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 5

BEHAVIORAL ADAPTATION OF YOUNG AND OLDER DRivers TO AN INTERSECTION CROSSING ADVISORY SYSTEM

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Abstract

An Advanced Driver Assistance System (ADAS) provided information about the right of way regulation and safety to cross an upcoming intersection. Effects were studied in a longer-term study involving 18 healthy older drivers between the ages of 65 and 82 years and 18 healthy young drivers between the ages of 20 and 25 years. Participants repeatedly drove 25 km city routes in eight sessions on separate days over a period of two months in a driving simulator. In each age group, participants were randomly assigned to the control (no ADAS) and treatment (ADAS) group. The control group completed the whole experiment without the ADAS. The treatment group drove two sessions without (sessions 1 and 7) and six times with ADAS. Results indicate effects of ADAS on driving safety for young and older drivers, as intersection time (intersection waiting and crossing time) and percentage of stops decreased, speed and critical intersection crossings increased, the number of crashes was lower for treatment groups than for control groups. The implications of results are discussed in terms of behavioral adaptation and safety.
5.1 Introduction

According to recent European crash statistics, more young drivers (18-24 years) and older drivers (65 years and older) are killed in car crashes than drivers in any other age group (EuroStat, 2011). Over the last few decades, efforts have been put into designing support systems with the intention to make driving safer. Advanced Driver Assistance Systems (ADAS) which support drivers have been developed. For example, ADAS help with the longitudinal (Adaptive Cruise Control and Collision Warning) and lateral control (Lane Departure Warning) of the vehicle, or prevent losing control in a curve (Electronic Stability Control). Other ones such as Intersection Assistance Systems are being researched. In a recent driving simulator study, an intersection assistant designed to give tailored support to older drivers taking into account age-related limitations in processing speed and divided attention, was studied (Dotzauer et al., 2013a). Even though it is often assumed that support given to older drivers will be beneficial for young drivers as well, considering the underlying causations for crash involvement, the assumption can be questioned. Crash situations and determinants are quite different for these two age groups (Mayhew et al., 2003; McKnight & McKnight, 2003) and interventions needed to reduce the occurrence of crashes also might be quite different. So, young drivers might not profit from or respond to an assistance system that is tailored to fit the needs of older drivers. For example, in an early study on a speed feedback system, De Waard et al. (1999a) found that older drivers’ response to feedback messages was different than for younger drivers; young drivers looked upon the system as an enforcement device while older drivers welcomed the system as a support system.

Across the lifespan, a shift in crash contributing factors but also a shift in crash characteristics is noticeable. As young drivers start driving, they lack experience and maturity (Deery, 1999; Mayhew et al., 2003; Borowsky et al., 2009; Trick et al., 2009; Curry et al., 2011; Vlakveld, 2011; Mueller & Trick, 2012), relatively more frequently, they do not maintain attention (Simons-Morton et al., 2004; Jaccard et al., 2005; Beede & Kass, 2006; Kass et al., 2007), search inappropriately (Pradhan et al., 2009; Vidotto et al., 2011), fail to recognize hazards (Borowsky et al., 2009; Trick et al., 2009; De Craen et al., 2011, Vlakveld, 2011; Mueller & Trick, 2012), and make poor decisions with regard to speed choice and time headway (THW) (Simons-Morton et al., 2005), reflecting a lack of driving skills (McKnight & McKnight, 2003; Curry et al., 2011) which results in poorer
driving performance. But young inexperienced drivers evolve into experienced drivers who estimate their driving skills more realistically, learn to search the environment better, identify and assess critical traffic situations more realistically and react in an appropriate manner to changes in road and traffic situations. Results from Graduated Driver Licensing Systems also support this; the highest rate of crash involvement is during the first months of solo driving with relatively higher crash involvement for younger drivers and males (e.g. Mayhew, 2007; Lewis-Evans, 2010). Crash statistics of middle-aged drivers further reflect those changes; this age group’s fatal crash involvement is the lowest. Over the years, the number of fatal crashes and the risk of being involved in fatal crashes decreases, up until 65 years of age. Approximately from that age, risks of being involved in and causing a crash as well as being seriously injured increases (EuroStat, 2011).

Unlike young drivers, older drivers do not lack driving skills, but many of them struggle with age-related declines that affect driving performance (McGwin & Brown, 1999) and because of their physical vulnerability injuries are more severe (Evans, 2004). The most typical crashes that older drivers are involved in are at-fault crashes at an intersection (McGwin & Brown, 1999; Davidse, 2007) struggling most with decision making under time pressure and divided/selective attention (Brouwer & Ponds, 1994; De Waard et al., 2009; Musselwhite & Haddad, 2010).

According to older drivers’ specific crash characteristic, the ADAS used in the previous study (Dotzauer et al., 2013a) was designed. It gave tailored support to older drivers providing relevant traffic information in advance counteracting difficulties with decision making under time pressure and divided/selective attention. Considering that young drivers’ difficulties may mainly be based on inexperience and immaturity often resulting in inadequate speed choices and inaccurate anticipation of hazards, the question that rises is whether providing information about priority regulation and gap sizes in intersections (see Dotzauer et al., 2013a) in advance might also be suitable for young drivers. Predominantly, young drivers are involved in single-vehicle crashes on rural roads rather than multiple-vehicle crashes in intersections. Nonetheless, crossing an intersection might be a hazardous task for young drivers as well; especially, when the view of the crossing road is obstructed. Crossing requires divided attention among several pieces of information, perceiving and processing changes in the traffic situation, perceiving and processing signals and traffic signs, determining and executing a course of action (Braitman et al., 2007), decision making under time pressure (Brouwer & Ponds, 1994),
and anticipating hazards. Intersection crossings might be a dangerous undertaking for young and older drivers even though the underlying causations are different. Older drivers are more likely to struggle with intersection crossing due to their limited attentional resources. Young drivers might struggle with appropriately assessing the traffic situation and therefore might engage in risky crossing behavior. Providing relevant traffic information (e.g. gap sizes) about the upcoming intersection in advance might support drivers of both age groups on the tactical level of the driving task.

Based on Michon’s hierarchical task analysis (Michon, 1985), the driving task is divided into three levels. The strategic level (navigation) is the highest level. On this level, decisions with regard to route, navigation, and time of driving are made. Decisions are usually made before the trip has begun, but also, occasionally, during the trip, for example when deciding to take an alternative route because of a traffic jam. On the tactical level, while driving, safety margins are set and adjusted for the trip. This includes deciding on speed, time-headway, and lane position, but also involves considering various maneuvers such as overtaking, passing, and crossing. On the operational level (control), 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. The difference between tactical and operational level decisions and actions is that the latter are reactive and the former are proactive (anticipatory), not a reaction to immediate danger but a setting of safety margins in the case that actual danger (e.g. vehicle on collision course) manifesting itself in the near future.

Therefore, receiving information in advance may serve two purposes for older drivers. It may take away uncertainty and may counter difficulties with divided attention, for example, when receiving information about gap size to crossing traffic. Knowing that the gap size is either large enough or too small to cross supports drivers when deciding on going or stopping. Therefore, decision making under time pressure might be countered. Young drivers might benefit from the information, but differently because their weakness is not limited attentional resources but rather identifying hazards and acting appropriately. For example, providing information about gap size might teach young drivers to assess crossable gap sizes more accurately. This augmented information also implies the presence of other vehicles at the intersection even though they might be hidden behind
bushes; therefore, young inexperienced drivers might become more sensitive to potential hazards.

In a recent driving simulator study, an intersection assistance system which provided relevant information about gap sizes to crossing traffic in advance (Dotzauer et al., 2013a) was proposed. As research of ADAS effects on driving performance over longer time periods is lacking, the study was conceptualized to investigate changes in performance over a period of two months including 14 repeated measures. In order to assess the effects of the intersection assistant, safety-critical situations were created. Bushes were placed along intersections that needed to be crossed, blocking the view into the intersection. The system was tested with healthy older drivers (65 to 82 years) in order to investigate effects of ADAS use on performance over time, and to scrutinize the need for tailored support (Dotzauer et al. 2013a). Older drivers’ performance data used for the present paper was obtained during the first experiment. The aim of the present study was to examine the performance of older drivers in relation to the performance of young less experienced drivers. The main focus laid on the investigation and evaluation of the intersection assistant. Young drivers completed the same drive as older drivers and followed the same protocol as older participants, but instead of completing 14 sessions, they only completed the first eight sessions of the experiment. The number of sessions was limited to eight because of time constraints but also to minimize the drop-out rate in the group of young inexperienced drivers.

We expect an age effect in all driver performance parameters. Dependent measures such as intersection time, maximum speed in intersections, number of stops before crossing, minimum average time-to-collision to crossing traffic, and number of critical crossings will differ between groups. Moreover, we assume that over time, drivers supported by ADAS will show changes in performance.

5.2 Materials and methods

5.2.1 Participants

In a recent study (Dotzauer et al., 2013a), 25 older drivers were recruited of which 40% dropped out because of simulator sickness. Data of 18 older drivers between the ages of 65 years and 82 years ($M = 71.4$, $SD = 4.8$), 15 male and three female drivers were
collected. In addition, after a 20% drop-out rate among the young drivers, 18 drivers between the ages of 20 years and 25 years ($M = 22.3$, $SD = 1.74$), nine male and nine female, participated in the study. On average, older drivers reported a total driving experience of 965,000 km, with an average of 17,900 km driven the past year; whereas, young drivers averaged 22,900 km experience with a yearly average of 5,800 km. Participants were assigned to the control and treatment group by means of controlled randomization.

5.2.2 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 sound simulated driving sound. Three screens (4.5 m diameter) resulting in 180 degrees horizontal and 45 degrees vertical projection were placed in front of the open cabin 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.

5.2.3 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 the 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 (whether drivers had right-of-way or to yield to crossing traffic) at the intersection and the travelling direction (as indicated by the activation/deactivation of the indicator) of the driver were taken into account by the
assistant system. Based on trial and error, values for gap acceptance were determined. When the gap between the driver and the crossing 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 the red flag. In order to calculate gaps and give advice on whether to proceed through the intersection, the driver’s time-to-intersection (TTI) and time-to-collision (TTC) with other cars approaching the intersection were taken into account. TTI and TTC values are based on course, speed, and distance.

5.2.4 Design

The driving simulator study is a mixed study design with 13 or 14 repeated measurements (older drivers) or eight repeated measures (young drivers). Data of older participants were collected during an earlier study (Dotzauer et al., 2013a) and analyses will be limited to session one to eight for the present study. Data of young drivers were collected during a follow-up experiment. Younger drivers completed eight sessions. The experiment had been approved by the Medical Ethical Committee (METc) of the University Medical Center Groningen. Participants were assigned to the control and treatment group by means of controlled randomization. Selected sessions for the control group were all without the intersection assistant; the treatment group drove two times without assistance (namely, session 1 and 7) and six times with ADAS (see Figure 5.1). 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. The order of the routes was counterbalanced. Drivers encountered various driving tasks such as changes in priority regulation, variations in speed limits, and slower moving vehicle in front of them. All participants completed the first session without the system. The treatment group completed session two to six with ADAS, session seven without ADAS, and session eight with ADAS again.

Young drivers were also randomly assigned to the control and treatment group. The control group completed the experiment without ADAS and the treatment group with ADAS, except for sessions 1 and 7.
During each session, participants crossed 130 intersections. Out of these intersections, based on the priority regulation (see below), 16 intersections per session were selected to assess the effects of ADAS use on driving performance and driving behavior. Half of those intersections had bushes placed along the crossing road in order to obstruct the view into the intersection forcing the driver to slow down before crossing the intersection. The other eight intersections had no view obstructions. All selected intersections had a speed limit of 30 km/h and the priority was regulated by yield-to-the-right.

5.2.5 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 completing the informed consent, participants were invited, completed other questionnaires and completed 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 (40% of older drivers and 20% of young drivers) 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, the treatment group was introduced to the ADAS. The functions and functioning of the ADAS was explained to participants with the help of a user manual. In addition, participants completed a five minute ride during
which all functions were demonstrated in particular traffic situations. They also took home a user manual and were asked to read it thoroughly. Older participants returned to the driving simulator three times per week for four weeks and after the retention interval of four weeks returned for a final assessment. Control group drivers came back for one final assessment and drivers of the treatment group for two assessments. Younger participants returned three times for the first two weeks and two more times during the third week of the experiment. All participants were financially compensated for their participation.

5.2.6 Data analyses and dependent measures

For the present study, sessions 1 through 8 were selected for further analysis. For treatment groups, sessions 1 and 7 were without ADAS; sessions 2 through 6, and session 8 were with ADAS (see Figure 5.1). Control groups completed all sessions without ADAS. Per session, eight intersections with obstructed view and eight intersections without obstructed view were chosen for further analysis. For all dependent measures, intersections at which participants had another car in front of them were excluded from 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, time, and critical events. In particular, for each session, mean intersection time, that is the average sum of waiting time (velocity= 0 km/h) and crossing time of all intersections, was determined. The average maximum speed on all intersections, which covers 12 meters before and after the intersection midpoint and the stopping behavior, that is the percentage of intersections where the intersection approach speed was between 0 and 1 km/h covering the same area were also extracted. Extracted TTC values were limited to the entrance and exit of the second crossing lane at an intersection. For this time frame, minimum time-to-collision to crossing traffic was also determined and the percentage of critical crossings (TTC to crossing traffic ≥ 1 second) calculated. Throughout sessions, the number of collisions was counted and categorized into either crashes in intersections or other.

In order to analyze the gaze behavior, video recordings of participants’ faces were coded and analyzed. The videos were coded using ELAN, a tool used to annotate videos (Max
Planck Institute for Psycholinguistics, 2013; Lausberg & Sloetjes, 2009). Based on the eye movement, gaze was coded with center, left, and right, the category other was used for all other eye movements. Out of the output file, the percent road center (PRC), which is defined as the percentage of gaze that falls within the area of the road center (Victor et al., 2005), for each participant and each session was calculated. The value of PRC is the cumulative time of fixation in the center over the total time. The data includes the gaze behavior for approaching the intersection (approximately 160 meters) and crossing the intersection (approximately 24 meters).

5.3 Result

5.3.1 Gaze behavior

Figure 5.2 shows the percent gazing at the road center (PRC) for all four groups in both types of intersection (obstructed view (OV) and unobstructed view (UV)) separately. PRC is displayed for sessions 1, 6, 7, and 8. In the case of the treatment groups, sessions 1 and 7 were without ADAS; whereas, sessions 6 and 8 were with ADAS. Effects of ADAS use on gaze patterns were analyzed with an analysis of variance with Session serving as within-subject factors and Age x Treatment as between-subject factors. Repeated contrast analysis was used to assess significant main and interaction effects in more detail.

Obstructed view

Analysis of PRC revealed significant main effects of Treatment, $F(1,36) = 32.83, p < .001, \eta^2 = .447$, and Session, $F(3,36) = 31.82, p < .001, \eta^2 = .499$, and also a significant interaction effect of Session x Treatment, $F(3,36)= 14.42, p< .001, \eta^2 = .311$, but no significant effect of Age. Table 5.1 lists means and standard deviations of groups individually as well as control and treatment groups combined. Repeated contrast analysis showed a significant interaction of Session x Treatment from session 1 to session 6 ($F(1,36) = 34.12, p < .001, \eta^2 = .516$), from session 6 to session 7 ($F(1,36) = 16.79, p < .001, \eta^2 = .344$), and from session 7 to session 8 ($F(1,36) = 9.38, p = .004, \eta^2 = .227$). For treatment groups, an increase in PRC from session 1 to 6, a decrease from session 6 to 7, and an increase again from session 7 to 8 were observed. Control groups, on the other hand, did not show changes in PRC across sessions.
Unobstructed view

On UV intersections, the same significant effects of Treatment \((F(1,36) = 32.26, p < .001, \eta^2 = .502)\), Session \((F(3,36) = 5.24, p = .002, \eta^2 = .141)\), and Session x Treatment \((F(3,36) = 11.4, p < .001, \eta^2 = .263)\) were revealed. Repeated contrast analysis showed that interaction effects of Session x Treatment were significant from session 1 to 6 \((F(1,36) = 14.19, p = .001, \eta^2 = .307)\) and from session 7 to 8 \((F(1,36) = 7.55, p = .01, \eta^2 = .191)\). Means and standard deviations are listed in Table 5.1.

Table 5.1: Summary of means and standard deviations of PRC for intersections with view obstruction and without view obstruction of control groups (YCG and OCG) and treatment groups (YTG and OTG).

<table>
<thead>
<tr>
<th>Obstructed view</th>
<th>Unobstructed view</th>
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<tr>
<td></td>
<td>M</td>
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<tr>
<td>YCG</td>
<td>45.1</td>
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<tr>
<td>OCG</td>
<td>40.3</td>
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<tr>
<td>Control group</td>
<td>42.7</td>
</tr>
<tr>
<td>YTG</td>
<td>46.2</td>
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<tr>
<td>OTG</td>
<td>47.9</td>
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<tr>
<td>Treatment group</td>
<td>47.1</td>
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</tbody>
</table>

Figure 5.2: Mean percent road center (PRC) for session 1, 6, 7, and 8 of all for groups on intersections with (OV) and without (UV) obstructed view. Left: Obstructed view. Right: Unobstructed view.
5.3.2 Driving performance in intersections

Intersection time, maximum speed on intersection, percentage of stops before crossing an intersection, average minimum TTC, and percentage of critical crossings served as dependent measures assessing intersection performance. Data were analyzed in an analysis of variance with Age x Treatment and Group as between-subject factors and Session (Session 2 vs. Session 8) and Intersection (obstructed view vs. unobstructed view) as within-subject factors. For all variables, it was tested whether type of intersection (view obstruction) affected the outcome. Neither the main effect Intersection nor the two-way and three-way interactions of Intersection and Age and Treatment and Session were statistically significant for intersection time, maximum speed in intersections, and absolute minimum TTC. Therefore, for those variables data of OV and UV intersection were combined for further analyses.

**Intersection time**

![Figure 5.3: Means of intersection times in seconds for sessions 2 and 8 for OCG, OTG, YCG, and YTG.](image)

Intersection times for each group over the eight sessions are displayed in Figure 5.3. Overall, main effects of Age ($F(1,36) = 6.23, p = .02, \eta^2 = .163$) and Session ($F(1,36) = 7.24, p = .01, \eta^2 = .185$) and a significant interaction effect of Session x Treatment ($F(1,36) = 4.93, p = .03, \eta^2 = .134$) were observed. Post-hoc analysis revealed significant differences in intersection time for treatment groups (Older driver Treatment Group (OTG) and Young driver Treatment Group (YTG)), $F(1,18) = 9.34, p = .008, \eta^2 = .369$. On average, intersection time decreased from 5.95 s ($SD = 6.02$) in session 2 to 2.24 s ($SD = 1.54$) in session 8. Control groups’ (Older driver Control Group (OCG) and Young
driver Control Group (YCG)) changes in intersection time ($M_2 = 6.3$, $SD_2 = 6.39$ vs. $M_8 = 5.94$, $SD_8 = 7.51$) were not significant, $F(1,18) < 1$, ns.

Significant differences in intersection time for individual groups ($F(2,36) = 3.69$, $p = .04$, $\eta^2 = .188$) were also found. Therefore, testing for changes over time for each group, a large effect (after adjusting the $\alpha$-level) was found for OTG, $F(1,9) = 6.41$, $p = .04$, $\eta^2 = .445$. OTG decreased their intersection time from 7.50 s ($SD = 6.26$) to 3.07 s ($SD = 1.72$). Even though YTG decreased intersection time from session 2 ($M = 4.41$, $SD = 5.69$) to session 8 ($M = 1.41$, $SD = .75$), changes were not significant, $F(1,9) = 3.15$, $p = .1$, $\eta^2 = .283$. OCG showed a non-significant ($F(1,9) < 1$, ns) decrease in intersection time from 9.69 s ($SD = 7.61$) to 8.51 ($SD = 9.81$) and YCG increased intersection time ($M_2 = 2.91$, $SD_2 = 1.75$ vs. $M_8 = 3.39$, $SD_8 = 2.94$) non-significantly, $F(1,9) < 1$, ns.

**Maximum speed**

Figure 5.4 shows changes of maximum speed in intersections for all four groups. Analyses of maximum speed in intersections revealed that young drivers had a significantly higher maximum speed in intersections compared to older drivers, $F(1,36) = 8.19$, $p = .007$, $\eta^2 = .204$. Even though the analysis did not reveal a significant main effect of Session (session 2 vs. session 8) or a significant interaction effect of Session x Treatment, it is noteworthy to mention that regardless of treatment, it was observed that young drivers of the control group ($M_2 = 34.02$, $SD_2 = 4.07$ vs. $M_8 = 37.25$, $SD_8 = 10.33$) and of the treatment group
(\(M_2 = 36.29, SD_2 = 4.85\) vs. \(M_8 = 38.43, SD_8 = 7.17\)) increased speed in intersections. On the other hand, it was observed that older drivers of the control group decreased speed (\(M_2 = 33.29, SD_2 = 3.09\) vs. \(M_8 = 31.55, SD_8 = 2.56\)); whereas, drivers of the treatment group increased speed in intersections (\(M_2 = 33.26, SD_2 = 3.51\) vs. \(M_8 = 34.35, SD_8 = 3.82\)). This trend of older drivers is also reflected in the interaction effect of Session x Treatment, \(F(1,18) = 3.45, p = .08, \eta^2 = .177\).

**Percentage of stops**

Figure 5.5 shows the number of stops in percentage separately for intersections with (OV) and without (UV) obstructed view. The percentage of stops of young and older drivers differed significantly, \(F(1,36) = 34.98, p < .001, \eta^2 = .516\). Overall, young drivers stopped less frequently before crossing an intersection than older drivers (\(M_{\text{young}} = 19\%\), \(M_{\text{older}} = 47\%\)).

Figure 5.5: Mean number of stops in percent before crossing intersections for sessions 2 and 8 of OCG, OTG, YCG, and YTG. **Left:** Obstructed view. **Right:** Unobstructed view.

Moreover, ANOVA with repeated measures revealed a significant main effect of Session, \(F(1,36) = 9.87, p = .004, \eta^2 = .236\) and a significant interaction of Session x Treatment, \(F(1,36) = 7.46, p = .01, \eta^2 = .189\). Analysis of treatment groups’ (OTG and YTG) percentage of stops showed significant differences over time, \(F(1,18) = 19.53, p < .001, \eta^2 = .550\). The percentage of stops decreased from about 40% in session 2 to about 23% in session 8. Control groups’ (OCG and YCG) percentage of stops did not change significantly over time, \(F(1,18) < 1, ns\). The percentage of stops amounted to about 35% in both sessions.
Type of *Intersection* also resulted in a significant main effect, $F(1,36) = 64.48$, $p < .001$, $\eta^2 = .668$. The percentage of stops in OV was greater than the percentage of stops in UV. The interaction effect of *Intersection x Age*, $F(1,36) = 6.59$, $p = .01$, $\eta^2 = .171$, was also significant. Post-hoc analyses showed a significant effect of *Intersection* on young, $F(1,18) = 15.24$, $p = .001$, $\eta^2 = .488$, and on older drivers, $F(1,18) = 54.95$, $p < .001$, $\eta^2 = .774$. Young drivers stopped at around 28% of the intersections with view obstruction and on 12% of the intersections without obstructed view. On average, older drivers stopped 64% of the time at OV and 32% of the time at UV before crossing the intersection.

The three-way interaction *Session x Intersection x Treatment* was close to being significant, $F(1,36) = 3.89$, $p = .06$, $\eta^2 = .108$. Post-hoc analyses showed that treatment groups’ changes in percentage of stops were significant on OV intersections, $F(1,18) = 12.54$, $p = .003$, $\eta^2 = .440$, as well as on UV intersections, $F(1,18) = 11.48$, $p = .004$, $\eta^2 = .418$. On both types of intersections the percentage of stops decreased from session 2 to session 8. Results for control groups did not reveal significant difference for OV intersections, $F(1,18) = 2.53$, ns, or UV intersections, $F(1,18) = 1.81$, ns. In more detail, OTG’s decrease in stops resulted in large effects for OV ($M_2 = 73\%$, $M_8 = 55\%$), $F(1,9) = 7.51$, $p = .03$, $\eta^2 = .484$, as well as for UV ($M_2 = 47\%$, $M_8 = 14\%$), $F(1,9) = 9.18$, $p = .02$, $\eta^2 = .535$. Results of OV intersections for YTG also yielded a large effect, $F(1,9) = 5.24$, $p = .05$, $\eta^2 = .396$. The percentage decreased from 33% to 16%. On UV intersections, no significant changes were observed, $F(1,9) = 3.02$, ns, even though the percentage decreased from 10% to 4%.

**Collisions and absolute minimum time-to-collision (TTC)**

Figure 5.6 shows detailed information of the crashes which occurred during a total of 288 sessions. With respect to crashes in intersections, crashes were classified as *at-fault* when drivers failed to yield to crossing traffic. Drivers were *not at-fault* when other drivers failed to yield to them. Crashes that occurred at one of the 16 selected intersections were not included in the analysis of the absolute minimum (time-to-collision) TTC. The absolute minimum TTC is lowest TTC value of all 16 intersection crossings averaged for each group per session. Scores per group per session are shown in Figure 5.7.
Testing for differences in absolute minimum TTC, significant differences between young and older drivers, $F(1,36) = 5.41, p = .027, \eta^2 = .145$, were found. Young drivers’ absolute minimum TTC ($M = .38, SD = .41$) was smaller than older drivers’ TTC ($M = .7, SD = .56$). Testing for within-subject effects, a significant interaction of Session x Age, $F(1,36) = 6.86, p = .01, \eta^2 = .177$, was revealed. Older drivers’ TTC slightly decreased across sessions; whereas, young drivers’ TTC increased from session 2 to session 8.

In addition, a significant main effect of Group, $F(2,36) = 7.46, p = .002, \eta^2 = .318$, and a trend for the interaction of Session x Group, $F(2,36) = 2.6, p = .09, \eta^2 = .140$, was found.
Therefore, an analysis of changes over time in the absolute minimum TTC from session 2 to session 8 was done for groups individually. Post-hoc analysis revealed no significant changes in TTC for OCG, OTG, and YCG from session 2 to session 8. For YTG, on the other hand, a large effect ($F(1,9) = 7.51, p = .02, \eta^2 = .484$) was found for the increase in absolute minimum TTC from .15 ($SD = .25$) in session 2 to .76 ($SD = .59$) in session 8.

Critical intersection crossings

The absolute minimum TTC only gave information about the lowest TTC on one occasion, meaning one out of the 16 intersection crossings. As Figure 5.7 shows, that one TTC is below 1 second for all drivers in sessions 2 and 8. One critical crossing can already result in a crash; frequently crossing intersections with low TTC heightens that risk. Six of the twelve crashes that occurred at intersections happened at the selected intersections.

Young drivers’ percentage of critical crossing differed significantly from older drivers’ percentage, $F(1,36) = 8.77, p = .006, \eta^2 = .215$ (see Figure 5.8). On average, young drivers crossed 28% of the time with a TTC smaller than one second, whereas older drivers crossed 14% of the time with a critical TTC value.

![Figure 5.8: Mean number of critical crossings in percent for sessions 2 and 8 of OCG, OTG, YCG, and YTG.](image)

Testing for within-subject effects, a significant interaction of Session x Age, $F(1,36) = 4.73, p = .037, \eta^2 = .129$, was found. Older drivers crossed less frequently with a critical TTC during session 2 (12%) compared with session 8 (19%). Young drivers, on the other hand, decreased the percentage of critical crossings across sessions from 34% to 24%.
The three-way interaction of Intersection \( \times \) Age \( \times \) Treatment, \( F(1,36) = 4.73, p = .037, \eta^2 = .129 \), was also significant. Post-hoc analysis of intersections with obstructed view (OV) revealed a significant main effect of Group \( (F(2,36) = 5.08, p = .01, \eta^2 = .241 \). OCG crossed about 13% of the intersections with a critical TTC in session 2 as well as session 8. OTG increased the percentage of critical crossing from 8% to 12%. Young drivers showed a decrease in the percentage of critical crossings. YCG decreased from 29% to 23% and YTG from 34% to 29%.

Analysis of data of intersections without obstructed view (UV) revealed a significant interaction of Session \( \times \) Group \( (F(2,36) = 4.71, p = .01, \eta^2 = .227 \). The percentage of critical crossings increased from 12% to 20% for OCG, but the change did not reach significance, \( F(1,9) = 1.65, ns \). A large effect was found for OTG in intersections without obstructed view, \( F(1,19) = 4.50, p = .07, \eta^2 = .360 \). The percentage increased from about 15% to 30%. Young drivers of the control group showed a decrease in the percentage of critical crossings \( (M_2 = 40\%, M_8 = 26\%) \), but the change was not significant, \( F(1,9) = 1.7, ns \). YTG also decreased from 31% to 18%, but the change was also not significant, \( F(1,9) = 2.47, ns \).

5.4 Discussion

This study was a follow-up on a previous study of us (Dotzauer et al., 2013a), focusing on comparing intersection performance of older and young drivers and testing for longer-term effects on performance due to ADAS use. Over a period of three weeks, the effects of an advice system (indicating whether it was safe to cross an intersection on performance) were investigated. Up to this point, investigation of ADAS effects on driving performance and behavior over longer time periods is lacking. A longer-term study, during which drivers returned for eight consecutive sessions within a period of three week, was administered, in order to acquaint drivers with the assistance system and examine changes in driving performance and behavior over time. In terms of the intersection assistant, we depicted eight intersections classified as safety critical because bushes placed along the road prevented drivers from having a good view into the intersection and forced them to slow down, to look to the left and right before being able to make a sound decision on crossing. Another eight intersections of the same make-up, but without view obstruction, were also added for further analysis.
An analysis of gaze revealed a significant treatment effect. Being equipped with the ADAS and having the information projected by means of a head up display (HUD) resulted in greater percent road center (PRC) during ADAS sessions compared to the non-ADAS sessions. In contrast with Dukic & Broberg (2012) and Romoser and colleagues (2013), no age effect was found. Gaze behavior of drivers was not affected by age but rather by the type of treatment. When equipped with ADAS, drivers appear to retrieve relevant traffic information from the HUD and spent less time looking to the left or right in order to comprise a picture of the current traffic situation. Per se, this behavior poses a safety risk. Relying on information presented without confirming the accuracy of the information might result in detrimental consequences in the case of a system failure. Moreover, visual inspection of changes in PRC over time tentatively suggests a negative carry-over effect in attention allocation in the older driver treatment group. When ADAS was deactivated in session 7, older drivers of the treatment group still spent less time looking to the left or right than young drivers of the treatment groups. It appears that older drivers adapted their gaze behavior and did not reverse the adaptation effect when driving without the assistance.

The analysis of the driving performance parameters provides more information on the effects of ADAS use on intersection performance. In line with our expectations, an age effect with respect to driving performance parameters was revealed. Young drivers were quicker in crossing intersections, had a higher maximum speed in intersections, and a lower percentage of stops before crossing an intersection. At the same time, young drivers had a smaller absolute minimum TTC value to crossing traffic and crossed more frequently with a critical TTC (< 1 second) than older drivers. Not surprisingly, young drivers were not only involved in more crashes; they also caused most of the crashes involved in (i.e. they failed to yield to the crossing traffic approaching from the right).

In addition, the previous study (Dotzauer et al., 2013a) showed that older drivers supported by ADAS shortened their intersection times over time; whereas, performance of the control group remained constant over sessions. In the present study, we found results to be in line with previous findings. Both treatment groups showed decreases in intersection time over time; whereas, control groups’ intersection times did not change significantly over time. The decrease in intersection time was greatest for older drivers of the treatment group. Intersection time is the sum of waiting and crossing time. Therefore,
a decrease in intersection time mainly results from shorter waiting times before crossing an intersection. Changes in the percentage of stops before crossing an intersection confirm this assumption. With ADAS, drivers decreased their percentage of stops; whereas, without ADAS, the percentage of stops did not change over time.

The effects on maximum speed in intersections are not as straightforward. With respect to older drivers, an increase in maximum speed was observed for drivers of the treatment group and a decrease for drivers of the control group. At least for older drivers, it seems that ADAS use affects maximum speed in intersections. Combined with the results of the intersection time and the percentage in stops before crossing, changes in maximum speed are a logical consequence. Young drivers, regardless of the type of treatment, increased their maximum speed in intersections. It appears that ADAS use did not affect maximum speed in intersection but rather the extent of familiarity of the environment. Charlton and Starkey (2013) found that when drivers become more familiar with the driving task and environment they tend to drive faster.

Whether changes observed affected driving safety might be answered looking at time-to-collision variables. Young as well as older drivers are at risk of being involved in a crash, but the causations differ. Older drivers experience difficulties with selecting and processing relevant information (Brouwer & Ponds, 1994; McGwin & Brown, 1999; De Waard et al., 2009; Musselwhite & Haddad, 2010) whereas, young drivers lack driving experience that is necessary to assess traffic situations accurately (McKnight & McKnight, 2003; Curry et al., 2011). It was expected that drivers would accept gaps that are too small. Young drivers might choose small gaps because of a lack of skills. They just might not know yet how to accurately assess crossable gap sizes (Borowsky et al., 2009; Trick et al, 2009; De Craen et al., 2011, Vlakveld, 2011; Mueller & Trick, 2012) and might learn with the help of the support system. Older drivers, on the other hand, possess the skills, but because of limited attentional capacity and deficits in divided/selective attention and information processing (Brouwer & Ponds, 1994; De Waard et al., 2009; Musselwhite & Haddad, 2010), they might miss information necessary to make a safe crossing maneuver. As a result of ADAS use, we expected to see an increase in safety over time. It was observed that young drivers increased their minimum TTC to crossing traffic over time and older drivers decreased their TTC over time. Against our expectations, only young drivers of the treatment group seemed to
benefit from the gap advice. From session 2 to session 8, they showed a strong increase in the minimum TTC. In session 8, their minimum TTC was even larger than older drivers’. But it is also noteworthy to mention that the absolute minimum TTC was below one second for all groups.

Even more interesting are the number of crashes and the frequency of critical crossings. Treatment groups were involved in three crashes within intersections and were at-fault on one occasion. Control groups, on the other hand, were involved in ten crashes and caused nine of those crashes. Six of those crashes were committed by young drivers. Overall, young drivers of the control group decreased their percentage of critical crossings and increased their absolute minimum TTC over time, but as crash statistics show, changes were not sufficient to prevent crashes from occurring. Young drivers of the treatment group, on the other hand, decreased their percentage of critical crossings, increased their absolute minimum TTC strongly, and caused fewer crashes than young drivers of the control group. It appears that information about gap sizes was beneficial for young drivers of the treatment group. It might have helped them to maneuver safer through intersections. Older drivers of the control group caused three crashes in intersections. They showed a slight decrease in the absolute minimum TTC but also a slight increase in the percentage of critical crossings in intersections without view obstruction. In contrast, older drivers of the treatment group did not cause a crash. They decreased their TTC and increased their percentage of critical crossings. Even though not reflected in their crash statistics, it appears that older drivers of the treatment group adapted negatively to the advice. Their crossing maneuvers became riskier over time and in the long-run might also lead to more crashes.

5.5 Conclusion

Overall, a positive effect on intersection time, especially for older drivers of the treatment group, was found. Drivers of the treatment group did not wait as long before accepting a gap. It appears that they became less hesitant over time; a trend which might be beneficial for the overall road traffic safety. Being less hesitant also means being less of a hindrance to other road users. The question is whether this is at the cost of safety. In the present study, drivers of the treatment groups caused fewer crashes than drivers of the control groups. Therefore, at a first glance, it appears that decisions made were not critical to road
traffic safety. At a second glance, it was observed that especially older driver adapted negatively to the ADAS as reflected in the absolute minimum TTC and frequency of critical crossings. Young drivers might have benefitted from the gap advice; we saw a strong increase in the absolute minimum TTC and also a low number of crashes in the treatment group compared to the control group.

Regardless of age, provision of information affected gaze behavior negatively. Drivers tended to focus primarily on the road center and neglected the left and right of the intersection. Such adaptation to the ADAS needs to be prevented in order to increase road traffic safety. One approach might be to present information were the attention of the driver needs to be. For example, if a driver approaching an intersection from the left fails to yield right-of-way, a driver should not also be warned, but the attention also drawn to the source of danger.

Results are not conclusive, but it is noteworthy to mention that this is one of the first attempts trying to investigate longer-term effects of ADAS use on driving performance. In addition, older drivers selected for the study were fairly young older drivers. Participation was also solely voluntarily. So we might have investigated a small sample of the older population without any prominent impairments rather than the general population. Support provided might have not been needed and drivers of the control group might have performed at an optimal level. With the support, the driving task at hand might have become too easy and drivers started to compensate by engaging in riskier driving maneuvers. In the future, a group of older drivers with impairments should be included in order to test the effectiveness of the information provided. Results also suggest that young drivers might benefit from ADAS. Receiving information about safe gap sizes might teach young drivers to make more sound crossing maneuvers. But taking into account different information processing speed and reaction time, thresholds should be set accordingly.