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Title Page

Title: The effect of presbyopic vision corrections on night-time driving performance

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ABSTRACT

Purpose

To investigate the effect of various presbyopic vision corrections on night-time driving performance on a closed road driving circuit.

Methods

Participants included 11 presbyopes (mean age: 57.3±5.8 years), with a mean best sphere distance refractive error of R+0.23±1.53 DS; L+0.20±1.50 DS, whose only experience of wearing presbyopic vision corrections was reading spectacles. The study involved a repeated measures design, where participant's night-time driving performance was assessed on a closed road circuit when wearing each of four power-matched vision corrections. These included single vision distance lenses (SV), progressive addition spectacle lenses (PAL), monovision contact lenses (MV) and multifocal contact lenses (MTF CL) worn in a randomized order. Measures included low contrast road hazard detection and avoidance, road sign and near target recognition, lane-keeping, driving time and legibility distance for street signs. Eye movement data (fixation duration and number of fixations) were also recorded.

Results

Street sign legibility distances were shorter when wearing MV and MTF CL than SV

and PAL ($p<0.001$) and participants drove more slowly with MTF CL than with PALs ($p=0.048$). Wearing SV resulted in more errors ($p<0.001$), more ($p=0.002$) and longer

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($p<0.001$) fixations when responding to near targets. Fixation duration was also longer when viewing distant signs with MTF CL than PAL ($p=0.031$).

Conclusions

Presbyopic vision corrections worn by naïve, unadapted wearers affected night-time driving. Overall, spectacle corrections (PAL and SV) performed well for distance driving tasks, but SV negatively affected viewing near dashboard targets. MTF CL resulted in the shortest legibility distance for street signs and longer fixation times.

The population of many countries is aging and this is reflected in growing numbers of older drivers who exhibit a range of declines in sensory, cognitive and motor skills performance. While the effects of the age-related declines in visual functions such as visual acuity, contrast sensitivity and visual field sensitivity, on driving performance have been investigated,[1, 2] the effects of presbyopia and presbyopic vision corrections on driving performance have received relatively limited attention. This is of importance because while the optical correction of presbyopia can take many forms, all of the current options have some unwanted visual limitations, many of which may impact on driving performance.

Surveys of presbyopes have shown that many forms of presbyopic corrections are associated with problems for driving under low illumination levels.[3,4] Adapted wearers of both monovision (MV) and multifocal contact lenses (MTF CL) report more problems under low light levels, with complaints of increased disturbance from haloes, glare and decreased clarity of the road ahead.[3,5-7] Monovision is also known to cause some loss of stereoacuity,[5,7-9] but its impact on practical task performance is thought to be limited.[10] The use of progressive spectacle lenses (PAL) is also known to create peripheral spatial distortion in the inferior field,[11,12] but little is known about their effect on driving performance, particularly under night-time conditions.

It has been reported that degraded visibility during night-time driving increases the risk of a crash by reducing the driver's ability to avoid a collision due to late recognition of other road users.[13-15] Given that presbyopic corrections can also degrade aspects of visual performance, the aim of this study was to investigate the effect of different presbyopic vision corrections on various measures of driving performance at night-time.

METHODS

Eleven older adults (mean age of 57.25 ± 5.78 years; range 45-64 years; 5 female, 6 male) were recruited for the study, whose only experience of wearing presbyopic vision corrections was reading spectacles. All participants were licensed drivers and their distance visual acuity (VA) with their habitual correction was better than 20/20. They all were free of ocular pathology as assessed by slit-lamp and ophthalmoscopic examination, had normal visual fields and were in good general health.

The study was conducted in accordance with the requirements of the Queensland University of Technology Human Research Ethics Committee and followed the tenets of the Declaration of Helsinki.

The study involved a repeated measures design using four vision corrections, single vision distance lenses (SV), PAL, MV and MTF CL. Subjective refraction was performed to ensure that their vision was best corrected for distance and near, and the spherical equivalent prescription was applied for all contact lens vision corrections for the distance power and near addition. The mean best sphere refraction of the participants was R+0.23±1.53 (range -3.50 DS to +2.00 DS); L+0.20±1.50 DS (range -3.50 DS to +2.00 DS), mean astigmatism was R–0.41±0.30 DC and L–0.43±0.34 DC with a maximum of 0.75 DC, the mean near addition power was +1.95±0.33 D and six of the participants habitually wore a distance refractive correction as well as reading spectacles.

The PALs selected for the study was a commonly worn multicoated design, which has an intermediate corridor width of 3.5 mm (for a typical +2.00D near addition).[12] For MV, a disposable soft contact lens was used. The sighting dominant eye was fitted for distance vision and the non-dominant eye with the near prescription, as has been previously recommended.[16,17] The MTF CL selected was a simultaneous vision design. It was a commonly prescribed multifocal contact lens, with aspheric center-near design, where the maximum plus power is in the centre of the lens (near correction), progressing to more minus (distance correction) in the periphery of the optical zone. Two addition powers are available for this MTF contact lens, low additions (for near addition powers up to +1.50 D) and high additions (for near addition powers +1.75 D to +2.25 D) and the appropriate addition power was chosen for each participant (two participants wore the low addition and nine participants wore the high addition power). Trial disposable contact lenses were worn for approximately 15 minutes at the initial visit to ensure that participants were able to tolerate CL wear and this amount of settling time was also allowed prior to commencing the driving-related assessments.

Visual acuity was measured under the conditions of the driving track using a high contrast Bailey-Lovie vision chart. The low headlight beam from the research vehicle illuminated the chart (measured illumination of the chart on white background area was 39 cd/m^2, TOPCON BM-7, Japan).

Night-time driving performance was measured on a closed-road circuit which has been used for a number of driving-related studies.[18,19] The experiment was only undertaken on nights when it was not raining and the road surface was dry. A 4 km circuit of the driving circuit was used which comprises a bitumen road with 2 and 3 lanes including hills, bends, straight stretches and standard road signs, and is representative of driving on rural roads. To simulate oncoming headlamp beams, a stationary vehicle with its headlamps on high beam was positioned in the opposite lane (two locations) on a stretch of straight road and facing the on-coming vehicle (Figure 1).

The experimental vehicle had automatic transmission, and low-beam headlamps settings were used during all testing conditions. A roof mounted global positioning system sampled the speed and position of the vehicle and two roof mounted cameras recorded the position of the vehicle front right and left fenders for measurement of lane position (VigilVanguard™ driver training system, Brisbane, Australia).

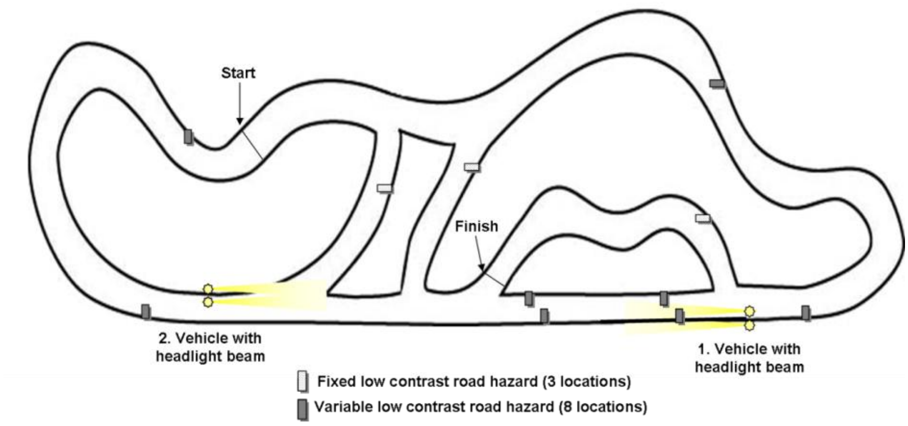

Figure 1. Schematic diagram of the closed-road circuit.

Eye movements were recorded while driving using the ASL Mobile Eye (Applied Science Technologies, Bedford, MA) which consists of an eye and scene camera (30 Hz) mounted over the spectacle frames to compute gaze within a scene by tracking the pupil and corneal reflections in one eye.[20] A calibration procedure was conducted for each participant while they were seated in the driver's seat prior to commencing data collection for each vision correction. The fixation duration and number of fixations made during viewing of distance and near targets were recorded and analysed using commercially available software (Gaze Tracker) which defined fixation as a static eye position lasting more than 0.1 sec.

Two experimenters were seated in the research vehicle (one in the passenger seat and the other in the back seat) to record driving performance and to activate visual stimuli (near targets). Each participant was required to wear the eye tracker with their habitual vision correction. One practice run of the course was completed along a different route to that of the experimental run, in order to familiarize the participant with vehicle handling, vehicle size, in-vehicle devices and the driving task (none of the participants had any experience in driving the circuit prior to participation in this study). Following this, participants drove around the circuit once with each vision correction. To control for the effects of learning, the order of wear of each vision correction type was randomized between participants.

Performance measures consisted of:

Road Sign Recognition: A total of 40 road signs were located along the route and contained a total of 67 pieces of information; participants were asked to report each sign they observed.

These signs included warning signs, regulatory signs and street signs. The number of road signs correctly identified was recorded.

Road Hazard Recognition and Avoidance: Eight, large low contrast foam road hazards (~95 cm x 170 cm and 5 cm thickness; reflectance, ~10%) were positioned in the path of the car on the road circuit at different positions for any given run. The position of the road hazards was changed between runs in a pre-determined order to minimise familiarity effects (there were a total of 11 potential positions (Figure 1) – those represented in white remained the same between laps, while those represented in grey were varied in position between laps). Participants were asked to report whenever they saw a road hazard and avoid it (steer around it) if it was safe to do so. The number of road hazards hit was recorded.

Lane Keeping: Lane keeping was recorded via the two roof-mounted cameras. The videotapes were analysed by calculating the time spent out of the lane for the left and right line markings separately, as a percentage of the total driving time.

Near Target Recognition: A simulated radio and speedometer (two digital numeric display panels) were mounted in the research vehicle at the typical location of the radio and speedometer. Random numbers were presented three times at each location for 2 sec (six times for each lap), with the experimenter saying either “radio” or “speedometer” to prompt the participant to view the relevant near target. The number of targets correctly recognized was recorded.

Distance to Recognize Standard Street Signs: In order to determine road sign visibility distance as well as the number of road signs recognized correctly, the distance to recognise a street name sign was measured separately at the end of each driving run. Participants were asked to drive slowly (approximately less than 5 km/h) toward the sign until they could first clearly read it, then to stop and the distance from the vehicle to the sign was measured using a digital ruler (BOSCH DLE 50). Four different street name signs (100 mm heights of black letters on white backgrounds letter) were used for this task and were changed between each driving run, so that each vision condition was tested using a different sign. The signs were positioned at a height of 1 m so that they were evenly illuminated by the low headlamp beam.

Fixation Duration and Number of Fixations: The number and duration of fixations when viewing the road signs along the closed-road circuit and near targets (a simulated radio and speedometer) were recorded using the ASL Mobile Eye. For road signs, four easily visible road signs (2 text signs with 100 mm height and 2 speed limit signs with 200 mm height) which were correctly identified by all participants were selected for analysis.

The driving performance outcome measures were analysed using repeated measures ANOVAs with correction type (SV, PAL, MV and MTF CL) as the within-subjects variable. There were some missing eye movement data when participants viewed the near targets due to loss of tracking by the system, usually from poor visibility of the pupil when it was covered by the lids, therefore data from only eight of 11 participants could be used for this analysis.

RESULTS

The group mean data for driving performance is presented in Table 1 and the eye movement data in Table 2.

Table 1. Mean (SD) of driving performance measures (N=11).

Driving performance measures	Vision Corrections				ANOVA	Significant Differences (p < 0.05)
	SV	PAL	MV	MTF CL		
Number of road signs recognized (n)	48.64 (5.55)	48.09 (3.45)	48.36 (3.61)	46.82 (4.02)	F(3, 30)=0.854 p=.476	NS
Number of road hazards hit (n)	0.64 (0.92)	0.91 (1.14)	1.27 (1.01)	1.73 (1.56)	F(1.74, 17.37)=3.25 p=.069	NS
Lane crossing time (%)	10.74 (1.93)	10.06 (1.73)	9.81 (2.77)	10.25 (3.08)	F(1.86, 18.59)=1.23 p=.312	NS
Near target recognition (%)	60.60 (26.11)	93.94 (11.24)	87.88 (15.08)	92.42 (11.46)	F(3, 30)=9.732 p<.001	SV<PAL, MV, MTF CL
Time to complete the circuit (sec)	424.45 (65.41)	426.18 (50.01)	447.64 (47.23)	449.82 (63.90)	F(3, 30)=2.955, p=.048	MTF CL<PAL
Distance to recognize standard street sign (m)	60.62 (10.13)	59.50 (8.94)	48.48 (13.76)	38.45 (16.58)	F(1.88, 18.83)=21.19 p<.001	MV, MTF CL<SV, PAL MTF CL<MV
Distance VA (logMAR)	-0.05 (0.06)	-0.05(0.04)	0.05 (0.08)	0.12 (0.09)	F(3, 30)=24.88 p<.001	MV, MTF CL<SV, PAL MTF CL<MV

Note: NS=Not Significant

Table 2. Mean (SD) of eye movement parameters (N=8).

Eye movement parameters	Vision Corrections				ANOVA	Significant Differences ($p < 0.05$)
	SV	PAL	MV	MTF CL		
Fixation duration when observing near targets (sec)	0.89 (0.28)	0.52 (0.16)	0.57 (0.17)	0.51 (0.17)	$F(3, 21)=10.795$ $p<.001$	PAL, MV, MTF CL<SV
Number of fixations when observing near targets (n)	2.65 (0.79)	1.77 (0.58)	1.97 (0.42)	1.72 (0.35)	$F(3, 21)=6.964$ $p=.002$	PAL, MV, MTF CL<SV
Fixation duration when viewing distance targets (sec)	1.33 (0.39)	1.04 (0.32)	1.18 (0.41)	1.44 (0.49)	$F(3, 30)=3.370$ $p=.031$	PAL<MTF CL
Number of fixations when viewing distance targets (n)	2.64 (0.86)	2.93 (0.42)	2.73 (0.49)	3.21 (1.09)	$F(1.53,15.34)=1.86$ $p=.193$	NS

Vision correction had a significant effect on the total driving time to complete the course (F(3, 30)=2.955, p=0.048), where participants drove more slowly when wearing MTF CL (mean=7 min and 29 sec) than when wearing PAL (mean=7 min and 6 sec). Multifocal CL also resulted in a greater number of road hazards hit, followed by MV then PAL and SV. The effect of correction type on the number of road hazards hit also approached significance showing higher numbers of hazards hit when wearing MTF CL (F(1.74, 17.37)=3.25, p=0.069).

While there was no significant effect of vision correction on the number of road signs correctly recognised where the percentage of correctly recognized ranged between 61% to 64% for the different vision corrections, the duration of fixations when the signs were correctly recognized varied between conditions (F(3, 30)=3.370, p=0.031). Interestingly, there was a significant interaction between the type of distance sign (speed sign and text sign) and vision correction (p=0.017), so the analysis was repeated for the different sign types separately. This indicated that differences in fixation duration were only evident when viewing the text signs, where MV and MTF CL resulted in significantly longer fixation durations when the participant correctly recognized the sign than did PAL (F(3, 30)=5.465, p=0.004). Multifocal CL also resulted in significantly longer fixation durations than did MV (p=0.02) (Figure 2). There were no significant differences in total fixation duration among vision conditions when viewing speed signs ($F(3, 30)=1.511$, $p=0.232$). The total number of fixations did not vary among vision corrections ($F(1.53, 15.34)=1.86$, $p=0.193$), nor was there any interaction between vision correction type and the type of distance sign ($p=0.089$).

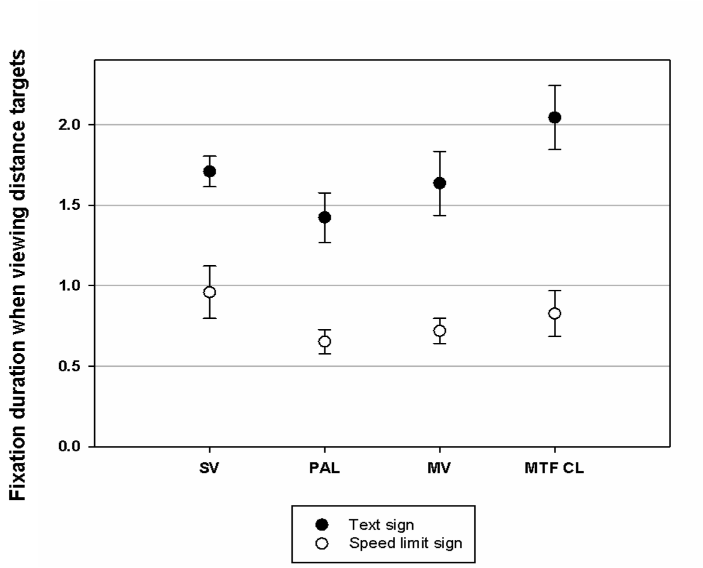

Figure 2. Mean (SE) of the total fixation duration when viewing distance targets

The distance at which a standard street sign was recognized was significantly affected by vision correction type ($F(1.88, 18.83)=21.19$, $p<0.001$), where the street sign could be recognised at significantly longer distances when wearing SV, PAL and MV than

MTF CL ($p \leq 0.03$), and the recognition distance was shorter when wearing MV than with SV and PAL ($p=0.002$) (Figure 3).

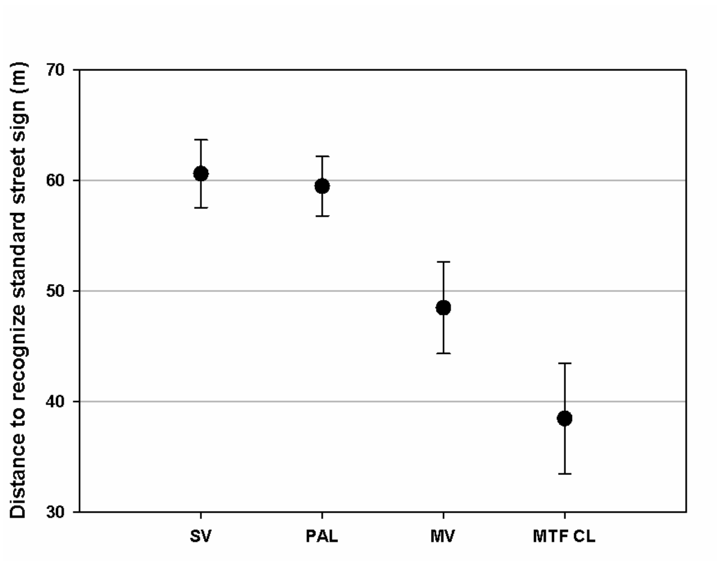

Figure 3. Mean (SE) of distance to recognize standard street signs.

Vision correction type significantly affected recognition of the near targets ($F(3, 30)=9.732$, $p<0.001$), but there was no interaction between vision correction and type of near target. Pairwise comparisons revealed that near target recognition was poorer with SV (distance correction) than with all other vision corrections ($p \leq 0.013$), however, there was no significant difference among the PAL, MV and MTF CL. Vision correction type significantly affected total fixation duration and the number of fixations when viewing the near targets (radio and speedometer) (($F(3, 21)=10.795$, $p<0.001$) and ($F(3, 21)=6.964$, $p=0.002$) respectively). Single vision resulted in significantly more fixations ($p\leq0.032$) and longer fixation durations ($p\leq0.007$) than all other vision correction types, however, there was no significant difference among the other corrections and no interaction between vision correction type and the type of near target (i.e., radio or speedometer location) (Figure 4).

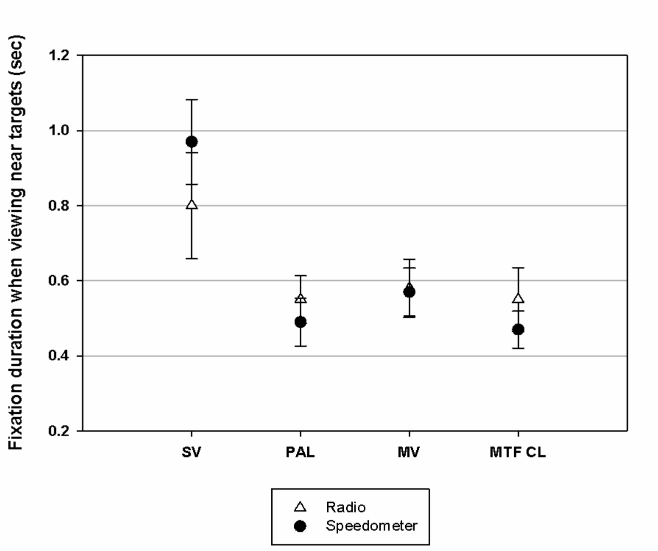

Figure 4. Mean (SE) of the total fixation duration when observing near targets.

DISCUSSION

The findings demonstrate that night-time driving performance on a closed-road circuit is significantly affected by wearing different types of presbyopic vision correction. Overall, MTF CL negatively affected more of the driving performance measures, and spectacle corrections (SV and PAL) performed better overall than the contact lens (MV and MTF CL) corrections. Single vision distance lens wearers showed significant loss of performance for recognition of near targets, such as the radio and speedometer.

Wearing MTF CL resulted in significantly slower driving speeds than PAL wear, presumably as a result of poorer overall vision leading to more cautious driving. It would thus be expected that slower driving when wearing MTF CL would have reduced the number of low contrast road hazards hit. However, MTF CL wear still increased the likelihood of hitting a low contrast object on the road, with the difference between MTF CL and SV wear approaching statistical significance. Studies by Higgins et al.[21] and Higgins and Wood[22] also indicated that drivers with poorer vision tend to slow their driving speeds to compensate for their degraded vision, however, this slower driving speed was not always sufficient to avoid errors in sign recognition and road hazard avoidance.

The mean distance to read a street sign was approximately 60 m with SV and PAL, and 48 m with MV and 38 m with MTF CL. This reduction in recognition distance may have important safety implications, as having a longer distance to recognize a sign allows a driver more preparation time to make navigational decisions and to undertake a manoeuver. It has been calculated that when driving at a speed of 40 km/h on a dry road, a stopping distance of 38 m (including perception and response time) is required,[23] and that this stopping distance is longer under dim lighting conditions due to increases in reaction time.[24] However, even though the measure of distance to identify the street name sign was affected by the type of vision correction, the number of road signs correctly identified along the closed-road circuit was not. Drivers with degraded vision were able to see the road signs, but at much shorter distances (for example with MTF CL). This hypothesis is supported by the finding that wearing MTF CL resulted in longer fixation durations than PAL when reading traffic signs, and this difference was greater with the smaller letter signs (100 mm letter height) than with larger signs (200 mm letter height).

Maintaining lane position is important for avoiding collisions with other road users and peripheral vision is used to keep the vehicle within the lane boundaries and for detecting peripheral hazards.[25] Despite PAL wear being associated with blur in the periphery[12] and peripheral vision being considered to be related to the task of lane keeping,[19] this did not affect steering within the lane lines when wearing this correction type. It may be that the peripheral blur from PAL in the lower half of the lens is not important for steering tasks, such as fixation of the tangents of curved roads.[26] Alternatively, lane keeping may not have been affected by correction type because it is robust to visual blur as noted previously by Wood et al.[19] and Owens and Tyrell.[27]

Not surprisingly, when wearing PAL, MV and MTF CL, participants were better able to perform the near target recognition task (simulated a radio and speedometer) (85% correct), than when wearing the SV distance correction (60% correct). This result is consistent with previous laboratory driving simulator findings.[28] In addition, the eye movement data indicated that SV wear resulted in significantly longer fixation duration and higher numbers of fixations than all of the other vision corrections when viewing near targets.

With the increasing number of in-vehicle devices available, including navigation and entertainment systems, drivers' interactions with these devices will become more frequent, which is of concern given that they are associated with increased physical and visual distraction.[29] If allocation of visual attention on these in-vehicle devices increases, it will result in longer periods of time looking away from the road which may have a detrimental impact on driving safety.[30] Importantly, drivers wearing the distance SV correction exhibited longer fixations to interpret the visual information from near devices in this study, while wearing PAL, MV and MTF CL demonstrated shorter times to acquire the necessary information. Therefore, correcting near vision for driving is another way to reduce the visual demand from in-vehicle devices.

It should be noted that the visual function and driving performance measures obtained in this study reflect those obtained when the contact lens prescribing criterion are based strictly on the spectacle equivalent prescription for distance and near addition. This was intentional so that comparison of correction types could be made using equivalent powers. Using this method, the difference in VA between spectacles and MV was 0.1 logMAR and 0.17 logMAR worse for MTF CL when measured at the driving track. There are alternative ways of prescribing presbyopic contact lenses which may result in better distance vision results. For example, reducing the near addition power in the MTF CL in one or both eyes, using a single vision lens in one eye and a MTF CL in the fellow eye (modified MV), or reducing the near lens power in MV.[9] Therefore, modification of powers in the prescribing of presbyopic contact lenses to optimize vision may result in different outcomes.

The findings should also be considered in the context of some study limitations. The sample size was relatively small, so that while there were a number of statistically significant differences in driving performance between the different presbyopic vision corrections, some of these failed to reach significance. In addition, the participants in this study were not adapted contact lens wearers and had no experience of wearing spectacle or contact lens presbyopic vision corrections except for reading spectacles. The results must therefore be considered representative of the impact of unadapted presbyopic correction wear on aspects of driving performance and may not necessarily reflect that of drivers who have adapted to their presbyopic correction, as the subjective impressions of visual performance can change following a period of MV wear, even though objective measures failed to show significant improvements over the same period.[31] Therefore, in future studies it would be interesting to examine the driving performance of a larger sample of participants which also included wearers of presbyopic corrections who were fully adapted to the correction.

In summary, this study demonstrates that wearing different presbyopic vision corrections affected real world measures of driving performance at night. Overall, the spectacle corrections performed better than did the contact lens corrections. Single vision distance lens wearers performed well for all distance driving tasks but were disadvantaged for recognition of near targets, such as the radio and speedometer. Since this study was conducted using naïve, unadapted wearers, who had no experience of wearing spectacle or contact lens presbyopic vision corrections except for reading spectacles, further research is required to investigate whether these effects persist in longer-term adapted wearers. In conclusion, this study highlights that it is important to optimize vision correction when prescribing for presbyopia to ensure the highest level of road safety.

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Legend for Table and Figures

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Table 2. Mean (SD) of eye movement parameters (N=8)

Figure 1. Schematic diagram of the closed-road circuit.

Figure 2. Mean (SE) of the total fixation duration when viewing distance targets

Figure 3. Mean (SE) of distance to recognize standard street signs.

Figure 4. Mean (SE) of the total fixation duration when observing near targets.