Intersection assistance

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Title:

Intersection assistance: A safe solution for older drivers?

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Abstract:

Within the next few decades, the number of older drivers operating a vehicle will increase rapidly (Eurostat, 2011). As age increases so does physical vulnerability, age-related impairments, and the risk of being involved in a fatal crashes. Older drivers experience problems in driving situations that require divided attention and decision making under time pressure as reflected by their overrepresentation in at-fault crashes on intersections. Advanced Driver Assistance Systems (ADAS) especially designed to support older drivers crossing intersections might counteract these difficulties. In a longer-term driving simulator study, the effects of an intersection assistant on driving were evaluated. 18 older drivers (M= 71.44 years) returned repeatedly completing a ride either with or without a support system in a driving simulator. In order to test the intersection assistance, eight intersections were depicted for further analyses. Results show that ADAS affects driving. Equipped with ADAS, drivers allocated more attention to the road center rather than the left and right, crossed intersections in shorter time, engaged in higher speeds, and crossed more often with a critical

time-to-collision (TTC) value. The implications of results are discussed in terms of behavioral adaptation and safety.

Keywords:

intersection assistance, older drivers, behavioral adaptation, safety, ADAS

Highlights:

- More attention is allocated to the road center when driving with the system
- Intersection assistance decreases intersection crossing time
- Drivers equipped with ADAS cross intersections more often with a critical TTC

1. Introduction

Because of demographical changes, the number of persons age 65 and above will increase rapidly over the next few decades and in particular this concerns the “older old”, those aged 75 and above (Eurostat, 2011). Driving is going to be the more frequently preferred mode of transportation of the older persons in the future, more than it is presently, due to increasing numbers of people possessing driver’s licenses and keeping them through advanced age, especially for women. Therefore, the number of older persons holding a valid driver’s license and being active drivers will probably rise substantially (OECD, 2001).

With rising age the probability of incidence of diseases and impairments which make the body more vulnerable increase and thus interfere with the capacity for safe driving practices (Hewson, 2006). Nonetheless we cannot ignore differences in health and functioning which vary with each individual. Even in case of significant impairments, older drivers are not necessarily considered unsafe drivers or unfit to drive, as illustrated by various legislations which still allow persons with mild dementia or macular degeneration to drive, granted they have shown in on-road tests that they are able to drive safely. It is actually thought that the driving task provides a lot of opportunities for assistance on an individual, infrastructural, and vehicular level. A recent development in terms of offering support to the driver is the implementation of Advanced Driver Assistance Systems (ADAS) which could be very helpful in case of age- related impairments. It can be argued that older drivers need more tailored support apart from what is currently offered on the market because of the specific crash profile of older drivers, that means at-fault crashes on intersections (Davidse, 2007; McGwin & Brown, 1999; Evans, 2004), are not targeted by currently popular ADAS such as Adaptive Cruise Control (ACC) and Lane Departure Warning (LDW). Consistent with the crash statistics, older drivers themselves report having difficulties identifying traffic signs, extracting the most relevant traffic sign, and also making decisions under time pressure, a reason why they, for example, travel at lower speeds (Musselwhite & Haddad, 2010). Several causes leading to crashes at intersections have been identified. Older drivers often fail to yield to the right-of-way (Aizenberg & McKenzie, 1997; McGwin & Brown, 1999). They experience problems estimating safe gaps between oneself and approaching cars (Oxley et al., 2006) which leads to an over-involvement of crashes when turning left (Griffin, 2004; Mayhew et al., 2006), but also makes passing straight through an intersection a problematic undertaking (Preusser et al., 1998). Approaching and crossing an intersection involves several processes resulting in a complex task. Crossing an intersection 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), and decision making under time pressure (Brouwer & Ponds, 1994). Attentional capacity deficits seem to be the key for their increased involvement in accidents (Owsley et al., 1998).

Michon’s hierarchical task analysis of driving (1985) as applied by Brouwer (2002) to the domain of driver impairments, distinguishes three task levels: the strategic level, the tactical level, and the operational level. 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 choose an alternative route because of expected traffic jams. On the tactical level, which takes place 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 and passing. Decisions on the tactical level are only performed occasionally, for example setting smaller time headway than normal if one is in a hurry or choosing the middle of three parallel lanes in an unfamiliar town. On the operational level (control), the driver performs 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 for the case that actual danger (e.g. vehicle on collision course) manifesting itself in the near future.

On the strategic and tactical level, drivers can make adjustments and compensate for their challenges on the operational level. On the strategic level this includes e.g. not driving during rush hours or avoiding highly complex intersections. On the tactical level, the driver can set a lower travelling speed or decide on keeping a larger gap between themselves and other cars which gives them more time to seek the necessary information and to make a decision. This compensation for challenges is not infinite. When the driving task becomes too complex and/or impairments are too severe, limitations of attentional capacity can no longer be compensated for and other means such as Advanced Driver Assistance Systems (ADAS), are needed to support the older driver. Currently marketed ADAS are not necessarily designed to fit the needs of the older driver.

Older drivers make adjustments on the tactical level in order to be able to extract more traffic-relevant information out of their surroundings (Musselwhite & Haddad, 2010). These results indicate that support on the tactical level might be a promising area of focus for the development of support systems for older drivers. Currently marketed ADAS such as ACC and LDW support the primary driving task, particularly speed control, distance to the car ahead, and lane positioning. Supporting lateral and longitudinal control of the vehicle means providing support on the operational level, which is not necessarily needed. Assistance on the tactical level can be given in form of an intersection assistant that provides relevant traffic information, including traffic signs, speed limits, and gap sizes, for the upcoming intersection in advance. Receiving information in advance serves two purposes. (1) It takes away uncertainty because the driver knows what to expect and what to anticipate. Receiving information in advance can compensate for difficulties in decision making under time pressure. (2) It also counters problems with divided attention because the important information, for example, priority regulation information at the upcoming intersection is fed to the driver before reaching the intersection. In theory, giving the older driver information about speed limit, priority regulation, and approaching traffic in advanced can compensate for attentional capacity challenges leaving enough resources to fulfill the primary driving task; freeing up just enough resources to drive. In the past, designing for in-vehicle signs has shown some promising results (Staplin & Fisk, 1991; Hanowski et al., 1999; Lee et al., 1999;

Luoma and Rämä, 2002; Caird et al., 2008; Ziefle et al., 2008; Davidse et al., 2009), but research has only been done sporadically. Staplin and Fisk (1991) investigated whether advanced information about left turns improved decision making performance in younger and older drivers. They found that younger and older drivers made more accurate go/no go decisions when the information was available. Lee and colleagues (1999), on the other hand, found that in-vehicle messaging led to deterioration in older drivers' performance in terms of crashes per hour, lane variability, and speed variability. Hanowski and colleagues (1999) investigated the effects of advanced warnings (related to unexpected events in traffic). They found that with the advanced information, subjects could anticipate upcoming events. Older as well as younger drivers benefitted from the advanced information. Caird et al. (2008) investigated an in-vehicle warning system which informed the driver about the status of the upcoming traffic light. They found that drivers run fewer red lights when the advanced information was present. Older drivers took longer than younger drivers to process the given information, but when they decided to stop, they compensated by faster reacting and decelerating. Ziefle et al. (2008) showed that presenting traffic information about priority regulation and traffic density of the upcoming intersection visually as compared to auditory led to better performance. Davidse and colleagues (2009) investigated an assistant system that provided information about priority regulation, gap size, obstructed view at the intersection, and one-way streets. The first three types of messages led to safer driver performance, but did not reduce workload. The information about the one-way street resulted in fewer route errors. The studies show changes in performance when driving with ADAS. However, conclusions drawn result solely from short-term studies in which participants encountered a system as novice users in a single assessment. Little is known about longer-term effects of ADAS use on driving performance and driving behavior over time or the effects of negative behavioral adaptation. Longer-term studies investigating the effects of ADAS use are a necessity.

1.1 Current study

As a follow-up of Davidse (2007), the present study was designed to investigate the effects of an intersection assistant on the driving performance and driving behavior of older drivers. A longer-term driving simulator study was realized in order to acquaint drivers with the support system and to examine changes in driving performance and behavior due to ADAS use over time. Participants completed 14 trials in the driving simulator, the first twelve trials within a four week time period and the last two after a four week retention interval. During each trial, participants drove through a virtual city and encountered several driving tasks. One of them was crossing uncontrolled intersections at which subjects had to yield the right-of-way. Bushes placed near the intersection obstructed the view into the intersection and made the crossing a safety-critical task forcing the driver to slow down before crossing. These intersections were used to test the effect of the intersection assistant on driving performance and behavior and to examine the effect on attention allocation due to information presentation in a head up display (HUD).

The implemented intersection assistant was designed to support the driver crossing an intersection safely. It gave advice on whether it is safe to cross an intersection. The advice was based on driver's time-to-intersection (TTI) as well as the time-to-collision (TTC) with other cars approaching the intersection. The information was presented in a HUD.

Even though older persons might learn new complex tasks at a slower pace (Lowe & Rabbit, 1997), we expect that over a longer period of exposure and experience with the intersection assistant, older drivers improve their overall intersection performance. It is expected that as drivers improve their overall driving performance they become quicker at crossing intersections and are also safer by choosing more appropriate gap distances when driving with ADAS. We also expect that drivers equipped with ADAS will use the ADAS and retrieve intersection information resulting in more attention allocation to the road center that is where the information is projected onto. Despite the information retrieval, we do not expect an adverse impact of the ADAS on attention allocation because drivers do not need to take their eyes-off-the road in order to seek out information about the upcoming intersection.

2. Materials and methods

2.1 Participants

Overall, 31 older drivers were recruited through distribution of flyers at different local senior clubs such as bridge and billiard and also through the local senior academy. They all reported feeling subjectively healthy and not having been diagnosed with a serious disease that interferes with driving. 42 percent of the recruited persons were excluded during the training session from the study due to simulator sickness. 18 older drivers between the ages of 65 years and 82 years old (M=71.44 ± 4.82), 15 males and three females participated in the study. On average, participants reported a total driving experience of 965.000 km, with an average of 17.900 km driven the past year. Subjects scored high on the Mini Mental State Exam (MMSE) (M= 29.28 ± .82) indicating intact normal functioning. On average, participants completed the Trial Making Test Part A in 44.33 seconds (SD ± 12.00), which corresponds to the 62nd percentile (Schmand et al., 2012), and Part B in 90.94 seconds (SD ± 22.28), corresponding with the 73rd percentile (Schmand et al., 2012). The mean ratio of Trail Making Test A and B (TMTb/TMTa) resulted in 2.13 (SD ± .58) indicating good task switching abilities, also corresponding to the 73rd percentile (Schmand et al., 2012). Participants assessed their overall driving ability as good. Eight participants felt that they drive better compared to their peer group; nine reported that their driving ability is as good as the peer group. One person reported driving worse compared to the peer group. Participants were randomly assigned to the control and treatment group.

2.2 Apparatus

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

2.3 ADAS

The ADAS consisted of four functions: traffic sign recognition, speed warning, collision warning, and intersection assistance, but in this paper, the intersection assistant will only be discussed. The intersection assistant was realized by providing information about approaching traffic at the upcoming intersection. The assistant system indicated whether it is safe to cross an intersection. The information was presented in form of a bar in front of the driver by means of a head-up display HUD). It was a three-stage system that dynamically changed from green to amber to red and vice versa as the traffic situation changed. The priority regulation at the intersection as well as the travelling direction (as indicated by the activation/deactivation of the indicator) of the driver were considered by the assistant system. A gap between cars greater than five seconds indicated safe crossing (green flag). Gap 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 as well as the time-to-collision with other cars approaching the intersection was taken into account. TTI and TTC values are based on speed and distance.

2.4 Design

The driving simulator study is a mixed study design with 13 or 14 repeated measures depending on the manipulation which had been approved by the Medical Ethical Committee (METc) of the University Medical Center Groningen. Participants were randomly assigned to the control and treatment group. The control group completed the experiment without the intersection assistant; the treatment group drove three times without assistance and eleven times with. The virtual driving environment was comprised of a 25 km city drive. Route instructions on when to turn left or right were given visually and auditorily 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 and speed limits,

slower moving vehicle in front of them, etc. All participants completed the first trial without the system. The treatment group completed trial two to six with ADAS, trial seven was without ADAS, and trials eight to twelve with ADAS again. After a retention interval of four weeks, the treatment group completing one trial with ADAS and one without; whereas, the control group completed one trial without ADAS.

For the present study, trial 1, 6, 7, and 8 were depicted for further analysis. The intersections used to assess the effect of ADAS use are characterized as safety critical because view was obstructed on these intersections forcing the driver to slow down look to the right and left before crossing an intersection. The speed limit was 30 km/h and priority was regulated by yield-to-the-right. For each trial, eight intersections were included for the analysis.

2.5 Procedure

Persons interested in participating in the study received an information package via regular mail or email including a detailed description of the study, the Motion Sickness Questionnaire (Golding, 1998), and an informed consent form. After filling in the questionnaire and signing the informed consent, participants were invited, filled in questionnaires and completed 4 rides in the driving simulator in order to get acquainted to the simulator but also to test for simulator sickness. Participants who experienced simulator sickness during the training were excluded from the study.

Participants returned for the experimental trials. They read a short description of the experiment, 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 trial, the treatment group was introduced to the ADAS. It was explained to them thoroughly and also presented to them. They also took home a user manual and asked to read it thoroughly. Participants returned to the driving simulator three times per week for four weeks and after the retention interval for a final assessment in order to complete participation in the experiment. Participants were compensated for their participation.

2.6 Data analysis and dependent measures

For the present study, trial 1, 6, 7 and 8 were depicted for further analysis. For the treatment group, trial 1 and 7 were without ADAS, trial 6 and 8 were with ADAS. The control group completed all trials without ADAS. Per trial, eight intersections characterized as safety critical because of view obstruction were depicted 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 with a frequency of 10 Hz and stored as ASCII files. A MATLAB routine was used to extract the information about speed, time, and critical events. In particular, for each trial we determined the mean intersection time, i.e. the average sum of waiting time and crossing time of all intersections, the average maximum

speed on all intersections, stopping behavior, i.e. the percentage of intersections where the intersection approach speed was between 0 and 1 km/h, and time-to-collision. Data were analyzed to investigate the effect of the implemented intersection assistant on intersection performance

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. The gaze of the participant was coded with center, left, right, or other. Out of the output file, the percent road center (PRC), which is defined as the percentage of gaze data points that falls within the area of the road center (Victor et al., 2005), for each subject and each trial 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 23 meters).

The extracted TTC values only include values from participants' entrance until exit of the second crossing lane. For this time frame, the mean TTC as well as the mean minimum TTC were determined. The absolute minimum TTC, i.e. the absolute lowest value while crossing the intersection, the percentage of critical and safe gap crossings also serve as a dependent measure. Safety critical gaps are gaps with a TTC equal to or smaller than one second. Safe crossing gaps have been defined as gaps with a TTC equal to or greater than 1.5 seconds.

3. Results

3.1 Gaze behavior

An analysis of Friedman's ANOVA shows that the gaze behavior (Figure 1) of the CG did not change significantly over time, χ^2 (3, N=9)= 3.4, p= .35; whereas, TG's gaze behavior changed over time, χ^2 (3, N=9)= 15.3, p< .001. Wilcoxon tests were used to follow up on the findings of TG. A Bonferroni correction was applied and all effects are reported at a .008 level of significance. It appeared that the differences in PRC are significant when comparing trial 1 (no ADAS) with trial 6 (ADAS), z= 2.66, p= .001, r= .89, and trial 1 (no ADAS) with trial 8 (ADAS), z= 2.55, p= .008, r= .85. Comparing other trials with each other did not lead to significant differences, but large effects were revealed. TG spend more time looking in the center on trial 7 (no ADAS) compared to trial 1, z= 1.96, p= .05, r= .65. Results comparing trial 6 (ADAS) and trial 7 (no ADAS), z= 2.07, p= .04, r= .70 show a decrease in PRC from one trial to the other, and comparing results of trial 7 (no ADAS) with the results of trial 8 (ADAS), z= 1.71, p= .09, r= .57, suggest an increase in PRC, again.

---INSERT FIGURE 1 ABOUT HERE---

Comparing mean ranks between CG and TG using a Mann-Whitney U test (α= .01) revealed significant differences in trial 6 (no ADAS vs. ADAS), z= 3.05, p= .001, r= .72, trial 7 (both no ADAS), z= 2.61, p= .008, r= .61, and trial 8 (no ADAS vs. ADAS), z= 3.13, p= .001, r= .74 indicating a higher PRC for TG compared to CG.

3.2 Intersection time

Figure 2 shows the average intersection time with the standard errors for both groups. Friedman's ANOVA was used to analyze differences in intersection time over time. No significant differences in intersection time were found for the control group (CG), χ^2 (3, N=9)= 1.8, p= .65, indicating no changes in intersection time over time. A trend was observed for the treatment group (TG), χ^2 (3, N=9)= 6.6, p= .08. As a post hoc analysis, the Wilcoxon test was applied to examine the difference in intersection time over time for the treatment group. A Bonferroni correction was applied and results are reported at a .008 significance level. The decrease in intersection time over trials for TG was significantly different when comparing trial 1 with trial 7 (both trials no ADAS), z= 2.55, p= .008, r= .85. A comparison of trial 1 (no ADAS) with trial 6 (ADAS) did not reveal a significant decrease in intersection time, but a large effect was observed, z= 2.19, p= .02, r= .73. The same is true when comparing trial 1 (no ADAS) with trial 8 (ADAS), z= 2.07, p= .04, r= .70. The effect sizes show a decrease in intersection time when comparing trial 1 with the remaining three trials.

---INSERT FIGURE 2 ABOUT HERE---

In order to determine difference in intersection time between groups, per trial mean ranks were compared using Mann-Whitney U tests. The significance level has been adjusted to α= .01. No significant differences between groups have been revealed, but a large effect was found for trial 6 (no ADAS vs. ADAS), z= 2.61, p= .03, r= .51 and a medium effect for trial 7 (both groups no ADAS), z= 2.61, p= .06, r= .45 which tentatively suggests a faster intersection time for TG compared to CG.

3.3 Speed Information

3.3.1 Average maximum speed

Friedman's ANOVA did not reveal significant differences in maximum speed for either CG, χ^2 (3, N=9)= 1.13, p= .81, nor TG, χ^2 (3, N=9)= 3, p= .41, over time. Figure 3 shows the mean values for maximum speed on intersections including the standard errors. In order to analyze differences in maximum speed between groups, Mann-Whitney U tests were used. The tests did not reveal significant differences between groups in choice of speed on the

intersection, but medium effects for trial 6, z=1.37, p= .19, r=. 32, trial 7, z= 1.37, p= .19, r= .32, and trial 8, z= 1.81, p= .07, r= .43 have been observed which tentatively suggest that TG crosses intersection with a higher speed.

---INSERT FIGURE 3 ABOUT HERE---

3.3.2 Stopping at intersection

Investigating participants' stopping behavior (see Figure 4) at intersections using Friedman's ANOVA did not reveal differences over time for CG, χ^2 (3, N=9)= 2.6, p= .46, but significant difference for TG , χ^2 (3, N=9)= 8.9, p= .02. For a post hoc analysis, Wilcoxon tests have been administered with an adjusted level of significance set to .008. Significant differences were not found, but large effects, showing a decrease in the percentage of stops, were revealed when comparing trial 1 to trial 6, z= 2.31, p= .02, r= .77, to trial 7, z= 2.39, p= .01, r= .80, and to trial 8, z= 1.71, p= .09, r= .57. Between-subject comparisons did not yield significant differences.

---INSERT FIGURE 4 ABOUT HERE---

3.4 Time-to-collision (TTC)

3.4.1 Average TTC

On average, TG crossed the intersections with a smaller average TTC (see Figure 5), but Friedman's ANOVA did not reveal differences in average TTC over time for neither CG, χ^2 (3, N=9)= .10, p= .99 nor TG χ^2 (3, N=9)= .86, p= .85. Mann Whitney U tests also did not yield significant differences between groups, but on trial 1 (no ADAS) a large effect, z= 2.08, p= .40, r= .50, has been observed indicating a smaller TTC for TG. The differences between groups on trial 7 (no ADAS) were not significant either, but a medium effect, z= 1.63, p= .10, r= .39, in the same direction was observed.

---INSERT FIGURE 5 ABOUT HERE---

3.4.2 Minimum and absolute minimum TTC

Minimum TTC and absolute minimum TTC were also analyzed. Figure 6 shows the mean values for the average minimum TTC as well as the absolute minimum TTC including the standard errors. Friedman's ANOVA did not result in significant changes over time in

average minimum TTC for neither CG χ^2 (3, N=9)= .33, p= .97 nor TG χ^2 (3, N=9)= .20, p= .98. Between-subject comparison also did not reveal significant differences between the groups at the different measurements in time either.

---INSERT FIGURE 6 ABOUT HERE---

Analyzing the absolute minimum TTC data using Friedman's ANOVA did not yield significant results, neither for CG χ^2 (3, N=9)= 4.70, p= .20 nor for TG χ^2 (3, N=9)= .07, p= 1.00. Mann-Whitney U tests also did not reveal significant differences between groups.

3.4.3 Critical and safe gaps

Changes in critical gaps ($\leq$ 1s) over time were analyzed using Friedman's ANOVA. No significant differences for CG, χ^2 (3, N=9)= 1.08, p= .79 or TG χ^2 (3, N=9)= .67, p= .89, have been observed, even though, on average, TG crossed the intersection between critical gaps more often than CG (see Table 1). Looking at between-subject comparisons, Mann-Whitney U tests did not yield significant differences between CG and TG. Only for trial 1 (no ADAS) a medium effect, z= 1.86, p= .09, r= .44 was observed.

---INSERT TABLE 1 ABOUT HERE---

It was also analyzed whether choosing a safe gap ($\geq$ 1.5s) would change over time. Friedman's ANOVA did not result in significant differences for either CG, χ^2 (3, N=9)= 2.40, p= .51 or TG χ^2 (3, N=9)= .66, p= .89. Analyzing between subject differences did not reveal significant differences, but medium effects have been observed for the trials without ADAS. The differences in trial 1 result in z= 1.87, p= .07, r= .44 and in trial 7 in z= 1.44, p= .16, r=. 34.

4. Discussion

This study was conducted to evaluate the longer-term effects of an intersection assistant on driving. The support system was tailored to fit the needs of the older driver. It gave advice on whether it was safe to cross an intersection indicated by a green, amber, or red flag in an HUD. The experiment was realized as a longer-term study in order to acquaint drivers with the assistant and examine changes in driving performance and driving behavior over time. Of special interest were negative behavioral adaptations and whether these changes in behavior were carried over when ADAS was taken away from the driver. In order to investigate effects

of ADAS, intersections characterized as safety critical intersections had been depicted for further analyses. The view into the intersection was obstructed, which, in general, forced the driver to slow down and look to the left and right before being able to make a sound decision on crossing the intersection. A general trend that could be observed was that driving performance of the treatment group did not go back to the initial performance as displayed during the baseline trial when the ADAS was deactivated for one trial, after driving with ADAS over a longer period of time.

An analysis of the gaze behavior revealed no significant differences in attention allocation over trials for the control group. On the other hand, as expected, the treatment group showed changes in gaze behavior spending more time looking at the road center when driving with ADAS. The hypothesis that the treatment group will look more in the center than the control group, when driving with ADAS, was confirmed. When driving with ADAS, drivers retrieved relevant information about other cars approaching the intersection and gap information form the HUD. They spent less time looking to the left and right in order to comprise a picture of the current traffic situation. Even though the differences on trial 7 were not significant, calculating the effect size revealed a large effect. This suggests that after being equipped with the intersection assistant, drivers did not go back to their initial gaze behavior as displayed during baseline. They still allocated less attention to the left and right of the intersection and more attention to the road center. This could be an indication for a negative carry-over effect, not being able to suppress the new learned behavior. But it could also mean that with the help of ADAS, they learned to look and retrieve information more effectively considering the finding that the amount of crossings with a critical time-to-collision did not increase significantly in trial 7.

Intersection time was used to assess drivers' intersection performance. The results showed that over time and equipped with ADAS, older drivers crossed intersections faster than drivers not equipped with ADAS. The hypothesis has been confirmed. Contrary to expectations, the intersection times for trial 7, the trial where both groups drove without ADAS, were also different for the groups. Having the ADAS taken away from the driver did not increase drivers' intersection times. A difference was observed between the baseline trial (without ADAS) and the following trials for the treatment group; whereas, the control group did not improve over time. These differences between groups suggest that ADAS affects the overall intersection performance. It indicates that with the support system drivers do not wait as long as unequipped drivers before crossing an intersection. They seem to learn taking smaller gaps based on the advice on safe gaps given by the ADAS.

Speed has also been analyzed in order to find out whether ADAS has an effect on speed choice as well as on stopping behavior. No significant differences could be found between groups. It was expected that the treatment group engages in higher speeds when driving with ADAS compared to the control group. The hypothesis could not be confirmed. Nevertheless, medium effects were observed tentatively suggesting that the control group decreased speed on intersections over time. This might be an indication for a more cautious driving behavior; whereas, the treatment group showed an increase when driving with ADAS and a decrease in speed when driving without ADAS. Seeing this trend in the treatment group over trials and

conditions suggests that the green flag indicating safe crossing might have served as a trigger to drivers to clear the intersection as fast as possible. Taking the stopping behavior into account supports this assumption. The control groups' and treatment groups' stopping behavior on trial 6 and trial 8 did not differ significantly, but at the same time, the maximum speed on intersections is higher for the treatment group compared to the control group. Because speed analysis shows different trends for both groups, but the stopping behavior did not yield the same trend, we assume that the green flag triggers a response, namely, hitting the gas and crossing the intersection quickly. When driving without ADAS, even though the choice of speed did not change, the stopping behavior of the treatment group changed. A visual inspection of the figure on stopping behavior shows that on the trial 7 (no ADAS), the treatment group stopped fewer times compared to the baseline trial, and fewer times compared to the trials with ADAS, not what was expected. An explanation for the changes on trial 7 might lie in the analysis of TTC.

Time-to-collision has been analyzed as a safety indicator. Small TTC below a critical value can serve as an indication for unsafe behavior and decision making. It was expected that drivers equipped with ADAS choose for more conservative gaps than drivers not equipped with ADAS. This hypothesis could not be confirmed. Analyses of the TTC data did not yield any significant results. Yet, given the observation that drivers of the treatment group became less cautious over time as indicated by less attention allocation to the left and right, shorter intersection times, fewer stops before the intersection, we might expect more risky crossings in general, but also when drivers first equipped with an intersection assistance drive after an acquainting period without ADAS again. A visual inspection of figures 5 and 6 indicate that the average TTC as well as the average minimum TTC is lowest on trial 7 for the treatment group. It tentatively suggests that drivers made less conservative decisions when they drove without ADAS on trial 7. The figures suggest changes in driving over time for the treatment group. Inspecting changes over time, we can observe that drivers of the treatment group stopped fewer times and crossed intersections with an overall lower speed. The changes in the numbers of stops and speed suggest that crossings are made at the cost of safety margins. We can observe the smallest TTC (see Figure 6) on trial 7 compared to all other trials. Looking at the mean values (see Table 1) for the percentage of safe and critical crossings, we can also observe that the treatment group found more safety critical gaps and less safe gaps on trial 7.

5. Conclusion

To summarize, we investigated the effects of an intersection assistant on driving performance and driving behavior. We can conclude that the intersection assistant leads to changes in both driving performance and driving behavior. Driving with ADAS resulted in faster intersection crossings. Drivers of the treatment group tended to cross intersections with higher speeds and smaller TTC. According to the literature, critical TTC on intersections are defined as times smaller than 1.5 seconds (van der Horst, 1990). On average drivers kept TTC greater than that, even though the average minimum TTC of the treatment group was smaller than the

TTC of the control group and the absolute minimum TTC of the treatment group remained below 1 second on all trials. Moreover, an analysis of the gaze revealed that when driving with ADAS, drivers sought out information about the upcoming intersection from the HUD, spending less time looking to the left and the right. A trend also noticed when the ADAS was taken away from the driver on trial 7. This effect might also be due to the fact that the study was done in a driving simulator and participants were aware that a crash would have no serious consequences. We also saw that when driving without ADAS, after being exposed to the ADAS for a longer period of time, performance did not go back to the initial performance as displayed during the baseline trial. At this point, we cannot conclude whether these changes in performance and behavior are due to a safer and more efficient way of driving or whether they reflect a continuum of a risky behavior that resulted from driving with the system. One reason why we cannot draw exclusive conclusions from these findings is the sample size. The sample size was small, and therefore, we did not reveal too many significant differences between groups, but effect size calculations indicate that with a bigger sample size, results should allow for more explicit conclusions.

Moreover, the population investigated in this study were fairly young older drivers without prominent impairments. These drivers might have not benefitted from the implemented ADAS because they were still able to drive safely. In order to gain more insight, driving behavior and performance of the investigated group needs to be compared to young drivers but also to impaired drivers which will be done in a follow-up study.

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Figure 1: Mean of percent road center for CG and TG, standard er

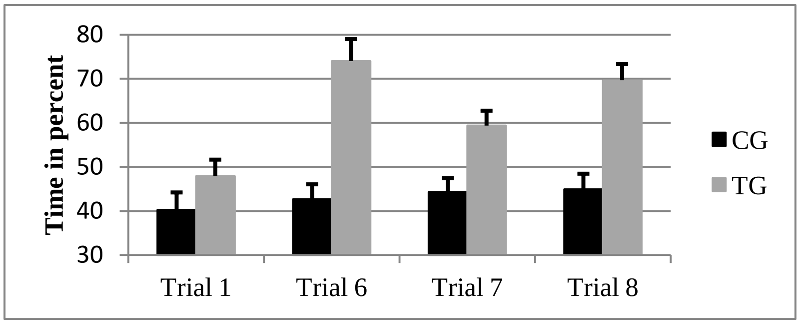

Figure 1: Mean of percent road center for CG and TG, standard error is represented in the error bars

Figure 2: Mean intersection crossing time for CG and TG, standar

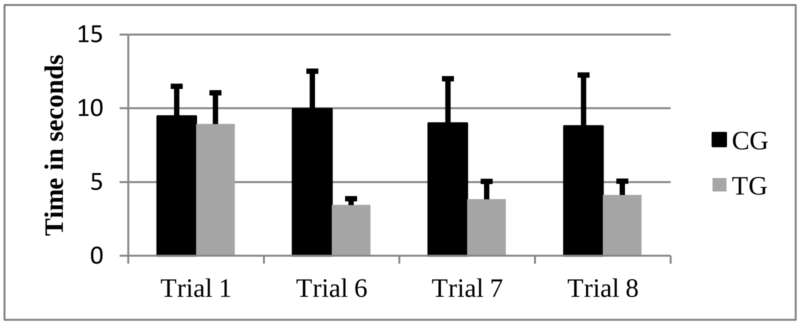

Figure 2: Mean intersection crossing time for CG and TG, standard error is represented in the error bars

Figure 3: Mean maximum speed for CG and TG, standard errors are

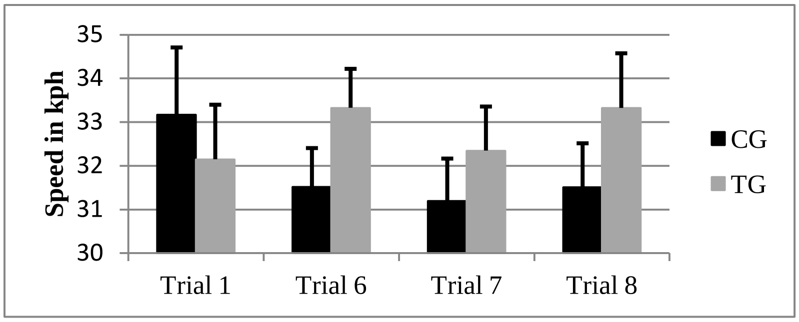

Figure 3: Mean maximum speed for CG and TG, standard errors are represented in the error bars.

Figure 4: Mean percentage of stops at an intersection before cro

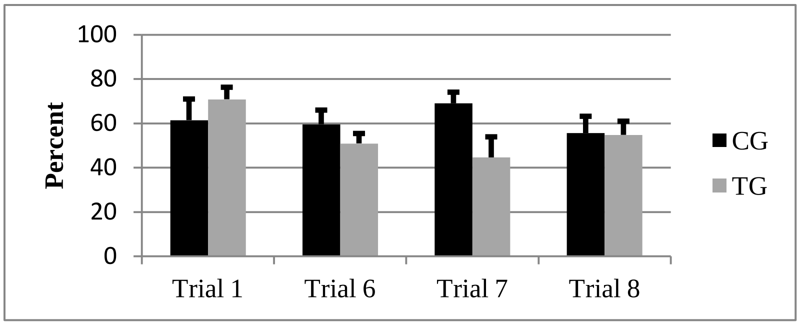

Figure 4: Mean percentage of stops at an intersection before crossing the intersection for CG and TG, standard errors are presented in the error bars.

Figure 5: Mean TTC when crossing an intersection for CG and TG,

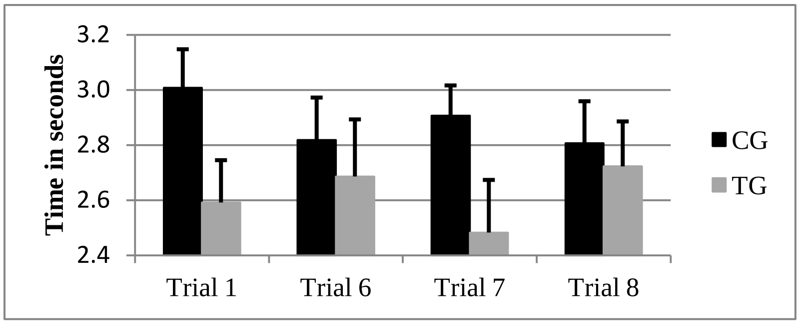

Figure 5: Mean TTC when crossing an intersection for CG and TG, standard errors are presented in the error bars

Figure 6: Mean of lowest TTC per trial for CG and TG as well as

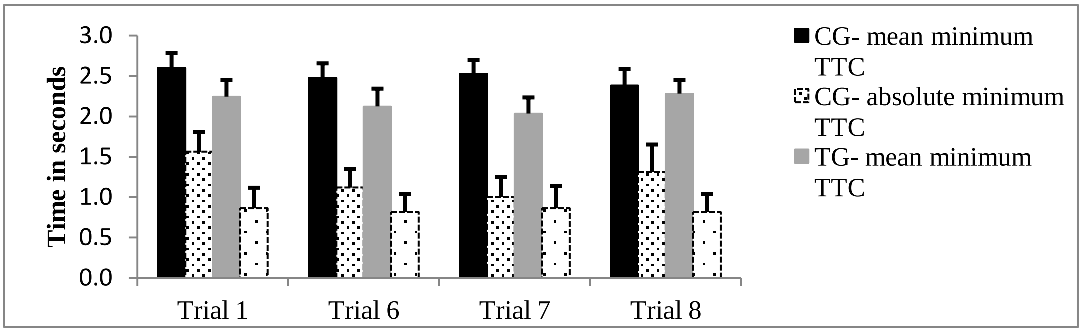

Figure 6: Mean of lowest TTC per trial for CG and TG as well as the mean minimum TTC for CG and TG, standard errors are presented in the error bars

Table 1: Descriptive statistics: Mean and SD for the number of critical (TTC $\geq$ 1s) and safe (TTC $\leq$ 1.5s) intersection crossings in percent for control group (CG) and treatment group (TG)

		Critical gap crossing				Safe gap crossing			
		Trial 1	Trial 6	Trial 7	Trial 8	Trial 1	Trial 6	Trial 7	Trial 8
CG	Mean	2.77	10.31	10.30	12.47	91.66	83.04	85.95	85.67
	SD	5.51	14.24	12.98	21.03	13.97	14.35	13.27	22.84
TG	Mean	13.11	17.28	17.90	12.03	77.47	77.62	71.29	78.66
	SD	14.33	23.99	18.92	13.69	19.79	24.48	23.24	15.36