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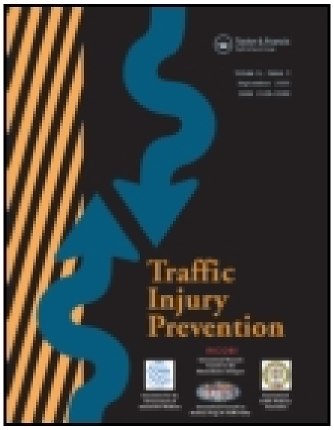

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Longer-Term Effects of ADAS Use on Speed and Headway Control in Drivers Diagnosed With Parkinson's Disease

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Objective: An advanced driver assistance system (ADAS) provided information about speed limits, speed, speeding, and following distance. Information was presented to the participants by means of a head-up display.

Methods: Effects of the information on speed and headway control were studied in a longer-term driving simulator study including 12 repeated measures spread out over 4 weeks. Nine healthy older drivers between the ages of 65 and 82 years and 9 drivers between the ages of 68 and 82 years diagnosed with Parkinson's disease (PD) participated in the study. Within the 4 weeks, groups completed 12 consecutive sessions (10 with ADAS and 2 without ADAS) in a driving simulator.

Results: 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.

Conclusions: These results suggest that provision of traffic information was utilized by drivers diagnosed with PD in order to control their speed.

Keywords: ADAS, older drivers, Parkinson's disease, speeding, headway control

Introduction

Parkinson's disease (PD) is a neurodegenerative disease that becomes more prominent in older persons. It is the second most common neurodegenerative disease after Alzheimer's disease. Approximately 1 to 2% 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 and Pillon 1992). Therefore, PD might affect driving safety (Heikkilä et al. 1998; Uc et al. 2009) because 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 2 driving tasks simultaneously or seeking out the most relevant traffic sign) have already been identified as a difficulty for the healthy older driver (Musselwhite and Haddad 2010), leading to delayed judgments and decisions (Brouwer and Ponds 1994; De Waard et al. 2009). These difficulties are even more evident in drivers with PD. As past research showed (Cordell et al. 2008; Heikkilä et al. 1998; Uc et al. 2009; Wood et al. 2005), 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 (Devos et al. 2007; Heikkilä et al. 1998). Revoking driver's licenses solely based on medical diagnoses is not the solution to maintaining traffic safety because driving contributes to quality of life (Carp 1988; Kaplan 1995), counters isolation and depression, and promotes subjective well-being and independence (Fonda et al. 2001; Marottoli et al. 2000). Moreover, if driver's licenses are revoked, the person may decide to cycle or walk, which, in many ways, might be more dangerous for him or her (Siren and Meng 2012).

Over the last few decades, in-vehicle information systems, such as navigation systems, and advanced driver assistance systems (ADAS), such as adaptive cruise control, lane departure warning, collision avoidance, or electronic stability

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program (ESP) have been designed and implemented with the aim of improving traffic safety. In-vehicle information systems 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 guiding 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. Adaptive cruise control and lane departure warning 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 occur, brakes are often engaged automatically and brake force applied. ESP autonomously activates in case of over- or understeering 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. Because older drivers have a great amount of driving experience, observed difficulties on the tactical and operational levels of the driving task might be the result of their deficits in selective/divided attention and decision making under time pressure (Brouwer and Ponds 1994; De Waard et al. 2009). Therefore, difficulties with speed control, lane position, steering, and turning (Cordell et al. 2008; Heikkilä et al. 1998; Uc et al. 2009; Wood et al. 2005) 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 et al.'s (2008) on-road assessment. They found that drivers diagnosed with PD have more difficulties addressing 2 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 driver 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 that provided relevant traffic information in advance (Dotzauer, Caljouw, et al. 2013) 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, Caljouw, et al. 2013). The study was conceptualized to investigate changes over a period of 2 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 to assess longer-term changes in driving performance. In a recent paper (Dotzauer, De Waard, et al. 2013), the effects of an intersection assistant on intersection performance were presented. In the present article, the effects of ADAS on speed and headway control are presented and discussed.

Speed and headway control of 2 groups (healthy older drivers and drivers diagnosed with PD) were investigated over a period of 4 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 and De Waard 1999). When drivers' THW dropped below 2 s, a symbol illuminated requesting drivers to increase the distance to the car in front. When THW dropped below 1 s 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. Changes in speed and following distance were recorded and evaluated. It is expected that advanced information manifests itself in changes in performance on the tactical level of the driving task: higher speeds, more speeding, and greater following distances. We also expect that over longer-term practice, differences between groups will become smaller.

Methods

Participants

Table 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 who were diagnosed with PD made up one group. The remaining participants reported not having any chronic diseases and made 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

Table 1. Summary (mean and standard deviation) of participants' demographic information and test scores

	Healthy drivers	Drivers with PD	$t = (\mathrm{df} = 16)$	P
N	9	9		
Age	72.4 years (±2.8)	72.8 years (±4.6)	<1	NS
Total driving experience	1,011,000 km (±493,000)	712,000 km (±393,000)	1.41	NS
Driving last year	21,000 km (±8,900)	9,000 km (±5,200)	3.7	.002
Driving per week (times per week)	4.3 (±1.4)	4.1 (±1.7)	<1	NS
MMSE score	29.4 (±0.7)	28.4 (±1.5)	1.79	.09
Trail Making Test, Part A (TMTa)	43.6 s (±13.6)	41.4 s (±22.1)	<1	NS
Trail Making Test, Part B (TMTb)	99.0 s (±26.8)	116.2 s (±59.9)	<1	NS
Trail Making Test, ratio (TMTa/TMTb)	2.3 (±0.6)	2.9 (±0.6)	1.79	.09

participants reported living independently. Diagnoses of PD and HRS ranged from one year ago up to 12 years ago with an average duration of 5.7 years.

According to the information provided on 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 to 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 and 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. The ratio for healthy older was smaller than that of persons diagnosed with PD.

Apparatus

A validated (e.g., De Waard and Brookhuis 1997) fixed-base 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 a 180° horizontal and 45° vertical out-window projection screen of 4.5 m diameter standing in front of the mock-up. Front and side windows as well as a rearview mirror and side mirrors were projected onto the screen. For more detailed specification, please see Dotzauer, Caljouw, et al. (2013).

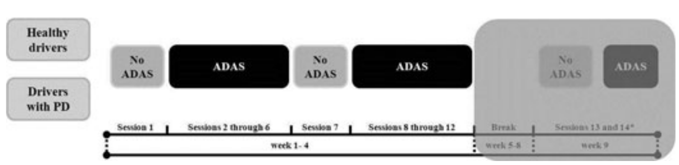

Fig. 1. Experimental setup. For the present study, sessions 1 through 12 were selected for further analysis. *The order of sessions with and without ADAS was counterbalanced across participants.

Design

The driving simulator study is a mixed study design with 14 repeated measurements (Figure 1). Data on healthy older participants were collected during an earlier study (Dotzauer, Caljouw, et al. 2013). Data on drivers diagnosed with PD were collected during a follow-up experiment (Dotzauer, De Waard, et al. 2013). The experiment was approved by the Medical Ethical Committee of the University Medical Center Groningen. Healthy participants made up one group and persons diagnosed with PD made up a second group. Within 4 weeks, groups completed 12 consecutive sessions, of which sessions 1 and 7 were completed without ADAS and the remaining 10 sessions were complete with ADAS. After the 12th session, participants took a 4-week break and returned for 2 final sessions (results of the retention interval concern a different research topic and will not be discussed here).

The virtual driving environment was composed of a 25-km city drive. Route instructions were given visually and auditorily 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 2,000 m) with speed limits of 50 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 2,000 m. Data collected were used to analyze performance in terms of speed, speeding, and following distance.

Procedure

Persons interested in participating in the study received an information package via regular mail or e-mail including a detailed description of the study and an informed consent form. After completing the informed consent, participants were invited to the hospital and completed other questionnaires and 4 rides (each of approximately 5–7 min) in the driving simulator to get acquainted with 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

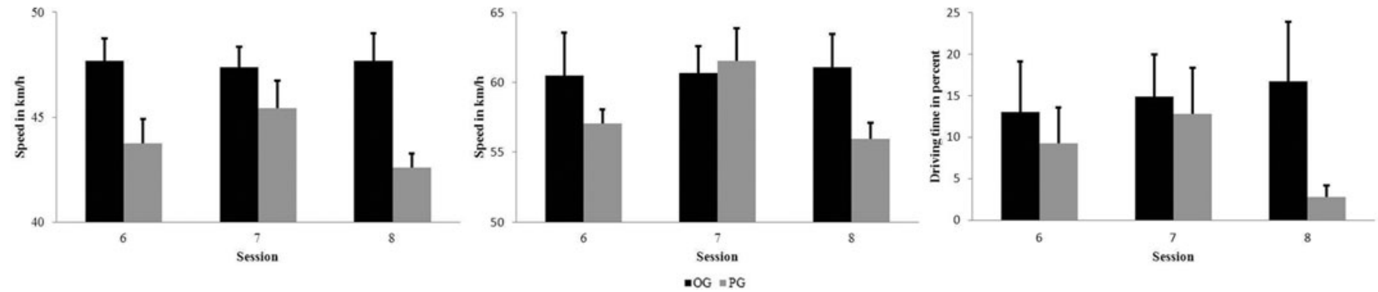

Fig. 2. Means and standard errors for sessions 6, 7, and 8 in sections with a posted speed limit of 50 km/h. Left: Presentation of average speed. Center: Display of maximum speed. Right: Graphs represent driving time spent speeding in percent.

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 3 times per week for 4 weeks. All participants were financially compensated for their participation.

Data Analyses

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 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 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 to analyze changes in performance between sessions 2 and 6. Longer-term effects were investigated to assess changes between sessions 2 and 12. For the effects of removing the intersection assistant, session 7 (no ADAS) was compared with session 6 (preremoval) and session 8 (postremoval). Data were examined with an analysis of variance with session as the within-subject comparison and group (healthy older drivers, OG and drivers diagnosed with Parkinson's disease, PG) as the between-subject comparison.

Results

Speed and Speeding (Speed Limit 50 km/h)

ADAS Removal (Sessions 6, 7, and 8)

Analyses of sessions 6, 7, and 8 revealed a significant main effect of *session*, $F(2,18) = 3.13$, $P = .05$, $\eta^2 = 0.164$, and group, $F(1,18) = 6.25$, $P = .02$, $\eta^2 = 0.281$, and a significant interaction of Session × Group, $F(1,18) = 4.82$, $P = .02$, $\eta^2 = 0.232$, 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 2 and Table A1, online supplement). Contrast analysis confirmed a significant interaction from session 6 to 7, $F(1,18) = 4.37$, $P = .05$, $\eta^2 = 0.215$, and from session 7 to 8, $F(1,18) = 8.35$, $P = .01$, $\eta^2 = 0.343$, but not from session 6 to 8, $F(1,18) = 1.2$, ns. Maximum speed indicated a similar trend (see Figure 2), but no significant interaction effect was found, $F(2,18) = 2.57$, $P = .09$, $\eta^2 = 0.139$.

Results of driving time spent speeding showed a different pattern over time for both groups (see Figure 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 × Group for driving time spent speeding was significant, $F(2,18) = 4.6$, $P = .02$, $\eta^2 = 0.223$. The interaction effect was not significant between sessions 6 and 7 but it was between sessions 7 and 8, $F(1,18) = 4.85$, $p = .04$, $\eta^2 = 0.233$, and sessions 6 and 8, $F(1,18) = 6.42$, $P = .02$, $\eta^2 = 0.286$.

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, $F(1,18) = 9.53$, $P = .007$, $\eta^2 = 0.373$, was significant. Average speed was higher for OG compared to PG (see Table A1). 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 A1, online supplement).

Effects of longer-term practice on average speed are comparable with effects of short-term practice. Group differences were significant, $F(1,18) = 9.11$, $p = .008$, $\eta^2 = 0.363$ (see Figure A1 and Table A1). Means of maximum speed and driving time spent speeding, as displayed in Figure A1, indicate differences between groups and over time, but the results were not significant.

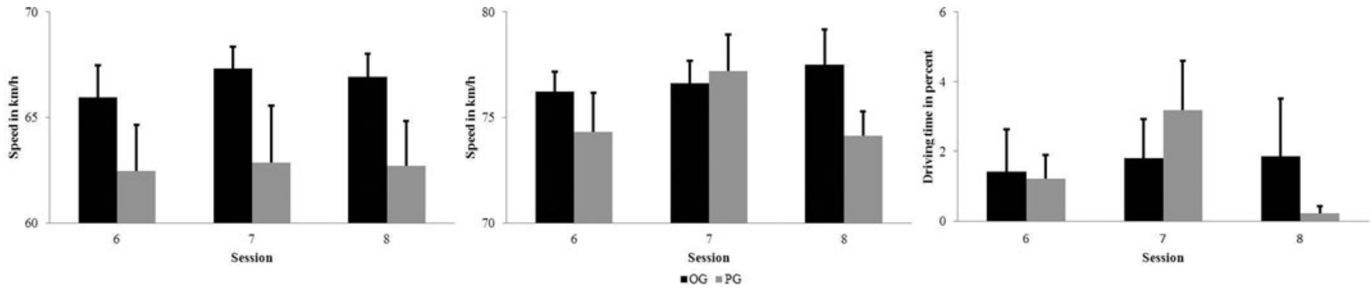

Fig. 3. Means and standard errors for sessions 6, 7, and 8 in sections with a posted speed limit of 70 km/h. Left: Presentation of average speed. Center: Display of maximum speed. Right: Graphs represent driving time spent speeding in percent.

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 3 and Table A1). This was also statistically confirmed by a significant interaction effect of Session × Group, $F(2,18) = 4.09$, $P = .02$, $\eta^2 = 0.204$, which was significant from session 6 to 7, $F(1,18) = 4.86$, $P = .04$, $\eta^2 = 0.233$, and from session 7 to 8, $F(1,18) = 7.95$, $P = .01$, $\eta^2 = 0.332$, but not from session 6 to 8. The same trend was observed for driving time spent speeding, but these effects were not significant.

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 spend speeding) were revealed over time or between groups.

Over the longer-term period, for average speed, the main effects of session, $F(1,18) = 10.07$, $P = .006$, $\eta^2 = 0.386$, and group, $F(1,18) = 4.25$, $P = .05$, $\eta^2 = 0.210$, 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. Group means also suggest lower maximum speed for PG compared to OG, but differences did not reach significance, $F(1,18) = 3.49$, $P = .08$, $\eta^2 = 0.179$. In addition no significant change between groups or over time was found for driving time spent speeding.

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.

Short-Term (Session 2 vs. 6) and Longer-Term Practice (Session 2 vs. 12)

Unlike significant group differences (OG: $M = 1.1$, SD = 0.56; *PG*: M = 1.5, SD = 0.5) over the longer-term period, $F(1,18) = 4.30$, $P = .05$, $\eta^2 = 0.212$, in the short term, differences in THW were not significantly different. As depicted in Figure 4, OG followed cars with a smaller THW than PG.

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. 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 the performance of healthy older drivers and drivers diagnosed with PD were investigated over a period of 4 weeks, including 12 repeated measures.

For the drivers diagnosed with PD the group means of the speed measures on both road segments fluctuate 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

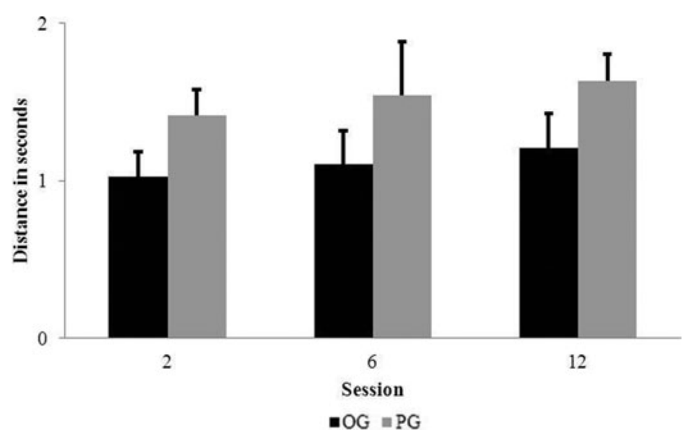

Fig. 4. Mean of minimum time headway of sessions 2, 6, and 12 for OG and PG. Standard errors are presented in error bars.

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 Figures 2 and 3, 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 OGs, 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. Contrary to our expectations, hardly any behavioral 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, De Waard, et al. 2013). 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 that 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 6,000 persons with PD, Meindorfner et al. (2005) found that although 60% still drove, over half said that they had reduced their amount of driving.

It is also noteworthy to mention that this was a first attempt to investigate the effects of ADAS use on driving performance not only over a period of 4 weeks, including 12 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 was 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.

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Supplemental Materials

Supplemental data for this article can be accessed on the publisher's website.

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