TITLE:

Visual Motion Perception Predicts Driving Hazard Perception Ability

Author names and affiliations:

Philippe Lacherez [a,b⊥]

[a] School of Optometry and Vision Science, Queensland University of Technology

[b] Institute of Health and Biomedical Innovation, Queensland University of Technology

Sandra Au [a,b]

a School of Optometry and Vision Science, Queensland University of Technology

b Institute of Health and Biomedical Innovation, Queensland University of Technology

Joanne M. Wood [a,b]

a School of Optometry and Vision Science, Queensland University of Technology

b Institute of Health and Biomedical Innovation, Queensland University of Technology

[⊥]Corresponding author: Dr Philippe Lacherez, PhD, School of Optometry and Vision Science and Institute of Health and Biomedical Innovation, QUT, Kelvin Grove, Brisbane Q 4059, Australia.

Tel: 61 7 3138 5713; Fax: 61 7 3138 5665; Email: p.lacherez@qut.edu.au

ABSTRACT

PURPOSE: To examine the basis of previous findings of an association between indices of driving safety and visual motion sensitivity and to examine whether this association could be explained by low-level changes in visual function.

METHODS: 36 visually normal participants (aged 19 – 80 years), completed a battery of standard vision tests including visual acuity, contrast sensitivity and automated visual fields. and two tests of motion perception including sensitivity for movement of a drifting Gabor stimulus, and sensitivity for displacement in a random-dot kinematogram (D_{min}). Participants also completed a hazard perception test (HPT) which measured participants' response times to hazards embedded in video recordings of real world driving which has been shown to be linked to crash risk.

RESULTS: D_{min} for the random-dot stimulus ranged from -0.88 to -0.12 log minutes of arc, and the minimum drift rate for the Gabor stimulus ranged from 0.01 to 0.35 cycles per second. Both measures of motion sensitivity significantly predicted response times on the HPT. In addition, while the relationship involving the HPT and motion sensitivity for the random-dot kinematogram was partially explained by the other visual function measures, the relationship with sensitivity for detection of the drifting Gabor stimulus remained significant even after controlling for these variables.

CONCLUSION: These findings suggest that motion perception plays an important role in the visual perception of driving-relevant hazards independent of other areas of visual function and should be further explored as a predictive test of driving safety. Future research should explore the causes of reduced motion perception in order to develop better interventions to improve road safety.

Keywords: driving, motion perception, hazard perception, vision

INTRODUCTION

It is well documented that many older drivers experience driving difficulties, which can impair their driving safety and significantly increase their crash risk (Morgan & King 1995; Hakamies-Blomqvist 1998). However, it is important to recognize that not all older drivers are unsafe. Rather, it seems that age-related changes in driving ability are mediated by functional changes that occur with increasing age, and not all older adults are equally affected. Among these changes, visual function has been consistently found to be a significant individual predictor of driving performance and safety (Owsley & McGwin 2010; Wood 2010). In terms of licensing, visual acuity (as measured by letter charts) is the main vision test used to determine driving eligibility, despite the fact that research has strongly indicated that visual acuity is less important than other aspects of visual function in terms of predicting driving safety (Owsley & McGwin 2010).

A small number of studies have suggested that motion perception may be predictive of a range of indices of driving performance and safety, particularly in older adults (Wood 2002; Henderson & Donderi 2005; Raghuram & Lakshminarayanan 2006; Wood et al. 2008; Henderson et al. 2010). In particular it has been noted that ageing is associated with poorer time-to-contact judgments, as well as impaired perception of speed and heading (DeLucia & Mather 2006; Conlon & Herkes 2008) which are important aspects of visual perception that relate to driving. Even brief delays in adequately responding to relevant moving targets in a driving environment are likely to have potentially dangerous consequences, and a reduced ability to adequately discriminate speed or time-to-contact could result in significantly increased crash risk (Schiff et al. 1992; DeLucia et al. 2003; DeLucia & Tharanathan 2009). Motion perception has also been strongly linked to self-reported failures of attention using established questionnaire measures (Henderson & Donderi 2005; Raghuram & Lakshminarayanan 2006; Henderson et al. 2010).

What is not clear is the functional connection between decreased motion perception and driving performance and safety. Some research has suggested that low-level perceptual mechanisms, including measures such as contrast sensitivity, can change perceptions of the speed of moving objects, so this might result in problems in accurately estimating time-to-contact and safe following distances (Stone & Thompson 1992; Snowden et al. 1998; Thompson et al. 2006). Such low-level processing deficits can potentially interfere with the ability to accurately estimate the 'optic flow' of surrounding objects in a natural driving environment, which may be key determinants of smooth visually guided behaviour (Loomis & Beall 1998; Li & Chen 2010). This information may also be important in guiding behaviours like steering and adjusting one's following distance (Cutting et al. 1995; Atchley & Anderses 1998; DeLucia & Tharanathan 2009).

It is important, therefore, to establish the extent to which the previously observed relationships between motion sensitivity and driving safety may be explained by low-level changes in visual function, for instance visual acuity, contrast sensitivity, or visual fields. Some previous studies (Wood 2002; Wood et al. 2008) have used random-dot kinematograms as a measure of motion sensitivity. In these tests, participants are required to detect the direction of movement of a field of dots, each of which are typically small in terms of the visual angle which they subtend (e.g., in Wood et al.,2008 each dot subtended around 5 seconds of arc). Perception of this kind of stimulus may be highly dependent on visual acuity as well as contrast sensitivity, and the intactness of a person's visual field. Conversely, the stimuli used by Hendersen et al. (2005; 2010) and Raghuram et al. (2006) consisted of drifting sinusoidal gratings, which are likely to place a lower burden on basic visual function mechanisms, as the stimulus is low spatial frequency and should not require fine resolution to enable detection of the motion presented.

In order to establish whether the previously reported relationships between motion sensitivity and driving safety might be explained by individual differences in visual function, or alternatively whether motion sensitivity is an independent predictor unrelated to other aspects of visual function, we presented participants with both a moving random-dot kinematogram pattern and a drifting sinusoidal stimulus (a Gabor patch). As additional visual function measures, we also measured visual acuity, contrast sensitivity, and visual fields. We used the Hazard Perception Test (HPT) as an index of driving safety (dependent variable), which consists of a computerized test in which the participant is presented with videos of road scenes which contain a road hazard and asked to identify the hazard as quickly as possible. Hazard perception tests are currently used in the UK and certain states of Australia for purposes of licensing (Horswill et al. 2011). Performance on such tests has been associated with self-reported crash involvement in retrospective (Quimby et al. 1986; McKenna & Horswill 1999; Darby et al. 2009; Horswill et al. 2010) and prospective (Wells et al. 2008) studies. We hypothesized that both motion thresholds would be positively associated with response times on the HPT (with higher thresholds associated with overall longer response times). Based on the above considerations of the role of visual function in resolving motion perception stimuli, we also hypothesized that the relationship between hazard perception and motion sensitivity in the random dot stimulus would be explained in part by differences in visual function between participants, while the relationship between hazard perception performance and motion perception of a sinusoidal grating would remain even after controlling for other aspects of visual function.

METHODS

Participants

Thirty-six visually normal participants were included in this study (18 male, 18 female) who ranged in age between 19 and 80 years (M = ~~58.28~~ 58.3, SD = ~~18.78~~18.8). All participants were licensed drivers and were recruited from the electoral roll, as well as from the QUT optometry clinic and friends and family of the researchers. Participants were mobile and living independently in the community, and reported no major health conditions that would preclude them from holding a driver's licence. We examined performance over a range of ages in order to establish whether the age-related changes in both motion perception and our index of driving safety could be explained by other changes in visual function.

Procedures

Testing was undertaken in one laboratory-based session which took approximately two hours. Participants completed a series of questionnaires and visual function tests, followed by the computer-based motion sensitivity testing. Participants wore their habitual correction used for driving (if any) with appropriate working distance correction. The research was approved by the Queensland University of Technology Ethical Review Committee and followed the tenets of the Declaration of Helsinki~~ and f~~. Full informed consent was obtained from participants.

Materials and Measures

Questionnaires

Participants completed a questionnaire describing their typical driving behaviours in terms of the times and situations in which they drove, the number of years driving, as well as reporting any significant crashes in the last 5 years (Wood et al. 2008).

Static Visual Acuity

Binocular visual acuity was assessed using a Bailey-Lovie logMAR chart at 6 m under standard testing conditions. Each letter scored as -0.02 log units. Participants were encouraged to guess letters even when they were not sure.

Pelli-Robson Letter Contrast Sensitivity

Binocular contrast sensitivity was measured with the Pelli-Robson chart under standard conditions at a working distance of 1 m with an appropriate correction for the working distance where necessary. Participants were encouraged to guess at letters; each letter was scored 0.05 log units.

Visual Fields

Right and left monocular visual fields were measured using the SITA standard 24-2 threshold program for a size III target using the Humphrey Field Analyser®. A binocular mean deviation (MD) score was derived by merging the right and left fields to create a binocular visual field, based on the more sensitive of the two eyes at each visual field location (Nelson-Quigg et al. 2000).

Motion Perception Tests

Two motion sensitivity tests were conducted in a dark room at a working distance of 3 m. The participants was instructed to guess a direction when they were not sure.

D_{min}

As with our previous work (Wood 2002; Wood et al. 2008), participants were presented with a series of random dot kinematograms (RDKs) on a 36.5 x 27 cm computer screen at a working distance of 3 m. The RDKs consisted of a 20.5 x 20.5 cm square of dots subtending 3.9 degrees of arc. During each trial, a central patch of dots within the square (2.9 degrees of arc) was moved in one of four cardinal directions (upward, downward, left or right) in 4 discrete steps, at a rate of one frame per 100 ms and with no interval between presentations (see Figure 1). Participants were required to verbally indicate the perceived direction of movement. Across trials the extent of the movement (in terms of the displacement of each pixel across frames) was varied in a 2-down 1-up staircase, with 8 reversals. The threshold (D_{min}) was defined as the average of the displacement for the last six reversals in the series. Stimuli were rendered using a Cambridge Systems VSG card. The dot density was 0.43%.

Gabor

A low-frequency Gabor patch (Henderson & Donderi 2005) consisting of a vertical sinusoidal grating with a spatial frequency of 5 cycles per degree of arc, filtered through a Gaussian envelope, was presented on a 32.2 x 24 cm computer monitor, and the phase angle of the Gabor was incrementally changed between refresh cycles of the monitor to produce a smooth horizontal motion (see Figure 1). The drift rate was varied in a 2-down 1-up staircase with 8 reversals, and the threshold was taken as the average of the last six reversals for the session. Participants responded in a two-alternative forced-choice using the arrow keys of the computer keyboard whether the stimulus appeared to be moving to the right or left.

Hazard Perception Test

A modified version of the Hazard Perception Test (HPT) was used as an index of driving safety. This test required participants to recognize potential traffic hazards in video clips of traffic scenes filmed from the driver's point-of-view (Wetton et al. 2010), by pressing the relevant area of the touch-screen whenever they identified a potential incident. Twenty-two traffic conflicts (across 20 traffic clips of between 15-40 seconds duration) were selected on the basis that (1) there were anticipatory cues available, and (2) the conflict became unambiguous such that nearly all participants would be expected to respond eventually. The software recorded a response time for each potential conflict (starting from the first moment that the potential conflict was detectable) and these were averaged to obtain an overall hazard perception response latency. The response time in seconds, and the accuracy of response were recorded for each scene. A response was coded as correct only if the participant correctly tapped the relevant hazard while it was still presented on the screen.

Participants viewed a series of 13 videos of driving scenes on Queensland and Australian Capital Territory roads which had been selected and edited to be a maximum of 30 seconds each. All videos were filmed during the day. Due to the diversity of scenes and lighting conditions presented, luminance ranged from 5 to 40 cd/m^2. Participants were tested at a distance of 50 cm with appropriate working distance correction where necessary. The maximum target (hazard) eccentricity was approximately 22 degrees of visual angle. For a given video, the hazard could appear at any time during the video. Since there was no objective metric to define when the hazard theoretically might become visible to an ideal observer, response times were normalized by calculating the participant's deviation from the mean response time of the group for each hazard in seconds.

Analyses

Data analyses comprised descriptive statistics and bivariate correlations and were conducted using SPSS for windows®. To test the key hypothesis that the relationships between motion sensitivity and hazard perception would be explained by changes in visual function we examined also partial correlations adjusting for visual acuity, contrast sensitivity and visual fields. Since we wished to test predictions which were clear in terms of the direction of effect which should be obtained, while maximizing statistical power, all correlations were tested using 1-tailed hypothesis tests, as is recommended (Healey 2012).

RESULTS

Table 1 displays the demographic characteristics of the sample, in terms of age, gender, visual function and performance on the Hazard Perception Test. All participants had visual acuity and fields that met the minimum visual requirement for driver licensing in Australia and there was a range of performance for each of the functional measures. Participants had, on average, 38.17 years of driving experience (SD = 18.73, range = 1 to 63) and drove regularly, with an average of 9.3 trips per week (SD = 4.94, range = 3 to 20). Only six of the 36 participants reported a crash in the previous 5 years, and of these, only 1 reported two crashes. The crash-involved drivers did not differ significantly from the rest of the group on any of the measures.

Insert Table 1 around here

Bivariate correlations demonstrated that both of the motion measures were highly correlated with age (see Table 2), and that D_{min} was strongly related to the other functional measures of visual acuity, contrast sensitivity, and visual fields. In contrast, the Gabor test, while related to D_{min}, was not significantly related to the other visual function measures.

Insert Table 2 around here

As seen in Table 2, there were also strong relationships between the Gabor and D_{min} motion sensitivity measures in terms of predicting performance on the HPT. Of the other measures, only visual acuity was significantly related to HPT performance, while contrast sensitivity had only a small and non-significant predictive ability.

To establish whether the relationships between the measures of motion sensitivity and hazard perception performance were explained by differences in visual function, we also examined the partial correlations between the two motion sensitivity measures and the hazard perception score, controlling for the other measures of visual acuity, contrast sensitivity, and the merged binocular visual field MD. D_{min} was not significantly related to hazard perception after controlling for these covariates, indicating that some of the predictive power of this stimulus may be explained by other components of visual function, $r(30) = 0.23$, $p = 0.099$ (partial Pearson correlation). However, the Gabor stimulus remained a strong predictor of hazard perception even after controlling for the covariates, $r(30) = 0.32$, $p = 0.034$. The same pattern of results was obtained even after controlling for age as well as the visual function measures (r(30) = 0.23, p = 0.105 and r(30) = 0.34, p = 0.029, for Dmin and Gabor respectively).

DISCUSSION

This study demonstrated that both tests of motion sensitivity – minimum displacement as measured by a random-dot kinematogram paradigm and the threshold drift rate for a drifting Gabor stimulus – significantly related to participants' response times to video recordings of road hazards presented in the HPT. Additionally, while the relationship between D_{min} and hazard perception ability was partly explained by the combination of age and other tests of visual function (visual acuity, contrast sensitivity, visual field MD) the relationship between the threshold for the drifting Gabor and hazard perception ability was not. This serves as evidence that visual motion sensitivity is a significant factor in perception of driving-relevant events, independent of other areas of visual function.

Our finding that the relationship between D_{min} and HPT performance was reduced after controlling for age and the other visual function measures is not unexpected, as an important part of the perception of RDK stimuli relates to being able to adequately resolve the moving dots displayed. Given that these are typically quite small dots (in this experiment each dot subtended 5.07 seconds of arc) this resolution is likely to depend to a large extent on both the visual acuity and contrast sensitivity of the participant, as well as the intactness of their visual field. Conversely, the drifting Gabor stimulus, has a low spatial frequency (2.5 cycles per degree), and does not depend on visual acuity to be resolved.

This finding of a unique contributory role for motion perception in visual recognition of road hazards has important potential implications for our understanding of the issues surrounding driving safety. Many important cues in driving involve visual motion: hazards such as bicycles and other vehicles and even pedestrians continually move against their background, and the coherence, or lack of coherence among these objects in the environment is likely serve as an important cue for discriminating them against their backgrounds (Warren et al. 1989; Cutting et al. 1995; Loomis & Beall 1998). In addition, continuous driving tasks such as maintaining a safe speed and distance from nearby vehicles as well as maintaining an appropriate heading, all rely on a finely tuned discrimination of patterns of movement vectors in the visual field (DeLucia & Mather 2006; Conlon & Herkes 2008). Even small differences in sensitivity to these visual cues might have large effects on overall driving safety.

Given the relevance of this form of perceptual difficulty, a further important issue is the physiological mechanisms to which reduced motion perception may be linked. Although visual function, as well as motion sensitivity, can decline with increasing age, it is important to distinguish between normal ageing and pathological changes. Some studies have found that motion sensitivity is reduced in eye diseases such as glaucoma (Shabana et al. 2003; McKendrick et al. 2005) and congenital nystagmus (Acheson et al. 1997; Eggert et al. 1997), Alzheimer's disease (e.g., Gilmore et al. 1994; Rizzo & Nawrot 1998) and vestibular disorders (Gianna et al. 1995; Kalla et al. 2011). However the data from the present study, and others by our group suggest that sensitivity to visual motion (and consequently also difficulties in visual activities related to driving) vary even among samples not affected by these diseases (Wood 2002; Wood et al. 2008). In this study we did not collect detailed information about medical or cognitive status, and we aim to collect this detail in future research. Better understanding of the physiological basis of individual differences in motion sensitivity are needed in order to better understand the underlying processes involved in the relationships presented here. It is possible that these may relate to structural brain changes which are responsible both for reductions in motion sensitivity and slowing of overall processing and therefore also response times. It is worth noting, in this context, that the motion perception tasks used in this study were not timed tests, and therefore changes in response time alone cannot explain the relationships observed.

In conclusion, these findings reinforce those of previous studies suggesting that impairments of visual motion processing may be directly related to driving ability in terms of recognizing visual movement cues relevant to driving. Furthermore, our findings indicate that motion perception may be a discrete predictor of perception of hazards in a driving environment and that this is not simply due to impairments in other areas of visual function. Further work is needed to establish the level of processing involved in this relationship, however the evidence from this study suggests that the relationship between motion sensitivity and the perception of hazards in the HPT is not explained by low-level mechanisms (at least in terms of visual acuity, contrast sensitivity or visual fields) indicating that higher-level, potentially cortical areas are likely to be involved. It would be of interest in future research to investigate, within an on-road environment, whether attentional factors (in terms of the ability to isolate relevant moving stimuli from their backgrounds) interact with the impairments of motion processing studied here. In more complex environments it is likely that deficits of motion processing will be manifested as a reduced ability to extract important movement cues against their background, so understanding potential interactions between motion perception and other visual or attentional cues may be important.

These findings should be considered in light of some limitations. The sample size~~,~~ was relatively small, however, despite this strong and highly significant results were obtained, indicating that statistical power wa~~i~~s sufficient. The sample also consisted of drivers without any restrictions and it is possible that there might be some bias, in that drivers with overall higher function may be selectively more likely to volunteer for research participation. Nonetheless, these findings present important preliminary evidence for an independent role of visual motion processing in maintaining safe driving. Future research should aim to develop tests, similar to the currently available hazard perception tests, that involve a wide range of moving hazards, to identify the specific aspects of motion with which impaired drivers experience most difficulty, and investigate the predictive ability of the tests with measures of on-road driving safety in real traffic situations.

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Table 1. Characteristics of the sample, including mean and standard deviation of measures, age and gender.

Variable	Minimum	Maximum	Mean	SD
Age (yrs)	19	80	58.3	18.8
Visual Acuity (logMar)	-0.18	0.20	-0.05	0.09
Contrast Sensitivity (log CS)	1.60	1.95	1.79	0.11
Visual Fields binocular MD	-3.89	4.59	0.49	1.57
HPT (sec)	-2.03	1.94	.032	.889
D_{min} (log min arc)	-0.88	-0.12	-0.57	0.21
Gabor drift rate (Hz)	0.01	0.35	0.10	0.07

Table 2. Bivariate correlations between visual performance variables, age, and hazard perception

Variable	Age	VA	CS	MD	D_{min}	Gabor
HPT	.173	.319*	-.152	-.327*	.372**	.313*
Age		.448**	-.682**	-.244	.505**	.422**
VA			-.422**	-.161	.523**	.013
CS				.379*	-.427**	-.204
MD					-.263	-.148
D_{min}						.360*

* p < .05, ** p < .01 (1-tailed bivariate Pearson correlation)

VA = Visual Acuity, CS = Contrast Sensitivity, MD = merged binocular visual fields mean deviation

Figure 1. Stimuli used for the motion sensitivity measures. (A) Random dot kinematogram. A central region of dots moved discretely in four successive steps, within a larger homogenous field of dots. The white border and arrows are shown here only for purpose of demonstration. (B) Drifting Gabor patch. A drifting sinusoidal grating filtered through a Gaussian envelope underwent a continuous change of phase angle to the left or right over the presentation period. Arrows are presented below for demonstration.