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A brief peripheral motion contrast threshold test predicts older drivers' hazardous behaviors in simulated driving

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ABSTRACT

Our research group has previously demonstrated that the peripheral motion contrast threshold (PMCT) test predicts older drivers' self-report accident risk, as well as simulated driving performance. However, the PMCT is too lengthy to be a part of a battery of tests to assess fitness to drive. Therefore, we have developed a new version of this test, which takes under two minutes to administer. We assessed the motion contrast thresholds of 24 younger drivers (19–32) and 25 older drivers (65–83) with both the PMCT-10 min and the PMCT-2 min test and investigated if thresholds were associated with measures of simulated driving performance. Younger participants had significantly lower motion contrast thresholds than older participants and there were no significant correlations between younger participants' thresholds and any measures of driving performance. The PMCT-10 min and the PMCT-2 min thresholds of older drivers' predicted simulated crash risk, as well as the minimum distance of approach to all hazards. This suggests that our tests of motion processing can help predict the risk of collision or near collision in older drivers. Thresholds were also correlated with the total lane deviation time, suggesting a deficiency in processing of peripheral flow and delayed detection of adjacent cars. The PMCT-2 min is an improved version of a previously validated test, and it has the potential to help assess older drivers' fitness to drive.

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1. Introduction

It is expected that the U.S. population aged 65 and older will more than double in the next fifty years (U.S. Census Bureau, 2010), and that a growing proportion of older individuals will continue to be active drivers (Cheung and McCartt, 2011). With these shifts in demographics, the issue of older driver safety continues to increase in importance. It is widely documented that crash involvement per kilometer driven begins to increase after the age of 65 (Chipman et al., 1993; Dellinger et al., 2002; Eberhard, 2008; Li et al., 2003; NHTSA, 2009) with the greatest rise in crash rates seen in drivers of 80 years and older. Drivers of that age group have one of the highest degrees of crash risk and are the most likely to be found at fault (NHTSA, 2009).

Research on the accident characteristics of older drivers indicate that collisions most commonly occur at intersections and are often a result of failures to yield the right of way (Bao and Boyle, 2009; Braitman et al., 2007; Daigneault et al., 2002; Edwards et al., 2003; Hakamies-Blomqvist, 1993; Langford and Koppel, 2006; Levin et al., 2009; Oxley et al., 2006; Rakotonirainy et al., 2012; Retting et al., 2003; Schlag, 1993; Stamatiadis and Deacon, 1995; Staplin et al., 1998a,b; Subramanian and Lombardo, 2007). The highest crash risk is associated with navigating turns across oncoming traffic (i.e., left hand turns for countries that drive on the right. This data would be reversed in countries that drive on the left) (Chandraratna et al., 2002; Chandraratna and Stamatiadis, 2003; Mayhew et al., 2006), and angle crashes are the most common manner in which a collision occurs (Dissanayake and Perera, 2009; Dissanayake and Perera, 2009). In addition, older drivers require a longer critical gap when performing turns, as they often exhibit difficulty with estimating the distance between oncoming vehicles (Chandraratna et al., 2002). The occurrence of such incidents may also be associated with the presence of certain physical impairments of older drivers (reduction in neck range of motion, poor balance, slower reaction time, limb weakness and reduced peripheral sensation) (Lacherez et al., 2014).

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Several research groups have conducted large-scale analyses of multi-vehicle accidents where the driver was at fault. They have found that failure to detect an oncoming car is most frequently reported as the primary causal factor in older drivers' accidents. For instance, Hakamies-Blomqvist (1993) examined factors that were specifically related to at fault collisions and found that over half of older driver accidents resulted from an observation error where the other vehicle was never detected or was detected too late to avoid collision. Similarly, Braitman et al. (2007) examined crashes that involved right of way violations at intersections and found that inadequate search was to blame for more than 50% of the accidents of drivers aged 65 and older. In line with previous findings from Summala and Mikkola (1994), they also found that search and detection errors were the sole causal factor to increase significantly with age.

Henderson et al. (2010) suggest that these patterns of crash characteristics in older drivers arise from a failure to detect the vehicle in the right-of-way. The detection failure hypothesis posits that a reduction in peripheral motion sensitivity degrades the visual orienting reflex towards a moving object outside of central fixation. This capacity plays an essential role in detecting vehicles in the right-of-way.

In support of Henderson et al.'s hypothesis, declines in motion sensitivity have been repeatedly linked to an increase in collisions with age. For instance, Wood (2002) found that motion sensitivity was a strong predictor of driving performance in older drivers during an on road assessment. Her later work showed that, of a group of five visual measures, only motion sensitivity was significantly predictive of crash rates (Wood et al., 2008). Compatible with this are the results of De Raedt and Ponjaert-Kristoffersen (2000a,b); De Raedt and Ponjaert-Kristoffersen (2000a,b) who tested 84 older drivers on the Ergovision motion perception test (a commercial visual assessment device), which presents participants with moving arrow structures and asks them to indicate the direction of their movement. Their data showed that motion perception significantly predicted participants' on-road assessment score.

In another related study, Gabaude and Paire-Ficout (2005) examined the driving behaviors of two groups of older drivers. The experimental group consisted of 20 participants who had been involved in three or more accidents occurring in the last 3 years. The control group consisted of 20 participants who had no accidents during the same time period. Participants completed an on-road assessment in traffic and were also tested on three visual measures (Ergovision movement perception, visual acuity, and contrast sensitivity). Of these measures, only movement perception was predictive of on-road driving performance during the assessment.

More recently, Lacherez et al. (2012) have demonstrated the importance of motion perception in the detection of hazardous driving events. Motion sensitivity was assessed in their experiment via two measures: (1) participants' minimum coherence threshold for detecting motion direction in a random dot kinematogram and, (2) their minimum contrast thresholds to detect a centrally-presented drifting sine wave grating stimulus. Hazard detection was assessed via a modified version of the Hazard Perception Test (HPT) by Horswill et al. (2011). In the HPT, participants are presented with video clips filmed from a driver's point of view and are required to indicate any potential traffic hazards they see (e.g., a pedestrian walking out into traffic). Participants were asked to press the area on the touch screen where they detected a potential incident. Results showed a significant correlation between both measures of motion sensitivity and participants' HPT response times.

Most recently, Poulter and Wann (2013) measured motion processing at different eccentricities in drivers aged 21–83 years old. The stimuli used were photo-realistic images of cars that moved at varying speeds. During the central sensitivity task, participants were asked to make a judgment as to which of two cars was approaching faster. The peripheral sensitivity task required participants to fixate centrally and detect which peripherally located car had approached towards them. Results showed that older drivers were less sensitive than young- and middle-aged drivers to motion across the entire visual field. Furthermore, peripheral motion sensitivity was negatively associated with age. Drivers aged 75+ detected fewer than 30% of the stimuli located at 30° eccentricity, whereas young drivers detected more than 90% of such stimuli.

A possible explanation for why older drivers show deficits in motion detection in the periphery is that they experience a degradation of the magnocellular pathway. This is a processing channel in the mammalian visual system that primarily responds to low spatial frequency and high temporal frequency inputs in peripheral vision. Several lines of evidence indicate a deficit in this pathway in older individuals. For instance, previous research has demonstrated that older adults have a higher peripheral contrast threshold when presented with a stationary low spatial frequency sine wave grating (Schefrin et al., 1999). Additionally, an age related deficit in central motion contrast sensitivity is observed with the presentation of a dynamic low spatial frequency sine wave grating (Owsley et al., 1983; Sekular et al., 1980). Raghuram et al. (2005) found that older adults also had higher speed discrimination thresholds for dynamic high contrast gratings. These deficits in processing low spatial frequency high temporal frequency stimuli are likely due to an age related degeneration of the magnocellular pathway (Conlon and Herkes, 2008; Schefrin et al., 1999).

In order to investigate the relationship between magnocellular decline and hazardous driving in older individuals, our group has developed a motion test based on the known characteristics of the magnocellular pathway. The peripheral motion contrast threshold (PMCT) test is designed to specifically assess the magnocellular channel's sensitivity, with a low spatial frequency and high temporal frequency sine wave grating presented in the near visual periphery. Our previous work has demonstrated that peripheral motion contrast thresholds increase with age and that results from this test correlate with self-report accident risk questionnaires and crash rates during simulated driving (Henderson and Donderi, 2005; Henderson et al., 2010, 2013).

The PMCT uses the method of descending limits to obtain an accurate measure of peripheral motion contrast thresholds. However, the 10-min duration of this test does not make it easily field deployable as part of a battery of tests to assess driver performance. For this reason, we have developed a new 2-min version of the PMCT that uses an increasing contrast two-alternative forced choice variation on Békésy's (1947) threshold tracking method to assess peripheral motion contrast threshold. The current study will assess the ability of both the 10-min and 2-min PMCT tests to predict various measures of driving performance (i.e., crash rate, distance of approach to hazards, and lane deviation time). We hypothesize that PMCT results will be directly associated with crash rate. This prediction is based on our past work (Henderson and Donderi, 2005; Henderson et al., 2010, 2013) showing that the PMCT seems to capture an age-related deficit in the ability to orient towards and detect other vehicles and hazards. For the same reasons, we hypothesize that PMCT scores will be inversely related to the minimum distance of approach to hazards. We will also examine whether PMCT results are associated with other driving behaviors such as lane deviation. The tendency towards lane deviations may be related to a decline in the processing of peripheral visual flow as well as the late detection of adjacent vehicles. Finally, we aim to validate the new 2-min version of the PMCT by comparing the results from the 2-min test against those of the 10-min test. We hypothesize that the shorter

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