Title: **Effect of Uncorrected Astigmatism on Vision**

Running Head: **Effect of Uncorrected Astigmatism**

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Abstract

PURPOSE: To examine the effect of uncorrected astigmatism in older adults.

SETTING: University Vision Clinic

METHOD: Twenty-one healthy presbyopes, aged 58.9±2.8 years, had astigmatism of 0.0 to -4.0 x 90°DC and -3.0DC of cylinder at 90°, 180° and 45° induced with spectacle lenses, with the mean spherical equivalent compensated to plano, in random order. Visual acuity was assessed binocularly using a computerised test chart at 95%, 50% and 10% contrast. Near acuity and reading speed were measured using standardised reading texts. Light scatter was quantified with the cQuant and driving reaction times with a computer simulator. Finally visual clarity of a mobile phone and computer screen was subjectively rated.

RESULTS: Distance visual acuity decreased with increasing uncorrected astigmatic power (F=174.50, $p<0.001$) and was reduced at lower contrasts (F=170.77, $p<0.001$). Near visual acuity and reading speed also decreased with increasing uncorrected astigmatism power ($p<0.001$). Light scatter was not significantly affected by uncorrected astigmatism ($p>0.05$), but the reliability and variability of measurements decreased with increasing uncorrected astigmatic power ($p<0.05$). Driving simulator performance was also unaffected by uncorrected astigmatism ($p>0.05$), but subjective rating of clarity decreased with increasing uncorrected astigmatic power ($p<0.001$). Uncorrected astigmatism at 45° or 180° orientation resulted in a worse distance and near visual acuity, and subjective rated clarity than 90° orientation ($p<0.05$).

CONCLUSION: Uncorrected astigmatism, even as low as 1.0DC, causes a significant burden on a patient's vision. If left uncorrected, this could impact significantly on their independence, quality of life and wellbeing.

Corneal astigmatism, in which the window of the eye is oval in shape, cannot be fully corrected by a spherical lens. It is a common condition, occurring in about 85% of the general population, with 20-30% of the older population (>60 years, when cataracts are most common) having significant severity (>1 dioptre).[1,2] While it is standard practice to correct astigmatism when prescribing glasses and about one third of prescribed contact lenses correct astigmatism,[3] many public health services considers intraocular lenses that correct astigmatism as specialist. Therefore older astigmatic patients with cataract must pay for both the lens and the cost of private surgery if they wish to have optimum vision. Suboptimal vision is associated with reduced quality of life and an increase in falls in the elderly,[4,5] but the impact of uncorrected astigmatism has not previously been assessed.

Since the advent of intraocular lens correction following cataract surgery in the 1950’s, surgical techniques and intraocular lenses have developed rapidly to keep pace with the increasing demand created by expanding life expectancy and a corresponding more active lifestyle in patients experiencing cataracts. Therefore this study examines the challenges of uncorrected astigmatism in everyday life in people of the age when cataracts typically form to determine the need for toric intraocular lenses to be implanted as the routine standard of care.

Method

Twenty-one presbyopes, aged 50-69 years old (average ± standard deviation 58.9 ± 2.8 years, ten female) with no ocular pathology, not on medication likely to influence the stability of refractive error, having less than 0.75D of manifest astigmatism and who had an acuity better than 0.0 logMAR in both eyes were recruited. The study conformed to the declaration of Helsinki, was approved by the institutional ethics committee and subjects gave their informed consent to take part.

Each of the subjects was made familiar with the assessments of visual function. Visual acuity and contrast sensitivity assessed binocularly using a Thomson computerised logMAR progression Test Chart (Thomson Software Solutions, Hatfield, UK). Subjects were asked to read the smallest visible letters and were encouraged to guess when uncertain. Each letter was scored as 0.02logMAR and the acuity measured with 95%, 50% and 10% contrast letters, randomised between measures. Near acuity and reading speed at 0.2 logMAR larger than this acuity was assessed at a 40cm working distance with a +2.50D near addition using standardised reading performance texts of 830 ± 2 characters length.[6] The chart was presented on an LCD computer screen and the words were changed between each repetition. Light scatter in the right eye was assessed using the cQuant (Oculus Optikgerate GmbH, Wetzlar, Germany), recording the average of three repeated measured. Driving was simulated using a split attention task displayed on a 14” computer monitor. Subjects responded to the car in front travelling at a matched 60mph breaking (and increasing in visual angle) or a pedestrian initially seen at 3.6° eccentricity on the off or far side beginning to cross the path of the subject when they reached 6.5° eccentricity. Reaction times were averaged for 3 repeats of each condition over a 1.5 minute simulated drive. Finally mobile phone screen and internet computer screen clarity positioned at the subject's standard working distance for that task were each subjectively rated as a percentage.

Having practiced each of the tasks until they felt comfortable and had a consistent performance, subjects repeated the tasks seven times wearing a trial frame with spectacle lenses fitted to correct their refractive error together with a cylindrical addition of different powers and axes in randomised order compensated with a sphere so the mean spherical equivalent was always zero. The effect of power was simulated with +0.00/-0.00x90, +0.50/-1.00x90, +1.00/-2.00x90, +1.50/-3.00x90 and +2.00/-4.00x90. This simulated the typical situation of patients with an astigmatic corneal refractive error being implanted with a spherical intraocular lens of a power to compensate the average refractive error for distance, i.e. based on the average corneal curvature. To compensate for the effects of the trial lens surfaces, the minimal astigmatism comparison was simulated with the same number of trial lenses as the other conditions. The effects of uncorrected astigmatism power was assessed with the negative cylinder orientated vertically (90°) as this is the commonest cylindrical axis up to approximately 60 years of age.[2] The effect of the axis of astigmatism was simulated with +1.50/-3.00x90, +1.50-3.00x180 and +1.50/-3.00x45. A three dioptre cylinder was chosen as the power at which to assess the effect of the cylinder axis as this encompasses 95% of astigmatic errors in this population.[2] Subjects had approximately 5 minutes to adapt to each set of lenses before testing, although it appears the brain does not adapt to binocular astigmatism.[7]

Statistical analysis

Descriptive statistics of mean and standard deviation were plotted for each assessment. Visual acuity, contract sensitivity, reading speed, light scatter and reaction time data were compared using repeated measure analysis of variance with paired t-tests for post hoc testing. The linearity of changes was assessed with Pearson’s correlations. Subjective ratings of clarity were compared using Fisher non-parametric related sample comparisons with Wilcoxon signed rank tests for post hoc testing.

Results

Distance visual acuity decreased significantly with increasing uncorrected astigmatic power (F = 174.50, p < 0.001) and was reduced at lower contrasts as expected (F = 170.77, p < 0.001), with no interaction between these effects (F = 1.47, p = 0.26). Each dioptre of uncorrected astigmatism caused a significantly lower acuity than the previous power at each contrast level (p < 0.01; Figure 1). Distance visual acuity was significantly affected by uncorrected astigmatic axis (F = 5.19, p = 0.02) and was reduced at lower contrasts as expected (F = 129.75, p < 0.001), with no interaction between these effects (F = 0.36, p = 0.83). Uncorrected astigmatism at 90° orientation resulted in a significantly better acuity than with the axis at 45° or 180° at each contrast level (p < 0.05; Figure 1).

Near visual acuity decreased significantly with increasing uncorrected astigmatism power (F = 221.62, p < 0.001). Each dioptre of uncorrected astigmatism caused a significantly lower acuity than the previous level (p < 0.001; Figure 2). Near visual acuity was significantly affected by uncorrected astigmatic axis (F = 26.00, p < 0.001). Uncorrected astigmatism at 90° orientation resulted in a significantly better acuity than with the axis at 45° or 180° at each contrast level (p < 0.001; Figure 2). Reading speed decreased significantly with increasing uncorrected astigmatism power (F = 11.97, p < 0.001), but only with -3.0DC or greater (p<0.001; Figure 3). Reading speed was significantly affected by uncorrected astigmatic axis (F = 4.45, p = 0.026). Uncorrected astigmatism at 180° orientation resulted in a significantly worse reading speed than with the axis at 45° (p = 0.03; Figure 3).

Although there was no significant increase in light scatter with increasing uncorrected astigmatism power (F = 1.11, p = 0.559) or changes in axis (F = 0.13, p = 0.878; Figure 4), the reliability and variability of measurements decreased with increasing uncorrected astigmatic power (F = 2.93, p = 0.026; F = 2.44, p = 0.05). Responding to a car in front breaking (F = 0.813, p = 0.521) or a nearside (F = 1.266, p = 0.290) or offside (F = 0.200, p = 0.102) pedestrian was not significantly affected by uncorrected astigmatic power (Figure 5). Responding to a car in front breaking (F = 0.111, p = 0.895) or a nearside (F = 1.148, p = 0.327) or offside (F = 1.441, p = 0.249) pedestrian was unaffected by uncorrected astigmatic axis (Figure 5).

Subjective rating of clarity decreased significantly with increasing uncorrected astigmatic power when viewing a mobile phone (Chi Squared = 81.29, p < 0.001) or a computer screen (Chi-Squared = 79.91, p < 0.001). Each dioptre of uncorrected astigmatism caused a significantly lower rating of clarity (p < 0.01; Figure 6). Subjective clarity was significantly affected by uncorrected astigmatic axis when viewing a mobile phone (Chi-Squared F = 19.01, p < 0.001) or a computer screen (Chi-Squared = 21.53, p < 0.001). Uncorrected astigmatism at 90° orientation resulted in a significantly better rating than with the axis at 180°, and the 180° orientation was rated significantly better than the 45° orientation for both mobile phone and computer viewing (p < 0.01; Figure 6).

Discussion

This study assessed whether leaving patients with uncorrected astigmatism after cataract surgery and implantation of an intraocular lens has a significant impact on their visual function and visual performance. Visual acuity at high and low contrast sensitivity is critical to performing tasks as diverse as reading road signs and navigating. After cataract surgery, few patients report difficulties with vision for driving in daylight (5%), but almost half (43%) find night driving difficult due to glare associated with low contrast visual acuity.[8] The driving standard is usually around 0.3logMAR with high contrast letters, which patients with more than -2.0D of uncorrected astigmatism could not achieve. Visual acuity was further reduced by an axis of astigmatism off the vertical axis and with low contrast. Uncorrected astigmatism caused an average loss of visual acuity of 1.5 lines per dioptre (+0.15 ± 0.03 logMAR/DC, r = -0.76) at high contrast and a similar effect at 50% and 10% contrast (+0.14 ± 0.03 logMAR/DC, r = -0.91; +0.14 ± 0.05 logMAR/DC, r = -0.80 respectively) which is approximately half the effect of spherical blur as expected from the average blur circle at the retina.[9] Therefore even a relatively low amount of uncorrected astigmatism will significantly reduce visual acuity, which will further reduce ability to perform low contrast tasks. For example worse contract sensitivity has been shown to be associated with self restricted night driving in older adults,[10] with about 20% of those in their 70's and 55% of those in their 80's not driving at night.[11]

Reading tasks are considered the most critical to quality of life by older individuals.[12] Although less systematic than distance visual acuity (r = -0.42), reading acuity decreased a similar amount with uncorrected astigmatism power (+0.13 ± 0.07 logMAR/DC). Newspaper print (approximately 0.4 logMAR at 40cm) was only just resolvable with 2.0DC of uncorrected cylinder and made worse by the steepest axis not being in the vertical, as occurs with increasing age.[2] Allowing for an acuity reserve of 6 – 18 times the threshold letter size to achieve highly fluent reading speed,[13] even 1.0DC of uncorrected astigmatism will affect simple everyday reading tasks. Despite reading speed being assessed with words 0.2logMAR larger than the threshold reading acuity with each lens combination, the speed was significantly reduced with higher levels of uncorrected astigmatism which will make reading tasks more difficult to perform, less pleasurable, and often leading to a reduction in independence and quality of life.[14]

Difficulties with night driving and glare are reported by both elderly drivers with visual impairment and those with healthy eyes.[15] Trouble with driving at night is a commonly reported symptom in the elderly, occurring in 28.2% of drivers over the age of 50 years in the Australian Blue Mountains population study.[16] Although there was no significant increase in light scatter with increasing uncorrected astigmatism power or changes in axis, this was principally due to the systematic reduction in quality of the measurements. It would therefore appear that uncorrected astigmatism negatively affects glare even though this accepted test of light scatter was unable to quantify the effect. Interestingly, while visual acuity declines with decreasing luminance and / or blur, steering performance does not unless the visual field is restricted.[17,18] Therefore the driving simulator findings were not unexpected. However, performance with unexpected events and poorer driving conditions such as rain and on-coming traffic headlights may still be compromised by uncorrected astigmatism.

Patients’ rating of clarity was significantly reduced by increasing uncorrected astigmatic power. The patients were allowed to use their standard viewing conditions (kept constant between comparisons) and were masked as to the level of uncorrected astigmatism, so this was a real effect. Therefore as well as the effect on visual function, patients are aware of their reduced vision, so uncorrected astigmatism is likely to negatively impact on their quality of life. Although patients could choose to improve their vision by the use of spectacles or contact lenses, they are unlikely to do this if left with just astigmatic refractive error with improvements in biometry[19] or implantation of intraocular lenses that correct presbyopia.[20,21]

In conclusion, uncorrected astigmatism significantly compromises a patient's vision. This is likely in the long-term to lead to restricted independence, reduced quality of life and falls.[4,5] With modern intraocular lenses implanted after cataract surgery, astigmatism can easily be corrected[22] and the additional cost of these 'premium' lenses is likely to be far less than the consequences of leaving them with uncorrected astigmatism. Hence correction of corneal astigmatism during cataract surgery and intraocular lens implantation should be the standard of care.

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Table 1: Trial lens combinations used to simulate uncorrected astigmatism

FIGURE LEGENDS

Figure 1: Distance visual acuity with uncorrected astigmatism power and axis. N=21. Error bars = 1 S.D.

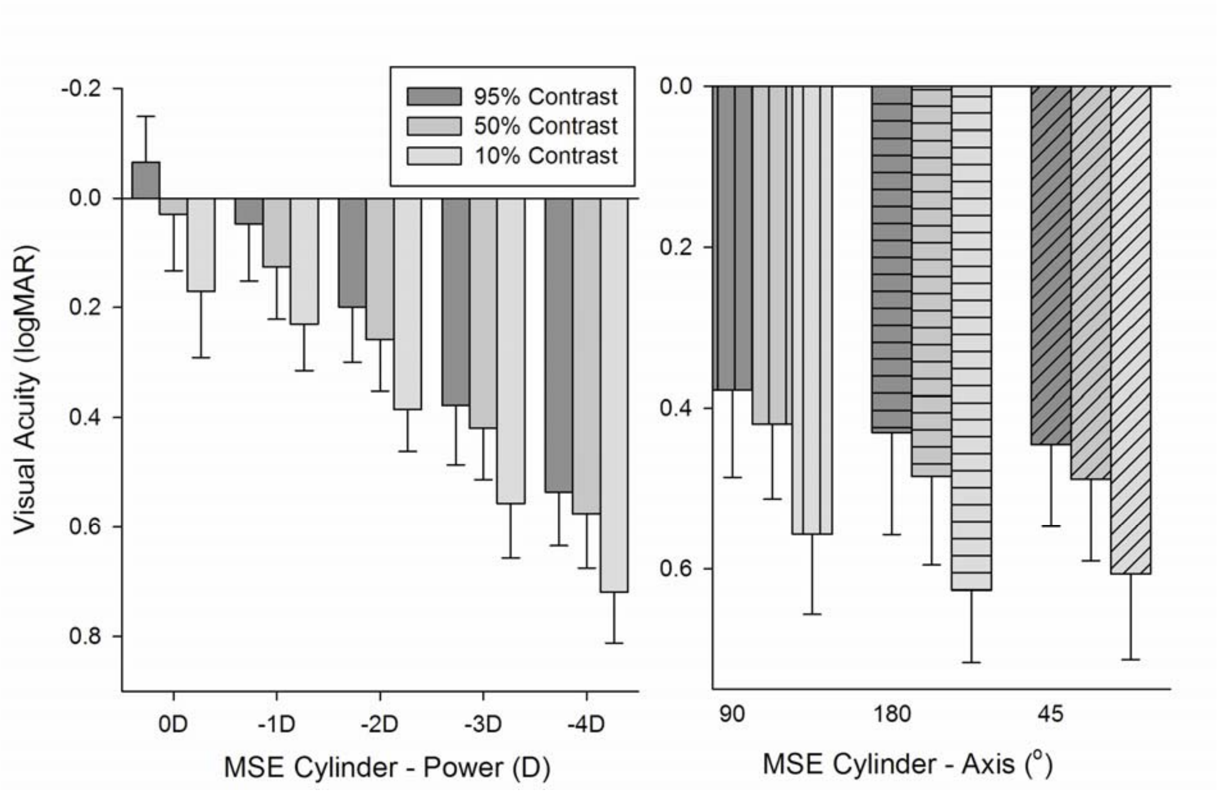


Figure 2: Near visual acuity with uncorrected astigmatism power and axis. N=21. Error bars = 1 S.D.

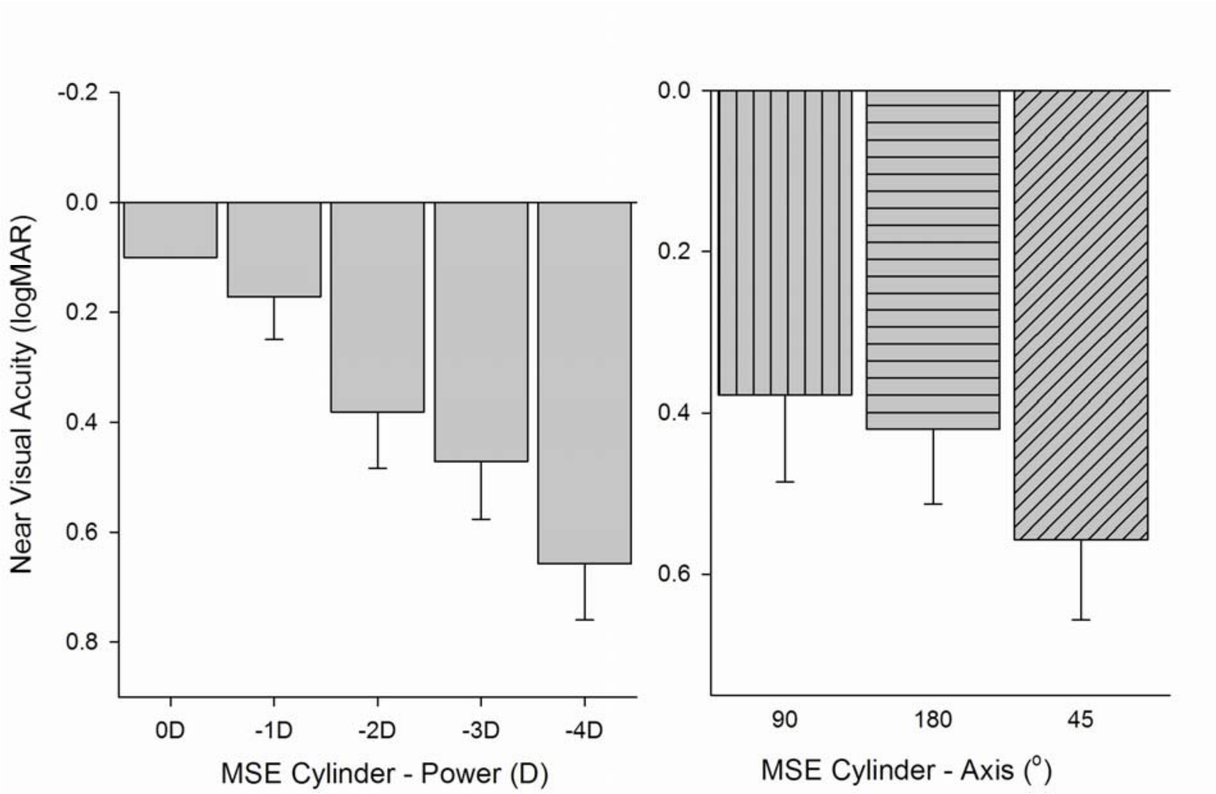


Figure 3: Reading speed with uncorrected astigmatism power and axis. N=21. Error bars = 1 S.D.

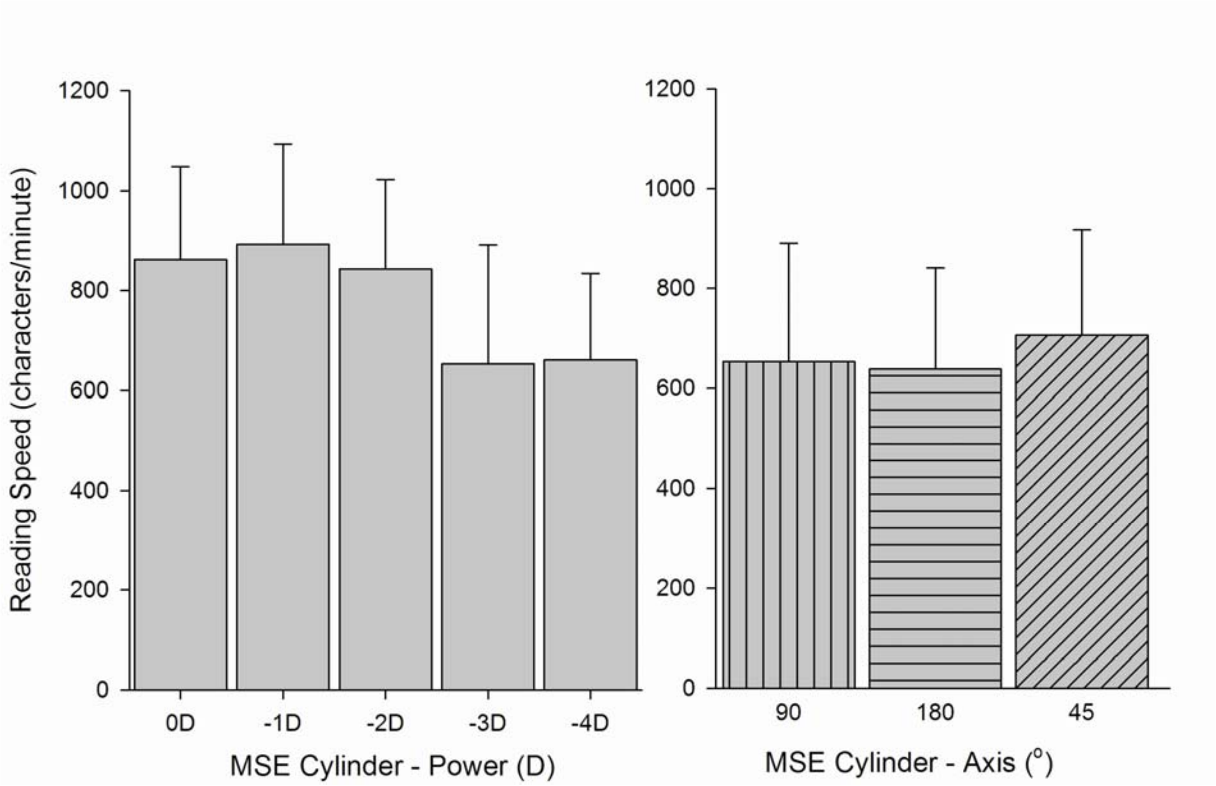


Figure 4: Light scatter with uncorrected astigmatism power and axis. N=21. Error bars = 1 S.D.

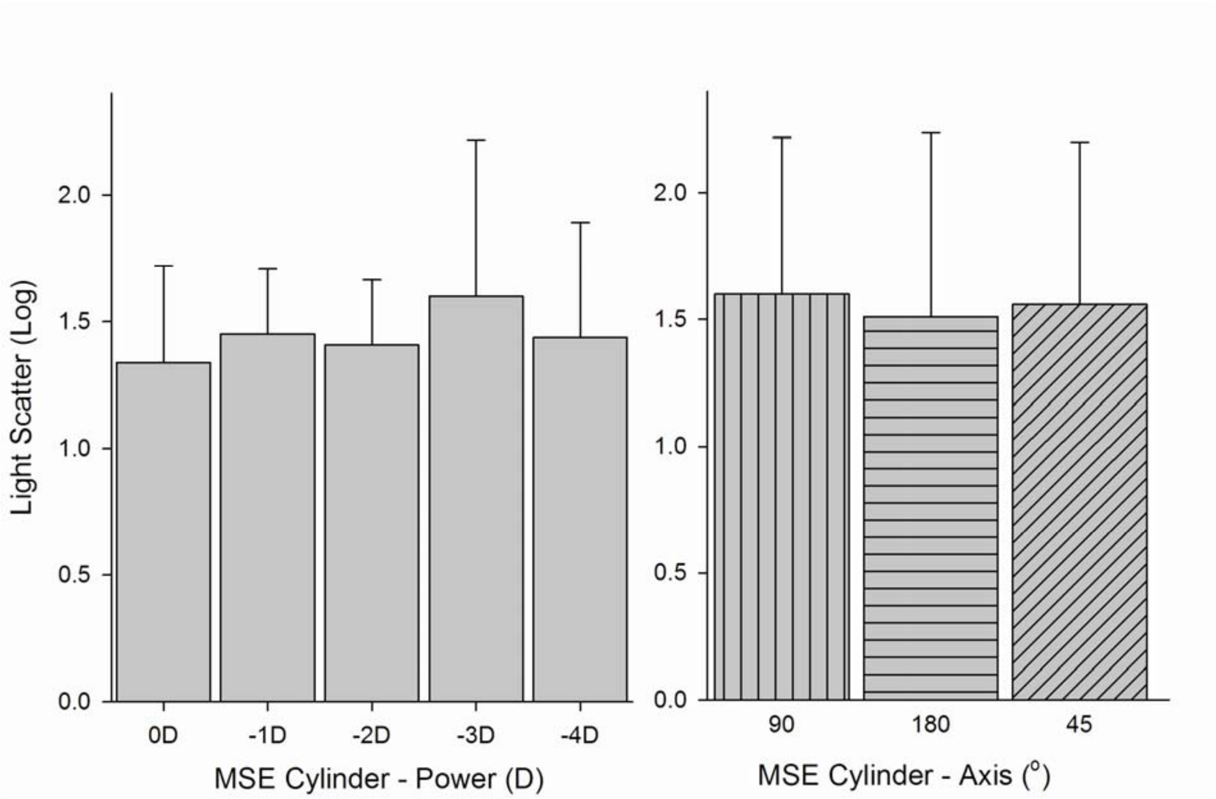


Figure 5: Driving task performance with uncorrected astigmatism power and axis. N=21.

Error bars = 1 S.D.

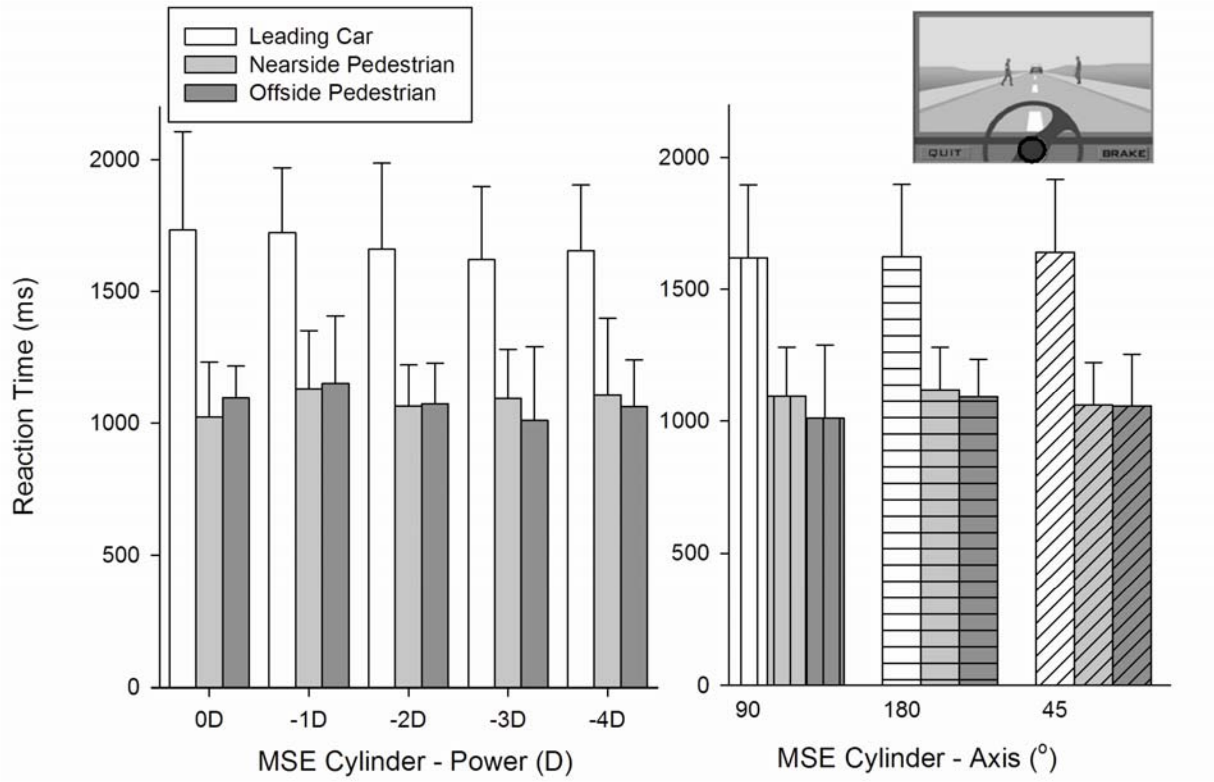
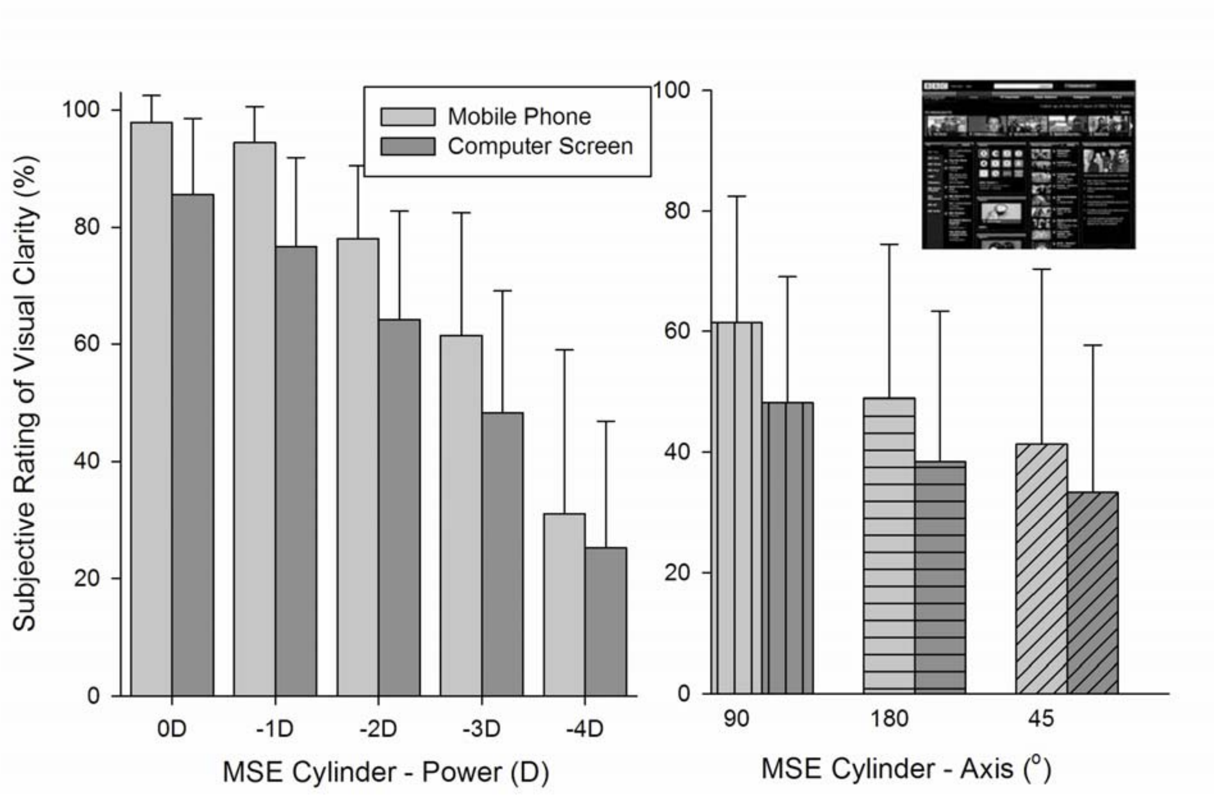


Figure 6: Subjective rating of clarity with uncorrected astigmatism power and axis. N=21. Error bars = 1 S.D.


Subjective Rating of Visual Clarity (%)
0
20
40
60
80
100
Mobile Phone
Computer Screen
0D
-1D
-2D
-3D
-4D
MSE Cylinder - Power (D)
0
20
40
60
80
100
90
180
45
MSE Cylinder - Axis (°)