Chapter 6

LONGER-TERM EXPOSURE TO AN INTERSECTION ASSISTANT: EFFECTS OF ADAS USE ON INTERSECTION PERFORMANCE OF DRIVERS DIAGNOSED WITH PARKINSON’S DISEASE

Abstract

An Advanced Driver Assistance System (ADAS) supported drivers in intersections providing information about gap sizes to crossing traffic. Effects were studied in a longer-term driving simulator study including 12 repeated measures spread out over one month. Nine healthy older drivers (65 to 82 years) making up one group and nine older drivers diagnosed with Parkinson’s disease (PD, 68 and 82 years) making up a second group participated in the study. Groups completed ten sessions with ADAS and two sessions without ADAS. Results showed, over the longer-term period, a decrease in time needed to pass the intersection and the number of stops before crossing an intersection, so they became less hesitant and more confident over time. It was also observed that healthy older drivers had a smaller minimum time-to-collision (TTC) value to crossing traffic and crossed more often with a critical TTC than drivers diagnosed with PD reflecting acceptance of smaller safety margins. At the same time, they caused less crashes than drivers diagnosed with PD. Nevertheless, ADAS use might have prevented crashes from occurring as it was found in previous studies.
6.1 Introduction

Over the next few decades, the number of persons aged 65 and above will increase rapidly, especially the “older old”, those aged 75 and above (EuroStat, 2010). It is projected that driving will be the preferred mode of transportation of older persons in the future, more than it is nowadays. The number of people, especially women, who possess a driver’s license, will increase and therefore the number of older persons holding a valid drivers’ license and being active drivers will increase (OECD, 2001). Unfortunately, older drivers struggle with age-related declines in cognitive, visual, and motor functions which affect driving performance (McGwin & Brown, 1999). In addition, increased physical vulnerability makes older drivers more prone to severe injuries or even death as a consequence of a crash (Evans, 2004). Most likely, older drivers are involved in at-fault crashes in intersections (McGwin & Brown, 1999, Davidse, 2007) as a result of struggling with decision making under time pressure and divided/selective attention (Brouwer & Ponds, 1994; De Waard et al., 2009; Musselwhite & Haddad, 2010).

When persons become older, the probability of being affected by diseases and impairments increases. A neurodegenerative disease which becomes more prominent in older persons is Parkinson’s disease (PD). It is the second most common neurodegenerative disease after Alzheimer’s disease. Approximately 1 to 2 percent of the population aged over 65 years is affected by PD (Alves et al. 2008). PD is typically characterized by motor dysfunctions such as tremor, rigidity, postural abnormalities, and slow movements. In addition, cognitive deficits such as impairments in attention, memory, information processing, and executive functioning frequently occur even in early stages of the disease (Dubois & Pillon, 1996). Nonetheless, as a large survey study conducted in Germany revealed, 82 % of persons diagnosed with PD still held a valid driver’s’ license and 60% of them were still active drivers (Meindorfner et al., 2005). But research also showed that PD might affect driving safety (Heikkilä et al., 1998; Wood et al., 2005; Cordell et al., 2008; Uc et al., 2009) as driving is a complex physical and cognitive task in a dynamic environment involving timely information perception and processing, decision-making, motor programming and execution, and fulfilling concurrent tasks (Heikkilä et al., 1998). Past research (Heikkilä et al., 1998; Wood et al., 2005; Cordell et al., 2008; Uc et al., 2009) showed that drivers diagnosed
with PD have more difficulties with the driving task as compared to healthy drivers of the same age group on the tactical and operational level (i.e. maintaining lane position, turning, steering, and with regard to speed control). They also experience difficulties with information processing in complex situations (e.g. addressing two driving tasks simultaneously) leading to delayed judgments and decisions (Cordell et al., 2008).

But revoking drivers’ licenses cannot be the solution to maintaining traffic safety because evidence for an elevated crash risks of drivers diagnosed with PD is inconclusive (Heikkilä et al., 1998; Devos et al., 2007) and driving contributes to quality of life (Carp, 1988; Kaplan, 1995), countering isolation and depression, promoting subjective well-being and independence (Fonda et al., 2001; Marottoli et al., 2000). Moreover, if drivers’ licenses are revoked, they may decide to cycle or walk, which, in many ways, might be more dangerous for themselves (Siren & Meng, 2012).

Over the last few decades, efforts have been put into designing and implementing advanced driver assistance systems (ADAS) intended to offer support to the driver. For example, ADAS help with longitudinal (Adaptive Cruise Control and Collision Warning) and lateral position control (Lane Departure Warning and Lane Keeping System) of the vehicle. They even prevent losing control in a curve (Electronic Stability Control). Based on Michon’s hierarchical model of driving (Michon, 1985), such systems support the driver on the tactical and operational level of the driving task. In accordance to Michon, the driving task is divided into three levels: strategic, tactical, and operational. On the strategic level, decisions with regard to route are made, usually before the trip has begun and sometimes altered during the trip because of traffic jams. On the tactical level, while driving, safety margins are set and adjusted. It includes setting speed and time headway and deciding on maneuvers such as staying behind a slower moving car or overtaking it. On the operational level, drivers perform second to second lateral and longitudinal control tasks in order to avoid acute danger and to stay within the margins set on the tactical level.

As stated earlier, older drivers struggle with decision making under time pressure and divided/selective attention (Brouwer & Ponds, 1994; De Waard et al., 2009, Musselwhite & Haddad, 2010). These declines, crucial for safe driving, are also shown in drivers diagnosed with PD, but in a more prominent way. Sharpe (1996) found that persons diagnosed with PD have more difficulties dividing their attention than healthy
controls. In the context of driving these results were confirmed by Cordell’s et al. (2008) on-road assessment of drivers diagnosed with PD and healthy controls. They found that drivers diagnosed with PD had more difficulties addressing two tasks simultaneously and making decisions and judgments in a timely manner. It can be theorized that struggles with divided/selective attention and decision making under time pressure are manifested in limitations on the tactical and operational level of the driving task.

Overall, drivers can make adjustments and compensate for these limitations. For example, on the strategic level, this might include not driving during rush hours or avoiding complex intersections. On the tactical level, drivers could choose for general lower traveling speeds. Drivers can also increase the following distance to the car in front. Both strategies enable drivers to gain more time to seek the necessary information and to make a decision. But when the driving task becomes too complex and/or impairments are too severe, limitations of slow information processing and divided attention can no longer be fully compensated for and other means such as ADAS might be needed. But currently marketed ADAS are not necessarily designed to fit the needs of older drivers or of specific groups such as persons diagnosed with PD. More tailored support, based on older drivers specific crash profile (i.e. at-fault crashes in intersections), might be a promising approach.

In a recent driving simulator study, we proposed an assistance system, which provided relevant traffic information in advance (Dotzauer et al., 2013a). As drivers approached an intersection, they received information whether the gap size to crossing traffic was large enough to cross the intersection safely. The system was tested with older healthy drivers (65 to 82 years) and young inexperienced drivers (20 to 25 years) in order to investigate the effectiveness of such system on intersection performance, to examine changes in behavior over time due to exposure to ADAS, to gain more insight into the development of trust and acceptance, and to scrutinize the need for tailored support (Dotzauer et al., 2013a; 2014b). In the previous studies, performance of eight consecutive sessions spread out over three weeks was analyzed. Because of the prevalence of neurodegenerative diseases in older persons which might interfere with driving, the current study aims to investigate the effects of an intersection assistant with a group of older active drivers diagnosed with Parkinson’s disease (PD). In a driving simulator study, data of twelve consecutive sessions spread out over a time period of
Providing information about gap sizes while approaching the intersection and continuously updating the information until the intersection is crossed, it is expected that after a longer period of exposure to the support system, drivers diagnosed with PD will show changes in performance as healthy older drivers did in the previous study (Dotzauer et al. 2013a; 2014b). Changes will manifest itself in changes in intersection time, speed on intersection, and time-to-collision (TTC). It is expected that drivers with PD will benefit more from the ADAS than healthy controls. At the same time, we expect acceptance ratings to be less positive than ratings of healthy older drivers because research has also revealed that persons diagnosed with PD are often unaware of their deficits and struggles (Leritz et al., 2004; Maier et al., 2012).

6.2 Materials and method

6.2.1 Participants

Table 6.1 summarizes participants’ information. Altogether, 40% of persons who were interested in participation could not be included due to simulator sickness. Eighteen persons between the age of 65 and 82 years were included. Nine participants were diagnosed with PD made up a second group. The remaining participants reported not having any chronic diseases making up the group of healthy controls. All participants were still active drivers. Persons diagnosed with PD were recruited from a local Parkinson’s association and through an article in the magazine of the national Parkinson’s association. Healthy older persons were recruited through the local senior academy and local leisure clubs for older persons. All participants reported living independently. Diagnoses of PD ranged from one year ago up to twelve years ago with an average duration of 5.7 years. According to the information they provided, persons with PD and HRS were on optimal and stable medication at the time of the experiment. As illustrated in Table 6.1, healthy older drivers and drivers diagnosed with PD differed significantly in kilometers driven in the past year, but total mileage did not differ significantly. A small difference was observed for the scores on the MMSE. Healthy older drivers scored higher on the MMSE. But the scores indicate that neither healthy persons nor persons diagnosed with PD showed signs of cognitive impairment. A small difference in the ratio of the Trail Making Test was also observed. Healthy older
drivers’ ratio was smaller than of persons diagnosed with PD.

Table 6.1: Summary (mean and standard deviation) of participants’ demographic information and test scores

<table>
<thead>
<tr>
<th></th>
<th>Healthy drivers</th>
<th>Drivers with PD</th>
<th>p=</th>
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<tbody>
<tr>
<td>N</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>72.4 years (+ 2.8)</td>
<td>72.8 years (+ 4.6)</td>
<td>NS</td>
</tr>
<tr>
<td>Total driving experience</td>
<td>1 011 000 km (+ 493 000)</td>
<td>712 000 km (+ 393 000)</td>
<td>NS</td>
</tr>
<tr>
<td>Driving last year</td>
<td>21 000 km (+ 8 900)</td>
<td>9 000 km (+ 5 200)</td>
<td>.02</td>
</tr>
<tr>
<td>MMSE score</td>
<td>29.4 (+ .7)</td>
<td>28.4 (+ 1.5)</td>
<td>.09</td>
</tr>
<tr>
<td>Trail Making Test, part A (TMTa)</td>
<td>43.6 s (+ 13.6)</td>
<td>41.4 s (+ 22.1)</td>
<td>NS</td>
</tr>
<tr>
<td>Trail Making Test, part B (TMTb)</td>
<td>99.0 s (+ 26.8)</td>
<td>116.2 s (+ 59.9)</td>
<td>NS</td>
</tr>
<tr>
<td>Trail Making Test, ratio (TMTa/TMTb)</td>
<td>2.3 (+ .6)</td>
<td>2.9 (+ .6)</td>
<td>.09</td>
</tr>
</tbody>
</table>

6.2.2 Apparatus

A fixed-based driving simulator located at the University Medical Center Groningen was used for the study. The simulator consisted of an open cabin-mock-up containing an adjustable force-feedback steering wheel, gas pedal, brake pedal, and audio sound simulated driving sound. Three projection modules resulting in 180 degrees horizontal and 45 degrees vertical out-window projection screen of 4.5 m diameter stood in front of the mock-up. Front and side windows as well as a rear view mirror and side mirrors were projected onto the screen. The computer system consisted of four PCs: two PCs were used for graphical rendering, one for the traffic simulation and one for system control with a user interface for the simulator operator. The graphical interface was designed by means of StRoadDesign, a program provided by StSoftware. The scenario was programmed by means of StScenario, a scripting language also developed by StSoftware.
6.2.3 ADAS

The ADAS consisted of four functions: (1) in-vehicle traffic sign display, (2) speed warning, (3) collision warning, and (4) intersection assistance. All information was presented by means of a head up display (HUD). This paper will focus on the intersection assistant. The assistant provided information about approaching traffic at the upcoming intersection and indicated whether it was safe to cross an intersection. The information was presented in form of a bar in front of the driver. It was a three-stage system that dynamically changed from green to amber to red and vice versa as the traffic situation changed. The priority regulation at the intersection and the traveling direction (as indicated by the activation/deactivation of the indicator) of the driver were taken into account when providing advice. When the gap between the driver and the approaching cars was greater than five seconds, a green light lit up indicating that it was safe to cross. Gaps between 2.5 and five seconds were classified as marginal indicated by an amber flag, and gap sizes smaller than 2.5 seconds were unsafe as conveyed by a red flag. In order to calculate gaps and give advice on whether to proceed through the intersection, driver’s time-to-intersection (TTI) and time-to-collision (TTC) with other cars approaching the intersection were taken into account. TTI and TTC values are based on course, speed, and distance.

6.2.4 Design

The driving simulator study is a mixed study design with 14 repeated measurements (Figure 6.1). Data of healthy older participants were collected during an earlier study (Dotzauer et al., 2013a). Data of drivers diagnosed with PD were collected during a follow-up experiment. The experiment had been approved by the Medical Ethical Committee (METc) of the University Medical Centre Groningen. Healthy participants made up one group and persons diagnosed with PD a second group. Within four weeks, groups completed 12 consecutive sessions of which sessions 1 and 7 were completed without ADAS and the remaining ten sessions with ADAS. After the twelfth session, participants took a four week break and returned for two final sessions, one with ADAS and one without (the order was counterbalanced across subjects). The effects of the retention interval are not subject of the present paper, therefore, sessions 1 through 12 will be analyzed.
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. Drivers encountered various driving tasks such as changes in priority regulation, variations in speed limits, and slower moving lead vehicles.

During each session, participants crossed 130 intersections each. Based on priority regulation 16 intersections per session were selected to assess the effects of ADAS use on driving performance. Half of those intersections had bushes placed along the crossing obstructing the view into the intersection forcing drivers to slow down before crossing the intersection. The other eight intersections had unobstructed view. All selected intersections had a speed limit of 30 km/h and drivers needed to yield-to-the-right.

6.2.5 Procedure

Persons interested in participation received an information package via regular mail or email including a detailed description of the study and an informed consent form. After signing the informed consent, participants were invited, completed questionnaires and four rides (each of approximately five to seven minutes) in the driving simulator in order to get acquainted to the simulator and to test for simulator sickness. Participants who experienced simulator sickness during the training were excluded from the study.

Participants returned for the experimental sessions. They read a short description of the experiment and took a seat in the simulator. The seat and steering wheel were adjusted to accommodate participants’ preferences. Participants were instructed to drive as they
would normally do. After the first session, participants were introduced to the ADAS. It was explained to them thoroughly and also presented to them during a five minute demonstration ride. They took home a user manual and were asked to read it thoroughly. Further questions were answered before the second session. After each ride with ADAS, groups filled in an acceptance scale containing nine Likert items such as useful-useless or nice-annoying (Van der Laan et al., 1997). They also indicated their perceived workload using the RSME scale (Zijlstra, 1993) after each session. Participants returned to the driving simulator three times per week for four weeks. All participants were financially compensated for their participation.

6.2.6 Data analyses and dependent measures

For the present study, effects of short-term practice (session 2 vs. session 6), longer-term practice (session 2 vs. session 12), and removal of ADAS (sessions 6 through 8) were assessed. Per session, eight intersections with obstructed view and eight intersections without obstructed view were chosen for further analysis. Intersection time, maximum speed, percentage of stops before crossing an intersection, absolute minimum TTC, and percentage of critical crossings served as dependent measures and were analyzed separately for intersection with and without view obstruction. For all dependent measures, intersections at which participants had another car in front of them were excluded from analyses, as behavior may have been affected or restricted by that lead vehicle. In addition, perceived workload was analyzed to test for effects of ADAS use on mental demand and acceptance of the gap advice as well as changes in ratings over time.

Driving performance parameters were sampled at a frequency of 10 Hz and stored on disk. A MATLAB routine was used to extract the information about speed, time, and critical events. For each session, intersection time was calculated, that is the average sum of waiting time (velocity= 0 km/h) and crossing time of all intersections. The average maximum speed on all intersections, which covered 12 meters before and after the intersection midpoint and the stopping behavior, that is the percentage of intersections where intersection approach speed was between 0 and 1 km/h covering the same area were also extracted. Minimum time-to-collision to crossing traffic was also determined, collisions counted, and the percentage of critical crossings calculated. Crossings with a TTC equal to or smaller than one second to crossing traffic were
classified as critical gap crossings. The extracted TTC values are limited to vehicles approaching the intersection from the right and only include values from participants’ entrance until exit of the second crossing lane.

6.3 Results

6.3.1 Subjective ratings

Acceptance

The acceptance scale (Van der Laan et al., 1997) gives, on the basis of nine Likert scales, ratings on two dimensions: usefulness and satisfaction. Gap acceptance advice was rated on a scale ranging from -2 to 2 after each session which was completed with ADAS. Results of the usefulness and satisfaction ratings of OG (healthy older drivers) and PG (drivers diagnosed with PD) are shown in Figure 6.2. In a first step, usefulness ratings as well as satisfaction ratings of all sessions completed with ADAS were averaged and tested against zero (indicating neither acceptance nor rejection). The overall usefulness of the gap advice, $t(17) = 3.11$, $p = .006$, $r = .60$, as well as satisfaction of it, $t(17) = 2.48$, $p = .02$, $r = .51$, differed significantly from zero. The average usefulness rating came out to .62 ($SD = .8$) and satisfaction rating to .45 ($SD = .7$). Independent-samples t-test did not reveal significant differences between groups in ratings of usefulness, $t(16) = 7.71$, ns. OG’s average rating amounted to .33 ($SD = 1.1$) and PG’s rating to .91 ($SD = .4$). A difference in the overall satisfaction was observed, $t(16) = 5.98$, $p = .09$, $r = .40$. OG’s ratings ($M = .14$, $SD = .95$) were lower than PG’s ratings ($M = .75$, $SD = .37$).

Effects of short-term (Session 2 vs. 6) and longer-term (Session 2 vs. 12) practice: A 2 (OG and PG) x 2 (sessions 2 vs. 6) RM-ANOVA was performed to assess the usefulness and satisfaction ratings over the short-term period. As shown in Figure 6.2 (left), OG’s ratings were lower and more variable than PG’s ratings. This was confirmed by trends in Group comparisons for both usefulness ($F(1,18) = 3.09$, $p = .09$, $\eta^2 = .162$) and satisfaction ratings ($F(1,18) = 3.54$, $p = .08$, $\eta^2 = .181$). OG’s average usefulness rating amounted to .36 ($SD = 1.14$) and PG’s to 1.07 ($SD = .59$). OG rated their satisfaction of the gap advice ($M = .23$, $SD = .91$) lower than PG ($M = .87$, $SD = .55$). Neither a significant effect of Session nor a significant interaction of Session x
Group could be revealed for usefulness ratings.

![Graph showing usefulness and satisfaction ratings over sessions for Group OG and PG](image)

**Figure 6.2:** Mean acceptance ratings of the gap advice of OG (healthy older drivers) and PG (drivers diagnosed with PD) of sessions completed with ADAS. Left: Usefulness ratings of gap advice. Right: Satisfaction ratings of gap advice.

Over the longer-term exposure, the trend seen in group differences of the usefulness ratings diminished, $F(1,18) = 1.46$, *ns*. The main effect of *Session* as well as the interaction effect of *Session x Group* were also not significant as seen over the short-term period. Results of the satisfaction ratings are in line with the results found for the short-term exposure. Groups’ ratings differed, $F(1,18) = 3.38$, $p = .08$, $\eta^2 = .174$. Here again, OG’s ratings ($M = .16$, $SD = .99$) were lower than PG’s ratings ($M = 1.29$, $SD = .51$).

**Effects of removing ADAS (Sessions 6 through 8):** Testing the effect of ADAS removal on subjective ratings, ratings of session 6 and session 8 were analyzed. Analysis of usefulness ratings did not reveal a significant main effect of *Session* or a significant interaction of *Session x Group*, but a trend of the effect of *Group*, $F(1,18) = 3.31$, $p = .09$, $\eta^2 = .172$. As seen in Figure 6.2, OG perceived the usefulness of the gap advice lower than PG.

Results of the analysis of satisfaction ratings did not reveal significant main or interaction effects.

**Perceived Workload**

Perceived workload was measured using the Rating Scale Mental Effort (RSME, Zijlstra, 1993). After each completed session, participants indicated their perceived workload on a scale ranging from 0-150 (Figure 6.3).
Effects of short-term (Session 2 vs. 6) and longer-term (Session 2 vs. 12) practice: As data points in Figure 6.3 already indicate, the statistical analysis confirms a significant effect of Session, $F(1,18) = 8.03$, $p = .01$, $\eta^2 = .334$. Ratings of perceived workload decreased from 34.2 ($SD = 19.1$) in session 2 to 24.9 ($SD = 14.4$) in session 6. The trend in workload ratings revealed for short-term practice was also revealed for longer-term exposure. The main effect of Session, $F(1,18) = 6.54$, $p = .02$, $\eta^2 = .290$, was significant. The average rating of workload decreased from 34.2 ($SD = 19.1$) to 22.2 ($SD = 12.3$). Neither for the short-term period nor the longer-term period, a significant effect of Group or interaction effect of Session x Group could be revealed. But it should be noted, based on visual inspection of Figure 6.3, that after session 7, healthy older drivers’ subjective workload ratings levelled off (ratings of about 20), but ratings of drivers with PD increased and levelled off at around 28.

Effects of ADAS removal (Sessions 6 through 8): Analysis of sessions 6, 7, and 8 revealed a trend of the main effect of Session, $F(2,18) = 2.62$, $p = .08$, $\eta^2 = .141$. Overall, ratings decreased from 24.9 ($SD = 14.4$) to 20.8 ($SD = 14.9$) and then increased to 21.2 ($SD = 14.6$). Repeated contrast analysis showed a trend for changes in ratings from session 6 to 7, $F(1,18) = 3.26$, $p = .09$, $\eta^2 = .170$. Ratings between groups did not differ significantly. The same is true for the interaction of Session x Group.
6.3.2 Performance on intersections

Intersection time, maximum speed on intersection, percentage of stops before crossing an intersection, absolute minimum TTC, and percentage of critical crossings served as dependent measures assessing intersection performance. Short-term practice effects were assessed analyzing changes in performance between sessions 2 and 6. Longer-term effects were investigated assessing changes between sessions 2 and 12. Testing effects of removing the intersection assistant, sessions 6, 7, and 8 were analyzed. Repeated contrast analysis was used to assess significant main and interaction effects in more detail. Overall, effects were examined separately for intersections with (OV) and without (UV) view obstruction. Data was analyzed with an analysis of variance with Session serving as within-subject factor and Group (OG vs. PG) as between-subject factor.

Intersection time

*Effects of short-term practice (Session 2 vs. 6):* Examining short-term changes in intersection time in OV (obstructed view) intersections (see Figure 6.4, left), a significant main effect of Session (2 vs. 6), $F(1,18) = 6.73$, $p = .02$, $\eta^2 = .296$, was found. Intersection time decreased from 9.41 s ($SD = 6.5$) in session 2 to 6.45 s ($SD = 6.2$) in session 6. Also a significant main effect of Group, $F(1,18) = 4.32$, $p = .05$, $\eta^2 = .213$ was revealed. OG needed less time ($M = 5.25$, $SD = 5.36$) to cross an intersection with view obstruction than PG ($M = 10.5$ s, $SD = 9.34$). The interaction of Session x Group was not significant.

![Figure 6.4: Means of intersection times across 12 sessions of OG and PG. Left: Times on intersections with obstructed view. Right: Times on intersections without view obstruction.](image)
In UV (unobstructed view) intersections (see Figure 6.4, right), a trend for the decrease in intersection time over sessions was found, $F(1,18) = 4.19$, $p = .06$, $\eta^2 = .207$. Intersection time changed from 9.36 s ($SD = 11.0$) to 4.9 s ($SD = 4.31$). Differences between groups and the interaction effect were not significant.

**Effects of longer-term practice (Session 2 vs. 12):** Over the longer-term period, results found are in line with short-term effects. For intersection times in OV intersections, a significant main effect of *Session*, $F(1,18) = 5.55$, $p = .03$, $\eta^2 = .258$, was observed and a trend for the *Group* effect, $F(1,18) = 3.45$, $p = .08$, $\eta^2 = .178$. No significant interaction effect was found. OG ($M = 5.9$, $SD = 4.1$) needed less time crossing an intersection than PG ($M = 9.2$, $SD = 5.5$). Overall, intersection time decreased from 9.41 s ($SD = 6.5$) in session 2 to 5.69 s ($SD = 3.5$) in session 12. Analysis of intersection times of UV intersections (see Figure 6.5, right) did not reveal significant main or interaction effects.

**Effects of ADAS removal (Sessions 6 through 8):** No significant main effect of *Session* or an interaction effect of *Group* x *Session* was observed. Only a significant effect of *Group*, $F(1,18) = 4.68$, $p = .05$, $\eta^2 = .226$, was revealed (Figure 6.6, left). OG crossed intersections in 3.65 s ($SD = 2.3$) and PG in 8.82 s ($SD = 7.3$). Similarly, in UV intersections, only a significant main effect of *Group*, $F(1,18) = 4.9$, $p = .04$, $\eta^2 = .234$, was revealed. OG crossed intersections with an average time of 2.7 s ($SD = 2.3$); whereas, PG needed 7.3 s ($SD = 6.4$) to cross intersections.

![Figure 6.5: Mean intersection times of OG and PG for sessions 2, 6, and 12 (all with ADAS). Standard errors are presented in the error bars. Left: Average time on intersection with view obstruction. Right: Average times on intersections without view obstruction.](image_url)
Maximum speed on intersections

**Effects of short-term practice (Session 2 vs. 6):** Figure 6.7 shows not much change from session 2 to 6 for both groups. Statistical analysis analyses of data of OV as well as UV intersections did not reveal significant main effects of Group or Session or an interaction effect.

**Effects of longer-term practice (Session 2 vs. 12):** Assessing the longer-term effect, no significant main effects of Group and Session were observed, but a trend for the interaction of Session x Group, $F(1,18) = 4.00$, $p = .06$, $\eta^2 = .200$, was revealed for OV intersections. As depicted in Figure 6.7, from session 2 to 12, an increase in maximum speed from 32.8 km/h ($SD = 3.0$) to 34.5 km ($SD = 3.3$) was observed for OG while PG decreased maximum speed from 33.6 km/h ($SD = 3.3$) to 31.2 km/h ($SD = 2.8$).
No significant main effects or interaction effect were found for maximum speed on intersections without view obstruction.

**Effects of ADAS removal (Sessions 6 through 8):** As illustrated in Figure 6.8 (left), maximum speed on OV intersections changed from 33.3 km/h ($SD = 2.6$) in session 6 (with ADAS) to 31.7 km/h ($SD = 3.1$) in session 7 (without ADAS) to 32.7 km/h ($SD = 3.6$) in session 8 (with ADAS). Statistical analysis revealed a significant main effect of *Session* of maximum speed in OV intersections, $F(1,18) = 4.22, p = .02, \eta^2 = .209$. Repeated contrast analysis showed a significant decrease in maximum speed from session 6 to 7, $F(1,18) = 8.32, p = .01, \eta^2 = .342$, and a trend for the increase in speed from sessions 7 to 8, $F(1,18) = 3.42, p = .08, \eta^2 = .176$.

Analysis of data of UV intersections (Figure 6.8, right) did not result in significant main and interaction effects of maximum speed in UV intersections.

**Percentage of stops before crossing**

**Effects of short-term practice (Session 2 vs. 6):** As depicted in Figure 6.9, on OV intersections, the percentage of stops before crossing an intersection decreased from session 2 to 6. Statistical analysis confirms a significant main effect of *Session*, $F(1,18) = 12.13, p = .003, \eta^2 = .431$. A trend of the interaction *Session x Group*, $F(1,18) = 3.05, p = .1, \eta^2 = .160$, was also observed. OG showed a stronger decrease in percentage of stops ($M_2 = 72.63, SD_2 = 17.4; M_6 = 50.9, SD_6 = 13.4$) than PG ($M_2 = 67.54, SD_2 = 21.1; M_6 = 60.34, SD_6 = 22.65$). Differences between groups were not significant.
On intersections without view obstruction neither the main effect of Session nor the main effect of Group were significant, but the interaction of Session x Group, $F(1,18) = 4.82, p = .04, \eta^2 = .232$, was significant. A decrease from 47% ($SD = 26.0$) to 26% ($SD = 18.2$) was seen for OG; whereas, PG increased their percentage of stops before crossing from 28% ($SD = 23.2$) to 36% ($SD = 19.4$).

**Effects of longer-term practice (Session 2 vs. 12):** Similar to the results of changes over the short-term practice, a significant main effect of Session, $F(1,18) = 10.83, p = .005, \eta^2 = .404$, was revealed for percentage of stops in OV intersections. The trend of the interaction of Session x Group diminished over the longer-term period. Differences between groups were also not observed. Overall, the percentage of stops before crossing an intersection decreased from 70% ($SD = 18.9$) to 48% ($SD = 25.3$).

Longer-term changes in UV intersections were different from short-term changes. A significant main effect of Session, $F(1,18) = 13.22, p = .002, \eta^2 = .452$, and a trend of Group, $F(1,18) = 3.63, p = .07, \eta^2 = .185$, were observed. The interaction of Session x Group was not significant. The percentage of stops decreased from 37% ($SD = 25.8$) to 17% ($SD = 12.8$). As depicted in Figure 6.9 (left), OG stopped more often before crossing an intersection ($M = 33.9, SD = 18.4$) than PG ($M = 20.1, SD = 18.6$).

**Effects of removal of ADAS (Sessions 6 through 8):** Testing for effects of removing ADAS, no significant main or interaction effects of percentage of stops were observed. This is true for data in intersections with and without view obstruction.
Collisions and absolute minimum Time-to-collision

Figure 6.10 shows detailed information of crashes which occurred during a total number of 216 sessions. Crash information is displayed separately for OG and PG, split up in crashes at intersections and other locations. Crashes have also been classified as driver being at-fault or not at-fault. PG caused 4 out of 5 crashes in intersections. Crashes that occurred at one of the 16 selected intersections were not included in the analyses of the absolute minimum TTC.

For each intersection type, absolute minimum TTC represented the lowest TTC value out of eight intersection crossings. Data is displayed in Figure 6.11.

Figure 6.10: Information of crashes for each group separately distinguishing between crashes on intersections and others as well as being at-fault or not at-fault.

Figure 6.11: Means of absolute minimum TTC across 12 sessions of OG and PG. Left: Means of TTC on intersection with obstructed view. Right: Means of TTC on intersections without view obstruction.
Effects of short-term practice (Session 2 vs. 6): As seen in Figure 6.11, short-term changes in absolute minimum time-to-collision (TTC) in OV as well as UV intersections were small. Even though, in OV intersections, PG decreased their minimum TTC over time and OG did not show a change in TTC, statistical analysis did not reveal any significant main and interaction effects. In UV intersections, an increase in TTC was observed for OG and a decrease for PG, but here again, statistical analysis did not reveal significant results.

Effects of longer-term practice (Session 2 vs. 12): Results of longer-term practice in OV intersections are in line with results of short-term practice. No significant effects could be revealed for performance in intersections with view obstruction. In intersections without view obstruction a decrease in TTC was observed for both groups, but main and interaction effects were insignificant.

Effects of ADAS removal (Sessions 6 through 8): Removing ADAS in session 7 did not affect drivers’ minimum time-to-collision significantly. On OV and UV intersections, changes were small and neither main nor interaction effects yielded significant results.

Percentage of critical crossings

The absolute minimum TTC only gave information about the lowest TTC on one occasion. For each type of intersection, it indicated the most critical crossing out of 8 crossings. As Figure 6.11 shows, OG’s TTC average minimum TTC is lower than PG’s, so it is interesting to see whether the frequency of critical crossings is higher for OG than for PG. Even though that one occasion can already result in a crash, frequently crossing intersections with low TTC heightens that risk.

Effects of short-term practice (Session 2 vs. 6): Figure 6.12 depicts the percentage of critical crossings. Statistical analysis confirms that short-term changes did not yield any significant main effects or interaction effects on either type of intersections.

Effects of longer-term practice (Session 2 vs. 12): Significant changes in OV intersections were also not found. In UV intersections, on the other hand, a significant main effect of Session, $F(1,18) = 9.29$, $p = .008$, $\eta^2 = .367$, a trend of the Group effect, $F(1,18) = 3.51$, $p = .08$, $\eta^2 = .180$, and the interaction Session x Group, $F(1,18) = 3.17$, $p = .09$, $\eta^2 = .165$, were observed. OG crossed intersections 25% of the times with a
critical TTC showing an increase of 20% over time. PG crossed intersections about 13% of the times with a critical TTC. Their percentage increased by 5% from session 2 to 12.

**Effects of ADAS removal (Sessions 6 through 8):** Removing ADAS (Figure 6.13) did not affect the percentage of critical crossings significantly in OV intersection. Neither significant main nor interaction effects were observed. In UV intersections only the main effect of *Group*, $F(1,18) = 3.96, p = .06, \eta^2 = .199$, was close to being significant. OG crossed 22% ($SD = 19.7$) of the time with a critical TTC and PG 19% ($SD = 12.3$).

**6.4 Discussion**

This study was a follow-up of Dotzauer and colleagues (2013a, 2014b) aimed to gain more insight into the longer-term effects of ADAS use on driving performance. Effects
of ADAS on patient groups are unknown. ADAS might be more beneficial for them than for healthy controls, at the same time, patient groups may have more difficulty, for example, with processing and responding to additional information. For that purpose of the present study, a group of drivers diagnosed with Parkinson’s disease was added and the effects of ADAS on intersections performance as well as workload and acceptance ratings investigated. Up until this point, research on ADAS effects on driving performance over longer periods is lacking, especially on patient groups of drivers, in this case persons diagnosed with PD. In the present study, the effects of ADAS were investigated over a period of one month including 12 repeated measures. During this time, drivers were acquainted to the system enabling us to detect changes in performance. Effects of short-term and longer-term practice were investigated as well as effects of removing ADAS in one session after completing five sessions with ADAS. Eight intersections were depicted and classified as safety-critical because bushes were placed along the road preventing drivers from having a good view into the intersection forcing them to slow down, checking for crossing traffic before being able to make a sound decision on crossing the intersection. A pendant was created as well: eight intersections without view obstruction. For both types of intersections, intersection time, maximum speed on intersections, percentage of stops before crossing an intersection, absolute minimum time-to-collision, and percentage of critical crossings were analyzed.

**Crossing performance over the short- and longer-term period**

Analyses of driving performance parameters showed that both groups decreased their intersection time over the short-term period in intersections with view obstructions. Healthy older drivers were quicker in crossing intersections than drivers diagnosed with PD. The same trend and differences were observed over the longer-term period: intersection time decreased and healthy older drivers were faster than drivers diagnosed with PD. On the short-term, ADAS use did not affect maximum speed in intersections with view obstruction, but over the longer-term, maximum speed changed. Healthy older drivers increased their maximum speed in intersections and drivers diagnosed with PD showed a decrease in maximum speed. The number of stops was affected in short-term as well as longer-term practice. A significant decrease in stops was observed. On the short-term, the decrease was stronger in healthy older drivers. Over the longer-term this interaction effect diminished. Time-to-collision was not affected at all. The
same is true for the number of critical crossings.

In intersections without view obstruction, a decrease in intersection time was also observed over the short-term, but the effect was not as large as in intersections with view obstruction. In the longer-term, the decrease in intersection time was not significant anymore. In addition, in these intersections, no differences in intersection times between groups could be revealed. Maximum speed was neither affected in the short-run nor the long-run. The decrease in intersection time over the short-term period was not realized by adapting the maximum speed in intersections but by decreasing the number of stops. Over the short-term period healthy older drivers showed a decrease in the number of stops before crossing an intersection. Drivers diagnosed with PD, on the other hand, increased their number of stops before crossing an intersection. This does not affect intersection time negatively as intersection time is determined by the sum of wait and cross time. Even though drivers stopped more often they spent less time waiting on the intersection before they crossed. In the long-run, a significant decrease in stops was noted as well as a trend in differences between groups. Healthy older drivers stopped more often than drivers diagnosed with PD. Other than that, it was observed that in the longer-term, healthy older drivers showed a strong increase in the number of critical crossings.

Overall, it was noticed that intersection time which is the sum of waiting time and crossing time decreased over time. These results indicate that over time drivers did not wait as long in intersections anymore and seemed to accept earlier gaps. Over time, it appears that drivers become less hesitant and more confident. This assumption is supported by the development in the number of stops before crossing an intersection. The percentage decreased over time as well. Neither intersection time nor the percentage of stops had an influence on maximum speed on intersection as this value did not change over time. These results on driving performance do not allow concluding on whether changes observed add to driving safety or compromise it. What can be seen is that changes in driving performance parameters are similar for both groups and for most part, performance of drivers diagnosed with PD (except for intersection time) did not differ from healthy older drivers. Information about time-to-collision and actual collisions can offer some more insight into driver safety. Drivers diagnosed with PD caused four out of the five crashes in intersections, healthy older drivers not one. At the same time, healthy older drivers crossed more often with a critical TTC and with a
minimum TTC below one second (see Figure 6.11). Motor impairments such as akinesia, hypokinesia and bradykinesia are the most prevalent consequences of Parkinson’s disease (Mardsen, 1989) and might have contributed to crashes. Drivers diagnosed with PD might have seen the danger, but unlike healthy older drivers it might have taken them too long initiating and executing a corrective movement such as braking quickly or putting more force on the accelerator. In addition, as also seen in results of the Trail Making Test Part B and the ratio of Trail Making A and B, persons diagnosed with PD also show deficits in task switching abilities (Cameron, et al. 2010; Crescentini et al. 2012); therefore, it might have been more difficult for them to suppress the initial plan of crossing the intersection and taking corrective actions to avoid a collision. This might also explain that they stopped fewer times before crossing intersections.

Effects of ADAS removal

In both types of intersections, differences in intersection times between groups were observed as this has also been observed to short- and longer-term practice effects; therefore, group differences cannot be due to ADAS removal. The most interesting finding was the change in maximum speed in intersections with view obstruction as this change could not be observed for intersections without view obstruction. From session 6 (ADAS) to session 7 (no ADAS) maximum speed decreased. From session 7 to session 8 (ADAS), maximum speed increased again. These results suggest that especially in situations with view obstructions (i.e. more safety critical situations) drivers relied on the advice given to them.

Subjective ratings

Results of acceptance ratings were against the expectation that healthy older drivers are more accepting than drivers diagnosed with PD. Literature suggests that persons diagnosed with PD have an impaired self-awareness of their daily struggles and difficulties (Leritz et al., 2004; Maier et al., 2012). As drivers are not aware of their struggles, they would not accept assistance given to them as they do not see the need for such support. In our study, drivers diagnosed with PD were more accepting than healthy older drivers. They also showed less variability in ratings than healthy older drivers. Participants were not referred to us from a physician, but interested in the study. Motivation for participation was solely based participants’ decision, which might have
also contributed to the results. Participants selected for the study might not represent the general population of persons with PD but rather a small proportion that might has more insight in the struggles and difficulties encountered in everyday life and therefore was more positive about technology that supports them.

With the introduction of ADAS, perceived workload decreased over time. Even though ratings between groups did not differ significantly, healthy older drivers showed a stronger decrease in perceived workload than drivers diagnosed with PD. The graph of workload ratings (Figure 3) displays that drivers diagnosed with PD showed an increase in workload ratings right after the midpoint of the study and also a greater variability in perceived workload compared to healthy older drivers. Persons diagnosed with PD experience good and bad days which includes, for example, fluctuations in their motor abilities (Richard, et al., 2004). These ups and downs might be reflected in their subjective workload ratings as tasks and activities become more difficult on bad days. It might also be that the experiment was more exhausting for them. About half of the drivers diagnosed with PD lived between one hour and two hours away and traveled a long distance three times per week. This additional strain might also be reflected in their ratings as this was observed during the last two weeks of the experiment.

6.5 Conclusion

In Dotzauer et al. (2013a; 2014b) performance of older drivers was compared to a matched control group (completing sessions without ADAS) and it was concluded that ADAS affected driving performance. The current study showed that performance of drivers diagnosed with PD did not differ greatly from healthy older drivers and changes were in the same direction as those observed for healthy older drivers. Therefore, we can conclude that performance of drivers with PD was similarly affected by ADAS use. However, alarming at this point are the at-fault crashes that occurred more frequently in the patient group. But in Dotzauer et al. (2014b) we found that young and older drivers of control groups who drove without ADAS caused more crashes than groups with ADAS leading to the conclusion that ADAS prevented crashes from occurring. The same might have happened with drivers diagnosed with PD too. Here again, ADAS might have diminished crashes. Past research has shown that drivers diagnosed with PD have more difficulties with the driving task compared to healthy drivers of the same age group (Heikkilä et al., 1998; Wood et al., 2005; Cordell et al., 2008; Uc et al., 2009).
Without ADAS, it is possible that even more crashes could have occurred. Their acceptance ratings also indicate that the advice given to them was useful and helpful.

It is also noteworthy to mention that this was a first attempt investigating potential safety benefits of an intersection assistant on the performance of not only healthy older drivers, but also drivers diagnosed with PD. Results suggest that more tailored support might help impaired older drivers to stay on the road safer. More research needs to focus on beneficial longer-term effects as a response to ADAS use instead of focusing on identifying drivers who are no longer fit to drive.