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Low Vision Rehabilitation

Development and Validation of a Novel Night-Time Hazard Visibility Test

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Purpose: Night-time driving is dangerous, with increased crash rates, particularly involving vulnerable road users. A Night-Time Hazard Visibility Test (NHVT) was developed and validated by exploring the effects of refractive and cataract blur on performance.

Methods: The NHVT comprised video clips of night-time roads from the driver's perspective, including different hazards (pedestrians, cyclists, and vehicles). Participants responded when they first recognized hazards requiring them to take evasive action to avoid a collision. In experiment 1, there were 16 young visually normal drivers (mean age = 22.3, standard deviation [SD] = 2.2 years) who completed 2 NHVT sets, viewed separately through best-correction and refractive blur (+1.00 diopter sphere [DS]). In experiment 2, a refined version of the NHVT was administered to an additional 16 young visually normal drivers (mean age = 21.1, SD = 1.2 years) with best-correction and cataract blur. The order of visual conditions and NHVT sets were counterbalanced.

Results: In experiment 1, refractive blur significantly reduced photopic visual acuity (VA) compared to best-corrected vision (+0.09 vs. −0.21 logMAR, $P < 0.001$) and delayed response times by 0.69 seconds (3.10 vs. 2.41 seconds, $P < 0.001$) compared to best-corrected vision. In experiment 2, cataract blur reduced VA compared to best-corrected vision (+0.03 vs. −0.17 logMAR, $P < 0.001$) and delayed response times by 0.63 seconds (2.92 vs. 2.29 seconds, $P < 0.001$).

Conclusions: The NHVT was sensitive to refractive and cataract blur, providing preliminary support of its validity as a measure of night-time hazard visibility performance.

Translational Relevance: The NHVT has potential as an off-road assessment of visibility for night driving and application for assessment of drivers with different refractive corrections and ocular diseases.

Introduction

Night-time driving is dangerous for all road users. Fatality rates are up to three times higher at night compared to the day when adjusted for driving exposure,[1] with the crash risk at night being particularly high for collisions between pedestrians and vehicles. Pedestrians are three to seven times more likely to be involved in a fatal collision with a vehicle at night than in the day.[2] Similarly, cyclist crash rates at night are relatively high,[3–5] with the seriousness of cycling injuries sustained from involvement in crashes with vehicles also being greater at night.[4] Although there are many factors that vary between day and night-time roads, analyses of crash databases demonstrate that reduced visibility, rather than other factors such as driver fatigue or alcohol consumption, is a key contributor to the increased risk of injury and fatalities at night.[2,6,7]

An important component of driving is hazard perception, which is the ability to anticipate potential road hazards in order to avoid a collision.[8] One approach used to determine drivers' skills in anticipating and detecting potential road hazards are computer-based hazard perception tests (HPTs).[8–11] These tests involve drivers being presented with video clips of real daytime driving scenes that contain a range of

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traffic hazards, filmed from the driver's perspective. Participants are asked to respond as quickly as possible when they detect the appearance of a hazard.[12] These tests have been used as an index of daytime driving ability, where delayed HPT response times have been shown to be associated with crash involvement in younger drivers in both retrospective[13,14] and prospective studies,[10] as well as with increased frequency of heavy braking events during real-world driving.[15] Studies involving older drivers have also shown that delayed HPT times are associated with increased self-reported crash involvement,[11] as well as poorer on-road driving performance,[16] and that response times of older drivers with eye disease are significantly slower than those without eye disease, even when adjusted for age.[17]

Currently, however, there is no test of hazard perception for night-time driving, despite the increased safety risk on night-time roads. Given the visual challenges of night driving, including low light levels, limited anticipatory cues, and the fact that road hazards at night are often of low contrast (e.g. pedestrians), it would be useful to develop a test of night-time hazard perception which specifically targets these night-time visibility challenges. There is also evidence from a range of studies that the negative effects of vision impairment are exacerbated when driving at night.[18–21] A night-time HPT has the potential to predict how well a driver can recognize and respond to low visibility hazards on night-time roads and would have application in identifying drivers for whom night driving is more visually challenging. While this strategy of assessing off-road performance using video-based testing may not fully represent all aspects of night driving, particularly in terms of matching the low light levels and glare intensities from oncoming headlights, it can provide a representative range of night driving scenarios in a safe and controlled environment. Such a test could also be used to assess the impact of a patient's refractive error, or the impact of eye disease, and as such could serve as the basis for informing appropriate interventions (e.g. cataract surgery, change in refractive correction, development of new refractive designs, or eye treatments).

Constructing a test that would be sensitive to the impacts of refractive error on night driving is important given that refractive blur impairs night-time recognition of road signs and pedestrians.[18,20–25] Closed road studies have demonstrated that the effects of blur are greater at night compared to the day,[18] and that even low levels of blur (0.50 diopter sphere [DS]) reduce drivers' capacity to recognize pedestrians at night,[20] as well as identify their walking direction.[25] Correction of low levels of astigmatism (0.75–1.25 diopter cylinder [DC]) using toric contact lenses has also been shown to improve sign recognition, avoidance of low contrast hazards, pedestrian recognition distances, and overall driving scores assessed on a closed road at night.[26]

Providing insight into the positive effects of interventions, such as cataract surgery, on night-time driving is also relevant, given that closed road studies have explored the effects of simulated cataracts on night-time driving and found reductions in recognition of road signs, road hazards and pedestrians at night, despite driving speeds being slower.[19,21] These findings are supported by a night-time driving simulator study which demonstrated that simulated cataracts impaired night-time pedestrian detection which was exacerbated by the effects of glare.[27]

The main aim of this research was to develop and validate a Night-Time Hazard Visibility Test (NHVT) involving presentation of real-world video clips of hazards on night-time roads. The night-time scenes included hazards with varying levels of anticipatory cues (i.e. semantic or contextual cues regarding the upcoming presence of a hazardous event in the scene, for example, an intersection ahead), and contained hazards commonly encountered on night-time roads, many of which are visually challenging (for example, low contrast pedestrians within visually complex scenes or in the presence of glare). In some scenes, the hazards had minimal anticipatory cues, with hazard recognition relying on visual detection, which is representative of the night-time driving environment. This differs to standard daytime HPT tests, which have been designed to maximally discriminate novice from experienced drivers, and include anticipatory cues regarding the onset of a hazard within the scene.[8] In this study, the validity of the NHVT was explored by determining whether it could discriminate between the performance of drivers viewing with and without vision impairments, including refractive blur (experiment 1) and cataract blur (experiment 2), which have been shown to have a significant negative effect on night-time driving performance.

Methods

Development of the Night-Time Hazard Visibility Test

Raw footage of night-time driving scenes was collected to include a range of traffic hazards. Footage of driving scenes was gathered from dashboard cameras mounted inside a series of vehicles driven by members of the research team under night-time conditions along city and urban roads in Brisbane, Australia. For all footage, the images captured the road environment from the drivers' perspective and included a range of potential traffic conflicts, including pedestrians, cyclists, scooters, motorbikes and cars, and large vehicles, such as buses and lorries.

Video clips were selected for inclusion if they had reasonably clear image quality, provided a clear view of the night-time road ahead, the traffic hazard was relatively distinct and separate from other events during the video clip, and the traffic hazards/conflicts required drivers to respond by slowing, stopping, or changing direction to avoid an incident. Forty-six videos met these criteria which were included in the NHVT – version 1 (NHVT-v1) used in experiment 1. The videos varied in length, ranging from 12 to 35 seconds (mean = 25.5 ± 5.3 seconds) and included 66 hazards, the most common being pedestrians (n = 37), followed by cycles/scooters (n = 15), and cars (n = 14). A second version of the NHVT was developed (NHVT-v2) following experiment 1, using 17 videos from the NHVT-v1, and adding a further 33 videos. Reasons for excluding some of the videos from the NHVT-v1 included poor response rates (8 videos with less than 50% responses in the best-corrected condition), a better range of driving scenarios and better-quality videos. A total of 50 videos were included in the NHVT-v2, which was used in experiment 2. The videos varied in length, ranging from 21 to 55 seconds (mean = 29.7 ± 5.0 seconds), and included 71 hazards in total, with the most common being pedestrians (n = 39), followed by cars (n = 22), and cycles/scooters (n = 10).

For both versions of the NHVT, participants were instructed to view the videos presented on the computer monitor and to indicate the presence of any traffic hazards by clicking the computer mouse on the road user involved. A traffic hazard was defined as "any road user or object within the driving scene that has the potential to become a hazard and would require you as a driver to take evasive action such as slow down, brake, or change course to avoid a crash."

Participants

Participants included 2 separate samples of young adults for experiment 1 and experiment 2 recruited from Queensland University of Technology (QUT) staff and students and their associates. All participants were licensed to drive in Queensland and had normal vision with binocular visual acuity of 6/6 (20/20) or better (Snellen equivalent) with habitual refractive correction, if used, for driving. Slit lamp examination and ophthalmoscopy were conducted to confirm the absence of ocular disease. The best-corrected distance correction was determined by subjective refraction using maximum plus for best visual acuity. The study adhered to the tenets of the Declaration of Helsinki and was approved by the QUT Human Research Ethics Committee. All participants were provided with an explanation of the nature of the study and procedures, and written informed consent was obtained.

Procedures

Visual function and performance on the NHVT were measured binocularly with best-corrected vision and simulated refractive blur (an additional +1.00 DS spherical blur added to the best-correction) in experiment 1, and for best-corrected vision and cataract blur (Hoya diffusing filter added to the best-correction) in experiment 2.

Vision Assessments

Visual acuity and letter contrast sensitivity were measured for each of the 2 visual conditions in experiments 1 and 2, in a laboratory-based session. High contrast distance visual acuity was assessed at 4 m both binocularly and monocularly using an Early Treatment Diabetic Retinopathy Study (EDTRS) logMAR chart, with a chart luminance of 96.6 cd/m^2, and scored on a letter-by-letter basis. Letter contrast sensitivity was determined binocularly using the Pelli-Robson chart at 1 m, scored on a letter-by-letter basis. Visual acuity and letter contrast sensitivity were measured again with either the +1.00 DS lenses added to the participant's distance correction in a trial frame to induce blur in experiment 1 or the cataract blur filter in experiment 2, with a working distance correction (+1.00 DS) added for the Pelli-Robson chart to account for the near working distance. An adaptation period to the vision conditions of 6 minutes was allowed given that the time course of short-term adaptation is approximately 6 minutes, with any improvement leveling off after this period.[28] For the mesopic condition background illumination was 0.38 cd/m^2 with a 6-minute dark adaptation period, and visual acuity and contrast sensitivity were retested under the best-corrected and refractive blur (experiment 1) and cataract blur (experiment 2) conditions.

Night-Time Hazard Visibility Test

Participants completed the NHVT under the two vision conditions: best corrected and either refractive blur (experiment 1) or cataract blur (experiment 2). Videos were presented on a computer monitor with a mean luminance of 3.0 cd/m^2 (range = 0.3–6.2 cd/m^2), screen resolution of 1920 × 1080 pixels, and dimensions of 51 cm × 28.5 cm (38–40 degrees × 24–26 degrees) at a working distance of 60 to 65 cm, with working distance correction (+1.50 DS) added to the best corrected or refractive blur or cataract blur lenses mounted in a trial frame. The videos were split into two sets (sets A and B) that were approximately balanced for the numbers of hazards, to enable administration of a different set of videos for each of the two visual conditions. The vision condition and video sets were randomized, such that half of the participants completed set A with their best correction and set B with blur, whereas the remaining participants completed set A with blur and set B with their best correction.

Analysis

The hazard response time was defined as the time between when the hazard first appeared and the first time that the participant correctly clicked the mouse on a defined area of interest (AOI) within the scene. These AOIs represented areas of the screen for a given time point when there was an active hazard present and were defined using the Tobii Studios software (Tobii Technology, Danderyd, Sweden). This allowed separation of mouse clicks in response to valid hazards from false positives that involved clicking on other objects.

As the time point at which hazards appeared varied across the different videos, the response times for each hazard were converted to z-scores, using the mean and standard deviation (SD) of all responses to each hazard to standardize responses. Participants' z-scores were then averaged across all clips for the two vision conditions.[12,29] The average response time was calculated across all hazards, being the mean (and SD) of the first correct click on a hazard relative to when the hazard first became visible; this was used to convert the z-scores in each condition to a HPT response time to aid in interpretation of the findings, and was conducted separately for each experiment. Paired *t*-tests were used to compare NHVT performance under the two visual conditions included in each of the experiments.

Results

Experiment 1: Effect of Refractive Blur

Participants included 16 adults with normal vision (mean age = 22.3 ± 2.2 years, range = 21−29 years; 10 women and 6 men) and 5.2 ± 2.4 years of driving experience. Mean binocular visual acuity and contrast sensitivity as a function of refractive blur and light level are given in Table 1. Refractive blur had a significant effect on binocular visual acuity ($F_{1,15} = 147.81$, $P < 0.001$), as did light level ($F_{1,15} = 367.99$, $P < 0.001$), where blur and mesopic lighting both reduced visual acuity. There was also a significant interaction effect ($F_{1,15} = 20.94$, $P < 0.001$), where the negative effect of blur was greater for the mesopic (around 4.5 lines reduction) compared to the photopic lighting (around 3 lines reduction). Refractive blur also significantly reduced binocular letter contrast sensitivity ($F_{1,15} = 60.17$, $P < 0.001$), as did light level ($F_{1,15} = 81.26$, $P < 0.001$), but there was no significant interaction effect ($F_{1,15} = 1.70$, $P = 0.212$).

Eight hazards were excluded from the analysis due to a low response rate (less than 50% during the best-corrected condition), leaving a total of 58 analyzed hazards (set A = 15 pedestrians, 7 cars, and 4 cycles/scooters and set B = 17 pedestrians, 7 cars, and 8 cycles/scooters). On average, participants failed to respond to 12.5% of these hazards for the best-corrected condition (pedestrians 12.1%, cars 13.4%, and cycles/scooters 12.5%) and 21.8% for the refractive blur condition (pedestrians 25.8%, cars 18.8%, and cycles/scooters 14.6%).

There was a significant difference in NHVT response times between the two vision conditions ($t_{15} = −7.86$, $P < 0.001$; Fig. 1). Drivers performing the NHVT with refractive blur (mean = 3.10 ± 0.42 seconds) were, on average, 0.69 seconds slower to recognize and respond to night-time traffic hazards than when performing the NHVT with their best correction (mean = 2.41 ± 0.28 seconds).

In an additional subanalysis, NHVT response scores were generated for the three different hazard types to explore whether the negative effect of blur on

Table 1. Mean Visual Acuity and Letter Contrast Sensitivity as a Function of Vision Condition (Best Corrected and +1.00 DS Refractive Blur) and Light Level (Photopic and Mesopic)

	Visual Acuity (logMAR)		Contrast Sensitivity (logCS)	
Vision Condition	Photopic	Mesopic	Photopic	Mesopic
Best corrected	−0.21 ± 0.05	+0.05 ± 0.07	1.90 ± 0.06	1.62 ± 0.15
Refractive blur	+0.09 ± 0.18	+0.49 ± 0.08	1.80 ± 0.12	1.45 ± 0.12

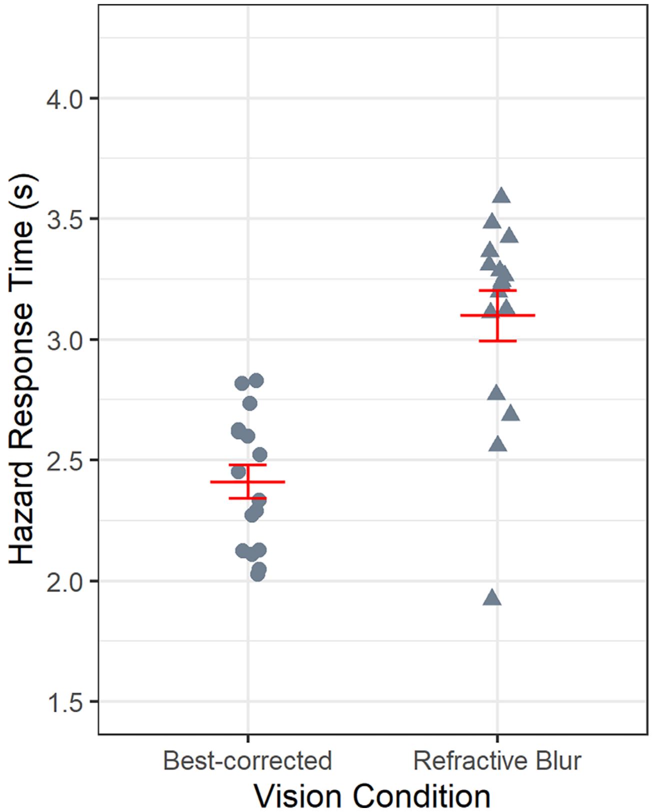

Figure 1. Hazard response times as a function of vision condition (best corrected and +1.00 DS refractive blur), with *red lines* representing means and SE; individual data points are plotted in *grey*.

response times was consistent (Table 2). Refractive blur significantly increased NHVT response times for all hazard types: pedestrians ($t_{15} = -8.10$, $P < 0.001$), cycles/scooters ($t_{15} = -3.84$, $P = 0.0016$), and cars ($t_{15} = -3.28$, $P = 0.005$).

Experiment 2: Effect of Cataract Blur

Participants included an additional group of 16 adults with normal vision (mean age = 21.1 ± 1.2 years, range = 19–21 years, 11 women and 5 men) and 4.0 ± 1.6 years of driving experience. Binocular visual acuity and contrast sensitivity as a function of visual condition and light level are given in Table 3. Simulated cataracts had a significant effect on visual acuity ($F_{1,15} = 323.31$, $P < 0.001$) as did light level ($F_{1,15} = 328.73$, $P < 0.001$) and there was a significant interaction effect ($F_{1,15} = 21.67$, $P < 0.001$) where the effect of simulated cataracts was greater for the mesopic condition (4 lines reduction) compared to photopic (2 lines reduction). Cataract blur also significantly reduced binocular letter contrast sensitivity ($F_{1,15} = 768.84$, $P < 0.001$), as did light level ($F_{1,15} = 140.88$, $P < 0.001$) but there was no significant interaction effect ($F_{1,15} = 0.31$, $P = 0.584$).

Nine hazards were excluded from the analysis due to a low response rate (less than 50% during the best-corrected condition), leaving a total of 62 analyzed hazards (set A = 16 pedestrians, 10 cars, and 5 cycles/scooters and set B = 17 pedestrians, 9 cars, and 5 cycles/scooters). On average, participants failed to respond to 12.3% of these hazards for the best-corrected condition (pedestrians 12.5%, cars 11.8%, and cycles/scooters 12.5%) and 23% for the cataract blur condition (pedestrians 27.5%, cars 17.9%, and cycles/scooters 17.5%).

Table 2. Mean Response Times as a Function of Vision Condition (Best Corrected and +1.00 DS Refractive Blur) and Hazard Type

	Hazard Response Time, s	
Hazard Type	Best Corrected	Refractive Blur
Pedestrians (*n* = 32)	2.34 ± 0.28	3.24 ± 0.52
Cycles/scooters (*n* = 12)	2.21 ± 0.45	2.75 ± 0.52
Cars (*n* = 14)	2.72 ± 0.42	3.16 ± 0.50

Table 3. Mean Visual Acuity and Letter Contrast Sensitivity as a Function of Vision Condition (Best Corrected and Cataract Blur) and Light Level (Photopic and Mesopic)

	Visual Acuity (logMAR)		Contrast Sensitivity (logCS)	
Vision Condition	Photopic	Mesopic	Photopic	Mesopic
Best corrected	−0.17 ± 0.08	+0.02 ± 0.06	1.97 ± 0.11	1.57 ± 0.12
Cataract blur	+0.03 ± 0.10	+0.42 ± 0.10	1.16 ± 0.14	0.79 ± 0.18

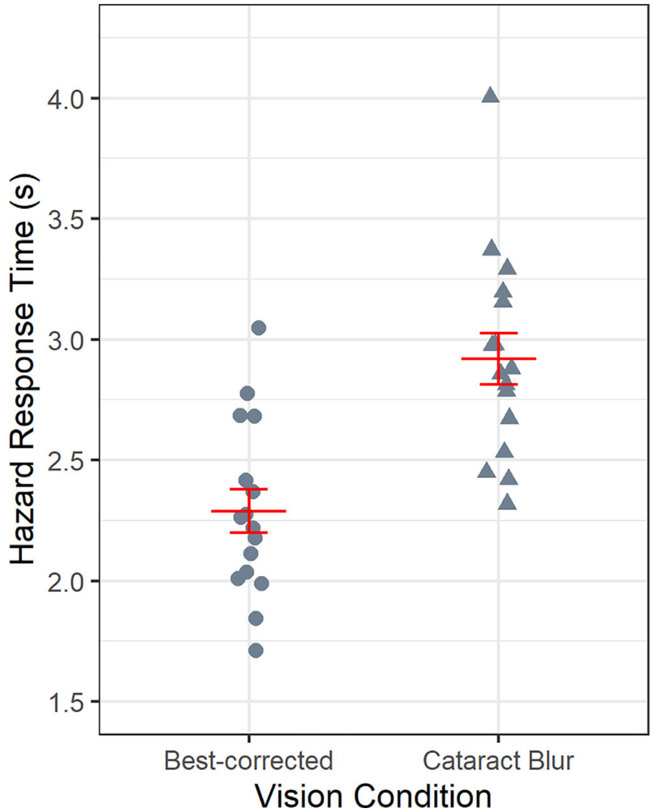

Figure 2. Hazard response times as a function of vision condition (best corrected and cataract blur), with *red lines* representing means and SE of the mean; individual data points are plotted in *grey*.

There was a significant main effect of vision condition on hazard perception response times ($t_{15} = -6.02$, $P < 0.001$; Fig. 2). Drivers performing the NHVT with best corrected vision (mean = 2.29 ± 0.36 seconds) were, on average, 0.63 seconds faster to recognize and respond to night-time traffic hazards than when performing the NHVT with cataract blur (mean = 2.92 ± 0.43 seconds).

In a subanalysis, NHVT response scores were generated for the three different hazard types for the two visual conditions (Table 4). Cataract blur was shown to have a significant negative effect on NHVT response times for all hazard types including pedestrians ($t_{15} = -5.32$, $P < 0.001$), cycles/scooters ($t_{15} = -4.31$, $P < 0.001$), and cars ($t_{15} = -2.96$, $P = 0.009$).

Discussion

A novel computer-based night-time hazard visibility test was developed to assess the ability of participants to recognize and respond to hazards appearing on night-time roads. The validity of the test was explored in two experiments, which assessed the ability of the NHVT to discriminate between performance with best corrected vision and simulated vision impairment using refractive blur (experiment 1) and cataract blur (experiment 2). Collectively, the results from both experiments demonstrated significant delays in hazard response times when viewing with simulated vision impairment compared to viewing with best-corrected vision. Furthermore, response times were delayed for all hazard types in the presence of simulated vision impairment in both experiments, with pedestrians being the most affected.

In experiment 1, low levels of refractive blur resulted in a 0.69-second delay in hazard response times when compared to best corrected vision and validates the ability of the NHVT to assess night-time hazard visibility performance. This level of refractive blur reduced visual acuity by 3 lines to 6/7.5 (20/25) in a young population with normal vision. Note that visual acuity would have been slightly worse when viewing the NHVT, as a 4 m working distance correction was not included in the visual acuity measurement (by +0.25 DS). Nevertheless, visual acuity would still have been better than typical driver licensing requirements (6/12 or 20/40), reflecting those individuals who may be driving with this level of uncorrected refractive error, with one study reporting that uncorrected refractive error was the main reason that drivers did not meet the legal vision standards for driving.[30]

The finding that refractive blur delays hazard response times for the NHVT is in accord with a previous study of young and older drivers that reported

Table 4. Mean Response Times as a Function of Vision Condition (Best Corrected and Cataract Blur) and Hazard Type

Hazard Type	Hazard Response Time, s	
	Best Corrected	Cataract Blur
Pedestrians ($n = 33$)	2.11 ± 0.45	2.71 ± 0.48
Cyclists/scooters ($n = 10$)	2.56 ± 0.80	3.46 ± 0.73
Cars ($n = 19$)	2.54 ± 0.46	3.01 ± 0.50

delayed response times on a daytime HPT test when viewed through +2.00 DS blur relative to best corrected vision, of 0.42 seconds.[29] The magnitude of blur in that study was twice that used in the current study, resulting in a decrease of six to seven lines of visual acuity in the participants, yet the impact of blur in that study resulted in much shorter delays than in the current study, (0.42 seconds vs. 0.69 seconds). The fact that lower levels of blur resulted in a greater delay in hazard response times in the NHVT than in the previous daytime HPT study, reflects the fact that under night-time conditions there are typically fewer anticipatory cues to inform hazard detection. The greater effect of blur on NHVT compared to daytime HPT response times is also likely to reflect the increased pupil size and its negative effect on visual acuity under mesopic levels.

Interestingly, our subanalysis demonstrated that the negative effects of refractive blur were significant for all hazard types, but were greater for pedestrians. This supports findings from closed road studies that even low levels of blur reduce pedestrian recognition distances,[20] as well as the ability to recognize the direction of pedestrian walking.[25] This may be explained by the fact that pedestrians are smaller, lower in contrast, not self-illuminated, and typically located in dimmer regions of the road than other road users, and laboratory-based studies have demonstrated that the effects of blur are greater for low contrast compared to high contrast targets and exacerbated under lower light levels.[31]

In experiment 2, we refined the set of video clips in the NHVT and explored the effect of simulated cataract blur on response times, demonstrating a 0.63 second delay in hazard response times, which further validates the ability of the NHVT to assess night-time hazard visibility performance. Although there has been no previous research on true cataracts and night driving, the effect of simulated cataracts has been explored in both closed road[19,21] and driving simulator studies,[27] which reported impaired night-time recognition of pedestrians, as well as road signs and hazards, for simulated cataracts compared to normal vision.

The finding that simulated cataract blur significantly reduced NHVT response times is also supported by a previous HPT study that reported that older drivers with real eye diseases (including cataract, glaucoma, and age-related macular degeneration [AMD]) had a 0.73 second delay in response times compared to age-matched control drivers.[17] It should be noted, however, that when the response times were compared as a function of the eye disease group in a subanalysis of the data in that study, there was a trend for delayed response times for the participants with cataract compared to controls (0.51 seconds) but the differences failed to reach significance. Importantly, the HPT used in that study included daytime driving scenes.

The magnitude of the delays in NHVT were similar for refractive and cataract blur, despite the use of two different samples of visually normal participants and video sets. For a car travelling at a speed of 60 kilometers per hour (km/h) (approximately 37 miles per hour [mph]) the delay in response times for refractive blur would translate to an increase in stopping distance of 11.5 m, and 10.5 m for cataract blur, which is likely to have important consequences in terms of collisions with other vehicles, pedestrians, or cyclists.

As discussed previously, the NHVT differs to daytime HPTs in having a focus on the visual challenges of night-time roads, including low contrast hazards and glare, but also featuring anticipatory cues. This is likely to have contributed to the strong effect of both refractive and cataract blur on recognition response times to pedestrians in both experiments, given that pedestrians are smaller in size, lower in contrast, lack any self-illumination, and are often positioned in poorly illuminated locations on the road. However, while our findings demonstrate that the ability to recognize pedestrians was most affected by the effects of refractive and cataract blur, which is highly promising, exploring the association between NHVT response times and night-time pedestrian recognition in closed road studies would provide further confirmation of the validity of the NHVT in better understanding the visual challenges of night-time driving. Our finding that the novel NHVT was sensitive to the effects of relatively low levels of refractive blur and cataract blur suggests that the test would be useful for providing an index of drivers' night-time recognition of road hazards.

The aim of this study was to develop a test to assist in better understanding the visibility challenges of night-time roads and the various factors, such as age-related declines, that may affect hazard perception response times at night. Ongoing work is exploring the NHVT in other populations, such as older drivers, who often report visual challenges when driving at night, including oncoming glare and difficulties seeing pedestrians, animals, and road lane markings.[32] Although previous studies demonstrate that daytime hazard response times are similar in older adults aged 65 to 74 years to those aged 35 to 55 years,[12] potentially due to their extensive driving experience which offsets the effects of age-related sensory and neuropsychological declines,[33] this has not been explored for night-time hazard response times. The NHVT also has potential application for older drivers using more

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complex refractive corrections, for instance, multifocal spectacle lenses or intraocular lens (IOLs), which have been associated with night-time driving difficulties.[34,35] In addition, this test may aid in understanding the visual challenges of individuals with eye disease who report most difficulty with night driving compared with age-matched controls, including those with AMD,[36,37] glaucoma,[38–40] and cataracts.[41–43]

An advantage of the approach taken in this study is that the only factor that varied between tests in both experiments was the visual status of the participants, that was manipulated through viewing with refractive blur in experiment 1 and cataract blur in experiment 2. It was also possible to minimize the effects of practice on the tests by randomizing the order in which the blurring lenses were worn and using two different sets of videos for each of the vision conditions.

There are, however, inherent limitations in simulating the effects of either type of blur, in that while the use of simulated vision impairments allowed us to isolate the effects of vision, it is recognized that the effects observed may not exactly reflect those of individuals who have longer term experience of living with blur. There is evidence that individuals can adapt to some extent to the presence of blur and that the time course of short-term adaptation is approximately 6 minutes, with any improvement leveling off after this period.[28] Because the participants in our study were exposed to each of the blur conditions for at least 6 minutes prior to testing, their responses are likely to represent those of a person who is largely adapted to blur, however, we cannot rule out the possibility that adaptation over longer periods of time may further reduce the impact of blur on performance. An additional limitation, as is the case for any simulation of night driving, is the challenge of matching the luminance profile of the NHVT with that of real night-time roads, particularly the effects of glare from oncoming headlights,[44] which has been shown to impair night-time driving, including the ability to recognize road hazards and pedestrians.[21,45–48] Future enhancements to the NHVT could include expansion of the video library to extend the range of hazards, the use of advanced camera technology to improve the resolution and contrast of the night-time driving scenes, and the use of advanced monitor technologies with wider luminance and contrast profiles.

In addition, despite the significant differences in mean response times when performing the test under different visual conditions, additional research is required to further evaluate the performance of the NHVT. It is particularly important to explore the relationship between hazard response times measured with NHVT and real-world measures of night-time driving performance, particularly night-time pedestrian recognition given that pedestrians are highly vulnerable road users at night. Future work should also establish the test-retest reliability of the NHVT, to ensure that performance is repeatable over time.

In conclusion, it is well established that night-time driving is dangerous, particularly for vulnerable road users such as pedestrians and cyclists, however, little is understood about the hazard perception ability of drivers at night. To address this, we successfully developed and validated a novel NHVT which focused on the visual challenges of night-time driving, and which significantly discriminated between performance with best-corrected conditions versus performance with refractive or cataract blur in a sample of young healthy observers. While this strategy of assessing off-road performance using video-based testing may not capture the full complexity of night-time roads, it can provide a range of night driving scenarios in a safe and controlled environment. The NHVT thus has the potential to provide an index of night-time hazard perception and could serve as a useful tool in research investigating the visual difficulties experienced by different road users at night.

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