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Near peripheral motion contrast threshold predicts older drivers' simulator performance

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ABSTRACT

Our group has previously demonstrated that peripheral motion contrast threshold (PMCT) is significantly associated with self-reported accident risk of older drivers (questionnaire assessment), and with Useful Field of View® subtest 2 (UFOV2). It has not been shown, however, that PMCT is significantly associated with driving performance. Using the method of descending limits (spatial two-alternative forced choice) we assessed motion contrast thresholds of 28 young participants (25–45), and 21 older drivers (63–86) for 0.4 cycle/degree drifting Gabor stimuli at 15° eccentricity and examined whether it was related to performance on a simulated on-road test and to a measure of visual attention (UFOV® subtests 2 and 3). Peripheral motion contrast thresholds (PMCT) of younger participants were significantly lower than older participants. PMCT and UFOV2 significantly predicted driving examiners' scores of older drivers' simulator performance, as well as number of crashes. Within the older group, PMCT correlated significantly with UFOV2, UFOV3, and age. Within the younger group, PMCT was not significantly related to either UFOV® scores or age. Partial correlations showed that: substantial association between PMCT and UFOV2 was not age-related (within the older driver group); PMCT and UFOV2 tapped a common visual function; and PMCT assessed a component not captured by UFOV2. PMCT is potentially a useful assessment tool for predicting accident risk of older drivers, and for informing efforts to develop effective countermeasures to remediate this functional deficit as much as possible.

1. Introduction

Collisions per mile begin to increase after the age of 65, and more so after the age of 70 (Carsten, 1981; Cerrelli, 1973; Chipman et al., 1993; Dellinger et al., 2002; Eberhard, 2008; HLDI, 2005; Li et al., 2003; Massie et al., 1995; NHTSA, 2001; Rallabandi and Dissanayake, 2009). However, accidents per licensed driver do not increase until about the age of 85, due to the downward trend in driving miles with age (Braver and Trempel, 2004; Chipman et al., 1993). Numerous cohort effects, aging effects, technological advances and demographic trends are impacting on older drivers' safety. The older population is increasing in absolute terms and in proportion of the population as the first members of the Baby Boom generation reached 65 years of age in 2010. The U.S. population aged 65 and older is expected to more than double in the next thirty years, from 40.2 million in 2010 to 81.2 million by 2040 (U.S. Census Bureau, 2008). The proportion of the older population who are active drivers is increasing (Cheung and McCartt, 2011), and the annual mileage of each older driver is increasing (Burkhardt et al., 1998).

1.1. Biases

1.1.1. Frailty bias

The frailty bias inflates the fatality rate of older drivers. Because older drivers are frailer, they are more likely to die than a younger driver in a crash of a given energy (Evans, 1988). Dellinger et al. (2002) applied a "decomposition" analysis to determine the relative influences of frailty, accident risk per distance driven, and exposure in older drivers' overall fatality risk, and determined that frailty (fatal crashes per 1000 crashes) had a lesser influence on older driver fatality rate than either crash propensity or annual mileage.

1.1.2. Urban driving

Urban driving exposes drivers to a higher accident risk than highway driving. Although traffic experts consider limited access highways to be safer because they offer far fewer opportunities for traffic conflict than urban streets do (Bédard et al., 2008b) and Ontario drivers living in rural areas have a significantly lower accident rate by distance traveled or by traveling time than Ontario

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drivers living in urban areas (Chipman et al., 1993), older drivers tend to avoid highways and other high-speed roads, increasing their accident rate relative to younger drivers (Dissanayake and Perera, 2009; Di Stefano and Macdonald, 2003; Janke, 1991). (However, the lower energy of urban crashes will somewhat mitigate the effect of frailty.)

Chipman et al. (1993) reported that crash rates (both by distance driven and by total driving time) increased beginning at age 70–79 in a sample of 3158 Ontario drivers. They proposed that using driving time rather than driving distance as a risk exposure metric would eliminate some of the bias against drivers who travel more in urban, intersection-dense high-risk environments, and against older drivers who prefer to drive in that environment.

1.2. Accident characteristics

Accident-involved older drivers are more likely to have committed causal right-of-way violations and to be assigned accident responsibility (Clarke et al., 2010; Di Stefano and Macdonald, 2003; Langford et al., 2005; Massie et al., 1995; Mayhew et al., 2006; Stamatiadis and Deacon, 1995), and older drivers are most significantly overrepresented in motor vehicle crashes involving undetected crossing vehicles at intersections (Bao and Boyle, 2009; Braitman et al., 2007; Caird et al., 2005; Clarke et al., 2009, 2010; Daigneault et al., 2002; Dissanayake and Perera, 2009; Edwards et al., 2003; Hellinga and MacGregor, 1999; Langford and Koppel, 2006; Levin et al., 2009; Oxley et al., 2006; Ragland and Zabyshny, 2003; Retting et al., 2003; Schlag, 1993; Skyving et al., 2009; Stamatiadis and Deacon, 1995; Staplin et al., 1998a,b; Subramanian and Lombardo, 2007). Consistent with older drivers' tendency to have multivehicle collisions at intersections, older drivers are particularly at risk of incurring side impact crashes (Austin and Faigin, 2003; Viano et al., 1990). Given accident involvement, older drivers are more likely to have committed a right of way (ROW) violation and to be found at fault for the accident (Bédard et al., 2008a; Braitman et al., 2007; Clarke et al., 2009, 2010; Dissanayake and Perera, 2009; Di Stefano and Macdonald, 2003; Eustace and Wei, 2010; Hakamies-Blomqvist, 1993; Langford et al., 2005; Levin et al., 2009; Massie et al., 1995; Mayhew et al., 2006; NHTSA, 2010; Rabbitt and Parker, 2002; Rallabandi and Dissanayake, 2009; Retting et al., 2003; Schlag, 1993; Stamatiadis and Deacon, 1995; Strauss, 2005; Subzwari et al., 2009; Williams and Shabanova, 2003).

A Finnish study involving immediate and rigorous investigation of 1357 fatal multi-vehicle accidents (not involving alcohol) by an on-site expert team determined that of the five largest categories of primary causal factors, only visual attention failures (i.e., ". . . the drivers missed one or more other vehicles, according to the conclusion of the investigation team. (p. 320")) increased with driver age (Summala and Mikkola, 1994).

1.3. Vision measures and driving

Visual acuity (VA) declines strongly and monotonically with age from the age of 18 (Owsley et al., 1983; Salthouse, 1996). However, although widely used by most licensing authorities around the world to assess older drivers, VA is a poor predictor of older driver performance (Wood and Owens, 2005) or accident risk (Cross et al., 2009; Keffe et al., 2002), although Rabbitt and Parker (2002) did find that VA was significantly associated with older driver performance, although not with their accident involvement.

Stronger results have been achieved with attention-based visual assessments such as UFOV®. These tests are known to be valid and reliable instruments for identifying older drivers with a history of prior accidents (Ball et al., 1993; Clay et al., 2005; Goode et al., 1998; Owsley et al., 1991; Sims et al., 1998), predicting subsequent motor vehicle collisions (Ball et al., 2006; Clay et al., 2005; Cross et al., 2009; Rubin et al., 2007; Sims et al., 2000), and predicting performance in a driving simulator (Roenker et al., 2003). UFOV® has also been found to correlate with driving performance on closed (Wood, 2002; Wood and Troutbeck, 1995) and open road circuits (De Raedt and Ponjaert-Kristoffersen, 2000; Roenker et al., 2003), and to correlate with self-report assessments of driving ability (van Rijn et al., 2002). See Clay et al. (2005) for a meta-analysis of much of that work.

Stronger results have also been achieved using sensory-based measures of contrast sensitivity (CS) such as the Pelli-Robson Low-Contrast Letter Chart or VISTECH gratings (Horswill et al., 2008; Wood and Owens, 2005). However, the association between stationary central contrast sensitivity measures and driving safety remains equivocal (Owsley and McGwin, 2010).

Visual motion sensitivity is a strong predictor of driving ability (Wood, 2002; Wood et al., 2008), and motion contrast sensitivity in central vision is known to decline with age (Owsley et al., 1983; Sekuler and Owsley, 1982) as does speed discrimination of high contrast drifting gratings (Raghuram et al., 2005). Other researchers have also found that age-related motion processing declines correlate strongly with driving performance (Conlon and Herkes, 2008; De Raedt and Ponjaert-Kristoffersen, 2000; Gabaude and Paire-Ficout, 2005; Raghuram and Lakshminarayanan, 2006). These researchers used central or near-central motion stimuli, according to the model that an age-related decline in motion perception may reduce their ability to process complex motion patterns and respond to changes in their driving environment quickly and safely.

Our model proposes that a critical visual function is to detect and orient on novel stimuli, and that measuring that function will help to identify high-risk drivers. Motion contrast sensitivity declines with age in central vision (Owsley et al., 1983; Sekular et al., 1980; Sekuler and Owsley, 1982). Henderson and Donderi (2005) proposed that an analogous age-related decline in motion contrast sensitivity in the near periphery may reduce the power of a moving stimulus to attract visual attention (Steinman et al., 1997) and to produce a reflexive saccadic eye movement towards it (Fuchs et al., 1985; Stein, 1984), thereby impairing some older drivers' visual orienting reflex toward unexpected objects. Henderson and Donderi found that peripheral motion contrast thresholds (PMCT) correlated significantly with self-report accident risk questionnaires.

Our group's earlier work (Henderson et al., 2010) replicated and extended those findings. Our motion processing test was designed to tax the magnocellular pathway, which is widely understood to be responsible for detecting movement, identifying its retinal location position, and allocating attention to that location (Chikashi et al., 1999; Horwitz and Newsome, 1999; Livingstone and Hubel, 1988; Steinman et al., 1997). The magnocellular pathway is optimally responsive to spatial frequencies below about 1.5 cpd (Skottun, 2000); it is responsive to relatively higher temporal frequencies than the sustained, form processing parvocellular pathway (Skottun and Skoyles, 2008); and it is relatively more peripherally distributed than the parvocellular pathway. The magnocellular pathway also manifests age-related deficits (Schefrin et al., 1999). Henderson et al. (2010) explained why a peripheral low spatial high temporal frequency sine wave grating is an optimal magnocellular stimulus, and provided a detailed rationale for using a peripheral motion contrast threshold test to probe older driver performance. Results from that study showed that the visual capacity of peripheral motion processing (as measured by PMCT) diminished with age and that it correlated well with self-reported failure to detect hazards while driving. The study also showed that PMCT correlated strongly with UFOV® subtest 2 (divided attention) and subtest 3 (selective attention), although those UFOV® subtests were not significantly related to self-reported accident risk.