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With Motion Perception, Good Visual Acuity May Not Be Necessary for Driving Hazard Detection

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Purpose: To investigate the roles of motion perception and visual acuity in driving hazard detection.

Methods: Detection of driving hazard was tested based on video and still-frames of real-world road scenes. In the experiment using videos, 20 normally sighted participants were tested under four conditions: with or without motion interruption by interframe mask, and with or without simulated low visual acuity (20/120 on average) by using a diffusing filter. Videos were down-sampled to 2.5 Hz, to allow the addition of motion interrupting masks between the frames to maintain video durations. In addition, single still frames extracted from the videos were shown in random order to eight normally sighted participants, who judged whether the frames were during ongoing hazards, with or without the diffuser. Sensitivity index d-prime (d′) was compared between unmasked motion ($n = 20$) and still frame conditions ($n = 8$).

Results: In the experiment using videos, there was a significant reduction in a combined performance score (taking account of reaction time and detection rate) when the motion was disrupted ($P = 0.016$). The diffuser did not affect the scores ($P = 0.419$). The score reduction was mostly due to a decrease in the detection rate ($P = 0.002$), not the response time ($P = 0.148$). The d′ of participants significantly decreased ($P < 0.001$) from 2.24 with unmasked videos to 0.68 with still frames. Low visual acuity also had a significant effect on the d′ ($P = 0.004$), but the change was relatively small, from 2.03 without to 1.56 with the diffuser.

Conclusions: Motion perception plays a more important role than visual acuity for detecting driving hazards.

Translational Relevance: Motion perception may be a relevant criterion for fitness to drive.

Introduction

Visual cues are major sources of information when driving. Visual acuity has been used as a universal visual criterion to determine an individual's fitness for driving licensure. However, years of driving research suggest that visual acuity is "at best, very weakly linked to driver safety."[1,2] It should be noted that this conclusion may be valid within a certain range of visual acuity. For example, one large study that did not find a relationship between visual acuity (VA) and motor vehicle crashes was the Salisbury Eye Evaluation (SEE) Study,[3] in which 1801 active drivers were enrolled, and only 3.2% of them had VA worse than 20/40. Cross' further study included the SEE project cohort and added cohorts from Alabama and Kentucky for a total 3158 drivers.[4] Still, only 4% of drivers had VA worse than 20/40. One may ask, therefore, if people with reduced visual acuity are allowed to drive, will they quickly be involved in collisions?

Our recent multiweek naturalistic driving study on drivers with reduced visual acuity (as low as 20/160), who wore bioptic telescopes but used them for only 1.6% of driving time,[5] did not find a significantly higher near collision hazard ratio as compared with normally sighted controls.[6] Dougherty et al.[7,8] analyzed the traffic collision records of bioptic drivers in Ohio

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(mean visual acuity 20/120) and did not find any significant relationships between collision and visual acuity or contrast sensitivity. Taken together with earlier studies that found bioptic drivers had similar collision rates[9,10] or even lower collision rates than normally sighted drivers,[11] it seemes to suggest that moderate loss of visual acuity might not necessarily lead to unsafe driving. So what visual functions are essential for driving safety?

Some studies have investigated other visual functions, and concluded that visual field is an important factor. For example, in their study, Johnson and Keltner[12] reported that drivers with reduced visual field in both eyes had twice the rate of collisions and traffic violations as drivers with normal visual field. Kwon et al.[13] studied at-fault collisions among people with glaucoma and found that severe visual field loss was associated with collision. Similarly, Haymes et al.[14] in their study of the self-reported collision among patients with glaucoma, reported that worse useful field of view score and smaller visual field were risk factors of collision. It is still an open question what visual functions within the visual field, for example, contrast sensitivity, color vision, and motion perception, are essential for driving safety.

In recent years, the relationship between motion perception and driving performance has been investigated.[15–19] Wilkins et al.[17] demonstrated that motion perception training could improve motion perception score, as well as emergency brake performance in a driving simulator study. Wood et al.[19] showed that for drivers with macular degeneration (mean VA 20/22, all met acuity requirement for driving in Australia), motion sensitivity was the only visual function significantly associated with driving performance rated by an occupational therapist, among other measures such as visual acuity and contrast sensitivity. Lacherez et al.[16] found a significant relationship between hazard perception and motion perception, which were measured with random-dot kinematogram and drifting Gabor patches.

Driving hazard perception is drivers' ability to anticipate hazardous situations on the road and predicting what will happen next. Hazard perception is an important driving skill identified as one of the main safety related driving skills.[20] An individual applying for a driving license in the UK and Australia must pass a hazard perception test.[21] Detecting hazards in a timely manner is crucial for safe driving. It is likely that motion perception is involved in hazard perception or braking response to hazards. While seeing fine details is important for many daily activities, motion perception can provide additional information, especially when performing navigation and collision avoidance tasks.[22]

The aforementioned studies on motion perception were conducted under good visual acuity conditions. To further understand the role of motion perception and compare it with visual acuity, which is commonly believed to be important for driving, the interaction between motion perception and visual acuity should be investigated. The methodology in this study was to reduce visual acuity to lower than the normal range, making it possible to disentangle these roles of the two visual functions for driving hazard perception. We hypothesize that impaired motion perception is more detrimental to hazard perception than loss of visual acuity.

Method

Two experiments were conducted in this study using different methods to manipulate motion. In the first experiment, motion was interrupted by an interframe mask, and in the second experiment motion was completely prohibited by presenting a single still image frame in each trial. For both experiments, the baseline test was the driving hazard perception test based on videos without motion interruption.

This study was approved by Massachusetts Eye and Ear's Institutional Review Board and was conducted in accordance with the tenets of the Declaration of Helsinki. Participants provided their informed consent before participation in the study.

Hazard Perception with Motion Mask—Experiment 1

Hazard perception is a part of the UK and Australia's driving license examination, and an applicant must pass a hazard perception test to acquire driver's license. The hazard perception test used in this study is based on the hazard perception test and videos used in the UK. The hazard perception test in the UK uses a series of one-minute videos presenting driving events recorded with forward-facing egocentric cameras from the driver's perspective in real world driving. Each video includes a driving hazard. Participants are directed to press a key as soon as they see a "potential hazard" or a "building hazard,"[23] which would require the driver to respond by braking or steering. Examples of potential hazards include a pedestrian on the sidewalk walking toward the road, a vehicle braking in front of the driver, or a car on the side of the road pulling out (an example is shown in Fig. 1).

Figure 1. Snapshot of a hazardous situation in a sample hazard perception video. The car (indicated by a *red oval*) entering the road from the right side is a potential hazard.

Participants are instructed to respond before the hazardous situation ends. The duration that the hazard exists in the video is called the hazard window and is defined as from the moment hazard appears until either it disappears or the driver in the video (ego-driver) reacts to the hazard. This window is defined by the test developer. Participants' performance is calculated on the basis of whether they notice the hazard and how quickly they do so. Two direct outcomes can be derived from the hazard perception test: detection rate (whether the participant notices the hazard and responds to it) and reaction time (how quickly the participant responded to the observed hazard). Using the first outcome, a detection rate is calculated as the percentage of hazards detected. Using the second outcome, the reaction time is measured for detected hazards only; undetected hazards are not included in the calculation of average reaction time.

In the hazard perception test used for licensure in the UK, a hazard perception score is used, calculated by combining the reaction time and detection rate. For each hazard, the hazard window is linearly divided into five segments and mapped to five points. The sooner the response occurs, the higher the point the participant receives. (A response within the first segment receives five points.) Such an integrated score may help resolve possible conflicts between detection rate and response time measures, as shown in this study. This type of hazard perception score has been used in our previous driving studies and by other researchers.[24,25]

To investigate the role of motion perception in hazard perception in this experiment, motion was manipulated by inserting an inter-frame mask image into the hazard perception videos to disrupt/reduce the perception of the motion. During the pilot phase, several mask images were tested, a blank frames (black, gray, or white) and an average image created based on the average Fourier spectrum of 500 frames randomly extracted from the hazard perception videos. The created mask had the same spatial frequency characteristics as the original video frames, but did not include any meaningful scene information, except for the overall brightness pattern. Participants reported that the blank frames were too distracting because of the sudden changes in brightness. In response to this feedback, the average image was used as the motion interruption mask.

The frame rate of the original hazard perception videos was 25 Hz. The testing videos were down-sampled to 2.5 Hz by extracting one frame from every 10 frames to accommodate the insertion of the mask-frame and maintain the original duration of the video—ensuring the reaction time could be measured meaningfully. In the no-mask conditions, each extracted frame was shown for 0.4 seconds, instead of the original 0.04 seconds. In the with-mask conditions, the video image frame and the mask were shown for a combined duration of 0.4 seconds. This kept stimulus duration constant, allowing for comparable reaction time measurements. Because the total number of road scene video frames is equal between with and without mask conditions, the visual information about the driving scenes is equal. To test whether the duty cycle of the mask impacts hazard perception performance, two mask durations of 0.1 and 0.3 seconds were used. For 13 participants, the image was shown for 0.1 seconds and the mask was shown for 0.3 seconds. For the remaining seven participants, the image was shown for 0.3 seconds, and the mask was shown for 0.1 seconds. Figure 2 illustrates the three timings used.

Twenty normally-sighted participants (mean age: 32, standard deviation = 9.45, range 20–56, VA 20/20 or better, 10 male) were recruited for this study. To simulate reduced visual acuity, the participants wore a pair of plano lens glasses covered with two stacked 0.1 diffusing foils (Bangerter occlusion foils; Ryser Optik AG, St. Gallen, Switzerland). The diffusing filter reduces the binocular contrast sensitivity (measured using Mars chart; Mars Perceptrix, Chappaqua, NY, USA) to about 1.3 from 1.8 log units and the mean of visual acuity to 20/120.[26] The design of the experiment was a two-by-two combination of visual acuity (with/without diffusing filter) and motion conditions (with/without the motion mask). The order of the four conditions was counterbalanced across participants.

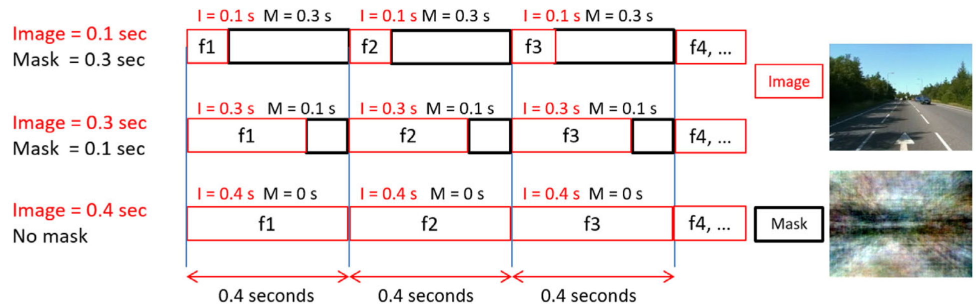

Figure 2. Image and mask timings in experiment 1. The original 25 Hz videos were down sampled to 2.5 Hz by dropping some frames, to accommodate the interframe mask. Thus, in without-mask condition, each frame duration was 0.4 seconds. In with-mask condition, the mask was inserted and the duration of road scene video frames was shorter than 0.4 seconds. Two mask durations, 0.1 seconds and 0.3 seconds, were tested in this study. Sample video: https://www.youtube.com/watch?v=rcEkENCPKHM.

To ensure timing accuracy in the presentation of the hazard perception videos, a program was created using PsychToolbox.[27–29] A set of 10 hazard videos were randomly chosen for each of the four conditions, with each video lasting approximately 60 seconds and containing one hazard. Each video was watched only once during the test by each participant. The videos were taken from a commercial training DVD used for the driving licensure test in the UK (Driving Test Success Hazard Perception; Imagitech Ltd, Swansea, UK). The training DVD includes ground truth of hazards for all video clips. The hazard perception videos (image resolution 786 × 576) were played on a 51 × 28.7 cm monitor (Asus model VX238H-W, 60Hz refresh rate) from a 60 cm viewing distance. The horizontal field of view of the image is 46°. The experiment was conducted in normally lit room (680 lux). The brightness of the screen was 180 cd/m^2 when showing a white background.

Participants were first briefed on the hazard perception test and what they were expected to do. They were then asked to watch five sample hazard perception videos, which included different types of potential hazards. In order to confirm participants' understanding of the task expectations, during the practice participants were asked to verbally explain the hazard they observed. For the actual test, participants were asked to report hazards they detected by clicking the mouse button, rather than responding verbally as they had in practice.

Hazard Perception with Still Images—Experiment 2

As one may observe in the demo video (https://www.youtube.com/watch?v=rcEkENCPKHM), motion may not be completely masked in experiment 1. To further investigate the role of motion, a second experiment was conducted with eight subjects (seven new subjects who were not in experiment 1) without using the interframe mask. In this new experiment, the perception of motion was completely obscured by showing a single road scene image in each trial. For each still image presented, participants reported on whether they considered the image could be within the epoch of a hazard by saying yes or no, while they freely viewed the image. Their judgment was compared with the 20 participants' responses for videos without interframe mask in experiment 1.

To make the stimuli in the two tasks (one based on video and another based on still images) match in terms of visual content and probability of hazards, the still images were extracted in the following manner. First, the duration of the hazard event within each video was obtained from the data file in the hazard perception DVD. For a given video, the total video duration (approximately 60 seconds) was divided into blocks that were roughly equal to the duration of the hazard event (approximately five seconds) in that video. One frame was then extracted at a random time-point from each of the blocks, making a total of 324 images for all 30 videos. Thus one image from hazard window and an average of 10 images from the nonhazardous blocks were extracted. The images were then presented in random order, with randomly selected 162 images (50%) shown for 0.4 seconds and the other 50% for 0.1 seconds. The eight participants wore the diffusing filter in half of the 324 trials (images and image duration were randomly assigned).

Statistical Analysis

For the experiment 1, there were two binary independent variables: interframe mask and diffusing filter, and three dependent variables: detection rate

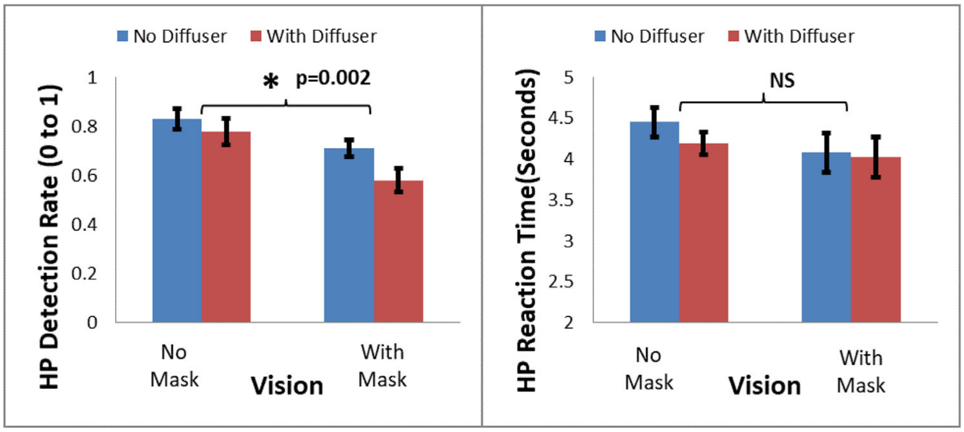

Figure 3. (*Left*) hazard perception detection rate. Hazard detection rates were significantly reduced in the presence of motion mask ($P = 0.002$), but diffusing filter did not have significant effect ($P = 0.126$). (*Right*) Hazard perception reaction time: Neither mask ($P = 0.148$) nor diffusing filter ($P = 0.385$) had a significant effect on the reaction time. Data include both 0.1- and 0.3-second mask durations. *Error bars:* Standard error of the mean.

(between 0 to 1), reaction time (in seconds), and hazard perception scores (0 to 5). Repeated measures analyses of variance (ANOVAs) were used to determine the effects of the mask (interruption in motion) and diffusing filter (simulated low vision) on each of the dependent measures. A P value < 0.05 was considered as statistically significant.

For experiment 2, the main outcome measure was sensitivity index d-prime (d′). The hit rate (H) and false alarm rate (FA) were used to calculate the index ($d' = z(H) - z(FA)$, where $z()$ is z-transform) for each participant. False alarms were positive responses to still images extracted outside the hazard time window. In a similar way, d′ was also calculated for each of the 20 participants in experiment 1, based on their responses to videos without interframe mask. Their false alarms were mouse-clicks outside the hazard time window. The d′ results for unmasked video and still frame conditions were compared to investigate the effect of diffusing glasses and motion perception. There was one within-subjects factor, diffusing filter (simulated low vision) and one between-subjects factor (video or still image). A repeated measures ANOVA was conducted to test the two factors.

Results

As the left panel in Figure 3 shows, in experiment 1, the motion mask caused a significant reduction in detection rate from 0.78 to 0.65 ($F_{1, 18} = 13.49$, $P = 0.002$, $\eta^2 = 0.43$), but the diffusing filter did not have any significant effect on detection rate ($F_{1, 18} = 2.57$, $P = 0.126$, $\eta^2 = 0.125$). The interaction between the motion mask and diffusing filter conditions was not significant ($F_{1, 18} = 1.28$, $P = 0.27$). The mask duration did not show a significant effect on detection rate (0.73 for 0.1 seconds and 0.70 for 0.3 seconds, $F_{1, 18} = 0.174$, $P = 0.68$).

As the right panel in Figure 3 shows, we did not find a significant effect of motion mask on reaction time, ($F_{1, 18} = 2.29$, $P = 0.148$), nor the diffusing filter, ($F_{1, 18} = 0.80$, $P = 0.39$). The interaction between the diffusing filter and the motion mask was not significant either ($F_{1, 18} = 0.33$, $P = 0.57$). Mask duration did not show a significant effect on reaction time (4.15 for 0.1 second and 4.25 for 0.3 seconds $F_{1, 18} = 0.15$, $P = 0.70$).

Although the mask and the diffuser did not have a significant effect on reaction time, the mean reaction time with either of them seemed to be shorter (at least not significantly longer) than without them (right panel of Fig. 3). It would be unreasonable to assume that the mask and the diffuser could help improve performance. Considering that the detection rate dropped because of the mask (left panel of Fig. 3), a reasonable explanation could be that, when motion mask and diffuser were used, only easy-to-spot hazards were detected, which required only a short time to detect. A further analysis was conducted to determine whether there might be some slightly late responses after the defined hazard time window.

The end of the hazard window in all the videos was extended by a brief duration of 0.4 seconds, equivalent to one down-sampled frame (i.e., 10 original video frames), to include slightly later recorded responses to the hazards. Following this change, the analyses

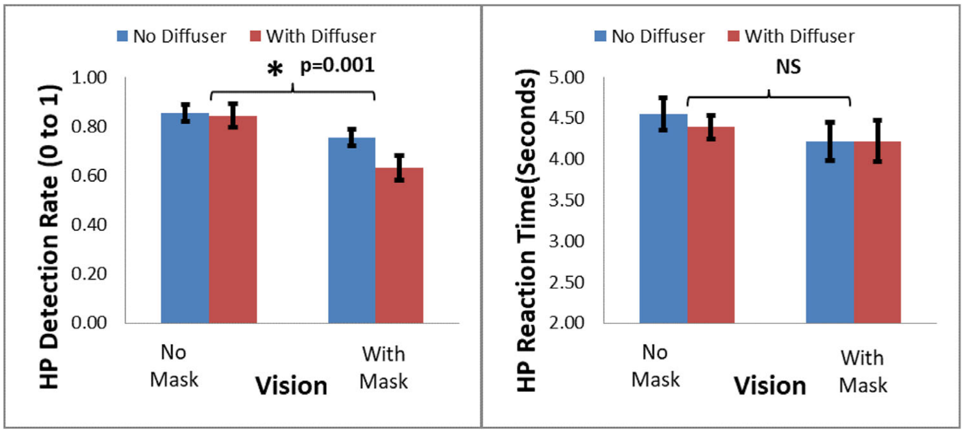

Figure 4. (*Left*) hazard perception detection rate with 0.4 seconds extension of the hazard response time window. Similar to performance without extension, hazard detection rates significantly reduced in the presence of motion mask ($P = 0.001$), while the effect of the diffusing filter was not significant ($P = 0.19$). (*Right*) hazard perception reaction time with 0.4 seconds extension. Neither mask ($P = 0.16$) nor diffusing filter ($P = 0.58$) had a significant effect on the reaction time. The finding is essentially same as analysis without extension. Data include both 0.1- and 0.3-second mask durations. *Error bars:* Standard error of the mean.

were conducted again on the results that included "later" responses, and the mask duration (0.1 and 0.3) was considered as between subject factor. As shown in Figure 4, the impact of diffusing filter on detection rate remained nonsignificant, (0.79 without vs. 0.75 with filter $F_{1,18} = 1.86$, $P = 0.19$, $\eta^2 = 0.10$); similarly, the impact of the motion mask remained significant (0.84 without mask vs. 0.70 with mask, $F_{1,18} = 15.25$, $P = 0.001$, $\eta^2 = 0.46$). As for the reaction time, neither the motion mask ($F_{1,18} = 2.18$, $P = 0.16$) nor diffusing filter ($F_{1,18} = 0.32$, $P = 0.58$) had a significant effect. Mask duration did not have a significant impact on either of reaction time ($P = 0.419$) or detection rate ($P = 0.981$).

Although it was not statistically significant, the mean reaction time with mask was still shorter than without mask. Compared with original hazard window, the extended hazard window only captured 5% more hazards for the with-mask condition (from 0.65 increased to 0.70), which was still significantly less than the without-mask condition (0.84). It is likely that many hard-to-spot hazards were completely missed in the mask condition. Because the reaction time for those missed hazards could not be included in reaction time evaluation, this created an ambiguous problem to the evaluation method based on detection rate and reaction time separately. Therefore it is necessary to use the hazard perception score to combine the detection rate and reaction time.

As Figure 5 shows, the hazard perception score was significantly reduced from 1.33 to 1.1 per hazard in the presence of the motion mask ($F_{1,19} = 7.00$, $P = 0.016$, $\eta^2 = 0.28$). The use of the diffusing filter did not have a significant impact on the hazard perception scores ($F_{1,19} = 0.683$, $P = 0.419$, $\eta^2 = 0.037$). The interaction between the use of the diffusing filter and the motion mask was not significant ($F_{1,19} = 1.02$, $P = 0.33$). Mask duration (0.1 or 0.3 second) was included as a between-subject factor in the repeated measures ANOVA, and it did not have a significant effect either (1.30 for 0.1 and 1.13 for 0.3 seconds, $F_{1,18} = 0.45$, $P = 0.51$).

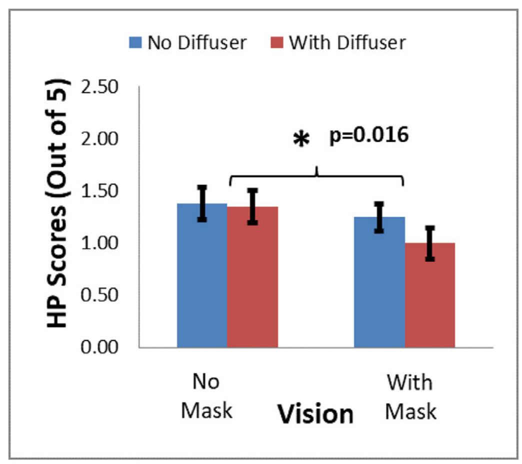

Figure 5. Hazard perception score results in experiment 1. There was a significant effect of mask on hazard perception score ($P = 0.016$), while the diffusing filter did not show a significant impact ($P = 0.42$). *Error bars:* Standard error of the mean.

The hazard perception scores were reanalyzed using the 0.4 second extended threshold, similar to detection rate and reaction time results, to find the impact of late responses. Similar to the initial threshold, only the motion mask showed a significant impact on hazard

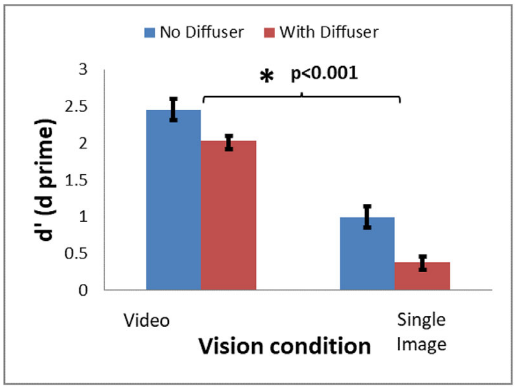

Figure 6. Analysis results based on d′. Data include judgment based on unmasked videos and single still images. The d′ with still images was significantly lower than that with video ($P < 0.001$). The diffusing filter was a significant factor ($P = 0.004$), but the decline in d′ due to the use of diffusing filter was relatively small. *Error bars:* Standard error of the mean.

perception score (1.49 without vs. 1.25 with mask $F_{1,18} = 10.73$, $P = 0.012$, $\eta^2 = 0.305$). Mask duration (0.1 and 0.3 seconds) did not have a significant effect ($F_{1,18} = 0.41$, $P = 0.53$)

In experiment 2, as shown in Figure 6, d′ was significantly lower ($F_{1,26} = 75.5$, $P < 0.001$, $\eta^2 = 0.74$) when a still image was presented in a trial (d′ = 0.68) compared to a video was presented in a trial (d'=2.24). The diffusing filter showed statistically significant effect on d′ ($F_{1,26} = 9.7$, $P = 0.004$, $\eta^2 = 0.27$), but the difference between without and with diffusing filter conditions was relatively small (2.03 without vs. 1.56 with filter).

The effect of diffusing filter and image duration (0.1 vs 0.4 seconds) was also tested on the basis of the data from the eight participants as within-subject factors in repeated measures ANOVA. Neither diffusing filter (0.38 with and 1.42 without filter, $P = 0.112$) image duration (0.59 for 0.1 second vs. 1.2 for 0.4 second, $F_{1,7} = 1.6$, $P = 0.241$) showed significant effect on d′.

Discussion

This study was conducted to investigate the roles of motion perception and visual acuity in driving hazard perception. We argue that motion perception may be a crucial visual function for safe driving, while years of driving research suggests that visual acuity is not a good predictor and driving safety in terms of collision likelihood.[2] Some previous studies have also shown that motion perception is correlated with driving performance.[15,16,18,19] However, most of these studies were conducted under fairly good visual acuity conditions, primarily in normally sighted participants. It is still an open question whether those findings are still valid for visually impaired drivers. This is not a hypothetical question, because there are many people with reduced visual acuity driving on the road every day. In more than 40 states in the United States, as well as the Netherlands and Québec, Canada, it is legal for a person with reduced visual acuity, as low as 20/200 in some cases, to drive with the assistance of a visual aid called a bioptic telescope.[9,30] Although the telescopes improve visual acuity, it was found that bioptic drivers spend more than 98% of their driving relying on their impaired vision, not through bioptic telescopes.[5,30] In other words, they are driving with low visual acuity most of the time. However, as some studies found, the bioptic telescope users did not seem to be less safe than normally sighted drivers.[11,31,32] Our recent naturalistic driving study added more evidence consistent with the finding, because we did not find a significant increase in near collisions for bioptic drivers when compared with normally sighted control drivers.[6] The finding is motivating us to study whether, to some extent, motion perception might explain why at least some visually impaired bioptic drivers do not have universally, substantialy worse safety performance than normally sighted people. This study suggests that motion perception may be one of the key factors contributing to their safe driving performance. Numerous studies have shown that optical flow, an expanding pattern of motion information, can be used in heading estimation,[33–36] and collision detection.[37,38] It is likely that there is a link between motion perception and driving performance. When visually impaired driver was asked about his strategy to avoid collision in driving, his response was "I use motion to detect everything. You don't need to see objects. You should learn to detect them."

Understanding how low spatial frequency information is used by the human visual system in motion perception may help explain why low visual acuity did not affect the hazard perception score in this study. Ramachandran et al.[39] argued that perceived movement is determined primarily by low spatial frequencies. Tadin et al.[40] showed that there were no adverse effects of visual acuity loss on motion perception for low spatial frequency stimuli. Our recent motion perception study also showed that low frequency components are critical for quantitative estimation of speed.[41] Lappin et al.[42] showed that motion detection thresholds in some low vision participants were similar to normally sighted participants. It is also known that very coarse biological motion, using a few bright spots on some of human body joints, can be sufficient for recognizing human motion such as walking, running, and dancing.[22] Wood et al.[43] showed that biological motion information helped drivers improve their detection of pedestrians in night driving tasks. For collision avoidance, optical flow "would be sufficient for controlling braking," according to Lee's Tau theory.[37,38] Wolfe et al.[44] recently found that a brief view of road videos as short as 220 ms could be sufficient for subjects to detect critical hazards. Observers could barely move their eyes multiple times to search for hazards within such a short duration. So even for normally sighted observers, they could not completely rely on high-resolution central vision for hazard perception. It was likely they used motion information perceived by their low-resolution peripheral vision.

Studies have shown that interframe mask can have dramatic effects causing change blindness.[45,46] Therefore we expected it also to have a strong effect on motion perception. However, according to our visual experience, when one attends to an object, its movement trajectory can still be estimated, although it is indeed more difficult than without mask. In other words, the motion perception cannot be completely blocked by the mask. What might happen in the absence of motion information? This question motivated our still frame condition in Experiment 2.

Because the hazard perception scores cannot be used for still image stimuli, performance was evaluated based on d′. Although response time cannot be incorporated in d′ measure, an extra value of this sensitivity index is that false alarms are taken into account, which is an important measure for evaluating visual task performance. Consistent with experiment 1, it was found that hazard perception performance measured by d′ indeed dropped significantly and substantially from 2.24 to 0.68 if motion cues were prohibited. So experiment 2 further strengthened the argument for the role of motion in hazard perception.

Unlike hazard perception score analysis, the d′ analysis found a significant effect of the diffusing filter (i.e., low visual acuity). Hazard perception score and d′ take into account different measures. Therefore, what they evaluate can be slightly different. From a driving perspective, the hazard perception score may be more meaningful because it accounts for timely detection of hazards (earlier responses receive higher scores), and it does not penalize false-positive responses, because they may represent extra cautiousness in driving. The computation of d′ considers judgment accuracy and weighs true-positive and false-positive responses equally. However in reality, the consequences of missed detections and false alarms in driving are very different. The former may lead to motor vehicle crashes, and the latter is much less likely to do so.

Since the diffusing filter reduces visual acuity, the participants wearing the filter might not be able to see hazardous objects when they are far away because they appeared small in the still images. Thus missed detections resulted in reduced d′ values. This can explain why a significant effect of the diffusing filter was found in experiment 2. In reality, however, visual experience in driving is rarely stationary. Motion perception, originating from self-movement or object movement, may assist in hazard detection. As this study shows, interruption or prohibition of motion can have larger impacts on hazard perception than low visual acuity.

In experiment 1, the hazard perception performance was evaluated using the same scoring methods as in the UK test for driver licensure. The baseline score of 1.4 (watching videos without mask and diffusing filter) is below the passing mark (2.67 per video) in UK, probably because of three reasons: (1) the subjects could not detect hazards from the low frame rate videos used in this study as reliable as the full frame rate (25Hz) videos, due to lags in low frame videos and reduced motion continuity. In our previous study, normally sighted subjects watched 25Hz videos and their performance score (1.9 per video) was a little higher than that in this study,[24] but was still lower than the passing mark. (2) Unlike drivers in UK, where hazard perception is part of their training (the hazard videos used in this study are made for drivers to practice), subjects in this study and our previous study only had a few practice trials. (3) The hazard perception videos were recorded in the UK, making them less familiar for participants in the US. Consequently, it is not surprising that they scored lower than their counterparts in the UK. Nevertheless, frame rate was not a factor investigated in this study, and all the conditions in experiment 1 were tested using 2.5 Hz frame rate. The 0.3-point drop from the baseline (relatively 21%) due to the mask was not a small reduction, especially when comparing with the insignificant effect of the diffusing filter.

Although this study barely found an effect of a moderate loss of visual acuity when motion information was available, logic dictates that there must be limits to visual acuity for safe driving. The role of motion perception and visual acuity, as well as the interaction between them, for driving safety requires further investigation within an even wider visual acuity range in laboratories, as well as real world driving.

With this study, we are not advocating for replacing visual acuity criterion with motion perception thresholds to determine fitness to drive. Driving is a complex task, in which cognitive factors (e.g., attention), physological factors (e.g., visual field), coping strategies (e.g., self-restriction), and experience are believed to play roles. Over-simplified evaluations may have prohibited many qualified drivers while allowing some risky drivers to pass, for instance, some cognitively impaired drivers.[47] Building on previous and future human factor studies, innovative fitness evaluation methods that are comprehensive and operationally feasible could remove unnecessary barriers preventing people with low vision from exercising their driving previliage.

Conclusion

Motion perception plays an important role in driving hazard perception. In our experimental settings, the degradation of visual acuity to 20/120 had a much smaller effect on hazard perception than loss of motion information. These findings might be informative for understanding why some bioptic drivers are able to drive for years without involvement in crashes, even though they drive with low visual acuity most of the time.

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