Longer-term effects of ADAS use on driving performance of healthy older drivers and drivers diagnosed with Parkinson’s disease
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Chapter 7

LONGER-TERM EFFECTS OF ADAS USE ON SPEED AND HEADWAY CONTROL IN DRIVERS DIAGNOSED WITH PARKINSON’S DISEASE

Abstract

An Advanced Driver Assistance System (ADAS) provided information about speed limits, speed, speeding, and following distance. Information was presented to participants by means of a head up display (HUD). Effects of the information on speed and headway control were studied in a longer-term driving simulator study including twelve repeated measures spread out over four weeks. Nine healthy older drivers between the ages of 65 and 82 years making up one group and nine drivers diagnosed with Parkinson’s disease (PD) between the ages of 68 and 82 years making up another group participated in the study. Within the four weeks, groups completed twelve consecutive sessions (ten with ADAS and two without ADAS) in a driving simulator. Results indicate an effect of ADAS use on performance. Removing ADAS after short-term exposure led to deterioration of performance in all speed measures in the group of drivers diagnosed with PD. These results suggest that provision of traffic information was utilized by drivers diagnosed with PD in order to control their speed.
7.1 Introduction

Parkinson’s disease (PD) is a neurodegenerative disease which becomes more prominent in older persons. It is the second most common neurodegenerative disease after Alzheimer’s disease. Approximately 1 to 2 percent of the population aged 65+ is affected by PD (Alves et al., 2008). PD typically affects motor functions causing tremor, rigidity, postural abnormalities, and slow movements. Cognition might also be affected leading to impairments of attention, memory, information processing, and executive functioning (Dubois & Pillon, 1996). Therefore, PD might affect driving safety (Heikkilä et al. 1998; Uc et al. 2009) as driving is a complex physical and cognitive task in a dynamic environment involving information perception and processing under time pressure, decision-making, motor programming and execution as well as fulfilling concurrent tasks (Heikkilä et al. 1998). Deficits in information processing in complex situations (e.g. addressing two driving tasks simultaneously or seeking out the most relevant traffic sign) have already been identified as a difficulty of healthy older drivers (Musselwhite & Haddad, 2010) leading to delayed judgments and decisions (Brouwer & Ponds, 1994; De Waard et al. 2009). These difficulties are even more evident in drivers diagnosed with PD. As past research showed (Heikkilä et al. 1998; Wood et al. 2005; Cordell et al. 2008; Uc et al. 2009), drivers diagnosed with PD experienced more difficulties driving than healthy controls on the tactical and operational level of the driving task (i.e. maintaining lane position, controlling speed and time headway (THW)).

Nonetheless, a large survey study conducted in Germany revealed that 82% of persons diagnosed with PD held a valid driver’s license and 60% of them were active drivers (Meindorfner et al. 2005). Evidence of an elevated crash risk of drivers diagnosed with PD is also inconclusive (Heikkilä et al. 1998; Devos et al. 2007). Revoking driver’s licenses solely based on medical diagnoses is not the solution to maintaining traffic safety as driving contributes to quality of life (Carp, 1988; Kaplan, 1995), counters isolation and depression, promotes subjective well-being, and independence (Marottoli et al., 2000; Fonda et al. 2001). 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, in-vehicle information systems (IVIS), such as navigation systems, and advanced driver assistance systems (ADAS), such as Adaptive Cruise
Control (ACC), Lane Departure Warning (LDW), Collision Avoidance, or Electronic Stability Program (ESP) have been designed and implemented with the aim of improving traffic safety. IVIS and ADAS offer support to drivers on different levels of the driving task (Michon, 1985). On the strategic level, high level decisions, for example, with regard to route planning are made. Navigation systems support drivers by planning a trip and guide them from point A to B. On the tactical level, safety margins are set and adjusted. This includes deciding on speed, THW, and lane position. ACC and LDW support drivers by maintaining a safe distance to the car in front and warning them when they are about to leave their traveling lane unintentionally. On the operational level, drivers perform second to second lateral and longitudinal control tasks to avoid acute danger and to stay within the margins set on the tactical level. Here, systems such as Collision Avoidance and ESP come into play. If a collision is about to happen, brakes are often engaged automatically and brake force applied. ESP autonomously activates in case of over- or under-steering to prevent loss of control, for example, in a curve.

ADAS support on the tactical and operational level is often characterized by aiding the primary driving task (longitudinal and lateral control), but this is not necessarily the type of support older drivers need. As older drivers have a great amount of driving experience, observed difficulties on the tactical and operational level of the driving task might be the result of their deficits in selective/divided attention and decision making under time pressure (Brouwer & Ponds, 1994; De Waard et al. 2009). Therefore, difficulties with speed control, lane position, steering, and turning (Heikkilä et al. 1998; Wood et al. 2005; Cordell et al. 2008; Uc et al. 2009) might not be the source of the problem, but rather the quantifiable outcome of the above mentioned deficits. These deficits are even more prominent in persons diagnosed with PD. Sharpe (1996) found that persons diagnosed with PD have more difficulties dividing attention than healthy controls. In the context of driving, these results are confirmed by Cordell’s et al. (2008) on-road assessment. They found that drivers diagnosed with PD have more difficulties addressing two tasks simultaneously and delay their decisions and judgments compared to healthy controls. As compensation, drivers may choose lower traveling speed and larger gaps between themselves and other cars. Both tactics enable drivers to gain more time to seek necessary information and to make sound decisions. But limitations of slow information processing and divided attention can only be compensated for up to a certain point under certain task conditions. When the driving task becomes too complex, those strategies cannot fully
compensate for impairments anymore, and other means, such as ADAS, are needed. More tailored support, based on specific drivers’ characteristics (i.e. impairment of divided/selective attention and decision making under time pressure), might be a promising approach to keep drivers mobile and traffic safe.

In a recent driving simulator study, an assistance system which provided relevant traffic information in advance (Dotzauer et al. 2013a) was proposed. In theory, receiving relevant traffic information in advance frees resources, which, in turn, might counter problems with divided/selective attention. The system was tested with healthy older drivers (65 to 82 years) in order to investigate effects of ADAS use on driving, and to scrutinize the need for tailored support (Dotzauer et al. 2013a). The study was conceptualized to investigate changes over a period of two months including 14 repeated measures. In addition, in the past, driving performance of drivers diagnosed with PD has only been evaluated a few times and no research has been done investigating the effects of ADAS use on speed and headway control. Because of the prevalence of neurodegenerative diseases in older persons, a group of older drivers diagnosed with PD was added assessing longer-term changes in driving performance. In a recent paper (Dotzauer et al. 2013b), the effects of an intersection assistant on intersection performance were presented. In the present paper, the effects of ADAS on speed and headway control are presented and discussed.

Speed and headway control of two groups (healthy older drivers and drivers diagnosed with PD) were investigated over a period of four weeks. A speed advisory system and collision warning were implemented. Drivers’ speed and following distance were monitored at all times. When drivers exceeded the speed limit by more than 10%, the speedometer color changed from green to amber. When the speed limit was exceeded by more than 15%, the color changed to red (Brookhuis & De Waard, 1999). When drivers’ THW dropped below two seconds, a symbol illumined requesting drivers to increase the distance to the car in front. When THW dropped below one second a different symbol lit up, warning drivers for a high likelihood of a rear-end collision. Traffic signs were also presented in car. When drivers approached an intersection, they received information about the priority regulation at the intersection. Icons of traffic signs such as Yield, Stop, or Right-of-way were projected onto the virtual front screen. After they had passed the intersection, information about the legal speed limit was presented to them. The
information was presented to the driver by means of a head-up display (HUD). Changes in speed and following distance were recorded and evaluated. It is expected that advanced information manifests itself in changes of performance on the tactical level of the driving task: higher speeds, more speeding, greater following distances. We also expect that over longer-term practice, differences between groups will become smaller.

### 7.2 Materials and methods

#### 7.2.1 Participants

Table 7.1 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 making up one 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 and HRS ranged from one year ago up to twelve years ago with an average duration of 5.7 years.

According to the information provided in the demographic questionnaire, persons with PD were on optimal and stable medication at the time of the experiment. In addition, on the open-ended questions about driving experience, drivers diagnosed with PD reported driving significantly fewer kilometers in the past year compared with healthy older drivers. At the same time, the reported total mileage and frequency of driving per week did not differ significantly. A small but insignificant difference was observed for the scores on the Mini Mental State Exam (MMSE, Kok & Verhey, 2002) and the ratio of the Trail Making Test. Even though healthy older drivers scored higher on the MMSE, scores indicate that neither healthy persons nor persons diagnosed with PD showed signs of cognitive impairment. Healthy older drivers’ ratio was smaller than of persons diagnosed with PD.
<table>
<thead>
<tr>
<th>Table 7.1: Summary (mean and standard deviation) of participants’ demographic information and test scores.</th>
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<tbody>
<tr>
<td><strong>Healthy drivers</strong></td>
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<tr>
<td>N</td>
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<tr>
<td><strong>Age</strong></td>
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<tr>
<td><strong>Total driving experience</strong></td>
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<tr>
<td><strong>Driving last year</strong></td>
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<td><strong>Driving per week</strong></td>
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<td><strong>MMSE score</strong></td>
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<td><strong>Trail Making Test, part A (TMTa)</strong></td>
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<tr>
<td><strong>Trail Making Test, part B (TMTb)</strong></td>
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<tr>
<td><strong>Trail Making Test, ratio (TMTa/TMTb)</strong></td>
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</table>

7.2.2 Apparatus

A validated (e.g., De Waard & Brookhuis, 1997) 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 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. For more detailed specification, please see Dotzauer et al. (2013a).

7.2.3 Design
The driving simulator study is a mixed study design with 14 repeated measurements (Figure 7.1). 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 (Dotzauer et al. 2013b). The experiment was approved by the Medical Ethical Committee (METc) of the University Medical Center 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 (Results of the retention interval concern a different research topic and will not be discussed here).

![Figure 7.1: Experimental set-up (ADAS= Advanced Driver Assistance System). For the present study, sessions 1 through 12 were selected for further analysis. Note: * the order of sessions with and without ADAS was counterbalanced across participants.](image)

The virtual driving environment was comprised of a 25 km city drive. Route instructions were given visually and auditory through a navigation system. Four different routes (the order was counterbalanced) comparable in length and events were used to avoid learning effects. Various driving tasks, such as changes in priority regulation, variations in speed limits, and slower moving vehicles were implemented.

During each session, participants drove in sections (length of 2000 meters) with speed limits of 50 km/h and 70 km/h without a car in front of them. In addition, in sections, with a speed limit of 50 km/h, car following tasks were implemented. These sections were also of an approximate length of 2000 meters. Data collected were used to analyze performance in terms of speed, speeding, and following distance.

### 7.2.4 Procedure

Persons interested in participating in the study received an information package via regular mail or email including a detailed description of the study and an informed
consent form. After completing the informed consent, participants were invited to the hospital, completed other questionnaires and four rides (each of approximately five to seven minutes) in the driving simulator to get acquainted to the simulator and to test for simulator sickness. Participants who experienced simulator sickness during the training session 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, groups were introduced to the ADAS. It was explained to them in detail and also presented to them. They took home a user manual and were asked to read it thoroughly. Participants returned to the driving simulator three times per week for four weeks. All participants were financially compensated for their participation.

7.2.5 Data analyses and dependent measures

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, speeding, and following distance. Per session, participants drove through sections with posted speed limits of 50 and 70 km/h and completed car-following tasks in separate sections with posted speed limits of 50 km/h. Average and maximum speed, the percentage of driving time spent speeding, and time headway served as dependent measures. Speeding was defined as traveling at a speed 10% or more above the speed limit. The percentage of driving time spent speeding was calculated by dividing “the total driving time of exceeding the speed limit” by “the total driving time needed to complete sections”. Calculations were done separately for stretches with posted speed limits of 50 km/h and 70 km/h. Minimum THW, defined as the lowest THW value during the car-following task, was used to assess performance of the car-following task. 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. For the effects of removing the intersection assistant, session 7 (no ADAS) was compared with session 6 (pre removal) and session 8 (post removal). Data were examined with an analysis of variance with Session as within-subjects and Group (OG and PG) as between-subjects.
7.3 Results

7.3.1 Speed and speeding (speed limit 50 km/h)

ADAS removal (sessions 6, 7, and 8)

Analyses of sessions 6, 7, and 8 revealed significant main effects of Session, \( F(2,18) = 3.13, p = .05, \eta^2 = .164 \), and Group, \( F(1,18) = 6.25, p = .02, \eta^2 = .281 \), and a significant interaction effect of Session x Group, \( F(1,18) = 4.82, p = .02, \eta^2 = .232 \), for average speed. OG’s average speed did not change across sessions; whereas, PG’s increased from session 6 to 7 and decreased from session 7 to 8 (see Figure 7.2 and Table 7.2). Contrast analysis confirmed a significant interaction from session 6 to 7, \( F(1,18) = 4.37, p = .05, \eta^2 = .215 \), and from session 7 to 8, \( F(1,18) = 8.35, p = .01, \eta^2 = .343 \), but not from session 6 to 8, \( F(1,18) = 1.2, \text{ns} \). Maximum speed indicated a similar trend (see Figure 7.2), but no significant interaction effect was found \( F(2,18) = 2.57, p = .09, \eta^2 = .139 \).

![Figure 7.2: Means and standard errors for sessions 6, 7, and 8 in sections with a posted speed limit of 50 km/h. Left: Presentation of average speed. Center: Display of maximum speed. Right: Graphs represent driving time spent speeding in percent.](image)

Results of driving time spent speeding showed a different pattern over time for both groups (see Figure 7.2), OG’s percentage of driving time spent speeding increased over sessions irrespective of ADAS removal in session 7, but PG’s percentage decreased when ADAS was reintroduced in session 8. Indeed, the interaction of Session x Group for driving time spent speeding was significant, \( F(2,18) = 4.6, p = .02, \eta^2 = .223 \). The interaction effect was not significant between sessions 6 and 7, but between sessions 7 and 8, \( F(1,18) = 4.85, p = .04, \eta^2 = .233 \), and sessions 6 and 8, \( F(1,18) = 6.42, p = .02, \eta^2 = .286 \).
Short-term (session 2 vs. 6) and longer-term practice (session 2 vs. 12)

For average speed, in the short-term, the main effect of Group, $F(1, 18) = 9.53, p = .007, \eta^2 = .373$, was significant. Average speed was higher for OG compared to PG (see Table 7.2). Means of maximum speed and driving time spent speeding suggest differences between OG and PG, but analysis did not reveal significant results. The same is true for changes over time between groups (see Figure 7.3).

![Figure 7.3: Means and standard errors for sessions 2, 6, and 12 in sections with a posted speed limit of 50 km/h. Left: Presentation of average speed. Center: Display of maximum speed. Right: Graphs represent driving time spent speeding in percent.](image)

Effects of longer-term practice on average speed are comparable with effects of short-term practice. Group differences were significant, $F(1, 18) = 9.11, p = .008, \eta^2 = .363$ (see Figure 7.3 and Table 7.2). Means of maximum speed and driving time spent speeding, as displayed in Figure 7.3, indicate differences between groups and over time, but result were not significant.

### 7.3.2 Speed and speeding (speed limit 70 km/h)

ADAS removal (sessions 6, 7, and 8)
The average speed was not significantly affected when ADAS was removed, but group differences were revealed for the change in maximum speed. Experimental results of OG showed a small but steady increase in speed over sessions. PG, on the other hand, showed effects of ADAS removal. They increased speed from session 6 to 7 and decreased speed from session 7 to 8 (see Figure 7.4 and Table 7.2). This was also statistically confirmed by a significant interaction effect of Session x Group, $F(2,18) = 4.09, p = .02, \eta^2 = .204$.

Short-term (session 2 vs. 6) and longer-term practice (session 2 vs.12)

In the short term, comparing session 2 with session 6, no significant differences in speed measures (average speed, maximum speed and time spent speeding) were revealed over time or between groups.

Over the longer-term period, for average speed, the main effects of Session, $F(1,18) = 10.07, p = .006, \eta^2 = .386$, and Group, $F(1,18) = 4.25, p = .05, \eta^2 = .210$, were significant. Average speed increased from 63.4 km/h ($SD = 5.3$) in session 2 to 66.6 km/h ($SD = 4.9$) in session 12 (see Figure 7.5). Group means also suggest lower maximum speed for PG compared to OG, but differences did not reach significance, $F(1,18) = 3.49, p = .08, \eta^2 = .179$. Also no significant change between groups or over time was found for driving time spent speeding.
Table 7.2: Means and SD’s of average speed, maximum speed, percentage driving time spent speeding listed for sessions 2, 6, 7, 8, and 12 for OG and PG individually.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Healthy older drivers (OG)</th>
<th>Drivers diagnosed with PD (PG)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Session 2</td>
<td>Session 6</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>50 km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average speed</td>
<td>47.3</td>
<td>3.9</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>60.7</td>
<td>7.0</td>
</tr>
<tr>
<td>Percentage speeding</td>
<td>18.5</td>
<td>17.9</td>
</tr>
<tr>
<td>70 km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average speed</td>
<td>65.4</td>
<td>6.4</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>75.3</td>
<td>3.8</td>
</tr>
<tr>
<td>Percentage speeding</td>
<td>3.3</td>
<td>8.8</td>
</tr>
</tbody>
</table>
7.3.3 Time headway in the car-following task

ADAS removal (sessions 6, 7, and 8)

Removing ADAS did not affect THW. No significant main and interaction effects were found.

![Figure 7.5: Means and standard errors for sessions 2, 6, and 12 in sections with a posted speed limit of 70 km/h. Left: Presentation of average speed. Center: Display of maximum speed. Right: Graphs represent driving time spent speeding in percent.]

Short-term (session 2 vs. 6) and longer-term practice (session 2 vs. 12)

Unlike significant group differences (OG: $M = 1.1$, $SD = .56$; PG: $M = 1.5$, $SD = .5$) over the longer term period ($F(1,18) = 4.30, p = .05, \eta^2 = .212$), in the short term, differences in THW were not significantly different. As depicted in Figure 7.6, OG followed cars with a smaller THW than PG.

![Figure 7.6: Mean of minimum time headway of sessions 2, 6, and 12 for OG and PG. Standard errors are presented in error bars.]

7.4 Discussion
The study aimed to gain more insight into longer-term effects of ADAS use on driving performance of drivers diagnosed with PD and healthy older drivers. Changes in speed, speeding, and THW over time as a result of ADAS use were investigated. Up until this point, little is known about ADAS effects on driving performance over longer periods, especially of drivers diagnosed with PD. In the present study, the effects of ADAS use on performance of healthy older drivers and drivers diagnosed with PD were investigated over a period of four weeks including twelve repeated measures.

For drivers diagnosed with PD, group means of the speed measures on both road segments fluctuated more over sessions when ADAS was removed (session 7) and reintroduced (session 8) compared to the healthy older drivers. Results of different speed measures (maximum speed, average speed and time spent speeding) on both road segments were affected in the same direction when removing and reintroducing ADAS, but often failed to reach significance. In sections with a speed limit of 50 km/h, significant differences were found between groups over time for average speed and driving time spent speeding. In sections with a speed limit of 70 km/h, significant differences between groups over time were found for maximum speed. As displayed in Figure 7.2 and 7.4, PG’s speed performance was affected more by removing and reintroducing ADAS than OG’s performance. Broadly speaking, compared to the more stable performance of OG, PG’s speed values increased and decreased when ADAS was removed and reintroduced, respectively. Whether these fluctuations were truly due to ADAS use or due to the disease (i.e. experiencing “good” and “bad” days) cannot be answered based on this sample. Research including a larger sample size might shed more light on this. Our data tentatively suggest that removing ADAS affected speed performance of drivers diagnosed with PD and this might indicate that the presented information was utilized.

Effects of short-term and longer-term practice with ADAS on speed and speeding did not develop as expected over time. Against our expectations, hardly any behavioural adaptation over time due to ADAS use was observed and group differences in average speed remained over all sessions. The average speed on both road segments was significantly lower for PG than for OG. Different patterns were observed in terms of maximum speed and driving time spent speeding for OG and PG. OG tended to increase their maximum speed over time and decrease driving time spent speeding; whereas, PG’s maximum speed slightly decreased and driving time spent speeding increased. Whether
observed trends were in response to ADAS use cannot be determined. Larger sample sizes are needed to study the effects of ADAS on speed and speeding more thoroughly.

The most relevant result revealed from the analysis of the performance on the car-following task was the difference between groups. OG followed cars with a smaller THW than PG. Differences in THW were about half a second. Previous research suggested that following distance positively correlates with perceived workload (Lewis-Evans et al. 2010); therefore, the greater THW might reflect drivers’ experienced task difficulty. In the previous study, an increase in workload ratings for PG was observed right after the midpoint of the experiment which is in line with the observed increase in following distance over time for PG (Dotzauer et al. 2013b). On the other hand, the observed small following distances of OG might reflect a low task demand.

All findings need to be considered with caution because of the small sample size in combination with heterogeneity. Even healthy aging does not occur in a linear manner. One might experience stronger declines in vision, whereas another might experience strong cognitive declines. Symptoms of PD are also very heterogeneous. This heterogeneity might be reflected in the results; therefore, samples of subcategories of PD might be needed to evaluate the added benefit. Differences in annual mileage might have also contributed to the results, but we believe equating groups on similar recent experience is not a good solution. Either the healthy older driver group or the PD group would be less representative for their population. For instance, in a survey of over 6000 persons with PD, Meindorfner et al. (2005) found that although 60% still drove, over half said they had reduced their amount of driving.

7.5 Conclusion

It is also noteworthy to mention that it was a first attempt to investigate the effects of ADAS use on driving performance not only over a period of four weeks, including twelve consecutive sessions, but also including a group of drivers diagnosed with PD. Instead of identifying drivers who are no longer fit to drive, the focus laid on investigating means that support drivers without active interference. The question of whether drivers diagnosed with PD utilized information about speed and speeding, whether the changes observed were by chance, and whether the information presented was beneficial for speed
control cannot be answered conclusively, but results suggest that provision of traffic information was utilized by drivers diagnosed with PD in order to control their speed.