The observed increase in driving time spent speeding might have resulted from being more familiar with the traffic environment and simulation. Charlton and Starkey (2013) found that as drivers become more familiar they tend to speed. Considering that their maximum speed was lower
than that of older drivers of the treatment group (Chapter 7), it is more likely that changes resulted from impairments of motor functions. Provision of information might have offered drivers the opportunity to increase their speed. As a result, drivers diagnosed with PD might have engaged the accelerator, but were not able to reverse the movement in a timely manner in order to avoid speeding.

In contrast to healthy older drivers, removing ADAS in session 7 after completing five consecutive sessions with ADAS had an effect on speed control. Average speed, maximum speed and time spent speeding were affected: increases in those dependent measures were observed in session 7. It appears that drivers diagnosed with PD utilized the information about speed limit and current speed as the effect was reversed again in session 8. The change observed in variables might reflect drivers’ inability to scan the environment for relevant traffic information due to cognitive overload and/or attentional limitations. As drivers’ diagnosed with PD also experience more problems with memory (Lee et al., 2010) and knowledge consolidation (Muslimovic et al., 2007; Ros et al., 2013) compared with healthy controls, this might further contribute to the effects found. The virtual environment comprised reoccurring distinguishable infrastructural features. For example, roads with speed limits of 70 km/h were always double carriageways and roads with a speed limit of 50 km/h were comprised of single carriageways: information that might have not been utilized by persons diagnosed with PD. Drivers diagnosed with PD might have not been able to recall those details due to memory problems or they might have not even been able to observe those details because they were busy with the driving task itself.

Drivers diagnosed with PD were the only ones who appreciated the collision warning (see Appendix A). Their usefulness and satisfaction ratings differed positively from zero. In addition, drivers diagnosed with PD kept the greatest distance between themselves and the car in front. This might be because they followed the advice and kept a long distance to the car in front. On the other hand, as following distance relates closely to perceived demand (Lewis-Evans et al., 2010), the distance to the car in front might also reflect that. After the midpoint of the experiment, an increase in workload was observed for drivers diagnosed with PD. This observation is in line with the observed larger following distance. Because of their impairment of motor functions, drivers might have adjusted their following distance to it. If a driver needs more time to release the accelerator and engage the brake pedal, this ideally should be reflected in a larger following distance (van Winsum and Brouwer, 1997).
It also suggests that our participants diagnosed with PD accurately assessed their abilities and adjusted their actions to it.

8.3 Young inexperienced drivers

8.3.1 Performance in intersections

According to the usefulness and satisfaction ratings of the gap size function (see Appendix A), young drivers’ mean ratings did not differ significantly from the test value of zero (indication of neither acceptance nor rejection), meaning that the advice on gap size to crossing traffic was neutral and not deemed needed. At the same time, objective measures such as percentage of stops before crossing an intersection and gaze behavior tell a different story. According to the analysis of the number of stops before crossing an intersection, young drivers of the treatment group showed a significant decrease in the number of stops over time, especially in intersections with view obstruction. Because bushes were placed along the intersection, it was impossible to detect crossing traffic in the periphery while approaching the intersection. Drivers needed to slow down and even stop before making a sound decision on crossing. Gaze data show that, when driving with ADAS, participants retrieved their information about crossing traffic in form of gap size information from the system instead of looking left and right in the intersection. The percentage of time spent looking at the road center while approaching an intersection was significantly higher in sessions completed with ADAS. How this behavior affected traffic safety directly, is reflected in safety indicators such as number of collisions, minimum time-to-collisions, and number of critical crossings. For young drivers, neither the minimum TTC value nor the number of critical crossings differed. For both groups, even a decrease in the percentage of critical crossings was observed in both types of intersections, but drivers of the control group were involved in six at-fault crashes in intersections. For the treatment group, only one such crash was observed. The number of crashes suggests that young driver of the treatment group were safer than young driver of the control group. Groups’ exposure to risk was similar as indicated by similar frequencies of critical crossings and minimum TTC to crossing traffic, but it seems that drivers of the treatment group were able to avoid collisions. Differences in the number of collisions might be due to the information on safe and unsafe gap sizes. This information might have helped drivers making a sound crossing decision. Choosing the right gap is a matter of experience. As young drivers lack driving
experience, gap selection might be a hazardous situation and the system might have supported drivers with the task successfully.

### 8.3.2 Speed and headway control

Surprisingly, young drivers’ acceptance ratings of the speed advisory system differed significantly from zero (see Appendix A). Measured on a scale from -2 to 2, the average usefulness rating came out to 1.11 ($SD = .97$), and the satisfaction rating to .74 ($SD = .87$). Results indicate that drivers perceived the advice as useful and were satisfied with it. At the same time, results of speed data are in contrast with subjective ratings. Young drivers, regardless of treatment, showed an increase in maximum speed as well as driving time spent speeding (see Appendix C) indicating that drivers of the treatment group either ignored the speed advice or used it in a way not intended (i.e. driving within the margins used to classify speeding). What was found is in line with Charlton and Starkey (2013) who saw that when drivers become familiar with a route they tend to speed. It is also in line with findings that drivers speed within enforcement tolerances (Fleiter & Watson, 2006). Speeding was defined as exceeding the speed limit by more than ten percent. At the same time, the speed advisory changed its color from green to amber and to red when the legal speed limit was exceeded by more than 15%. Red is a color that indicates danger in many different situations. Inside the vehicle, we can find several examples utilizing red to indicate danger. When a driver runs out of fuel, he/she reaches the red zone of the fuel gauge or when accelerating without changing gears, the red zone of the RPM gauge is reached. Outside the vehicle, red is not only used for traffic lights, but also for signs expressing prohibition. The red zone is something drivers might want to avoid; therefore, they speed but only within the amber zone. The speed advisory system might be helpful to young drivers but not as initially intended to prevent speeding, but to stay within enforcement tolerances.

As mentioned earlier, following distance and workload relate closely (Lewis-Evans et al., 2010). Results of young drivers’ minimum distances to the car in front may suggest that the driving task was too easy for them. Their minimum THW values were smaller than those of healthy older drivers and drivers diagnosed with PD. On average, their minimum THW was one second and below indicating that warnings about close following distances were ignored. Acceptance ratings support the assumption. According to these results, advice on following distance was not appreciated.
8.4 General discussion

As the previous section showed, whether ADAS was beneficial cannot be easily answered with yes or no. Results are manifold and need to be considered differentially for age and impairment. A change seen in older drivers and drivers diagnosed with PD was a decrease in intersection time. Changes in intersection time suggest that drivers do not wait as long on intersections anymore before they decide to cross. Shorter wait times at intersections may improve efficiency and traffic flow. If an otherwise hesitant driver starts to take earlier gaps, a queue of waiting traffic might be minimized or even avoided, granted that an earlier gap did not lead to a crash. In addition, value to road traffic safety might also be added, because drivers might not wait “unnecessarily” long anymore before they cross an intersection. Sitting behind a hesitant driver and perceiving gaps to crossing traffic as long enough might provoke impatience. As a result of impatience, a driver might put pressure on the driver in front by honking and gesturing that he/she needs to cross. This might lead to making an unsafe crossing choice. Impatient drivers might also try to pass the waiting vehicle or cross quickly but dangerously after the slower moving vehicle. In that sense, gap advice might add positive value by minimizing uncertainty and hesitation in otherwise longer waiting drivers and minimize potential impatience of following traffic. In either case, hectic and/or unsafe crossing decisions might be reduced.

Using the number of collisions in intersections as the safety indicator, we might also conclude that ADAS added value to traffic safety. Young and older drivers of the treatment groups caused fewer crashes than control group drivers. Because this pattern was not only observed for one age group, it appears that the advanced information about crossing traffic might have prevented crashes from occurring. Seeing this trend in young and older drivers, suggests that the advanced information might have also prevented crashes in the group of drivers diagnosed with PD.

Changes in driving performance and behavior were also observed that might have jeopardized road traffic safety. Especially for young and older drivers of the treatment groups, fewer stops before crossing an intersection, in intersections with view obstruction, were observed. It indicates that drivers relied on the advice on gap size to crossing traffic. Higher concentration of gaze on the road center confirms the assumption and suggests that drivers followed the advice without confirming the accuracy of the information. This, in addition to low minimum TTC values and a higher frequency of the number of critical
crossings, suggests risky behavior and mitigating effects on traffic safety. The benefits of ADAS are questionable for those groups. Also, excessive speed, short time headway, and low workload ratings observed in those groups suggest that the driving task at hand was too easy. In their case, the high gaze concentration on the road center, is not interpreted as high demand or not having enough time to survey the surrounding. It seems that in their case, an undesirable behavior was provoked. They misused and abused (see Parasuraman & Riley, 1997) the information provided. Even though, drivers diagnosed with PD also showed a high concentration of gaze in the road center when driving with the ADAS, driving performance parameters as well as workload ratings, on the other hand, indicated high demand. According to their data, the driving task at hand was not too easy. Drivers diagnosed with PD experience more cognitive impairments than healthy older drivers and therefore experience more difficulties with the dynamics in driving situations (Heikkilä et al. 1998; Wood et al. 2005; Cordell et al. 2008; Uc et al. 2009). Not looking to the left and right, might not be the result of over-reliance on the system, but rather the result of not having enough time and resources to survey the surrounding. Either way, failing to look left and right in an intersection and taking the provided information as granted, may have detrimental consequences for everyone involved.

In addition, it was found that subjective ratings and objective measures do not necessarily correlate. Here again, differences between young and older drivers of the treatment groups and drivers diagnosed with PD were observed. Overall, young and older drivers gave more modest ratings. At the same time, their ratings and their performance were not necessarily in agreement. For example, speed advice was rated as fairly high (i.e. mean ratings differed positively significant from a test value of zero), but those drivers still exceeded the speed limit. On the other hand, gap advice was rated rather low, but still drivers stopped fewer times and crossed intersections quicker. Even though acceptance was low, the information was utilized. In general, these results show that subjective measures and objective measure need to be examined together. Individual examination might lead to wrong conclusions as seen in the present examples. Acceptance ratings alone might not predict the use, misuse, disuse, or abuse of a system. The same is true for objective measures.

This discrepancy between objective and subjective measures might hint that the support provided was not needed as differences in measures were not observed for drivers diagnosed with PD. It is often stated in the literature that persons diagnosed with PD are less aware of their daily deficits and struggles (Leritz et al., 2004; Maier et al., 2012), which
in turn should lead to low acceptance ratings or discrepancies between subjective and objective measures. It appears that the tested sample of drivers diagnosed with PD, was aware of their struggles in traffic and therefore not only appreciated the ADAS but also showed positive effects in response to ADAS use. Results suggest that added value and benefits to road traffic safety are not achieved by putting systems into cars that are thought to be beneficial for everyone. It seems that support needs to be tailored and match drivers’ abilities and capacities in order to add the intended value. Giving support when it is not needed might jeopardize safety as freed resources might be used to engage in unrelated secondary tasks. Not providing enough support to the driver might result in being overwhelmed with the situation which also might jeopardize safety. In the end, support systems should not be about “must haves on a general level” as it is today, but rather “should haves on an individual level” (e.g. see Bagdadi & Varhelyi, 2011).

A question that remains is whether it was really necessary to complete so many sessions and whether results and conclusions would have been different with fewer consecutive sessions. The question might also be asked the other way around. For example, young inexperienced drivers completed only the first eight sessions of the experiment. Based on the assumption that young drivers learn quicker, in other words, need less time to get acquainted with the driving simulator, the new driving environment, and the ADAS, their number of consecutive sessions was limited to eight. The question that rises is whether their limited number of sessions was sufficient. Because of their driving inexperience, most steps of the driving task were not automatized already. In addition, drivers could not rely on an extensive repertoire of knowledge which could be applied to, for example, novel situations. In turn, cognitive effort had to be put forward to process general driving information and act upon it. Therefore, the benefits of repeated training might have manifested itself later on in time. In addition, according to Jenssen (2010), drivers go through five phases of learning in the behavioral adaptation to ADAS. After driving 200 km in eight sessions within three weeks, young drivers were still in the second phase, the learning stage. They were still novices when interacting with the system and their behavior was rather unstable. Being novice drivers and novice ADAS users might have contributed to their performance. Therefore, more sessions and longer exposure to ADAS might have been worthwhile for young drivers as well.

Considering that line of argumentation, we might be able to conclude that the completed number of sessions for older drivers was ideal. The large amount of sessions was justified
under the assumption that older drivers learn, but at a slower pace (Lowe & Rabbitt, 1997), and therefore need more sessions to show learning effects and also under the premises that longer-term exposure to ADAS is needed in order to observe practice effects. According to Jenssen’s (2010) understanding of behavioral adaptation to ADAS, older drivers were in the third learning phase, the trust stage. At that point, their behavior was relatively stable and they were relatively experienced with interacting with the system. It takes about one month of exposure to reach the third learning phase. Considering that older drivers need more time to learn new complex task and their age-related cognitive, visual, and motor declines, they might have just been at the verge of entering the third learning phase. Drivers diagnosed with PD show symptoms in a more prominent way; therefore, it might be possible that they were still in the learning phase and results might have been different if exposure to ADAS would have been increased.

8.5 Shortcomings and drawbacks

A major drawback of driving simulator studies is the occurrence of simulator sickness resulting in high numbers of drop-out. Being aware of the persistent issue, an extensive screening was done testing tendencies towards motion sickness and proneness to simulator sickness before the experimental sessions started in order to eliminate drop-outs during the experiment. The method was successful and no one suffered from simulator sickness during experimental sessions. Nonetheless, about 40 % of all older drivers and drivers diagnosed with PD, who were interested in participation, could not take part in the study due to simulator sickness. The same is true for approximately 20% of young inexperienced drivers. Simulator sickness has not been fully understood yet (Stoner et al., 2011), therefore, it is not clear in how far persons experiencing simulator sickness differ from persons who are not affected negatively.

In addition, it should also be noted that healthy older drivers who participated in the study were fairly young and also still very active as they were recruited from a local senior academy as well as leisure clubs. Those participants might not reflect the general population of older persons but rather a small proportion of it. Other older persons who might not feel confident driving might have refrained from participation because they might have been afraid of negative consequences such as referral to driving authorities or even revocation of their driver’s license. Therefore, results obtained need to be considered carefully as results might not be applicable to the general population of older drivers. The
same is true for participants diagnosed with PD, participation was fully voluntary. Drivers were not referred by doctors or authorities. Here, it might have also been the case that only drivers confident enough decided to participate also represented a small sample rather than the general population. The general population of drivers diagnosed with PD might experience more difficulties driving and might benefit even more from driving support.

Another shortcoming that needs to be kept in mind when interpreting the results is that the number of participants per group was fairly small, and therefore, not all results reached significance, but effect sizes indicated that with a larger sample, results obtained might reach significance allowing for more exclusive conclusions. In addition, a control group of drivers diagnosed with Parkinson’s disease would have been advantageous for more direct comparison. But recruiting persons of such a specific group turned out to be more difficult than anticipated. Unfortunately, we did not succeed in recruiting enough persons diagnosed with PD locally. Additional recruitment efforts were made throughout the Netherlands enabling us to investigate at least a treatment group.

Driving simulators provide a safe environment for investigating effects of ADAS use on driving performance and behavior without putting drivers in jeopardy which is a great benefit of driving simulator studies. At the same time, driving simulator studies lack realisms which may affect the outcome. Drivers might drive less carefully, riskier and more recklessly in a driving simulator because they are aware that for example a crash would not bear serious consequences. Therefore, results obtained need to be interpreted carefully and cannot be transferred to the real-world setting without validation.

In addition, the proposed ADAS worked 100% reliable which is not something than can be guaranteed; in particular early after introduction this may be rather an exception to the rule. Reliability influences how a system is perceived affecting acceptance and trust and in turn how it is used (Parasuraman & Riley, 1997). Results obtained might be due to the fact that the system worked perfectly. Participants might have relied on the information given to them without cross checking the information, a behavior that might have been triggered even more because the study was set out in a driving simulator instead of real traffic.

**8.6 Further research**

As the tested system was 100% reliable it is not surprising that trust ratings were generally high. On a scale ranging from 0 to 6, the average rating came out to 4.6 ($SD = .7$). Observed
differences between groups were at most marginal. Drivers diagnosed with PD rated their trust in the system highest ($M = 4.5$, $SD = .5$), followed by young inexperienced drivers ($M = 4.2$, $SD = .8$). Healthy older drivers ratings were lowest with $M = 4.1$ ($SD = .9$). A 100% reliable system is unrealistic, so further research should also investigate changes in not only subjective perception of the system but also in performance and behavior. We found that participants trusted the information provided and also relied on the information without confirming the accuracy of the information as indicated by the observed gaze patterns. It is of interest to see whether this behavior persists when the system either fails or provides inaccurate information. According to Jenssen (2010), experiencing malfunctions, limitations, and system failures leads to adjustment and readjustment and as a result, the system at use might be resented.

Results of the gaze pattern are also somewhat alarming. The intention of such a system is to support the driver, but even with such a system, drivers must not neglect surrounding traffic as this jeopardizes safety. Drivers take responsibilities for their decisions in traffic; therefore, decisions made must be safe and sound. Further research might also focus on presenting information in a different manner. One option would be to not present all information in HUD in front of the driver, but to present the information where, for example, danger might happen. In case of the intersection assistant, if another car approaches the traffic from the right, information should be presented there instead of the road center. Also, if a car approaches the intersection from the left and it appears that it fails to yield-to-the-right, attention should be drawn to the incident. Drawing attention to potential danger might encourage drivers to scan the surrounding more appropriately again making them more conscious.

In addition, based on Wickens’ resource model (2002), resources are limited. In the studies, all information was presented visually. Considering that the driving task itself also already requires a great amount of visual resources, other modalities such as the auditory channel should be used too to present information to the driver. That way visual attention is not drawn away from the road and the traffic environment. Instead, drivers can survey their surrounding and receive, for example, spoken messages, on speed limit signs or priority regulation. Information might also be conveyed haptic. If drivers speed, the gas pedal might signalize that by providing counter pressure.
Driving simulator studies might carry the risk of being unrealistic and certain behavior such as risky maneuvers including speeding, unsafe crossing decision might be evoked by driving simulators. The same might be true for the gaze patterns observed. Those patterns might have been provoked because no real danger existed. In the end, driving simulator studies should be taking into the real world and replicated. Ideally, naturalistic field operational tests should be executed, but closed test tracks might be a safer alternative, especially not knowing what kind of safety-critical behavior might be evoked and what type of countermeasure might need to be in place.

Specifically for groups with impairments, in our case persons diagnosed with PD, a system that works solely on the level of information provision might not be enough. Persons diagnosed with PD experience not only motor impairments, but often also cognitive impairments, which make safe driving a manifold challenge. Information needs to be perceived, processed and acted upon in a timely manner. Because of the symptoms of PD, any scenario is possible and plausible. Because of difficulties with dividing/ selective attention, drivers might fail to perceive the most relevant information in a particular traffic situation. In this case, drivers might be helped with a system that provides that information. Because of slower reaction times, a driver might not be able to process information fast enough, especially in situations that require a quick response. Here, having information available in advance might counter slower reaction times. Taking into account motor impairments, this type of support might not be sufficient. An additional intervening system such as emergency braking or forward collision avoidance might be suitable for drivers diagnosed with PD. For example, akinesia, hypokinesia, and bradykinesia make it difficult for drivers to stop or adjust an action/ movement quickly. Even if a driver is able to seek out the most relevant traffic information and process that information quickly, motor impairments might hinder him/her to put a new plan in action calling for intervening actions. The relation between TTC values and collisions support this idea. Drivers diagnosed with PD had the greatest TTC to crossing traffic, being the most conservative in the study. Nonetheless, they caused four crashes in intersections. Moreover, these drivers also chose for the longest time headway, but one driver caused a rear-end collision because he dozed off. The occurrence of paroxysmal symptoms, such as sudden onset of sleep, is unpredictable, but also well documented (Hobson et al., 2002; Meindorfner et al., 2005). An alertness monitoring system might be helpful to detect drowsiness and sudden onset of sleep and prevent its consequences. In general, crashes are rare events, but it seems that in
critical situations drivers diagnosed with PD have a greater risk of being involved or causing a crash. Intervening systems might be utilized to avoid those crashes.

That action should not be limited to collision avoidance functions, but might also include an intervening speed monitoring system. Drivers diagnosed with PD do not speed intentionally. Exceeding the speed limit might be due to difficulties of fine-tuning or because inhibiting a movement such as releasing the accelerator. When the posted speed limit is reached, pressure should be applied to the gas pedal making acceleration more difficult. More research is needed to clarify the added safety benefits for specific groups of drivers. For example, studies investigating ISA using force feedback to minimize or even prevent speeding found that a counter on the accelerator is not appreciated. But such systems were not investigated with person who might experience motor impairments.

Most systems and interventions mentioned here have already been implemented or are investigated at the moment. It seems that in the end, tailored support is possible. But to support drivers, support should be custom-made for each individual. As drivers diagnosed with PD might need an intervening system due to their motor impairments. Healthy older drivers might only need advance information. Young drivers, on the other hand, might need an intervening system or a system that provides feedback on their performance, tutoring them to be safer drivers. As all this is possible, it might just be the question of finding the right mix for the individual.