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Individual differences in cognitive functioning predict effectiveness of a heads-up lane departure warning for younger and older drivers

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ABSTRACT

The effectiveness of an idealized lane departure warning (LDW) was evaluated in an interactive fixed base driving simulator. Thirty-eight older (mean age = 77 years) and 40 younger drivers (mean age = 35 years) took four different drives/routes similar in road culture composition and hazards encountered with and without LDW. The four drives were administered over visits separated approximately by two weeks to examine changes in long-term effectiveness of LDW. Performance metrics were number of LDW activations and average correction time to each LDW. LDW reduced correction time to re-center the vehicle by 1.34 s on average (95% CI = 1.12–1.57 s) but did not reduce the number of times the drivers drifted enough in their lanes to activate the system (LDW activations). The magnitude of reductions in average correction RT was similar for older and younger drivers and did not change with repeated exposures across visits. The contribution of individual differences in basic visual and motor function, as well as cognitive function to safety gains from LDW was also examined. Cognitive speed of processing predicted lane keeping performance for older and younger drivers. Differences in memory, visuospatial construction, and executive function tended to predict performance differences among older but not younger drivers. Cognitive functioning did not predict changes in the magnitude of safety benefits from LDW over time. Implications are discussed with respect to real-world safety systems.

1. Introduction

Extending the mobility of a growing aging population safely has relevance to public health and injury prevention. Cessation of driving restricts mobility and is associated with subsequent depression and decreased well-being (Marottolli et al., 1997; Windsor et al., 2007). At the same time, aging drivers are at increased risk for crashes (Lyman et al., 2002; National Highway Traffic Safety Administration, 2012; Evans, 2000). Research to date shows that age alone is a poor indicator of an older driver's safety (Anstey et al., 2005; Aksan et al., 2015a; Dawson et al., 2010) yet there is little consensus on criteria that distinguish safe from unsafe older drivers (Rizzo, 2011; Ball et al., 2006).

Emerging technologies that incorporate Advanced Driver Assist systems (ADAS) hold a particular promise in compensating for declining capacities of older drivers to extend safe mobility in later years (Eby and Molnar, 2012). ADAS are becoming more common in all types and price ranges of new vehicles. NHTSA has been considering mandating their inclusion in future vehicles (Telematics update, 2014; Telematics, 2013). An important scientific question with public health relevance is how much improvement in driving safety is actually realized with ADAS. A recent meta-analytic study showed that automatic emergency braking (AEB) systems has led to 38% reduction in rear-end crashes in the real-world and that these systems seemed to be equally effective in low and high speed zones (Fildes et al., 2015). Insurance Institute Highway Safety (IIHS) reports also show that property damage and collision claims have declined in models that offer AEB (Insurance Institute Highway Safety, 2016). Accumulating evidence with regard to effectiveness of this feature has paved the way for 20 automakers to recently enter into a historic commitment to make AEB standard on all light vehicles by 2022 (Insurance Institute Highway Safety, 2016).

In contrast, evidence is mixed on the effectiveness of lane-departure warning (LDW) systems in *production vehicles*. IIHS

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reports suggest some LDW systems are associated with increased claim rates (Insurance Institute Highway Safety, 2014). Specifically, Buick and Mercedes models equipped with LDWs had increased claim rates while Volvo's equipped with LDW showed decreased claim rates. The reasons for these discrepancies among vehicle makes are not clear. The report suggested that the decreased claim rates in Volvo models may have to do with AEB and/or fatigue warning features rather than LDW. An informative field study evaluated the effectiveness of a prototype integrated vehicle-based safety which included LDW (IVBSS) (Nodine et al., 2011; Sayer et al., 2010). This study showed that there were fewer lane departures from a 12-day baseline period when LDW was turned off compared to a 28-day period when it was turned on. IVBSS findings also showed both positive and negative behavioral adaptations. For example, turn-signal use increased, a positive behavioral adaptation but headway time was reduced, a negative behavioral adaptation.

An unaddressed question is whether ADAS or other in-vehicle safety technologies compensate for the declining capacities of older drivers. An important limitation of the IVBSS field study was that the older drivers recruited into the study were generally high functioning and thus may not be representative of the population of older drivers on the road. Nevertheless there was no evidence to indicate that effectiveness of LDW varied as a function of driver age (Nodine et al., 2011; Sayer et al., 2010). Insurance claims data are largely silent on differential effectiveness of these systems for older drivers as market penetration of these vehicles are limited. Most simulator studies to date on LDW also suffer from similar limitations of recruiting middle-aged drivers or generally high functioning older drivers3 (Navarro et al., 2007; Sayer et al., 2005; Beruscha et al., 2011).

As noted by several groups, individual differences in functional declines associated with aging are large4 (Anstey et al., 2005; Rizzo, 2011; Beaton and Grimmer, 2013; Salthouse, 1996) and many of these impairments in basic visual, motor function as well as cognition have been shown to affect driving safety in vehicles that are not equipped with modern safety technologies (Anstey et al., 2005; Aksan et al., 2015a, 2012; Dawson et al., 2010; Ball et al., 2006, 1993; Anderson et al., 2012; Anstey and Woods, 2011; Ross et al., 2009; Wood et al., 2008; Clay et al., 2005). Bivariate associations of these domains of functioning and driving safety measures range from fair to moderate. Multivariate analyses often show that cognitive function measures improve predictions of older driver safety beyond those based on age and visual function (Anstey et al., 2005; Aksan et al., 2015a; Ball et al., 2006; Anstey and Woods, 2011). In other words, effects of age on driving safety often diminish or disappear when individual differences in these functional domains is included in predictive models (Aksan et al., 2015a; Dawson et al., 2010). While high functioning older drivers may adapt to ADAS quickly those with impairments may not derive the full range of benefits or benefits may be slower to emerge. Impairments associated with cognitive functioning may limit older driver's ability to understand the warning system messages (Meyer, 2009; Morrow and Rogers, 2008) and impairments in basic visual and motor function may limit their ability to react to warnings in a timely manner (Anstey et al., 2005). The primary aim of this study was to evaluate the effectiveness of an 'idealized' heads-up LDW for older and younger drivers. The second aim was to examine whether cognitive functioning predicted any safety benefits beyond age in older and younger drivers.

1.1. LDW used in the current study

One of our goals was to test whether older adults who show a range of impairments in functioning typical of aging populations (i.e. poorer motor, visual, and cognitive function) could derive safety benefits from an idealized LDW that do ***not*** replicate the industry practice in important ways (Aksan et al., 2015b, 2016). The idealized warnings for this study used the following five principles: (1) has both advisory & imminence features; (2) visuals are heads-up displays; (3) visual displays are distinct from real objects in the scene to minimize confusion, (4) displays do NOT adapt to the scenery and thus do not require the driver to interpret the warning (e.g. warning displays do not change orientation to follow lane markers on curved roadways), but they do change 'message' from advisory to imminent (e.g. change color) in simple and consistent ways (Fig. 1); (5) the system is active at all speed ranges to increase user's experience of consistency and reliability. A yellow-advisory warning signal (Panel-a of Fig. 1) was activated when the driver drifted toward an adjacent lane. A red-imminent warning signal (Panel-b of Fig. 1) was triggered when the driver's tires touched the inside edge of lane marker (SAE, 2013). These signals remained activated as long as either of the above conditions was met. The warning system was turned off when the turn signal was activated and while crossing intersections. There was no auditory component to the warning system. Fig. 1 shows these visual alerts are distinct from the background scene to improve perception by drivers of all ages. The signals appeared in the lower half of the visual display to encourage drivers to sustain their attention on the roadway.

1.2. Repeated exposure to LDW and changes in long-term effectiveness

New technologies require a period of adaptation and the intended and/or maximal benefits of relying on that technology may take time to emerge depending on user characteristics and complexity of the technology (Meyer, 2009; Morrow and Rogers, 2008; UMTRI Human Factors Group, 2015; Lavie and Meyer, 2010). Data based on existing field studies such as the IVBSS do not inform the timeline for the emergence of safety benefits to LDW in that prototype system. For example, IVBSS reports have not addressed ***incremental*** improvements in lane keeping or rates of lane departure as a function of time (Nodine et al., 2011; Sayer et al., 2010). We examined changes in long-term effectiveness of the idealized LDW over four visits. We hypothesized that safety benefits from the idealized LDW would emerge more slowly in older drivers compared to younger drivers. Furthermore, we also hypothesized that individual differences in visual, motor, and cognitive function would predict changes in safety benefits from LDW over time. Older drivers with poorer functioning in these domains may show slower-to-emerge safety benefits over repeated exposures to LDW compared to higher functioning peers.

1.3. Study goals

We addressed several questions relevant to the idealized LDW in younger and older drivers. Questions of effectiveness and changes in long-term effectiveness over repeated exposures to the system were examined with two measures: number of LDW activations and average correction time for LDW activations (correction RT). We also asked whether (1) effectiveness in general and (2) effects of repeated exposure to LDW (or time) varied as a function of age group. We hypothesized that older drivers would show poorer performance than younger drivers on all lane keeping performance measures (i.e. main effect of age). We also hypothesized that safety gains, especially with respect to correction RT, would increase with repeated exposure to LDW (i.e. interactive effects of time with warning) and in particular for older drivers (three-way interaction of time, warning, age group). In other words, over time older drivers would benefit from the LDW more (e.g. faster correction RTs) as they gained more experience interacting with it. This prediction is consistent with findings that show older individuals can take longer