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The influence of age on the take-over of vehicle control in highly automated driving

Moritz Körber *, Christian Gold [1], David Lechner, Klaus Bengler [2]

Institute of Ergonomics, Technical University of Munich, Boltzmannstraße 15, 85747 Garching, Germany

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ABSTRACT

The growing proportion of older drivers in the population plays an increasingly relevant role in road traffic that is currently awaiting the introduction of automated vehicles. In this study, it was investigated how older drivers (⩾60 years) compared to younger drivers (⩽28 years) perform in a critical traffic event when driving highly automated. Conditions of the take-over situation were manipulated by adding a verbal non-driving task (20 questions task) and by variation of traffic density. Two age groups consisting of 36 younger and 36 older drivers drove either with or without a non-driving task on a six-lane highway. They encountered three situations with either no, medium or high traffic density where they had to regain vehicle control and evade an obstacle on the road. Older drivers reacted as fast as younger drivers, however, they differed in their modus operandi as they braked more often and more strongly and maintained a higher time-to-collision (TTC). Deterioration of take-over time and quality caused by increased traffic density and engagement in a non-driving task was on the same level for both age groups. Independent of the traffic density, there was a learning effect for both younger and older drivers in a way that the take-over time decreased, minimum TTC increased and maximum lateral acceleration decreased between the first and the last situation of the experiment. Results highlight that older drivers are able to solve critical traffic events as well as younger drivers, yet their modus operandi differs. Nevertheless, both age groups adapt to the experience of take-over situations in the same way.

1. Introduction

Nowadays, industrialized nations are witnessing a major change in demographics since the proportion of older people in the population is steadily growing. According to Cauley (2012), the proportion of people in the global population older than 65 years will double from 7% to 14% by 2040. Accompanied by that is an increased number of elderly drivers in road traffic. It is controversially discussed whether older drivers have increased involvement in accidents. Frailty bias (overrepresentation in registered accidents because of their increasing physical frailty) and low mileage bias (driver with low yearly driving distances have a higher risk per kilometer) show that a simple measurement by crash rate based on distance driven might result

* Corresponding author at: Institute of Ergonomics, Technical University of Munich, Boltzmannstraße 15, D – 85747 Garching, Germany. Tel.: +49 89 289 15376.

E-mail addresses: koerber@lfe.mw.tum.de (M. Körber), gold@lfe.mw.tum.de (C. Gold), lechnerd@lfe.mw.tum.de (D. Lechner), bengler@lfe.mw.tum.de (K. Bengler).

[1] Tel.: +49 89 289 15401.

[2] Tel.: +49 89 289 15400.

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in a skewed image (Langford, Methorst, & Hakamies-Blomqvist, 2006). In addition, older drivers differ from younger drivers in the type of crashes (Cicchino & McCartt, 2015; Dotzauer, de Waard, Caljouw, Pöhler, & Brouwer, 2015) and show compensatory driving behavior, i.e. driving in conditions and at demands that are appropriate for their abilities (Andrews & Westerman, 2012). Therefore, accounting for multiple factors (how much is driven, in what situation, where, when and how) is important for estimating elderly drivers' crash risk (Blanchard, Myers, & Porter, 2010).

Aging is accompanied by a decline in cognitive functions (Salthouse, 2009) and since driving is a complex task, such impairments may also be relevant for safe road behavior. Anstey and colleagues (Anstey, Wood, Lord, & Walker, 2005) give an overview of age-related changes relevant to driving and show that the relationship between the decline in performance in cognitive tests and reported crash involvement varies. Impairments and decline relevant to driving include executive functions (Bryan & Luszcz, 2000), impaired vision (Haegerstrom-Portnoy, Schneck, & Brabyn, 1999), perception of hazards (Horswill et al., 2008), reaction times (Der & Deary, 2006), and information processing speed (Salthouse, 1991; Verhaeghen & Salthouse, 1997). Additionally, their visual search is altered (Maltz & Shinar, 1999), older drivers make more mistakes in estimating the speed of other vehicles (Scialfa, Guzy, Leibowitz, Garvey, & Tyrrell, 1991), they take longer to switch tasks (Kray & Lindenberger, 2000), and solve novel problems worse (Baltes, Staudinger, & Lindenberger, 1999). However, although every aging individual is affected by this decline, its speed and intensity vary strongly between them (Hultsch, MacDonald, & Dixon, 2002) and this variability, in addition, increases with age (Morse, 1993). Hertzog, Kramer, Wilson, and Lindenberger (2008) describe the decline as a "zone of possible functioning" (p. 1) whose borders are set by person-specific endowments and age-related constraints. According to them, an individual's position in this zone is dependent on the individual engagement in gainful intellectual, physical, and social activities. Therefore, given the right conditions, proper cognitive functioning can be maintained even at an higher age. Furthermore, performance in naturalistic common tasks does not only depend on elementary general cognitive abilities but is also influenced by specific knowledge and expertise (Masunaga & Horn, 2001). Even performance in cognitive tasks, laboratory or naturalistic, is partially based on acquired relevant information structures (Hertzog, 2008), which limits the external validity of laboratory tests. Development of cognitive performance is thereby not only a function of age, but also of compensatory adaptations, experience-related changes, and acquisition of expertise. From this perspective, aging does not necessarily lead to a deterioration in driving performance for everyone, but depends on the situation and individual lifestyle.

While the impact of this decline on road safety has already been studied in manual driving (e.g. Devlin, McGillivray, Charlton, Lowndes, & Etienne, 2012; Horberry, Anderson, Regan, Triggs, & Brown, 2006), the planned introduction of vehicle automation to mass-production vehicles creates the need to investigate older drivers' interaction with vehicle automation. This introduction initiates a shift in vehicle control since the ability to let longitudinal control as well as lateral control be carried out by an automation is now provided (Gold & Bengler, 2014). This shift also influences the driver's tasks and their demands: In highly automated driving (Gasser, 2012; Level 3 in NHTSA, 2013), the driver is not actively taking part in the controller-vehicle loop and, therefore, it is now possible for him to engage in non-driving-related activities (e.g. reading e-mails). If the system detects a system limit, it then requests the driver to take over vehicle control in a certain amount of time. Thus, the driver now has to react quickly, must be able to switch from secondary tasks to manual driving and has to gather information about the environment as well as the reason for the takeover request (TOR) and has to choose the best reaction. If vehicle automation is to be introduced into road traffic, safe use for every potential user has to be ensured (Körber & Bengler, 2014). Since reaction times (Der & Deary, 2006), processing speed (Salthouse, 1991), task switching (Kray & Lindenberger, 2000) and hazard perception response time (Horswill et al., 2008) decline with age, it seems reasonable that older drivers could take longer to regain vehicle control in case of a TOR. Petermann-Stock, Hackenberg, Muhr, and Mergl (2013) investigated the influence of age on take-over time with a younger driver (25–35 years) and an older driver (50–70 years) group. They found a difference of up to 1200 ms (depending on the workload condition) between the means in take-over time of the two age groups, although this difference was not significant. A reason for this result could lie in the study design: the participants drove at rather low speed (35 km/h) and no immediate reaction by the participants was necessary. It is imaginable that the participants did not react as fast as possible and took their time to comfortably take over, which could have ruled out any age-related differences in reaction times. Thus, more research about take-over time of older drivers and, given the mentioned performance variations of older drivers dependent on the situation, relevant situational influences is needed. In this study, we, therefore, investigate the influence of age on take-over time in highly automated driving in varying conditions.

2. Situation complexity as intensifier of age effects

Depending on the time and location of the drive, the number of other road users might vary. Other road users increase the complexity of a situation and the number of objects that have to be monitored or taken into account in the decision-making process. Accordingly, Baldwin and Coyne (2003) found significant processing decrements, indicated by higher response times and lower accuracy, in a detection task as a function of increased traffic density, although subjective ratings and EEG results did not differ significantly between the conditions. Strayer, Drews, and Johnston (2003) report an exacerbation of the difference between single- and dual-task conditions by traffic density: participants were more often involved in a traffic accident while talking on a cell phone when the traffic density was high. Törnros and Bolling (2006) found performance in a peripheral detection task (PDT) to be remarkably poor in a complex urban environment, even when there was