Accident Analysis and Prevention 74 (2015) 24–32

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Behavioral adaptation of young and older drivers to an intersection crossing advisory system

Mandy Dotzauer[a,*], Dick de Waard[b], Simone R. Caljouw[c], Gloria Pöhler[d], Wiebo H. Brouwer[a,b]

[a] UMCG, Department of Neurology, Neuropsychology Unit, Hanzeplein 1, AB 60, 9700 RB Groningen, the Netherlands
[b] University of Groningen, Department of Clinical and Developmental Neuropsychology, Grote Kruisstraat 2/1, 9712 TS Groningen, the Netherlands
[c] UMCG, Faculty of Medical Sciences, University of Groningen, Center for Human Movement Sciences, Antonius Deusinglaan 1, Room 329 (3215), 9713 AV Groningen, the Netherlands
[d] Karlsruhe Institute of Technology, IFAB, Engler-Bunte-Ring 4, Building 40.29, Room 107, 76131 Karlsruhe, Germany

ARTICLE INFO

Article history:
Received 27 September 2013
Received in revised form 4 July 2014
Accepted 29 September 2014
Available online 17 October 2014

Keywords:
Intersection assistance
older drivers
Behavioral adaptation
Safety
ADAS

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 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.

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 (Euro Stat, 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., 2013). 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 and 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. (1999) 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 and Trick, 2012), relatively more frequently, they do not maintain attention (Simons-Morton et al., 2004; Jaccard et al., 2005; Beede and Kass, 2006; Kass et al., 2007), search inappropriately (Pradhan et al., 2009; Vidotto et al., 2011), fail to

* Corresponding author. Tel.: +49 531 295 3519.
E-mail addresses: mandy.dotzauer@dlr.de (M. Dotzauer), d.de.waard@rug.nl (D. de Waard), s.r.caljouw@umcg.nl (S.R. Caljouw), gloria.poehler@kit.edu (G. Pöhler), w.h.brouwer@rug.nl (W.H. Brouwer).

http://dx.doi.org/10.1016/j.aap.2014.09.030
0001-4575/

recognize hazards (Borowsky et al., 2009; Trick et al., 2009; De Craen et al., 2011; Vlakveld, 2011; Mueller and 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 and 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 and 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 and Brown, 1999; Davidse, 2007) struggling most with decision making under time pressure and divided/selective attention (Brouwer and Ponds, 1994; De Waard et al., 2009; Musselwhite and Haddad, 2010).

According to older drivers' specific crash characteristic, the ADAS used in the previous study (Dotzauer et al., 2013) was designed. It gave tailored support to older drivers providing relevant traffic information in advance countering 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., 2013) 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., 2008), decision making under time pressure (Brouwer and 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., 2013) 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 (65–82 years) in order to investigate effects of ADAS use on performance over time, and to scrutinize the need for tailored support (Dotzauer et al., 2013). 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.

2. Method

2.1. Participants

In a recent study (Dotzauer et al., 2013), 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,