NEAR PERIPHERAL MOTION DETECTION THRESHOLD PREDICTS DETECTION FAILURE ACCIDENT RISK IN YOUNGER AND OLDER DRIVERS

Steven Henderson
Transportation Safety Board of Canada
Hull, Quebec, Canada
E-mail: Steve.Henderson@tsb.gc.ca
Sylvain Gagnon, Alexandre Bélanger, Ricardo Tabone, Charles Collin
School of Psychology
University of Ottawa
Ottawa, Ontario, Canada

Summary: Motion contrast thresholds for 0.4 cycle/degree drifting Gabor stimuli were assessed at 15-degrees eccentricity for 16 younger drivers (ages 24 to 42), and 15 older drivers (ages 65 to 84), using a temporal two-alternative forced choice staircase procedure. Two self-report questionnaires assessed detection failure accident risk—the Driver Perception Questionnaire (DPQ5), and an abridged Aging Driver Questionnaire (ADQ15). The UFOV® test battery was also administered. Mean peripheral motion contrast thresholds (PMCT) of younger and older participants were –39.3 dB and –33.8 dB, respectively. For younger drivers, the correlation between PMCT and DPQ5 scores was .62 (p<.01), and between DPQ5 and ADQ16 (new and validated self-report measures, respectively) was .59 (p<.01). For older drivers, correlation between PMCT and DPQ5 scores was .49 (p<.01), between DPQ5 and ADQ16 was .73 (p<.01), and between PMCT and age was .49 (p<.05). For drivers overall, correlation was .48 (p<.01) between PMCT and DPQ5 scores, .63 (p<.0001) between DPQ5 and ADQ16, and .69 (p<.0001) between PMCT and age. For drivers overall, correlation was .30 (p<.05) between UFOV1 and age, .67 (p<.0001) between UFOV2 and age, .56 (p<.001) between UFOV2 and PMCT, .80 (p<.0001) between UFOV3 and age, and .58 (p<.001) between UFOV3 and PMCT. Holding age constant, partial correlation of PMCT with DPQ5 was .55 (p<.001), and of PMCT with ADQ15 was .39 (p<.05). PMCT significantly predicted self-reported driving performance in a laboratory setting, and worsened significantly with age. PMCT assessment should be made practicable. Informing high-risk drivers may encourage appropriate risk reduction countermeasures.

INTRODUCTION

Collisions per mile increase after the age of 65, and accelerate substantially after the age of 70 (Massie, Campbell & Williams, 1995; NHTSA, 2001; Yanik, 1986), although these statistics may be biased regarding older drivers for several reasons (Hakamies-Blomqvist, 2004), including overexposure to collision risk from compensatory changes to driving practices (Janke, 1991).

Age-related increases in both right of way (ROW) violations and accident responsibility (Cooper, 1990; Janke, 1991; Stamatiadis & Deacon, 1995; Verhaegen, Toebat, & Delbeke, 1988) may result from failure to detect other vehicles in the right-of-way. Accident characteristics support this hypothesis. Older drivers' accidents most frequently involve an undetected crossing vehicle at an intersection (Staplin, Gish et al., 1998; Staplin, Lococo et al., 1998; Viano, Culver et al., 1990). Furthermore, Summala and Mikkola (1994) reported that rigorous and immediate on-site expert team investigations of 1357 fatal multi-vehicle accidents (not involving alcohol) determined that of the five largest categories of primary causal factors, only "failures of attention" (including detection) increased with age.

Some of these age-related attention failure or detection failure accidents may be related to an age-related change in visual motion detection. Motion contrast sensitivity in central vision declines after 65 or 70 years of age (Owsley, Sekuler, & Siemsen, 1983; Sekuler & Owsley, 1982). Henderson and Donderi (2005) proposed that a similar age-related motion detection deficit in the near visual periphery may degrade an older driver's visual orienting reflex toward moving peripheral objects. They reported a significant correlation between peripheral motion contrast sensitivity and a self-report measure of driving risk (the *Driver Perception Questionnaire*, or DPQ). The DPQ was designed to elicit information about the subjective effects of reduced detection distances and/or an increased probability of detection errors, as a measure of detection failure accident risk.

The current study was conducted to determine if peripheral motion contrast threshold (PMCT) predicts detection failure accident risk at any age, and if PMCT deteriorates with age. We had two additional goals. The first was to determine if the DPQ measures substantially the same driver competencies as an subset of questions (subjectively selected *a priori* as likely related to detection failure accident risk) from the well-validated and widely used *Older Driver Questionnaire* (Parker et al., 2000; Parker, 2005). The second was to determine if PMCT tests the visual function tested by the UFOV® test battery (Ball et al., 2006), and by divided attention (UFOV2) in particular.

METHOD

Participants

The convenience sample of 31 volunteer participants consisted of 9 men and 7 women between 24 and 42 years of age (M = 29.4, SD = 4.36), and 8 men and 7 women between 65 and 84 years of age (M = 73.1, SD = 5.36). All participants had at least 5 years of driving experience, all reported good mental and physical health with no history of neurological, psychiatric or substance abuse problems, and all were tested with their normal visual correction. All were residents of the Ottawa area and were paid twenty dollars for their participation.

Driving Questionnaires

Participants completed a modified and abridged *Aging Driver Questionnaire* (ADQ) containing questions 2 to 24 from Parker et al. (2000), and 7 additional questions from the augmented ADQ set of 42 questions (Parker, 2005). The additional questions were:

How often do you

- find that the distance you have allowed for stopping is too short;

- turn left onto a main road into the path of an oncoming vehicle from the right that you hadn't seen, or whose speed you misjudged;
- fail to notice a green left turn arrow;
- fail to notice when a traffic signal turns green;
- turn right onto a main road into the path of an oncoming vehicle from the left that you hadn't seen, or whose speed you had misjudged.

Fifteen questions (ADQ15) hypothetically related to detection failures were selected *a priori* for analysis (Questions 4, 9, 11, 13,14, 17, 20, 21 from Parker, et al, (2000), and the 7 questions listed above). ADQ15 response scores to each question were standardized across all participants within each age group and then averaged across questions for each participant. All participants also answered five driver perception questions (DPQ5) from the *Driver Perception Questionnaire* (Henderson & Donderi, 2005) about how often they unexpectedly observe other cars, motorcycles, and pedestrians, how often they miss signs, and their level of anxiety while driving. DPQ5 responses were also standardized across participants within age groups and averaged for each participant. Additional DPQ5 scores and ADQ15 scores for each participant were calculated by standardizing question responses across all participants. This standardization procedure is equivalent to assigning equal weights in a regression equation, involves no capitalization on chance, and is unaffected by missing answers (Wainer, 1976).

The *Driver Perception Questionnaire* also contained 11 questions relating to perceived traffic changes for older drivers, and was intended to detect decreased sensitivity to peripheral visual motion. Those questions were not applicable to drivers under 50 years of age. As the 11 questions did not relate to any of the study's hypotheses, and as no significant correlation involving those questions was found for the older drivers, they will not be addressed further.

Vision Measures

Peripheral motion contrast threshold. PMCT was determined for 0.4 cycles per degree Gabor stimuli (a vertical sine wave grating drifted centripetally at 13.75 degrees/sec within a Gaussian window) presented at fifteen degrees eccentricity, within a raised cosine temporal window of 1.5 seconds duration, preceded and followed by a 0.5 second blank interval. Gratings were presented on two CRT monitors 74 cm distant from the head fixation point. The stimuli were generated using WinVis and MATLAB software on an IBM PC running Windows XP.

A temporal two-alternative forced choice staircase method (Henderson & Donderi, 2005) was used, which helps untrained participants to maintain central fixation. The procedure consisted of four randomly interleaved 2-down/1-up staircases rather than two randomly interleaved 4-down/1-up staircases, but was otherwise unchanged. During a single staircase trial, a participant looked directly ahead at a lit LED fixation point, and indicated whether the Gabor stimulus appeared in the first or the second 2.5-second temporal interval (i.e., "before or after the double beep" separating the intervals). Within a staircase, grating contrast increased after an incorrect response, and decreased after two successive correct responses. A trial was discarded before evaluation if the participant made an eye movement. The participant was blind to temporal interval and grating location, and the experimenter was blind to temporal interval. Peripheral motion contrast thresholds (dB) were averaged across the four staircases for each participant. All participants were able to complete the PMCT procedure within 20 minutes.

Useful field of view. All UFOV® subtests of visual attention (speed of processing, divided attention, selective attention), which are known to be valid and reliable for predicting older drivers' crashes and at fault accidents (Ball et al., 2006), were administered to all participants.

Statistical Analyses

Pearson Product-Moment correlations and associated tests of significance were calculated (SAS Version 9.1) across age, visual function (PMCT, UFOV®), and driving performance (DPQ5, ADQ15). Partial correlation coefficients adjusting for age were also calculated. All tests were directional (i.e., 1-tailed). A p-value of < .05 was considered statistically significant.

RESULTS

Mean PMCT of young participants was –39.3 dB (*SD* = 3.00 dB, *n*= 16), and of older participants was –33.8 dB (*SD* = 3.05 dB, *n* = 15).

Table 1. Pearson Product-Moment Correlations between Peripheral Motion Contrast Threshold, Age, and Questionnaire Scores

	Age	Driver Perception Questionnaire 5	Aging Driver Questionnaire 15
Contrast Threshold (PMCT)			
All (*n*=31)	.693****	.484**	.252
Younger (*n*=16)	-.262	.619**	.398
Older (*n*=15)	.491*	.492*	.395

* *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001, all tests are directional (ie., 1-tailed)

Correlations of PMCT with age and questionnaire scores are shown in Table 1. Age and PMCT were very strongly related across all participants, and strongly related within the restricted age range of older participants. PMCT was very strongly related to DPQ5 within the younger group, and strongly related within the older group and overall. PMCT was not significantly related to ADQ15 across either group or overall. Neither questionnaire score was significantly correlated with age (not shown).

Table 2. Correlations across Questionnaires, Within Groups and Overall, Validating the Driver Perception Questionnaire

	Aging Driver Questionnaire 15
Driver Perception Questionnaire 5	
All (*n*=31)	.627****
Younger (*n*=16)	.589**
Older (*n*=15)	.726**

* *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

The correlations between questionnaire scores within groups and overall are shown in Table 2. These very strong correlations validate the accident risk assessment utility of our questionnaire (DPQ5) against the well-validated and widely used *Aging Driver Questionnaire.*

Table 3. Correlations Across Vision Measures, Age, and Questionnaire Scores for Younger and Older Drivers (*n*=31)

	Age	Peripheral Contrast Threshold (PMCT)	Aging Driver Questionnaire 15	Driver Perception Questionnaire 5
UFOV1 (processing speed)	.303*	.136	.009	-.074
UFOV2 (divided attention)	.671****	.561***	.095	.184
UFOV3 (selective attention)	.796****	.577***	.002	.108
UFOV Category	.606***	.385*	.019	.087

* *p*<.05, ** *p*<.01, *** *p*<.001, **** *p*<.0001

Correlations of UFOV® with PMCT, age, and questionnaire scores are shown in Table 3. (UFOV Category is a categorical metric derived from the three UFOV® subtests.) UFOV® subtests that require processing of peripheral stimuli are very strongly related to age, and less strongly to PMCT, while UFOV1 (processing speed) is significantly related to age but not to PMCT. No UFOV® measure is related to either questionnaire score.

Table 4. Partial Correlations for Peripheral Motion Contrast Threshold by Selected Variables, Holding Age Constant (*n*=31)

	partial *r* (1-tailed, *n*=31)
Holding Age constant, Contrast Threshold by:	
Driver Perception Questionnaire 5	.549***
Aging Driver Questionnaire 15	.389*
UFOV Category	-.062
UFOV1	.02
UFOV2	.192
UFOV3	.058

* *p*<.05, ** *p*<.01, *** *p*<.001

Partial correlations between motion threshold and several measures, independent of age, are shown in Table 4. Comparing questionnaire correlations from Table 1 to the corresponding partial correlations in Table 4 shows that age effects obscure the association between PMCT and accident risk (as assessed by the questionnaires). In contrast, comparing the correlations shown in Table 3 to the partial correlations in Table 4 shows that age effects independent of PMCT underlie the significant correlations between UFOV® and PMCT shown in Table 3.

DISCUSSION

A fair test. Staplin et al., (2003) have called for "…*improved detection of deficits in the functional abilities most important for safe driving*....without regard to age *per se"* (p.4, italics theirs). The indicated strength of the direct association between PMCT and self-reported accident risk increased when age effects were partialed out, so PMCT is a fair test for identifying drivers with relatively higher detection failure accident risk at any age. That is, PMDD assesses a visual function known to decline with age without being an age-based test.

Assessment and compensatory strategies. Although older drivers are poor at assessing their own visual processing skills and at detecting gradual visual losses occurring over time, once informed of functional deficits, they do adopt compensatory strategies for age-related visual and driving deficits (Holland, 1993; Slzyk, Seiple, &Viana, 1995; Stalvey & Owsley, 2000). The 5-question driving perception questionnaire could be offered through convenient venues as an initial quick and private self-assessment tool. PMCT assessment could provide a more rigorous follow-up assessment, allowing at-risk drivers to develop compensatory strategies to reduce accident risk, including effortful scan-path training. Scheiber (1998) has suggested that research should be conducted to determine if drivers with peripheral vision deficits might benefit from training in eye movement strategies.

Useful field of view. Ball, Owsley, and co-workers have shown that age-related reduction in useful field of view (UFOV®) is substantially related to driving performance decline (Ball & Owsley, 1991; Owsley, 2004; Ball et al., 2006). Henderson and Donderi (2005) suggested that PMCT and UFOV® were complementary tests of visual functions required to drive safely, as they respectively evaluate the power of motion to produce a saccade target (bottom-up scan-path generation), and the extent of information available for visual search within a fixation. The current results demonstrate that PMCT and UFOV® are independent when age effects are eliminated, and that the visual function(s) assessed by the UFOV® are not substantially related to the type(s) of accident risks assessed by either of the two questionaires used in this study. Therefore, the power of functional ability test batteries to assess accident risk would be increased by including both PMCT and UFOV®.

PMCT and driver inattention. Neale, Dingus et al, (2005) reported that 78 percent of the crashes and 65 percent of the near crashes recorded during the *100-car Naturalistic Driving Study* involved the driver looking away from the forward roadway for more than 2 seconds just prior to the onset of the conflict. If drivers tend to schedule their long glances away from the roadway in the apparent absence of a developing critical situation, a driver with relatively better PMCT may more likely detect a situation more than 2 seconds before its arrival and postpone their glance. However, a driver with deficient PMCT may be more likely to misallocate attention away from the forward roadway as an undetected critical situation develops. Informing at-risk drivers of their reduced detection distance may encourage them to consciously reduce glance duration.

Future work. The validity and reliability of the PMCT measure and the driving perception questionnaire for predicting accident risk will be tested using both accident data and driving simulator performance measures. Further development of the forced-choice methodology and test equipment will also reduce test time to make PMCT assessment practical for driving examiners and medical professionals.

To test the PMCT-inattention accident model, a driving simulator may be equipped with an eye tracker and equipment such as telematic devices and complex radios. Participants will carry out a variety of self-scheduled secondary tasks that require looking away from the road. PMCT should significantly predict drivers' ability to safely schedule those tasks (and glances away from the road) according to leading visual indicators of developing critical situations.

Pursuing all reasonable means to maintain and enhance safe personal mobility and autonomy is ultimately an act of enlightened self-interest, as we create the future we hope to reach ourselves.

ACKNOWLEDGMENTS

This study has received approval from the University of Ottawa Ethic's review committee and was conducted in compliance with the regulations to govern research on human participants. This study was financially supported by an Ontario Neurotrauma Foundation grant and a National Sciences and Engineering Research Council grant to Dr. Sylvain Gagnon, and by a National Sciences and Engineering Research Council grant to Dr. Charles Collin. Alexandre Bélanger is funded by the National Sciences and Engineering Research Council.

REFERENCES

Ball, K., & Owsley, C. (1991). Identifying correlates of accident involvement for the older driver. *Human Factors, 33*(5), 583-595.

Ball, K., Roenker, D.L., et al. (2006). Can High-Risk Older Drivers Be Identified Through Performance-Based Measures in a Department of Motor Vehicles Settings? *The American Geriatrics Society, 54*, 77-84.

Carsten, O. (1981). Use of the Nationwide Personal Transportation Study to calculate exposure. *HSRI Research Review, 2*(6).

Cerelli, E.C. (1973). Driver exposure: the indirect approach for obtaining relative measures. *Accident Analysis & Prevention, 5*, 186-193.

Cooper, P.J. (1990). Different ages, different risks: The realm of accident statistics. In J. P. Rothe (Ed.), *The Safety of Elderly Drivers: Yesterday's Young in Today's Traffic*. New Brunswick: Transaction Publishers, 85-133.

Hakamies-Blomqvist, L. (2004). Safety of Older Persons in Traffic. In TRB's Conference Proceedings 27 — *Transportation in an Aging Society: A Decade of Experience.*

Henderson, A.S. & Donderi, D.C. (2005). Peripheral motion contrast sensitivity and older drivers' detection failure accident risk. In *Proceedings of the Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Rockport, Maine 2005, 41-50.

Holland, C.A. (1993). Self-bias in older drivers' judgements of accident likelihood. *Accident Analysis and Prevention, 25*(4), 431-441.

Janke, M.K. (1991). Accidents, mileage and the exaggeration of risk. *Accident Analysis & Prevention, 23*(2/3), 183-188.

Massie, D.L., Campbell, K.L., & Williams, A.F. (1995). Traffic accident involvement rates by driver age and gender. *Accident Analysis and Prevention, 27*(1), 73-87.

National Highway Traffic Safety Administration (2001). *Traffic Safety Facts 2000: Older Population*. DOT HS 809 328.

Neale, V.L., Dingus, T.A., Klauer, S.G., Sudweeks, J., & Goodman, M. (2005). An overview of the 100-car naturalistic study and findings. In *Proceedings of the International Technical Conference on Enhanced Safety of Vehicles*, June 6-9, Washington, DC. 2005.

Owsley, C. (2004). Driver Capabilities. In TRB's Conference Proceedings 27 — *Transportation in an Aging Society: A Decade of Experience.*

Owsley, C., Sekuler, R., & Siemsen, D. (1983). Contrast sensitivity throughout adulthood. *Vision Research, 23*(7), 689- 699.

Parker, D., McDonald, L., Rabbitt, P., & Sutcliffe, P. (2000). Elderly drivers and their accidents: the Aging Driver Questionnaire. *Accident Analysis and Prevention, 32*, 751-759.

Parker, D. (2005). Personal communication. December, 2005.

Schieber, F. (1998). *Recent developments in vision, ageing and driving 1988-1994.* Technical Report No. UNMTRI-94-26. Ann Arbor, MI.

Sekuler, R., & Owsley, C. (1982). The spatial vision of older humans. In R. Sekuler, D. Kline, & K. Dismukes (Eds.), *Aging and Human Visual Function*. New York: Alan R. Liss, 185-202.

Stamatiadis, N. & Deacon, J.A. (1995). Trends in highway safety: Effects of an aging population on accident propensity. *Accident Analysis and Prevention, 27*(4), 443-459.

Staplin, L., Gish, K. W., Decina, L.E., Lococo, K., & McKnight, A.S. (1998). *Intersection Negotiation Problems of Older Drivers, Volume I: Final Technical Report.* USDOT/NHTSA Contract No. DTNH22-93-C-05237. Washington, DC.

Staplin, L., Lococo, K., McKnight, A.J., McKnight, A.S., & Odenheimer, G. (1998). *Intersection Negotiation Problems of Older Drivers, Volume II: Background Synthesis on Age and Intersection Driving Difficulties*. USDOT/NHTSA Contract no. DTNH22-93-C-05237. Washington, DC.

Staplin, L., Lococo, K., Gish, K. W., & Decina, L.E. (2003). *Model Driver Screening And Evaluation Program Final Technical Report, Volume 1: Project Summary And Model Program Recommendations*. USDOT HS 809 582.

Stalvey, B.T., & Owsley, C. (2000). Self-Perceptions and Current Practices of High-Risk Older Drivers: Implications for Driver Safety Interventions*. Journal of Health Psychology, 5*, 441-456.

Summala, H., & Mikkola, T. (1994). Fatal accidents among car and truck drivers: Effects of fatigue, age, and alcohol consumption. *Human Factors, 36*(2), 315-326.

Szlyk, J.P., Seiple, W., & Viana, M. (1995). Relative effects of age and compromised vision on driving performance. *Human Factors, 37*(2), 430-436.

Verhaegen, P.K., Toebat, K.L., & Delbeke, L.L. (1988). Safety of older drivers: A study of their overinvolvement ratio. *Proceedings of the 32nd Conference of the Human Factors Society*, 185-188.

Viano, D.C., Culver. C.C., Evans, L., Frick, M., & Scott, R. (1990). Involvement of older drivers in multi-vehicle side impact crashes. *Accident Analysis & Prevention, 22*(2), 177-188.

Wainer, H. (1976). Estimating coefficients in linear models: It don't make no nevermind. *Psychological Bulletin, 83*(2), 213-217.

Yanik, A.J. (1986). *What accident data reveal about elderly drivers.* SAE Technical Paper #851688. Warrendale, PA: Society of Automotive Engineers.