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Effect of blur and subsequent adaptation on visual acuity using letter and Landolt C charts: differences between emmetropes and myopes

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Abstract

Purpose: To compare the effects of defocus induced blur and blur adaptation on visual acuity and to evaluate any differences between emmetropes and myopes using letter and Landolt C logMAR charts.
Methods: The sample consisted of 26 volunteers, with a mean age of 27 ± 3 years, comprising 13 emmetropes (spherical equivalent range: −0.63 to +0.50 D) and 13 myopes (spherical equivalent range: −0.75 to −5.00 D). Monocular visual acuity (VA) was measured in each eye using letter and Landolt C logMAR charts under the following conditions: (1) with the distance refractive correction, (2) immediately after exposure to +2.00 D defocus and (3) following 60 min of binocular adaptation to +2.00 D blur. Objective refraction at the beginning and at the end of the experimental procedure was evaluated. Averaged VA data between the two eyes were used for analysis.
Results: Deterioration in VA with +2.00 D defocus was greater in the emmetropes compared to myopes for both charts. The mean difference between the two refractive groups was more pronounced for the Landolt-C (0.17 logMAR) compared to the letter chart (0.10 logMAR). The reduction in VA with blur was related to the amount of the refractive error. Following 60 min of adaptation, a significant improvement in VA was observed in both groups that did not differ between the two charts. The improvement in VA following adaptation using the letter chart was linearly correlated with spherical equivalent refractive correction.
Conclusions: Myopes show higher tolerance to retinal defocus compared to emmetropes, which could be attributed to previous blur experience. The effect of blur on VA is more pronounced using Landolt C optotypes than with letters. Prolonged exposure to blur results in equally improved performance for both refractive groups.

Introduction

A general characteristic of all sensory systems is that they continuously adapt to the most recent sensory experience. This helps highly dynamic processes to efficiently encode stimuli, whose physical parameters vary in time.[1] Adaptation processes in the visual system reflect sensitivity and contrast adjustments at multiple stages of visual coding,[2] in the retina and the visual cortex (see Webster 2011[3] for review). Perceptually, prolonged viewing of a high-contrast pattern induces a substantial loss in the apparent contrast of a test stimulus (see Graham 1989[4] for review). On the contrary, visual performance may improve with time after viewing a blurred, close-to-threshold target, a phenomenon also known as *blur adaptation*.

Several features of visual perception, such as target detection, resolution and localisation[5–8] are hampered in the presence of blur. Its effect on spatial visual performance is variable, depending on the spatial characteristics of the target under observation (i.e. spatial frequency content, form, luminance and colour) and the methodology/task employed. Visual acuity is more seriously affected by defocus when using letters than gratings,[9] while the loss in contrast sensitivity with defocus is spatial frequency dependent, being greater for higher than for low spatial frequencies.[10,11] Adaptation to blur describes any change in the spatial visual performance of an observer after exposure to induced or uncorrected defocus, which is not accompanied by a change in the refractive error or any other optical factors (e.g. pupil size, accommodation accuracy).[12–14] These blur 'after-effects' have been shown to selectively adjust to the patterns of blur arising from the low- and higher-order aberrations of the eye[3,15,16] which compromise retinal image quality by reducing image contrast and resolution.

Perception of blur is influenced by a number of parameters, with blur experience/refractive error being the most investigated ones. Blur experience is expected to differentiate emmetropes from myopes, the latter often having undergone sustained periods of time without spectacle correction. Many studies have shown that myopes demonstrate higher experience-based blur compensation,[13,14,17–19] probably as a result of habitual adaptation to their uncorrected level of blur, when they do not wear their spectacles. Pesudovs and Brennan[18] recorded an improvement of 0.04 logMAR in high-contrast letter acuity in low myopes (with a refractive error < 2.00 D) following 90 min cessation of their spectacle wear. George and Rosenfield [14] demonstrated a significant improvement of 0.27 logMAR and 0.13 logMAR for myopes and emmetropes respectively, in Landolt C acuity, when measured through +2.50 D spherical lenses for a continuous period of 2 h. No significant difference was observed between the change in VA and the degree of defocus. Similarly, Rosenfield *et al.*[13] showed an improvement of 0.23 logMAR in letter acuity at the end of a 3-h period, during which subjects with moderate degree of myopia remained uncorrected. Interestingly, letter VA was found to be significantly different from the baseline only when the duration of adaptation period was longer than 90 min. Cufflin *et al.*[20] found no differences between emmetropes and myopes in the improvement of letter acuity following 30-min exposure to either +1.00 D defocus (0.16 vs 0.17 logMAR), or +3.00 D defocus (0.20 vs 0.25 logMAR). There is also evidence that adaptation of blur is independent of retinal eccentricity.[21]

Other factors, such as binocular vs monocular vision,[22] stereoacuity,[23] low- (astigmatism) and higher-order ocular aberrations[15,16,24] and personality characteristics[25] may also influence long-term perceptual adjustments. Blur tolerance also varies with age.[26,27] For example, Jung and Kline[27] postulated that older observers' ability to identify blurred text involves not only experience-mediated neural compensation but also age-related optical changes (e.g. pupil size).

Moreover, since visual acuity is usually evaluated with a variety of optotypes (i.e. letters, numbers, Landolt C, tumbling E), any blur effects may be influenced by the spatial characteristics of the type of optotypes tested.[28] It is now accepted that 'detecting a gap in a Landolt-C' introduces visual processes (resolution acuity) that do not implement the compensatory cognitive processes involved in letter interpretation (recognition acuity). In the current study the effect of defocus and subsequent blur adaptation were evaluated using logMAR charts containing letters or Landolt C optotypes. The study also tested for differences between emmetropes and myopes. In previous studies, simulation of myopic defocus was achieved with positive trial lenses[9,19] inserted over the habitual (contact lens) correction or by measuring uncorrected vision of myopes without their corrective spectacles.[18] It is expected that small amounts of residual refractive error and/or any uncorrected astigmatism[15,16,24] could have affected the results. The use of contact lenses could also influence stability in vision and comfort during the procedure. To overcome such disadvantages in the current study, blur was induced using custom-made spectacles for each participant, including any cylindrical refractive error and dispensed using personalised inter-pupillary distance and fitting heights of the frame. Participants wore the same spectacles in the blur adaptation period to ensure stability and comfort in vision during the procedure.

Methods

Participants

Thirty healthy volunteers, staff and students at the University of Crete, were recruited for the study. They were informed about the procedure and the general purpose of the study. Exclusion criteria included hyperopia > 0.75 D, astigmatism ≥ 1.25 D, anisometropia ≥ 1.50 D, best spectacle-corrected distance visual acuity worse than 0.00 logMAR (Snellen 6/6, 20/20) and any previous ocular surgery or ocular disease. Four volunteers were found with hyperopia or anisometropia, and were thus excluded. The final sample consisted of 52 eyes of the 26 adults. The study conformed to the tenets of the Declaration of Helsinki and followed a research protocol approved by the Institutional Review Board of the University of Crete.

The mean age of the participants was 27 ± 3 years. The mean spherical equivalent for the dominant eye was −1.40 D, ranging from −5.50 to +0.50 D. The volunteers were separated into two groups according to their refractive status (emmetropes vs myopes) based on their spherical equivalent (mean of the two principal meridians). Emmetropia was defined using a criterion of spherical equivalent refractive error in both eyes between +0.75 and −0.50 D. Myopia was defined using a criterion of spherical equivalent refractive error ≤ -0.75 D at least in one eye. The emmetropic group consisted of 13 subjects (five women and eight men), with a mean spherical equivalent of −0.05 D (range: −0.63 to +0.50 D) and a mean age of 27 ± 2 years. The myopic group consisted of 13 observers (eight women and five men), with a mean spherical equivalent of −2.70 D (range: −0.75 to −5.00 D) and a mean age of 26 ± 4 years.

Visual acuity recordings

Monocular VA was assessed for each eye using two logMAR charts (www.precision-vision.com) containing (1) letters (the University of Crete charts[29]) and (2) the Landolt C symbol presented in four orientations. Two versions of each chart (chart 1 and chart 2) were used for recording the VA for the right and the left eye, respectively. VA measurements were counterbalanced between subjects, i.e. VA was recorded first with letter charts in half of the subjects, while Landolt C acuity was measured first in the other half of the subjects. A back-illuminated slim stand (www.sussexvision.co.uk/) held the acuity charts at 4.0 m distance. Chart luminance was approximately 160 cd m^{-2}, in compliance with the recommendations for standardising the measurement of VA.[30]

All subjects were asked to identify each letter (or locate the gap in Landolt C) one by one in each line starting from the upper left-hand letter, and to proceed by row until they could no longer name correctly at least one letter in a line. They were instructed to read slowly every letter in any line of the chart and guess the letters when they were unsure. The termination rule was four mistakes on a line.[31] The experimenter scored correct responses on specially designed data forms. VA was derived from the calculation of missed letters up to the last readable line.

Experimental procedure

The experimental procedure included three sessions of monocular VA recordings, made in the following order: (1) with their spectacle sphero-cylindrical correction, (2) immediately after exposure to binocular +2.00 D defocus induced blur and (3) following one hour of sustained exposure to binocular +2.00 D defocus blur. No compensation was made for spectacle magnification and effectivity, since their effects were relatively small (<0.01 logMAR or <½ letter).

Sphero-cylindrical refraction was determined for each eye subjectively using trial frames. Refractive error was also measured with a HRK-7000 Auto Ref-Keratometer (http://huvitz.en.ec21.com) at the beginning and at the end of the experimental procedure. All myopic participants were asked to avoid wearing contact lenses for a period of at least 3 days before the experiment. Eye dominance was determined by looking through a central hole in an A4 card, held by the participant in both hands away from the body.

Subjects were exposed to +2.00 defocus by wearing blurring spectacles in front of both eyes for a continuous period of 60 min, while a film of their interest was displayed on a screen from a distance of approximately 6 m in a spacious room. Customized frames were dispensed for each individual, with the +2.00 sphere being incorporated in their sphero-cylindrical prescription, keeping the same amount (if any) of astigmatic correction. The frames were purposely chosen for each individual to provide satisfactory fitting. Inter-pupillary distance and heights were fitted according to each individual measure. This procedure ensured the same amount of spherical blur for all participants, whilst additionally providing comfort and stability in vision during the experimental procedure.

Statistical analysis

Statistical analysis was performed for the mean visual acuity of the two eyes, since differences between the dominant and the non-dominant eye were not significant (see below). There were no missing values. Average differences between two VA charts (Letters vs Landolt C) were assessed using two-tailed, paired *t*-tests. To compare characteristics between myopes and emmetropes two-tailed, independent samples *t*-tests were applied. A 5% significance level was chosen. Ninety-five per cent confidence intervals were also calculated. Pearson's correlation coefficient *r* was used to assess the correlations between pairs of quantitative variables and the Intraclass Correlation Coefficient (ICC) to assess possible correlations between recordings for the spherical equivalent of refractive error and the VA. The statistical package SPSS version 20.0 was used for data analysis (www.ibm.com/software/analytics/spss/).

Results

No differences were found when comparing the mean VA (for letter and Landolt C charts) between the dominant and the non-dominant eye at all conditions: when individuals were fully corrected ($p = 0.49$), at the +2.00 D blur condition ($p = 0.41$) and at the blur adaptation condition ($p = 0.81$).

When fully corrected, myopes showed a mean (±S.D.) logMAR acuity of −0.08 ± 0.08 logMAR and −0.10 ± 0.05 logMAR for the Landolt C and letter chart, respectively. For emmetropes, mean (±S.D.) logMAR acuity was −0.14 ± 0.07 and −0.15 ± 0.07 logMAR for the Landolt

C and letter chart, respectively. No statistically significant differences between emmetropes and myopes were found for the letter ($p = 0.07$) or the Landolt C chart ($p = 0.15$). Moreover, no statistically significant differences were found between the charts (letter and Landolt C) in emmetropes (mean difference −0.11, $p = 0.23$, 95% CI from −0.03 to 0.01) or myopes (mean difference −0.17, $p = 0.18$, 95% CI from −0.04 to 0.01). *Table 1* presents mean VA values using each and for the two refractive groups under each of the three tested conditions.

Figure 1 shows the changes in mean visual acuity in the presence of blur for the two charts used (letter vs Landolt C logMAR acuity) and for the two refractive groups. Mean letter acuity was reduced by 0.83 ± 0.12 logMAR in emmetropes compared to 0.66 ± 0.18 logMAR in myopes. An independent sample *t*-test identified a significant difference (0.17 logMAR, 8.5 letters) between the groups (95% CI from 0.05 to 0.29, $p = 0.024$). The effect of defocus on letter acuity for each individual (emmetropes vs myopes) is shown in *Figure 2*. Landolt C acuity was decreased by 0.87 ± 0.13 logMAR in emmetropes compared to 0.77 ± 0.17 logMAR in myopes: the mean difference between the groups was 0.10 (S.E. 0.01) logMAR (independent sample *t*-test; 95% CI from −0.02 to 0.22, $p = 0.10$).

Table 1. Mean (S.E.) visual acuity, measured in logMAR, for the two refractive groups (Emmetropes vs Myopes) at each condition tested

Charts	Emmetropes	Myopes	95% Confidence interval for the difference
	In-focus		
Letter	−0.15 (0.02)	−0.10 (0.02)	−0.10 to −0.003
Landolt C	−0.14 (0.02)	−0.08 (0.02)	−0.23 to 0.003
	Following +2.00 D defocus		
Letter	0.67 (0.03)	0.56 (0.04)	0.003 to 0.23
Landolt C	0.73 (0.03)	0.69 (0.04)	−0.05 to 0.14
	After 60 min of adaptation		
Letter	0.58 (0.04)	0.49 (0.04)	−0.02 to 0.20
Landolt C	0.64 (0.04)	0.56 (0.04)	−0.04 to 0.20

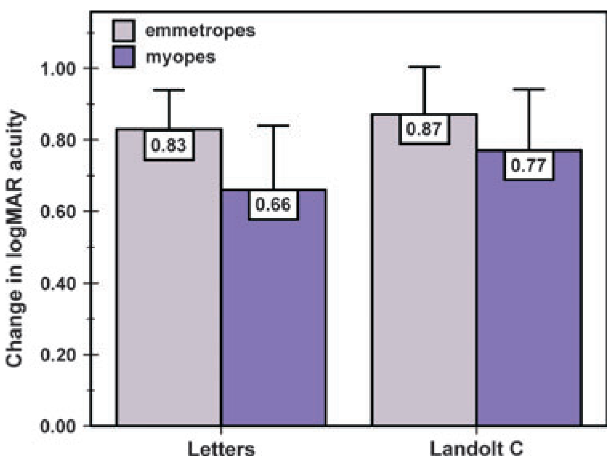

Figure 1. Mean changes in monocular visual acuity (logMAR) following +2.00 D defocus for the two acuity charts (Letter and Landolt C) and the two refractive groups (emmetropes vs myopes). Error bars represent ±1 S.D.

In emmetropes, following defocus, acuity was found to be higher using the letters compared with Landolt C chart, with the difference being 0.06, S.E. 0.03, logMAR (paired samples *t*-test, 95% CI from 0.00 to 0.11, $p = 0.051$). The difference between letters and Landolt C optotypes was more pronounced in myopes (0.13, S.E. 0.02 logMAR), which reached a statistically significant level (95% CI from 0.08 to 0.18, $p < 0.001$).

The improvement in visual acuity following a 60-min period of blur adaptation was also tested. The effect was statistically significant for both refractive groups and charts tested. The change in VA after exposure to blur was found to be statistically significant for both charts: 0.09 (S.E. 0.02) logMAR for letters (paired samples *t*-test, 95% CI from 0.05 to 0.12, $p < 0.001$) and 0.11 (S.E. 0.01) logMAR for the Landolt C chart (paired samples *t*-test, 95% CI from 0.08 to 0.14, $p < 0.001$). No difference was found between the two charts ($p = 0.81$).

Similar improvement in VA following blur adaptation was found in emmetropes (0.10 ± 0.08 logMAR) and myopes (0.07 ± 0.08 logMAR) when using the letter charts ($p = 0.37$). In contrast, similar ($p = 0.24$) improvements in VA with the Landolt C was found in myopes (0.13 ± 0.08 logMAR) compared to emmetropes (0.09 ± 0.07 logMAR).

Correlation between visual acuity improvement and refractive error

In order to test whether the effect of defocus and the subsequent adaptation was influenced by the amount of refractive error present, visual acuity changes were plotted as a function of the spherical equivalent for each participant. *Figure 3a* (left) shows a linear relationship between the change in logMAR acuity following defocus and the refractive error, with the effect of defocus (acuity loss) being higher for lower refractive errors. The slope of regression lines for both charts differs significantly from the 'zero' line (letters: $R^2 = 0.37$, $y = 0.83 + 0.61x$, $p = 0.001$; Landolt C: $R^2 = 0.27$, $y = 0.89 + 0.52x$, $p = 0.006$). *Figure 3b* plots the changes in VA following adaptation: a statistical significant association of refractive error with Landolt C ($R^2 = 0.19$, $y = 0.08–0.43x$, $p = 0.027$), but not with letter ($R^2 = 0.002$, $p = 0.85$) acuity was found.

Objective recordings of refractive error before and after adaptation presented a statistical but not clinically

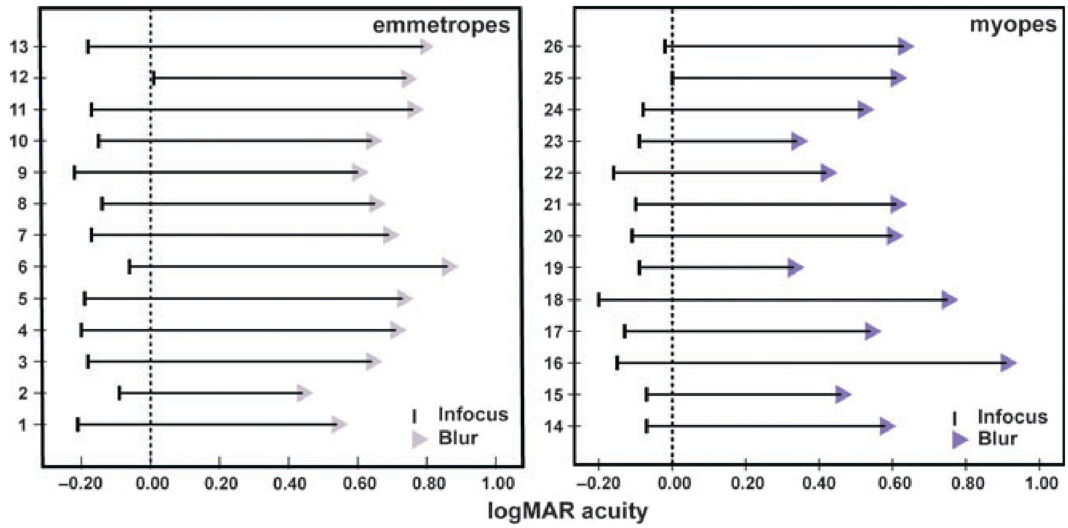

Figure 2. Visual acuity (logMAR) recordings for emmetropes and myopes with letters. Each arrow corresponds to an individual. The arrow vertical lines correspond to the fully corrected VA and the arrow triangle to the VA with a defocus of +2.00 D.

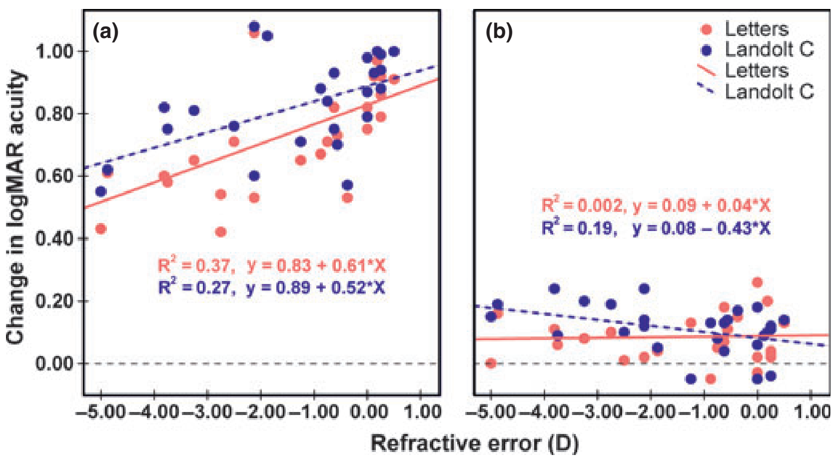

Figure 3. (a,b) Plots of the change in visual acuity (logMAR) following +2.00 D defocus (left – acuity loss) and after 1 h of adaptation (right – acuity improvement) as a function of the refractive error (spherical equivalent) for all participants (N = 26). Visual acuity was assessed with Landolt C optotypes (blue circles dashed lines) and letters (red circles; solid lines). The lines correspond to linear regressions.

significant difference in the spherical equivalent of -0.10 ± 0.21 D (95% CI from -0.19 to -0.17, $p = 0.021$). Moreover, a high correlation was found (ICC = 0.99, $p < 0.001$) in spherical equivalent between recordings at the beginning (-1.39 ± 1.67 D) and at the end (-1.29 ± 1.73 D) of the experimental procedure.

Discussion

The results of the present study indicate that subjects with myopia are less affected by blur than emmetropes and that the changes between the two refractive groups are more pronounced when visual acuity is measured with letters than Landolt C charts. Moreover, the reduction in VA upon the insertion of positive lenses was found to be related to the magnitude of the refractive error: the higher the myopia the less prominent the effect of defocus. The notable differences between the two refractive groups are in accordance with previous studies[32,33] and imply that myopic eyes show higher tolerance to retinal defocus, experiencing increased levels of blur compensation. Although optical factors, such as pupil size[34] and inherent ocular aberrations (e.g. astigmatism, coma and spherical aberration),[35,36] may influence the effect of blur on acuity, there is no evidence of such differences between myopes and emmetropes.[37]

Our findings indicate that, for the amount of blur considered here (2.00 DS), acuity is compromised most with Landolt C optotypes compared to letters in both emmetropes and myopes, with the difference between the two charts being minimal when optimally corrected. This is in agreement with studies comparing letter to Landolt C acuity, which show that the difference in VA between the charts correlates with the visual acuity of subjects, with the poorer VA (i.e. higher logMAR values) resulting in greater discrepancies between the charts.[38,39] Similar differences have been found in patients with impaired vision[38,40,41] and amblyopia.[42,43] Testing VA with Landolt C charts introduces a different task, since it requires detection of a gap (in Landolt C), rather than discrimination of a letter, which implements different visual processes, such as visual memory and shape recognition.[38] It is also possible that the complex spatial characteristics of the letters are differentially affected by defocus compared to Landolt C, resulting in the letters being more easily identified. Rajeev and Metha[14,44] demonstrated that 30 min of defocused-induced blur adaptation resulted in an enhancement of contrast sensitivity at high spatial frequencies and a concurrent reduction at low spatial frequencies. This observation may also explain the differences found between the two refractive groups, with myopes, exhibiting higher experience-based blur compensation,[13,14,17–19] and thus greater differences in the VA measured with the two charts. Interestingly, Jung and Kline[27] have demonstrated that older patients are better than younger patients at recognizing blurred targets, an effect of which they attribute partly to optical factors (smaller pupil sizes), but also to experience-mediated neural compensation.

Following 60 min of prolonged exposure to +2.00 D of defocus, a significant improvement in visual acuity was found in most participants. Since this VA improvement was not accompanied by refractive changes of clinical importance, a sensory-dependent blur adaptation mechanism is indicated, subserving post-retinal neural processes, possibly at binocular sites in the cortex.[12] A limitation of the study is that the same charts were used to measure VA with the subject's spectacle correction, with the +2.00 D blur and after adaptation with the +2.00 D blur, so that it is possible, although unlikely, that memorisation may have played a role.

In addition, the results of the current study show that there is no significant difference in VA improvement following blur adaptation between emmetropes and myopes, although It should be acknowledged that a larger sample size to the one used here might have proved some differences significant. This finding is in accordance with some previous studies investigated foveal[19,20] and parafoveal adaptation,[21] although others[13,14] have shown higher amounts of adaptation in myopes compared to emmetropes. It should be noted that a range of confounding variables may influence exploration of blur adaptation effects in natural myopes, such as the degree of refractive error, long-term perceptual adjustments and subjective expectations, with no real change in performance. In clinical work, although there are frequent claims that vision improves in myopes after short periods of uncorrected vision,[18] this may be attributed to short-time effects, as shown in this study, i.e. visual acuity of myopes just after defocus is induced is better compared to emmetropes with the difference being similar 2 h following adaptation.

An interesting issue is the role of binocular integration on such forms of plasticity. It is well established that vision with two eyes is enhanced over what would be expected with just one eye, a phenomenon called *binocular summation*, which is mainly attributed to the existence of neurons in the visual cortex that 'summate' the signals from the two eyes.[45] Interestingly, a recent study[22] has shown that binocular vision ameliorates the effect of blur, with the summation effect from the two eyes being more pronounced the higher the amount of retinal blur. Unfortunately, most studies, including the current one, have studied blur adaptation measuring only one eye at a time and it could be that myopes also show higher levels of binocular improvement compared to emmetropes.

In conclusion, in the presence of positive defocus VA is less affected in myopes than emmetropes, a finding which may be attributed to previous experience of blur. The reduction in VA with blur is related to the magnitude of the refractive error. The difference in VA between the two groups is more pronounced when using Landolt C optotypes compared to letters. Prolonged exposure to blur results in an improvement in VA for both myopes and emmetropes. No difference was found in the magnitude of blur adaptation between the two groups.

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Disclosure

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