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Time-to-contact estimation errors among older drivers with useful field of view impairments

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ABSTRACT

Previous research indicates that useful field of view (UFOV) decline affects older driver performance. In particular, elderly drivers have difficulty estimating oncoming vehicle time-to-contact (TTC). The objective of this study was to evaluate how UFOV impairments affect TTC estimates in elderly drivers deciding when to make a left turn across oncoming traffic. TTC estimates were obtained from 64 middle-aged ($n = 17$, age $= 46 \pm 6$ years) and older ($n = 37$, age $= 75 \pm 6$ years) licensed drivers with a range of UFOV abilities using interactive scenarios in a fixed-base driving simulator. Each driver was situated in an intersection to turn left across oncoming traffic approaching and disappearing at differing distances (1.5, 3, or 5 s) and speeds (45, 55, or 65 mph). Drivers judged when each oncoming vehicle would collide with them if they were to turn left. Findings showed that TTC estimates across all drivers, on average, were most accurate for oncoming vehicles travelling at the highest velocities and least accurate for those travelling at the slowest velocities. Drivers with the worst UFOV scores had the least accurate TTC estimates, especially for slower oncoming vehicles. Results suggest age-related UFOV decline impairs older driver judgment of TTC with oncoming vehicles in safety-critical left-turn situations. Our results are compatible with national statistics on older driver crash proclivity at intersections.

1. Introduction

Drivers aged 65 years or older are more prone to intersection and left-turn crashes than any other age group (Chandraratna and Stamatiadis, 2003; Mayhew et al., 2006). Older drivers are also more likely to be judged at fault in crashes at intersections, where drivers are challenged by environmental complexity, time pressure, and mental workload (Cantin et al., 2009; Caird et al., 2005). Driver ability to detect oncoming vehicles is affected by divided attention (Dewar, 2002), visual clutter (Bao and Boyle, 2008; Ho et al., 2001; Romoser and Fisher, 2009; Schall Jr. et al., 2010), threats from the periphery (Ball and Owsley, 1991), and social pressure (Chen et al., 2015). Misinterpretation of perceptual cues leading to time-to-contact (TTC) estimation errors with oncoming traffic has also been suggested as a risk factor for intersection crashes (Horswill et al., 2005; Marmeleira et al., 2007).

While each of these factors may contribute to crash risk in older drivers, previous research has also shown that older adults typically underestimate TTC (i.e., perceive objects as arriving relatively sooner) more often than younger adults (Hancock and Manser, 1997; Schiff et al., 1992). This behavior would decrease their risk for crashes (Scialfa et al., 1987). DeLucia et al. (2003) postulated that the higher rate of crashes for older drivers may, therefore, not be caused by (mis)estimation of TTC. Rather, they suggest that judgments about when a collision would occur must be preceded by judgments about whether a collision would occur. Their findings

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indicated that older drivers were 15% less accurate than younger drivers when judging whether a collision would occur. Age related differences were examined through a simple reaction time, mental rotation, and clock task (no significant correlations between judgments about collision and performance were found on the mental rotation and clock tasks).

DeLucia et al. (2003) noted that abilities important to judgments about potential collision subject to age-related decline include useful field of view (UFOV; Kline and Scialfa, 1997), sensitivity to motion (Sekuler et al., 1980), perception of angular movement and movement in depth (Henderson and Burg, 1974), and the ability to extract information from optic flow (Warren et al., 1989). To explain their findings, they suggested that older drivers may need redundant information sources (e.g., optical expansion [optic flow] coupled with ground-intercept information). Thus, when ground-intercept information was missing and/or insufficient drivers did not extract depth information effectively.

The aforementioned research did not evaluate UFOV, however, which is often associated with increased crash risk for older drivers (Ball and Owsley, 1993; Anstey et al., 2005; Clay et al., 2005; Sims et al., 2000). Sanders (1970) defined the UFOV as the area where information can be perceived during a brief glance without head or eye movement. By reducing perception of safety critical cues from the panorama, UFOV loss has the potential to increase errors for incurring threats, leading to unsafe traffic entry decisions. Driver judgments of personal threat posed by oncoming vehicles in an opposing stream of traffic (i.e., through a measure of depth perception) can be assessed through verbal report, perceptual matching (i.e., adjusting a target to match another referent object), and open- and closed-loop action-based tasks (a closed-loop task involves feedback whereas an open-loop task does not; Loomis and Knapp, 2003).

Driver judgments of potential risks appear to be distance dependent, especially for older drivers (Yan et al., 2007). Cutting (2003) divided perceptual space into a near (personal space; about 1.5 m), medium (action space; 1.5–30 m), and far-field (vista space: supported only by pictorial cues; 30 m to infinity). Gabbard et al. (2014) found that observers underestimate distances in the medium-field in the context of augmented reality (AR) applications and recommended that designers establish a margin or buffer to mitigate this effect. Swan et al. (2006) tested AR depth estimation using a perceptual matching task and suggested a linear relationship between distance and depth judgment variability and error. They also observed an inflection from underestimating to overestimating distance at roughly 23 m. Context, apparent risk, advancing age, and cognitive decline associated with UFOV loss may alter this bias.

In a related study that evaluated the potential benefits of AR cues for improving decision making during a gap estimation left-turn task for drivers with age-related cognitive decline (Rusch et al., 2014), UFOV was observed to play an important role in elderly driver behavior whereas their responses were adjusted to become consistent with cueing and comparable to unimpaired drivers. To better understand the safety of responses, the current study was conducted to obtain further information on baseline TTC in this cohort of drivers (i.e., without the assistance from environmental [ground-intercept information] and/or superimposed cues [AR]).

The study examined the effects of UFOV ability on older driver TTC estimation error and TTC estimation error variation using an open-loop action-based task. We hypothesized that drivers with the worst (greatest) UFOV scores would have the least accurate judgments for the arrival of oncoming vehicles and that TTC estimation error and variation would depend on oncoming vehicle speed and distance (referred to as "actual TTC" from this point forward). Patterns of safety-critical distance and speed dependent judgment can inform design of interventions aimed at improving the safety and mobility of aging drivers with perceptual or cognitive dysfunction.

Table 1
Demographic, UFOV scores, and travel frequency by driver category.

	Middle-aged (n = 17)	Older UFOV Unimpaired (n = 30)	Older UFOV Impaired (n = 17)
Mean (SD)			
Age (years)	46 (6.0)	72 (6.0)	77 (6.0)
UFOV Average	375.2 (139.6)	578.3 (200.8)	1053.5 (241.7)
UFOV Range[a]	171–638	262–999	686–1523
N (%)			
Gender			
Male	10 (58.8)	15 (50.0)	10 (58.8)
Female	7 (41.2)	15 (50.0)	7 (41.2)
Miles per week traveled			
0–50 miles	2 (11.8)	10 (33.3)	5 (29.4)
51–100 miles	7 (41.2)	9 (30.0)	8 (47.1)
101–150 miles	4 (23.5)	4 (13.3)	1 (5.9)
151 + miles	4 (23.5)	7 (23.3)	3 (17.6)

[a] Range values are presented as Minimum–Maximum.

2. Methods

2.1. Participants

Sixty-four drivers were recruited from the general community to participate in this study. The drivers comprised three groups: 17 middle-aged, 30 older-UFOV unimpaired, and 17 older-UFOV impaired (Table 1). All participants had a valid US driver's license, normal corrected vision (on near and far visual acuity and contrast sensitivity tests) and no neurological disease. One participant completed only 2 out of 36 trials (they did not appear to understand the task) and thus all data from this individual was excluded.

2.2. Useful field of view assessment

The UFOV was measured using the Visual Attention Analyzer, Model 3000 (Vision Resources, Chicago, IL; Ball and Owsley, 1993; Edwards et al., 2005). Consistent with previous studies (Schall et al., 2013; Rusch et al., 2013, 2014), four UFOV subtests measuring (a) processing speed, (b) divided attention, (c) selective attention, and (d) selective attention with a simultaneous same-different discrimination at fixation were summed to calculate a total UFOV score. Each subtest UFOV score represents the threshold in milliseconds at which the individual correctly responds to 75% of the trials (Ball and Owsley, 1992). UFOV impairment was defined by scores of at least 350 on Subtest (c) or 500 on Subtest (d).

2.3. Driving task

This experiment was conducted using the Simulator for Interdisciplinary Research in Ergonomics and Neuroscience (SIREN) (see Rusch et al., 2014 for details on simulator). Participants performed a driving task where asked to react to oncoming vehicles. The driver vehicle was positioned at the center of the intersection past the painted stop strip in all scenarios. This is the point where drivers tend to position themselves prior to commencing across the opposing lane of traffic. The oncoming vehicle (full-sized red Grand Prix) and road geometry (i.e., number of lanes, lane width, etc.) were the same for each scenario (Fig. 1). In contrast to Rusch et al., no ground-intercept information (e.g., construction and/or objects along the opposite lane) was made available that would have provided reference points as a redundant information source (in addition to