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Age-related changes in perception of movement in driving scenes

Philippe Lacherez, Laura Turner, Robert Lester, Zoe Burns

Joanne M Wood

School of Optometry and Vision Science and Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Queensland, Australia

Corresponding author:

Philippe Lacherez

School of Optometry and Vision Science, Institute of Health and Biomedical Innovation

Queensland University of Technology

Victoria Park Rd, Kelvin Grove Q 4059, Australia

Phone: 07 3138 5713

Fax: 07 3138 5880

Email: p.lacherez@qut.edu.au

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PURPOSE: Age-related changes in motion sensitivity have been found to relate to reductions in various indices of driving performance and safety. The aim of this study was to investigate the basis of this relationship in terms of determining which aspects of motion perception are most relevant to driving

METHODS: Participants included 61 regular drivers (age range 22 - 87 years). Visual performance was measured binocularly. Measures included visual acuity, contrast sensitivity and motion sensitivity assessed using four different approaches: (1) threshold minimum drift rate for a drifting Gabor patch, (2) D_{min} from a random dot display, (3) threshold coherence from a random dot display, and (4) threshold drift rate for a second-order (contrast modulated) sinusoidal grating. Participants then completed the Hazard Perception Test (HPT) in which they were required to identify moving hazards in videos of real driving scenes, and also a Direction of Heading task (DOH) in which they identified deviations from normal lane keeping in brief videos of driving filmed from the interior of a vehicle.

RESULTS: In bivariate correlation analyses, all motion sensitivity measures significantly declined with age. Motion coherence thresholds, and minimum drift rate threshold for the first-order stimulus (Gabor patch) both significantly predicted HPT performance even after controlling for age, visual acuity and contrast sensitivity. Bootstrap mediation analysis showed that individual differences in DOH accuracy partly explained these relationships, where those individuals with poorer motion sensitivity on the coherence and Gabor tests showed decreased ability to perceive deviations in motion in the driving videos, which related in turn to their ability to detect the moving hazards.

CONCLUSTIONS: The ability to detect subtle movements in the driving environment (as determined by the DOH task) may be an important contributor to effective hazard perception, and is associated with age, and an individuals' performance on tests of motion sensitivity. The locus of the processing deficits appears to lie in first-order, rather than second-order motion pathways.

Key words: Driving, motion perception, vision, age.

INTRODUCTION

The visual world is constantly in motion. Visually guided behaviours such as driving require adequate perception of the constantly changing and dynamic information within the driving environment, including awareness of objects in motion, as well as an awareness of the viewer's own position in space relative to the environment. Recent studies have demonstrated that age-related changes in sensitivity to visual motion may have an important influence over people's driving ability or safety.[1-5] In previous research we have shown that sensitivity to visual motion may predict older adults' performance in closed[4] and on-road driving environments,[5] as well as their ability to perceive hazards in video presentations of driving scenes.[6]

Moreover, we have also shown that these relationships are not merely a result of low-level visual changes (visual acuity or contrast sensitivity), suggesting that the ability to process visual motion represents a distinct predictor of driving-related hazard perception.[6] The measure of hazard detection that we employed was the Hazard Perception Test (HPT), in which participants were asked to identify road hazards in videos of real road scenes. Hazard perception tests are currently used in the UK and certain states of Australia for the purpose of licensing.[7] Performance on such tests has been associated with self-reported crash involvement in retrospective [8-11] and prospective [12] studies.

In the present study, we were interested in determining the basis of the previously demonstrated link between visual motion sensitivity and driving, in terms of the types of motion cues that might change with age and which might be important for driving, and the ways in which they might be compromised when motion sensitivity is decreased. We hypothesised that correct perception of the direction of heading of a vehicle (in terms of being able to detect deviations in approach path) would be one important component of driving that would be affected by changes in motion sensitivity, and might also be an effective indicator of participants' ability to effectively manoeuvre, as well as to easily identify moving hazards, in the driving environment. Given that in part the definition of a road hazard relies on whether or not a driver is on a collision course with respect to it, knowledge of one's trajectory or heading with respect to other road users is key to effective avoidance of collisions. Accuracy of direction of heading judgments has been shown to reduce with age.[13] In this study we administered the HPT, as used previously, and also tested participants on a new test which comprised short segments of the HPT videos, in which participants were asked to identify whether the vehicle was moving straight ahead, or veering to the left or right according to what would be considered 'ideal' lane-keeping (Direction of Heading – DOH task). We hypothesized that older participants would be compromised in terms of their motion sensitivity and perform more poorly on the HPT, as well as the DOH test. In addition, we hypothesised that the differences between participants on the DOH measure would in part explain the association between motion sensitivity and performance on the HPT.

To more closely examine the level of processing at which the changes in motion sensitivity affect driving, we used a battery of psychophysical motion sensitivity tests which are believed to be processed at different levels of the visual system. We measured sensitivity for a drifting Gabor patch, a stimulus which does not require fine resolution of detail in order to be seen, and therefore is unlikely to be affected by low-level visual changes.[6] Thus it is assumed that this is an effective stimulus for stimulating motion detectors at all levels of the visual system, but should not discriminate between individuals on the basis of their visual function. We also included two measures of motion perception using random dot kinematograms: D_{min} thresholds and coherence thresholds. D_{min}, the minimum displacement threshold of individual dots in a random dot kinematogram, is likely to be processed at the retinal level, but judgments of the overall direction of motion of the display (global motion) would also involve higher-level coding.[14, 15] D_{min} has been shown to be sensitive to retinal pathology in patients with glaucoma.[16] Coherence thresholds represent, for a given displacement, the proportion of dots which must move coherently to enable detection. Perception of motion coherence (i.e., separating the signal from noise dots) has been shown to correlate with higher level neural processes (in the medial temporal areas) and thus require higher level processing,[17] and was shown to be unrelated to retinal pathology in patients with glaucoma.[16]

Previous research has only used first-order motion displays in exploring the relationship between motion perception and driving.[1-5] First-order motion refers to the visual cues provided by a moving stimulus which are defined by differences in luminance across the image. Stimuli such as random-dot kinematograms and Gabor patches vary in luminance and it is the luminance changes which provide the cues relevant to motion. However, it has been shown that in real world stimuli, important motion cues can be provided by second-order motion (motion defined by differences in texture, contrast, or colour, but not luminance).[18] Previous research has suggested that separate pathways are responsible for coding of first and second-order motion.[19] In this project we also wished to establish whether a test of second-order motion would be differentially useful in predicting HPT performance in this sample.

Thus in this study we compared four different measures of motion sensitivity in terms of their capacity to predict changes in ability to detect hazards on the HPT and identify heading direction, in order to better understand the likely processing stage which is impacted in those older adults who have reduced performance on both tasks.

METHOD

Participants

Sixty one adults aged between 22 and 87 years of age (*M* = 51.31, *SD* = 20.36) were recruited to participate in the current study. The driving experience of participants ranged between 4 and 69 years (*M* = 32.22, *SD* = 19.41): all participants held a current Queensland drivers licence and drove regularly in the Brisbane metropolitan area. Participants were required to be living independently in the community and have no significant eye diseases or health conditions that might adversely affect their driving. Participants were recruited by word of mouth or via information flyers that invited adults to participate in a study of driving safety and motion perception. The procedure was approved by the Queensland University of Technology Human Research Ethics Committee and complied with the Declaration of Helsinki.

Procedure

Participants were tested individually in a single session which took approximately 1.5-2 hours to complete. Informed consent was obtained from all participants who were instructed that they could withdraw from the study at any time and that all data collected as part of the study would be completely confidential; the assessments were conducted as part of a larger study of driver safety. All tests were conducted with participants wearing their habitual distance vision correction for driving (if any) and an appropriate working distance correction lens.

Materials and Procedures

Vision measures. Visual performance was assessed binocularly. For all vision tests, participants were instructed to guess if they were unsure. Visual acuity was assessed at a working distance of 3.2 metres using the Bailey-Lovie chart [20] under standard testing conditions and each letter was scored as -0.02 log units. Binocular contrast sensitivity was measured with the Pelli-Robson chart under standard conditions at a viewing 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.

Motion perception measures. All motion tests were conducted in a dimly lit room (approximately 15 lux). Motion stimuli were displayed at the maximum contrast possible with the CRT display (>99% weber contrast) with the lowest luminance output of the display (black background for dot stimuli and darkest part of the grating for the grating stimuli) being less than 3 cd m^{-2} allowing for room illumination. Stimuli were displayed on a 365mm x 275mm NEC MultiSync E950 computer screen. The working distance was 3 metres and participants responded verbally and were instructed to guess when they were unsure.

Measures of motion perception from RDK stimuli. Two aspects of central motion perception; minimum displacement threshold (D_{min}) and coherence threshold (signal to noise ratio), were measured through the use of RDKs. These included a 3.9° square patch of white dots displayed across a black background. On each trial, a cluster of dots within the centre of this patch (subtending 2.9°) was displaced across four frames at a rate of one frame per 100 ms and with no interval between presentations, eliciting the sensation of uniform movement in one of four directions (upwards, downwards, left or right).[5] The density of dots (proportion of the screen area occupied by dots) was 0.43% and frames were depicted using a standard VGA card.

Minimum displacement threshold. A participant's minimum displacement threshold (D_{min}) represents the smallest amount of motion detected by that participant. Participants were required to identify the direction of movement on each trial; the degree of movement was varied in a 2-down 1-up staircase, with 8 reversals. A minimum displacement threshold (D_{min}; i.e., the smallest amount of movement detected by a participant) was defined as the average of the displacement for the last 6 reversals in the series of trials.

Coherence threshold. A participant's coherence threshold represents the minimum amount of coherent movement that is necessary in order for that participant to detect a uniform direction against a background of "noise". Participants were required to identify the most coherent direction of movement on each trial. Throughout trials, the proportion of coherent and random dots was varied in a 2-down 1-up staircase, with 8 reversals to determine a coherence threshold.

The drifting Gabor test consisted of a Gabor patch subtending 2°, which contained a 3 cycle/degree vertical sinusoidal grating filtered through a Gaussian envelope. The phase angle of the Gabor incrementally changed during each refresh cycle, producing a sensation of smooth horizontal motion. Participants were required to identify the direction in which the patch seemed to be drifting. The drift rate varied in a 2-down 1-up staircase with 8 reversals, and the average of the last six reversals was taken as the threshold. For any given bar in the grating, the speed with which the bar image moved across the screen was used as the dependent variable.

Second order motion test. The second-order motion stimulus was a contrast-modulated patch of dynamic noise subtending 3.5°, where the noise comprised pixels of random luminance ranging from the minimum to the maximum output of the display. The contrast modulation consisted of a vertical sinusoidal grating of 8 cycles whose phase angle was varied in the same manner as for the Gabor stimulus described above.

Hazard Perception Test. A shortened version of the HPT was used to provide an index of driving performance and safety [7, 9, 11, 21]. In the current study, the HPT was presented on a 50 inch LG50PJ650 plasma screen at a working distance of 1 metre and participants completed one of four possible versions of the HPT in a random order. All versions consisted of 25 previously validated video-clips of everyday driving scenes from the perspective of the driver, and each video-clip contained a unique traffic conflict (which was defined as anything that requires the driver to take immediate action, such as a change in steering or driving speed, to avoid a collision with another road user). [7, 9, 11, 21] Hazards presented in this test included pedestrians or cyclists entering the roadway or crossing the road, inappropriate merging by adjacent cars into the user's lane, cars and motor cycles crossing the centre line approaching from the opposite direction, and on occasion stationary objects, for instance cars or transit vehicles blocking the approach of the vehicle. Participants were required to identify each unique traffic conflict as quickly as possible, and respond by clicking on the identified traffic conflict with a mouse. Each participant was provided with a practice session consisting of approximately 10 video-clips from one of the other three versions that were not allocated to them for testing purposes. This was to minimise the potential of missing or inaccurate responses that may have occurred due to participants (1) not responding to the correct traffic conflicts or (2) not identifying traffic conflicts as worth responding to, and therefore not responding at all.[9] Once participants responded correctly to approximately 5 consecutive videos, or when participants reported that they fully understood the test, the practice condition was terminated and the test condition was commenced. Participants' response times in seconds, as well as the accuracy of the response, was recorded for each video-clip in the test condition. The mean response time was calculated as per our previous studies for the 25 video-clips, and video-clips that participants did not respond to were excluded from their score.[9]

Direction of Heading test. This consisted of 78 short video segments (1-2 s in duration) that were created from the original HPT videos. As for the HPT, the videos were taken from the perspective of a driver. The video segments were selected so that the direction of heading of the vehicle (relative to what would be considered ideal lane-keeping) was unambiguously either drifting left, drifting right, or driving straight ahead within the lane markings. The direction of heading of the vehicle in each of the video segments was confirmed by measuring the distance and angle between the car and lane markings during the course of the video. Participants were instructed to imagine themselves driving the vehicle and asked to indicate the direction of travel (relative to normal lane-keeping) by using the arrow keys (left for a leftward drift, right for a rightward drift, up to indicate 'straight ahead' or 'appropriate' lane-keeping). The selection of videos was based on the results of a pilot study and included only those videos to which the pilot participants responded correctly better than chance. The final set of videos included 21 scenes involving a leftward drift, 28 right, and 29 straight ahead. The DOH test was displayed on the same screen as the HPT, at 1 metre.

RESULTS

Table 1 shows the median and interquartile ranges for the measures used in this study. There was a range of visual function corresponding to the ages of the participants. Age was bimodal, with an overall higher proportion of participants aged <30 or >60 (in all there were 18 participants aged 21-30, 6 aged 31-40, 1 aged 41-50, 5 aged 51-60, 23 aged 61-70 and 8 aged 70+). The Gabor and second-order motion tests were positively skewed, and the number of correct responses on the HPT negatively skewed. To ensure robustness, the analyses were conducted using both parametric and bootstrap non-parametric analyses, and analyses flagged as significant only where both parametric and bootstrap analyses agreed. Given the large number of comparisons included in this study, Bonferroni correction would have reduced the power of the study to unacceptable levels,[22] therefore no adjustment for type I error was undertaken.

Table 1. Mean, standard deviation and range of each of the key measures used in the study

	Median	IQR	Minimum	Maximum
Age (years)	61	38	22	87
Visual Acuity (logMAR)	-0.08	0.15	-0.22	0.20
Contrast Sensitivity (log units)	2.05	0.13	1.60	2.30
D_{min} (log min arc)	-0.67	0.32	-1.04	-0.34
Motion Coherence threshold (%)	0.30	0.20	0.03	0.41
Drifting Gabor (Hz)	0.07	0.08	0.01	0.31
Second Order Motion (Hz)	0.05	0.09	0.01	0.31
Direction of Heading accuracy (%)	79.5	17.31	36	74
HPT Mean Response Time (sec)	5.08	1.18	3.25	7.81
HPT Accuracy (out of 25)	21	3	8	25

Table 2 shows the correlations between each of the vision tests (VA, CS and the motion tests) with the three measures of perception in the video driving scenes including HPT accuracy, HPT response time, and DOH accuracy. At the bivariate level, there were strong significant age-related changes for all measures. All of the vision measures related significantly to HPT accuracy. D_{min}, coherence, and the drifting Gabor measure all related significantly to the hazard perception response time, and also to the DOH accuracy.

Table 2. Bivariate correlations between all variables

	2	3	4	5	6	7	8	9	10
1. Age	-.37**	.41**	-.72**	.45**	-.53**	.71**	.37**	.32*	.27*
2. HPT (number correct)		-.51**	.48**	-.29*	.33*	-.39**	-.42**	-.36**	-.30*
3. HPT (reaction time)			-.31*	0.07	-0.24	.29*	.26*	.29*	0.20
4. Direction of Heading (number correct)				-.37**	.48**	-.55**	-.40**	-.38**	-0.23
5. Visual Acuity					-.38**	.51**	.41**	.38**	0.19
6. Letter Contrast Sensitivity						-.44**	-.28*	-.27*	-.34**
7. D_{min}							.62**	.31*	.35**
8. Coherence								0.25	.33*
9. Gabor									0.25
10. Second Order Motion									

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Listwise N=61

In order to examine the unique contributions of motion perception to the HPT and DOH measures, controlling for age and other aspects of visual function (visual acuity and contrast sensitivity), a series of partial correlations were conducted (Table 3). The Gabor motion test remained a significant predictor of HPT accuracy and response time. Coherence was also a significant predictor of HPT accuracy controlling for age and the visual function measures.

Table 3. Partial correlations between motion sensitivity measures and the HPT and Direction of Heading measures, controlling for age, visual acuity and contrast sensitivity

	2	3	4	5	6	7
1. HPT (number correct)	-0.45	0.31	-0.16	-0.29*	-0.24*	-0.19
2. HPT (reaction time)		-0.03	0.03	0.18	0.23*	0.10
3. Direction of Heading (number correct)			-0.06	-0.19	-0.21	-0.01
4. D_{min}				0.50	0.03	0.21
5. Coherence					0.06	0.24
6. Gabor						0.15
7. Second Order Motion						

* $p < .05$ (1-tailed)

To investigate whether the relationship between motion sensitivity and HPT accuracy was significantly mediated by the ability to detect motion direction in the hazard perception videos (as assessed by the DOH task), bootstrap tests of mediation were conducted for each of the motion tests shown to be significant in the partial regression analysis (ie. Coherence, and Gabor). The relationship between Coherence and HPT accuracy was significantly mediated by performance on the DOH task (indirect effect b = -4.33, 95% CI [-11.07, -0.23]), such that the relationship was significantly reduced after controlling for DOH, although it did remain significant (p = .029). In contrast the relationship between the Gabor motion sensitivity index and performance on the HPT was fully explained by differences in performance on the DOH task (indirect effect b = -6.53 95% CI [-17.52, -0.89]) and became non-significant after controlling for DOH (p = 0.13).

DISCUSSION

In this study we examined how the deficits in motion perception which occur with increasing age can lead to changes in performance on a range of driving-related tasks. As predicted, older adults performed significantly more poorly on all the tests included in this study, including the visual function measures, motion sensitivity and the HPT and DOH tests. The DOH judgment was significantly impaired in older participants, particularly those with impaired motion sensitivity, and performance on this task explained in part the association between motion sensitivity and performance on the HPT.

A number of the motion tests were significantly associated with performance on the HPT. The Gabor motion sensitivity task was a significant predictor of both accuracy and response time on the HPT, consistent with our previous findings.[23] Since perception of motion from this stimulus can be accomplished at all levels of the visual system, including both low (retinal) and higher (cortical) levels of processing, no definitive conclusions can be drawn regarding the level of the visual system which affects driving. However, the test which showed the strongest unique relationship with HPT accuracy in this sample was the coherence threshold, which is known to correlate with higher-level processing.[17] D_{min}, which has been shown to be sensitive to low-level (retinal) changes was not similarly associated with HPT performance after controlling for age or visual function. Thus we conclude that the relationship between motion perception and performance on the HPT is likely to be due to higher-level changes in the neural systems responsible for extracting motion from visual noise.

The DOH measure created for this study is novel, and elucidates an important aspect of visual perception in driving which can be compromised in those with reduced motion sensitivity. Correct perception of the direction of heading of one's own vehicle, as well as other vehicles on the road, is essential to maintaining correct lane position, as well as ensuring smooth handling and navigation through traffic. Certain hazards, for instance pedestrians or cyclists, may be defined as hazards only if the approaching vehicle is on a collision course with respect to them, and avoiding collisions with pedestrians or cyclists requires perceptual feedback regarding whether it is necessary to alter one's approach (either by braking or steering). Other hazards presented in the HPT used here featured appropriate or inappropriate merging of other vehicles (e.g., changing lanes). Successful merging largely relies on being able to correctly identify one's position with respect to other road users at all times. It is important to note, however, that this is only one of a number of motion cues important to driving (others might include judging the speed of vehicles crossing one's path, estimating time to contact for a looming object, and judging acceptable time headway to merge or enter traffic). Thus it is not surprising that performance on this task only partially mediated the relationship between motion perception and HPT performance in this study. Potentially the relationship observed between the DOH and the coherence test and HPT reflects the complex nature of direction judgments in real-world driving. Since the direction judgment requires simultaneous perception of looming as well as translational motion vectors (optic flow) it should also reflect some of the abilities used by drivers in judging the angle of approach to a hazard, and therefore being able to judge in some sense the location of the hazard in depth and whether they are on a collision course with it. It is important to note in this context that the sense of direction and velocity are derived here from 2-dimesional cues, and there may be other cues that are derived from real motion in depth (including somatic and vestibular cues as well as peripheral monocular cues) which could only be examined in real-world driving situations.

These results have potential implications for the future remediation of unsafe driving. Wilkins et al[24] reported that motion sensitivity can be improved among younger drivers following training and this translated to improvements in braking responses on a simulator task. If this were replicated in a wider population, it might be possible to remediate through training some of the deficits observed here, leading to overall higher safety among this population.

The second-order motion sensitivity test was related to HPT at the bivariate level, but was not a significant predictor after controlling for age and the visual function measures. Since the second-order motion stimulus used here consisted of a contrast-modulated grating we conjecture that this test may have acted as a surrogate measure for participant's contrast sensitivity, and not motion perception, in this study. Given that previous research has strongly indicated that first- and second-order motion are processed in different (possibly parallel) streams in the visual system,[19] the fact that the first-order motion tests used here correlated with hazard perception while the second-order stimulus did not, seems to indicate that first-order motion is the strongest contributor to the kind of motion judgments measured in the displays used here.

A strength of this study was the inclusion of visually normal adults over a wide age range, which enabled us to investigate the changes in motion perception with increasing age, effectively uncontaminated by eye disease. Although participants were not specifically screened by ophthalmoscopy, all performed within a normal range according to their visual acuity and contrast sensitivity (-0.22 to 0.20 logMAR visual acuity, and letter contrast sensitivity of 1.60 to 2.30 log units), and therefore the changes in both motion sensitivity and performance on the video-based driving perception measures are unlikely to be due to ocular pathology, but rather to represent 'normal' age-related changes in motion sensitivity. Although it is impossible to ever fully separate age from general sensory decline, the robustness of the relationships here, even controlling for visual acuity and contrast sensitivity, in addition to age, indicate that there is something unique in the changes in motion processing which is not explained by simple sensory decline.

The findings of this study should also be considered in light of some potential limitations. The HPT measure used in this study, while demonstrably a useful proxy measure of perceptual ability in driving, is nonetheless an artificial task, as was the DOH test constructed for this study. The high level of accuracy on the HPT is typical in this paradigm, as hazards are chosen to be such that most people do eventually detect them. This high accuracy created some ceiling compression in the data, which can suppress some effects. Thus it would be informative to also incorporate a test with greater variability in terms of accuracy (i.e., a more difficult measure) in future research. The sample, while evidencing strong and significant results, was nonetheless small. Volunteer participants recruited by word of mouth, as in the present study, may also differ in some characteristics from participants less willing to volunteer for research participation. It is necessary to validate these findings in on-road driving, and also through prospective examination of crash rates, among a larger sample of current drivers. However, these preliminary data support previous reports regarding the importance of motion sensitivity for the perception of dynamic cues in driving scenes, and suggest a possible mechanism through which these changes may be manifested.

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