Link to publisher version: *http://dx.doi.org/10.1111/opo.12323*

Citation: Khan KA, Cufflin MP and Mallen EAH (2016) The effect of interrupted defocus on blur adaptation. Ophthalmic and Physiological Optics. 36(6): 649-656.

Title Page

Full title: The effect of interrupted defocus on blur adaptation

Running head: Interrupted blur adaptation

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Keywords: myopia, blur, adaptation, defocus

Abstract

Purpose: Blur adaptation occurs when an observer is exposed to continuous defocus. However, it is unclear whether adaptation requires constant defocus, or whether the effect can still be achieved when the adaptation period is interrupted by short periods of clear vision.

Methods: The study included 12 emmetropes and 12 myopes. All observers wore full refractive correction throughout the experiment. 1D and 3D of myopic defocus was introduced using spherical convex lenses. An automated system was used to place the blurring lens before the RE for varying periods of blurred and clear vision during adaptation. Participants watched a DVD at 3m during each 15 minute trial. Visual acuity was measured using Test Chart 2000 before and after adaptation.

Results: Blur adaptation occurs to varying degrees depending on the periods of incremental blur exposure. Significant improvements in defocused visual acuity occur with continuous blur, equal blur and clear periods, as well as for longer blur periods. However, longer clear periods showed reduced adaptation and this trial is significantly different to the other three trials for both defocus levels ($p<0.001$). No refractive group differences were observed for neither 1D nor 3D defocus ($p=0.58$ and $p=0.19$ respectively).

Conclusions: Intervening periods of clear vision cause minimal disruption to improvements in defocused visual acuity after adaptation, indicating that blur adaptation is a robust phenomenon. However, when the exposure to clear vision exceeds the defocused periods, adaptation is inhibited. This gives insight into the effects of real-world tasks on adaptation to blur.

Introduction

Blur adaptation is a well-documented phenomenon and one that is often reported by myopes as an improvement in unaided distance vision after a period without their refractive correction.[1-3] Previous studies have used continuous periods of defocused viewing to demonstrate significant improvements in defocused visual acuity (VA) occurring after adaptation. Blur adaptation has been described as being robust due to its effects still being present 48 hours after the adaptation period.[4] Here, clear periods of vision did not attenuate the improvements in defocused VA once they were established. In addition, intervening periods of clear vision after a period of adaptation do not weaken the improvement in defocused VA.[5]

No study to date has attempted to decipher what happens prior to the establishment of blur adaptation when blurred viewing is interrupted by clear vision, as per a real-world scenario where the human visual system is constantly adapting to an ever-changing visual scene. It would be interesting to examine the phenomenon when the blur signal is interrupted by clear viewing of varying duration to examine if the adaptation effect can be modulated. In other words, can adaptation still occur despite the clear periods or is the phenomenon suppressed?

Effects of blur adaptation on vision after exposure to blur

Various studies have found improvements in defocused VA after adaptation to myopic defocus and the phenomenon of blur adaptation is well documented in this respect.[2 3 6-10] The period of adaptation has varied from 15 minutes to three hours, as has the level of imposed defocus, from 1D to 3D using lenses, or alternatively the subject's habitual myopic refractive error has been used.

Webster *et al* [11] demonstrated significantly altered perception of blur and judgments of best focus produced by vivid adaptation after-effects after an adaptation period of three minutes. From this, it can be postulated that the visual system responds rapidly to changes in the visual environment and begins counteracting defocus soon after exposure. After-effects, such as the tilt after-effect [12] have been found to be stronger after interrupted adaptation rather than continuous adaptation.

Rosenfield *et al* [4] examined the decay of blur adaptation over time after three hours continuous adaptation to blur (1.50 to 3.00 D), after which subjects wore their refractive correction. The blur adaptation effect was still present 48 hours after the adaptation. These previous studies observed the decay of blur adaptation once it had already been established in a participant. The study presented in this report will look at the effect of clear vision on the adaptation process itself. Whilst prior studies have shown significant improvement in blur adaptation within 30 minutes, a more recent study has shown significant improvements in defocused VA occurring at four minutes of blurred viewing.[13] As timescale is a vital component of adaptation, it would be more critical to observe how clear periods affect the phenomenon from the start of the adaptation period.

Aims

This study will use various permutations of blur and clear periods to investigate whether alternating periods of clear and blurred vision have an effect on the blur adaptation phenomenon.

As exposure to blur is not always constant, this study allows clearer insight into blur adaptation in the real world and its effects in myopic subjects. Previous studies have been unable to mimic typical situations, where exposure to defocus is interjected with periods of clear vision, and therefore this study aims to provide further information about blur adaptation in real-world situations.

Our hypothesis is that blur adaptation may occur in conditions where periods of blurred vision are interspersed with periods of clear vision. This will be tested by comparing the change in visual acuity in a range of adapting periods where the ratio of blurred conditions to clear vision is varied.

Methods

Participants

Twenty-four participants were recruited for this study (median age: 23 years, range: 18-34 years); 12 emmetropes (median age: 22.8 years, range: 18-31 years) and 12 myopes (median age: 23.3 years, range: 19-34 years). Emmetropes were classified as having a spherical refraction of < ±0.75 DS (mean spherical error: +0.04 ± 0.38 D). Myopes were defined as having a negative spherical refraction of at least ≥0.75 DS (mean spherical error: -3.63 ± 2.51 D, range: -0.75 to -7.25 DS). Astigmatic error was no more than 1.00 DC for all subjects in both refractive groups. Mean astigmatic error was -0.25 ± 0.24 DC and -0.33 ± 0.40 DC for emmetropes and myopes, respectively. All participants had best corrected VA of 0.00 logMAR or better and refractive errors were optimally corrected using full aperture trial lenses. Sample size calculations suggest that a cohort of 12 participants per group is adequate for this study.

All participants were free from any binocular vision abnormalities and ocular pathology. They were required to have undergone an eye examination within two years prior to data collection and possess up to date spectacles (if required). All prescriptions were rechecked and participants with more than 0.50 DS change from current refraction were excluded from the experiment. Ametropic participants had worn their correction for at least two hours prior to starting the experiment to ensure prior adaptation to blur had not already been established. Contact lenses were not worn on the day of the experiment to avoid problems such as dry eye and blurred or fluctuating vision.[14]

Informed consent was obtained from all participants and the study was conducted in accordance with the Declaration of Helsinki. Appropriate institutional ethical approval was also obtained.

Visual acuity measurement

VA was measured in the right eye only, and the left eye was occluded throughout the experiment. A Bailey-Lovie design chart was displayed on a standard LCD computer screen and calibrated for the test distance of 3m (NEC LCD Accusync 72VM – model no. ASLCD72VM-BK-1, mean luminance; 239.8 cd/m^2) using the Thomson Test Chart 2000 system (www.thomson-soft-ware-solutions.com). Randomisation of the letters displayed was essential to avoid learning of the letters, thus allowing accurate measurements of VA to be taken.[15] Letter by letter scoring was used to enhance repeatability[16] and scoring was completed once the subjects had named at least half of the letters incorrectly on a line.[17]

Protocol

An automated system was used to place the blurring lens before the right eye for varying periods. Participants watched a DVD at a three metre distance during each

15 minute adaptation trial. VA was measured using a Test Chart 2000 at three stages:

i) With optimal refractive correction pre-adaptation, (ii) correction and +1.25 D or +3.25 D blur pre-adaptation and (iii) correction and +1.25 D or +3.25 D blur post adaptation. These lenses induced 1 D and 3 D of blur respectively at the 3 metre viewing distance. The blurring lens was mounted on an arm attached to a rotary solenoid. When energised, the solenoid positioned the lens in front of the participant's eye. A control circuit was used to determine the duration of periods when the lens was in place.

Letters were randomised just before any VA measures were undertaken. Each participant underwent four different regimens for both 1D and 3D defocus. Each session was separated by one week to allow blur adaptation effects to dissipate, and the order of the sessions was randomised for each participant to avoid investigator bias. The four sessions were:

Trial 1 – Blur only for 15 minutes

Trial 2 – 36s blur /7s clear (Blur periods > Clear periods)

Trial 3 – 7s blur /7s clear (Blur periods = Clear periods)

Trial 4 – 7s blur /36s clear (Clear periods > Blur periods)

To be able to compare the effects of blur adaptation across all trials, it was important to recruit participants that showed an improvement in defocused VA when presented with the +1.00 D all blur trial. Any improvement in defocused VA of less than 0.10 logMAR was considered as non-adaptation and these participants did not continue any further. Once participants had completed the + 1.00 D trials, they were then screened to check for adaptation to +3.00 D. Once again, adaptation of less than 0.10 logMAR was considered to show non-adaptation and these participants did not continue any further with the +3.00 D trials. Out of the 12 participants in each refractive error group, seven emmetropes and eight myopes continued onto the +3.00 D blur sessions. The criterion of less than 0.10 logMAR was used due to test retest variability of VA measurements, which are particularly amplified when defocus is introduced.[18]

Analysis

Data were analysed using repeated measures Analysis of Variance (ANOVA) using SPSS Version 21 (www-01.ibm.com/software/analytics/spss). Repeated measures ANOVA allowed different comparisons between conditions to be made (within-subjects factors) as well as assessment of refractive group differences (between-subjects factors). Separate ANOVAs were conducted on the 1D and 3D data due to differences in the number of participants.

Results

Shapiro-Wilk tests indicated that the data for 1D and 3D blur levels were normally distributed. Blur adaptation occurs to varying degrees depending on the periods of incremental blur exposure. Improvements in defocused VA occur when blur periods are equal to clear periods of vision, as well as when blur periods exceed the length of the clear periods. However, when clear periods exceed blur periods, small improvements in defocused VA are observed. Mean improvements in defocused VA are shown in *Table 1*.

(TABLE 1)

Comparisons between trials are shown separately for the two different levels of defocus in *Figures 1* and *2*.

1D blur

Twenty four participants completed the 1D trials. Mauchly's test of sphericity indicates that the assumption of sphericity has not been violated (p=0.36) and no correction was applied. The interaction between refractive error group and blur condition narrowly missed statistical significance (p=0.064). There was a significant difference in the change in visual acuity between the four different adaptation protocols ($F_{(3,66)} = 60.31$, $p<0.001$). There was no significant difference between emmetropes and myopes (p=0.58); consequently the data for the two refractive groups were pooled.

Bonferroni post-hoc tests were used to compare the VA changes between trials. These comparisons indicated that trials 1, 2 and 3 were similar to each other, with equivalent blur adaptation occurring across all three (1 vs 2: p=0.079, 2 vs 3: p=0.21, 1 vs 3: p=1.00). Trial 4, where clear periods of vision were greater than the blurred periods was significantly different to the initial three trials (1 vs 4: p<0.001, 2 vs 4: p<0.001, 3 vs 4: p<0.001). *Figure 1* depicts the differences between trials.

(FIGURE 1)

3D blur

Fifteen participants from the 1D experiment completed the 3D trials. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated (p=0.058) and therefore no correction was applied. There was no interaction between refractive error group and blur exposure for the 3D level of defocus (p=0.80). There was a significant difference in the change in VA between the four different adaptation protocols ($F_{(3,39)} = 30.70$, p<0.001). There was no significant difference between emmetropes and myopes (p=0.19). Consequently the data for the two refractive groups were pooled.

Bonferroni post-hoc comparisons between trials showed that trials 1, 2 and 3 were similar to each other, with equivalent blur adaptation occurring across all three (1 vs 2: p=0.88, 2 vs 3: p=1.00, 1 vs 3: p=1.00). Trial 4, where clear periods of vision were greater than the blurred periods was significantly different to the initial three trials (1 vs 4: p<0.001, 2 vs 4: p<0.001, 3 vs 4: p<0.001). This is shown in *Figure 2* below.

(FIGURE 2)

Comparison of 1D and 3D data

3D of defocus yielded similar results to the 1D data, showing there was no difference between higher and lower levels of defocus. Both data sets appear to show similar levels of adaptation for each trial and this is seen in *Figure 3* below.

(FIGURE 3)

To summarise, as clear periods of vision exceeded the blur periods, the effects of blur adaptation were much diminished and thus we may be able to conclude that excess clear periods resulted in an inhibited blur adaptation process.

Discussion

Effect of blurred and clear images on visual acuity

Intervening periods of clear vision cause minimal disruption to improvements in defocused VA after blur adaptation. This indicates that blur adaptation is a robust phenomenon which is therefore more likely to occur in real-world situations, where the visual system is constantly experiencing ever changing visual information. Exposure to blur is not always constant and our results allow imitation of typical situations where exposure to defocus is interjected with periods of clear vision, thus giving a clearer insight into how blur adaptation occurs in the real world. However, it appears that as the clear periods exceed the blur periods, the signals for blur adaptation to occur (i.e. the neural compensatory mechanisms) are disrupted and this inhibits the adaptation process.

It is widely accepted that recalibration of spatial frequency processing channels by increasing the gain of high frequency selective channels and decreasing the gain of low frequency selective channels serves to improve resolution.[1 3] Our results may indicate that these alterations in the spatial frequency channels receive a mixed signal and thus are unable to detect if a change in the channel gains is required or alternatively, the presence of a clear signal does not allow for a change to be made. It may be postulated that a two-stage mechanism is responsible for the ability to adapt to defocus under various visual diets; a constant mechanism for longer periods of blur exposure and a cumulative one for when clear periods exceed the blur periods. In other words, when subjects view equal blur and clear periods and greater blur periods, the "dose" of blur is cumulative and the visual system is able to pick up the necessary signals for changes to occur in the recalibration of spatial frequency processing channels to cause an improvement in resolution. However, once clear periods of vision exceed the length of the blur periods, the system of gain channel changes is interrupted and a blur signal is not perceived. Therefore, there are no requirements for any alterations to be made.

Our previous data suggests that uninterrupted adaptation to blur causes a significant improvement in defocused visual acuity after a shorter adaptation period of only 15 minutes. This study can conclude that in addition to this, interleaving clear periods have little to no effect on the blur adaptation process unless the length of clear periods exceeds the length of exposure to blur. It would appear that as clear periods exceed the blur, the clear vision inhibits adaptation and overrides the blur effect.

Similarities to other types of adaptation

Magnussen and Greenlee showed an elevation of contrast thresholds after continuous and interrupted adaptation.[19] This study described adaptation to spatial contrast to be a two-stage process with each stage having a different time constant of adaptation decay. From this, Magnussen and Greenlee concluded that additional adaptation cannot be measured by determining the amount of decay occurring in the interrupting interval. Despite a brief decay of adaptation, a rapid growing after-effect was observed in the following two minute segment compared to when the adaptation was constant during the same time scale. Therefore, this lead the authors to suggest that decay and build-up of adaptation are controlled by partly independent processes.

A similar model is described by Magnussen and Johnson [12] for the tilt after-effect. Here, it was suggested that the short interruptions to adaptation allow for repeated gain adjustments to be made and an adapting stimulus introduced during recovery from the previous adaptation was more effective than when introduced to a fully recovered system. In this study, the tilt after-effect of a 10 minute adaptation period distributed over 15 minutes was stronger than the after-effects following 10 minutes of continuous adaptation, once again suggesting that some sort of rapid gain adjustment occurs. Similar results were also found by Rose and Lowe,[20] who suggested that summation of the adaptation after-effect is greater as the recovery between adaptation periods was not complete. These previous findings add weight to the theory of cumulative adaptation to defocus which is robust and not attenuated by short periods of clear vision.

Effect of ametropia

During the 1D trials, emmetropes and myopes showed comparable responses of adaptation to blur in each trial, thus showing congruency between refractive error groups. It has been widely anticipated that myopic subjects are more likely to adapt more strongly to blur due to frequent prior exposure to blur and reduced sensitivity to blur.[21-25] During the 3D trials, myopic subjects showed a greater level of adaptation to blur, i.e. a larger improvement in defocused VA was measured and this may in part be due to the reasons described in the aforementioned studies. Unfortunately, due to increased test-retest variability in experiments looking at effect of blur of vision, [16 26] any potential differences between refractive groups in terms of degree of improvement in defocused VA may be concealed. Our reduced sample size used for the 3D dataset may have also contributed to the failure to detect a difference between refractive groups. The use of trial case lenses to correct ametropia, and the use of a separate lens to induce the blur conditions produced a small difference in the effective blur between emmetropes and myopes. Myopic participants were subjected to 0.07 D and 0.12 D less blur for the 1D and 3D conditions (respectively) compared to emmetropes.

Test-retest variability

LogMAR charts are commonly used in optometric practice due to benefits such as controlling the visual task and crowding effects and increased repeatability when using letter by letter scoring.[17] Variations in the retesting measurements of VA are known to increase once myopic defocus is introduced and this in turn leads to reduced accuracy of endpoint of high-contrast VA measurments.[16 26] To enable the best measurements to be taken, subjects were pushed to read as many letters as possible and five measurements were taken. Bosch and Wall [27] state that a lower test retest variability is found if VA is scored using letter by letter or probit methods. Further to this, another study reported that a computerised system which averaged repeated acuity measurements showed reduced test retest variability when compared to a single ETDRS measurement.[18]

An interesting finding to note is the incomplete data for 3D defocus. This is due to no adaptation taking place when the defocus levels were increased from 1D to 3D. Non-adaptation was defined as <0.10 logMAR improvement in defocused VA in line with what is known regarding test retest variability. Rosser *et al* [18] findings state 95% test retest variability ranges to be ± 0.11 logMAR for 0 D defocus, ± 0.18 logMAR for 0.5 D defocus and ± 0.25 logMAR for 1.00 D defocus.

Clinical implications

These findings are applicable to low uncorrected myopes who are constantly exposed to defocus during distance vision and are likely to be in a constant state of adaptation to some extent. When clear periods are equivalent or less in duration than blurred periods, blur adaptation occurred to a similar level. These improvements in acuity range from 0.17 up to 0.24 logMAR units, which equate to an improvement of over 1.5 lines, even in those circumstances where periods of clear vision are equal to the periods of blur exposure. The implications for this are that uncorrected myopes will experience blur adaptation if they spend 50% or more of their time viewing targets located beyond their far-point of accommodation. These individuals will likely exhibit better unaided VA than expected compared to the degree of myopia present. Some studies report implications of exposure to myopic defocus with progression of myopia in children with under-correction of myopia resulting in greater increases in myopia compared to fully corrected myopes.[28]

Blur adaptation has primarily been examined in monocular conditions and therefore, our study used varying visual conditions in a monocular setting. To be able to compare this to a real-world situation, it would be interesting to examine the effects of clear periods during binocular vision.

Conclusions

Blur adaptation is a robust phenomenon that can withstand intervening clear periods and overcome these to cause an improvement in defocused visual acuity, except in those circumstances where clear periods exceed the periods of blurred vision. In this instance, the visual mechanisms responsible for blur adaptation are either slowed down or halted due to a lack of blur signal to drive the recalibration of spatial frequency channels.

Acknowledgements

Ms Kiren A. Khan was supported by a School of Optometry and Vision Science PhD studentship.

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FIGURES and TABLE

Table 1 - Mean (± 1 SD) change in defocused VA after 15-minute adaptation to 1D and 3D defocus levels. Mean values are given for all subjects and each refractive group separately.

		Mean improvement in VA (logMAR)			
Defocus	**Rx group**	**All blur**	**Blur > Clear**	**Blur = Clear**	**Clear > Blur**
1 D	All subjects	0.20 ± 0.06	0.20 ± 0.04	0.18 ± 0.05	0.07 ± 0.05
	Emmetropes	0.22 ± 0.07	0.20 ± 0.05	0.19 ± 0.05	0.06 ± 0.04
	Myopes	0.19 ± 0.05	0.19 ± 0.04	0.17 ± 0.04	0.08 ± 0.05
3 D	All subjects	0.22 ± 0.07	0.21 ± 0.06	0.19 ± 0.05	0.11 ± 0.05
	Emmetropes	0.18 ± 0.07	0.17 ± 0.05	0.17 ± 0.04	0.08 ± 0.04
	Myopes	0.25 ± 0.06	0.24 ± 0.06	0.21 ± 0.05	0.14 ± 0.05

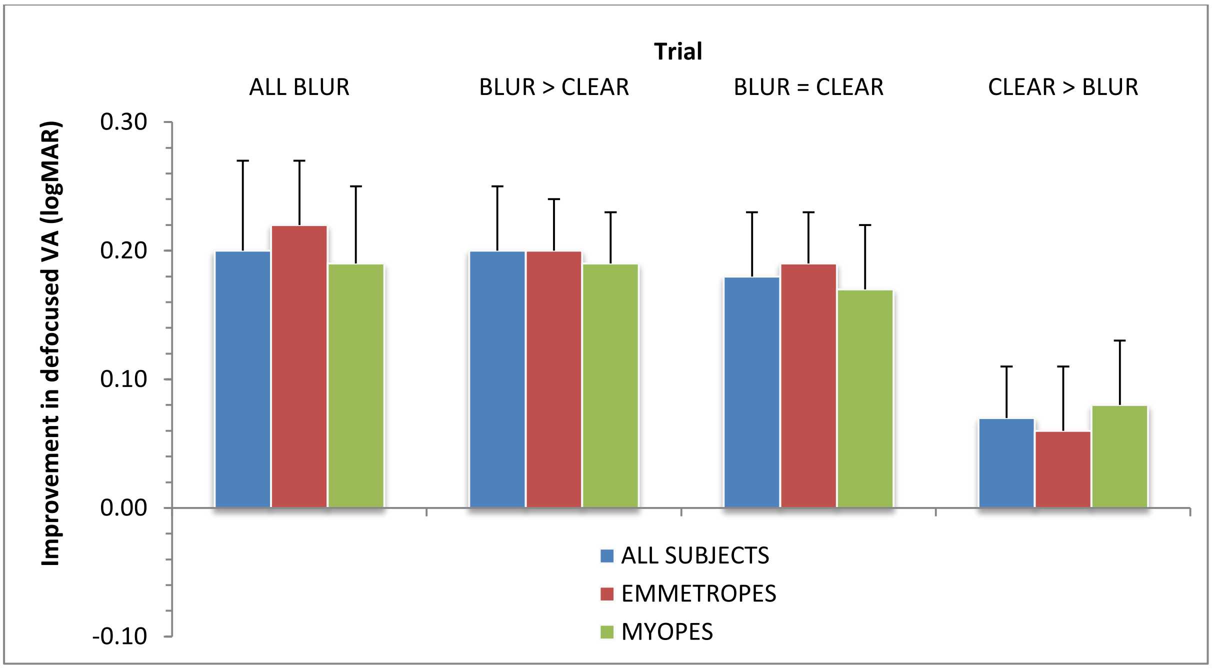

Figure 1 - Mean change in defocused visual acuity (VA) in logMAR after 15 minutes of adaptation to 1D for all subjects, emmetropes and myopes separately. Change in defocused VA is measured as the difference in pre-adaptation VA (with optimal refractive correction and a blur lens) and post-adaptation VA (with optimal refractive correction and the same blur lens once adaptation has been established). Error bars represent 1 SD.

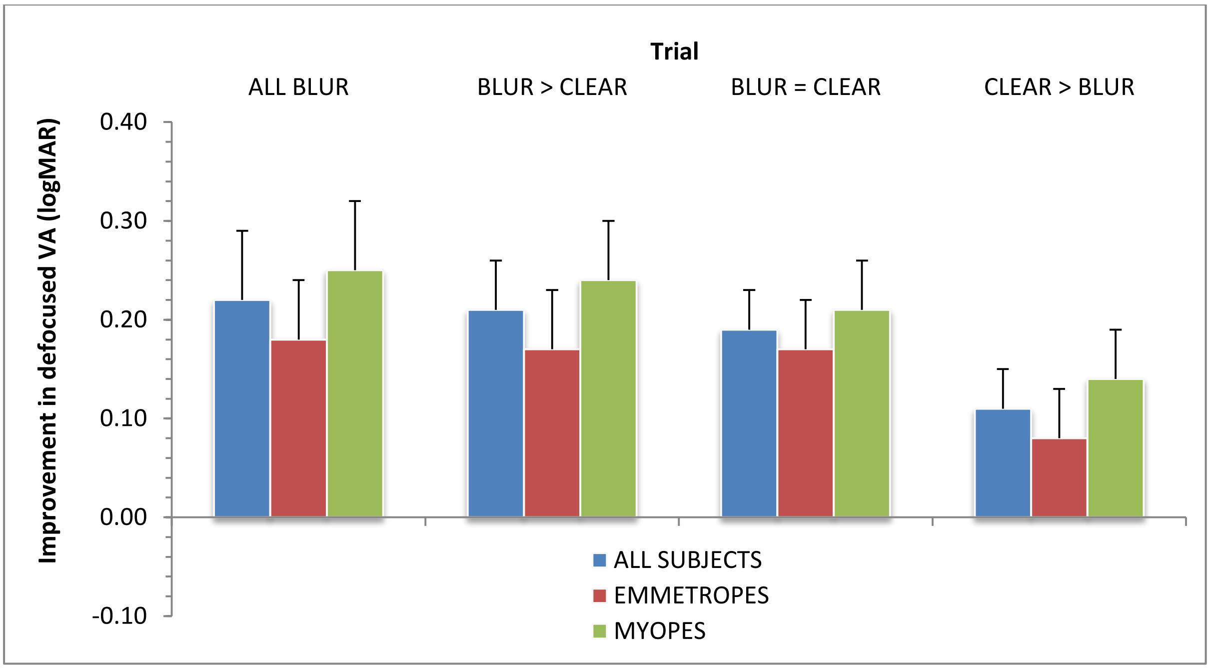

Figure 2 - Mean change in defocused visual acuity (VA) in logMAR after 15 minutes of adaptation to 3D blur. The data shown is for the fifteen subjects that completed the 3D trials. Change in defocused VA is measured as the difference in pre-adaptation VA (with optimal refractive correction and a blur lens) and post-adaptation VA (with optimal refractive correction and the same blur lens once adaptation has been established). Error bars represent 1 SD.

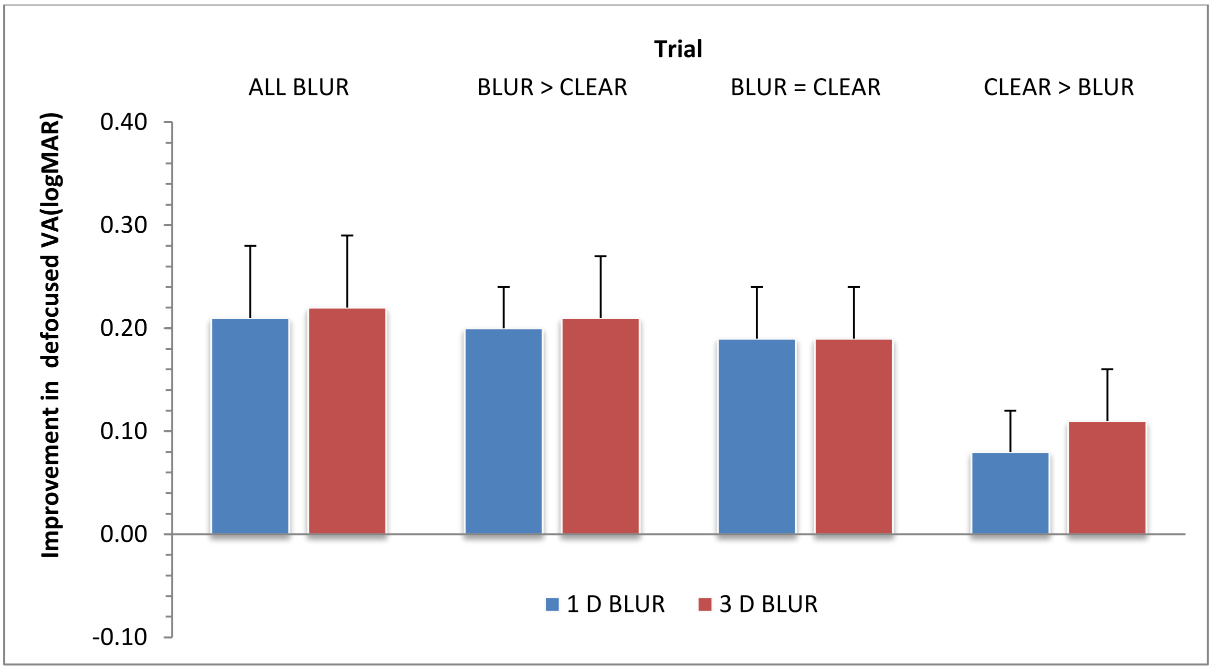

Figure 3 - Mean change in defocused visual acuity (VA) in logMAR after 15 minutes of adaptation to 1D and 3D. This data is shown for fifteen participants that took part in both 1D and 3D trials. Change in defocused VA is measured as the difference in pre-adaptation VA (with optimal refractive correction and a blur lens) and post-adaptation VA (with optimal refractive correction and the same blur lens once adaptation has been established). Error bars represent 1 SD.