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The effect of target proximity on the aniso-accommodative response

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Summary

Aniso-accommodation (unequal binocular accommodation) to lens-induced anisometropia has been demonstrated by subjective and objective measurement techniques (Marran and Schor, *Vision Res.* **38**(22), 3601–3619). The gain of the response was significantly reduced for some subjects when aniso-accommodation was stimulated by a target at 1 m compared to a target at 20 cm, even when the targets viewed were matched in retinal image size, convergence levels and *aniso*-accommodative stimuli. The two conditions did differ in both the accommodative level and proximity of the target. Thus the higher gain of the response in the 20 cm condition could have arisen from either high proximity, high accommodative level or a combination of both.

In this investigation, target proximity and accommodative level were manipulated independently while extra-retinal cues such as absolute disparity and image size were held constant. The results show that high target proximity alone rather than accommodative level or a combination of the two was responsible for the distance dependent effect demonstrated by subjects. Furthermore, accommodative level did not affect the response when target proximity was held constant. Subjects who demonstrated invariant aniso-accommodation with changes in viewing distance also demonstrated invariant aniso-accommodation with experimental manipulation of target proximity at the target distances tested, as would be expected.

These results suggest that high level processing, rather than a reflex blur response, is involved in aniso-accommodation. This conclusion is strengthened by the previous finding of long reaction and response times, 11 and 15 s respectively, to step aniso-accommodative stimuli (Marran and Schor, *Vision Res.* **38**(22), 3601–3619). Since the experimental target provided subjects with visual feedback of the relative blur of the dichoptically viewed letters, subjects had access to perceptual blur information cues. Some subjects seemed to have required both aniso-blur and proximity to exercise this volitional response. Those subjects who showed a distance invariant aniso-accommodative response may have been able to use perceived aniso-blur alone and their ability to disregard proximal cues may have resulted from greater experience with the aniso-accommodative stimuli. Alternatively, these subjects may have had a lower threshold to proximal stimuli and experienced target proximity at the more distant (1 m) viewing condition. © 1999 The College of Optometrists. Published by Elsevier Science Ltd. All rights reserved

Introduction

In a recent investigation using subjective and objective measures, we demonstrated that significant (> 0.50 D) unequal binocular accommodation (aniso-accommodation) will occur when subjects are given monocular dichoptic blur cues in a binocular stimulus target and allowed a training period (Marran and Schor, 1998). In viewing conditions found to elicit the greatest aniso-accommodative response, the aniso-accommodative response function was linear over the range of aniso-accommodative stimuli tested (0.5 to 3.0 D) with an average gain across subjects of 0.27. (Gain is the ratio defined by the aniso-accommodative response in diopters divided by the aniso-accommodative stimulus in diopters.) The gain was significantly reduced under conditions in which aniso-accommodation was stimulated while subjects viewed a target at 1 m compared

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to their response when the target was at 20 cm (x = 0.14 and 0.26, respectively; $p < 0.05$). However, although this reduction was significant in an across-subjects group analysis, 3 of 7 subjects experienced no significant reduction in their aniso-accommodative response for the 1 m viewing condition. For this 1 m viewing condition, the average gain of the distance invariant group was 0.22 compared to a gain of 0.07 for the distance dependent group.

In the 1 m and 20 cm viewing conditions, the targets viewed were matched in retinal image size, absolute disparity and aniso-accommodative stimuli. Only the accommodation level and proximal stimulus (subjects' awareness of the nearness of the target) around which the aniso-accommodative stimulus was manipulated were different at the two target distances. This suggests that distance cues associated with the 20 cm viewing condition played some role in eliciting the aniso-accommodative response for the subjects showing a distance dependent effect. Both perceptual and extra-retinal distance cues were present in the stimulus. Extra-retinal cues such as accommodative effort, accommodative level and accommodative driven vergence would have changed with target distance. If any of these extra-retinal cues or subjects' dependence on these cues varied in a systematic way between the two subject groups, this might explain their different responses. Accommodative and vergence stimuli were matched at the 20 cm target distance (5 D and 5 MA) but mismatched at the 1 m target distance (1 D and 5 MA). It is possible that one group of subjects could not respond to the mismatched condition because of difficulty in converging and accommodating accurately.

When the two subject groups were compared on extra-retinal cues such as accommodative level or on factors which would indirectly affect the extra-retinal cues, such as interactions between tonic and phasic accommodation and accommodative and disparity driven vergence, there were no systematic differences between the two groups to explain why target distance affected the aniso-accommodative response in one group but not the other. The fusional vergence ranges of the subjects in the two groups were also equivalent, so that the mismatch of the convergence and accommodative stimuli in the 1 m target should have affected both groups equally. Furthermore, two subjects who showed a distance dependent effect were retested at the 1 m viewing distance using matched accommodation and vergence stimuli (1 D and 1 MA) and continued to show a reduced gain of aniso-accommodation. This demonstrated that the accommodative vergence mismatch of the earlier experiment was not the cause of the low gain of aniso-accommodation at the 1 m viewing distance.

Awareness of target distance is another cue that changed with target distance but was not tested in this previous investigation. Knowledge of the nearness or proximity of a target has been shown to influence both the accommodative response (Hofstetter, 1942; Rosenfield and Gilmartin, 1991; Gwiazda *et al.*, 1994); and the tonic accommodative response (Rosenfield *et al.*, 1990). The accommodative response to this cue is called proximal accommodation.

A series of experiments was conducted to test the hypothesis that target proximity provided an important perceptual cue for driving the aniso-accommodative response for the distance dependent group. Inter-subject variability in the influence of target proximity on the accommodative response has been demonstrated previously, for both open-loop (Rosenfield and Gilmartin, 1991), and closed-loop (Gwiazda *et al.*, 1994) consensual accommodation. In addition, although no systematic differences in accommodative levels between the two groups were found, the distance dependent group may have been more dependent on accommodative level driving the aniso-accommodative response than the distance invariant group. Thus this investigation also addressed how accommodative level influenced subjects' aniso-accommodative response. Specifically, since both target proximity and accommodative level were high (20 cm and 5 D) when the target was viewed at 20 cm in the earlier investigation, either the high accommodative level or the high target proximity or a combination of both, could have been responsible for the higher gain of the response for this target distance. By the same argument, the low gain of the response for the target at 1 m could have resulted from an absence of either or both cues. This study investigated the relative importance of each of these cues by independently manipulating accommodative level and target proximity. This was accomplished by changing the physical distance of the target while subjects binocularly wore plus or minus lenses. The configuration of the experimental apparatus allowed subjects full awareness of the physical distance of the targets throughout the measurement sessions. Absolute disparity was held constant at 5 MA across all conditions.

General methods

Subjects

The same seven subjects (2 females and 5 males; aged between 16 and 22 years of age) that participated in the earlier investigation (Marran and Schor, 1998) participated in this study, according to their availability.

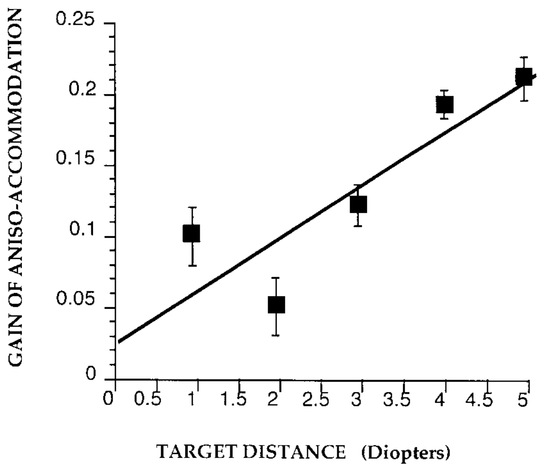


Figure 1. This figure represents the results of Experiment I, which tested the effect of target distance on the aniso-accommodative response. The *x*-axis represents target distance, expressed in diopters (the inverse of target distance in meters). The *y*-axis represents the gain or slope of the aniso-accommodative response function (aniso-accommodation (D)/aniso-accommodative stimulus (D)). The filled squares represent this response function averaged across subjects to a series of lenses which presented 0.5 to 3.0 D of anisometropic stimuli. The error bars represent the standard error of the mean between subjects.

Apparatus

Standard target. The Standard target used to train subjects to aniso-accommodate and to stimulate aniso-accommodation during the experiments was a binocular fusion target that contained dichoptic letters (see *Figure 1* and Marran and Schor, 1998). The target was created from two fusible targets, each of which contained a different dichoptic letter embedded in it ("R" for the right eye and "L" for the left eye). A rectangular outline and grid background surrounded the letters and served as a binocular stimulus for sensory and motor fusion. The grid background of the target provided a rich background of fusional and perspective cues. Subjects cross fused the target in a manner similar to the free fusion technique of an autostereogram. This act of binocular fusion created the percept of a third target, which by definition was binocular, and which by design contained a dichoptic letter for each eye. It was this binocular percept of the target that subjects attended throughout the measurement sessions. Subjects could check that they were fusing the target correctly, crossed fusing rather than uncrossed fusing, by *quickly* winking one eye shut and noting the disappearance of the corresponding letter. (For instance, if they had wrongly fused the target by *uncrossed* fusion, the "R" would disappear as they winked the left eye closed). The dichoptically viewed letters also provided subjects blur feedback on the accuracy of the accommodative response of each eye and served as a binocular suppression check. The overall subtense of each letter was 0.50°, while the width of the pen stroke, or line detail in the letter subtended 0.15°. The dichoptic letters of the target were spaced apart vertically 0.3 cm or 0.85°, center to center. The horizontal separation of the dichoptic letters was adjusted so that the absolute disparity of the target was held constant at 5 MA across all conditions.

Target size was physically changed according to the condition, to create a constant retinal image size of the target across all conditions. However, due to the binocularly worn concave and convex lenses in Experiment II, there would be a maximum 6.0% size change in the image, minification and magnification, respectively. These size effects would have slightly exaggerated the manipulation of proximal effects.

Stigmascope. The stigmascope apparatus and data acquisition methods previously described[1] were used for these experiments.

Subjects' Instructions

Subjects were trained to adjust their eyes' focus until both dichoptic letters in the fused target were simultaneously clear (meaning that both letters were well defined). They were allowed unlimited time to accomplish this during training. During measurement sessions, they were allowed three minutes to accomplish this. Typically after training, 30 s or less was required to clear both letters. Subjects then focused the stigmas (the illuminated, dichoptically viewed cross-hairs of the stigmascope used to measure their aniso-accommodative response) which were superimposed on the fused target. They did this, using the method of bracketing, by turning a knob which moved the stigma along an optical bench. When both pairs of letters and stigmas were simultaneously clear, voltage analogs of their settings were entered into the computer by pressing a response key. If at any time the subject could no longer keep both letters simultaneously clear after the three minute allowance period, they reported this to the examiner and were instructed to continue to set each stigma so that both *stigmas* were simultaneously clear. If the subject could not keep the target binocularly fused, or if one of the dichoptic letters disappeared, the session was terminated.

Lens Series

For each condition, a series of lenses were introduced, before one or both eyes, in 0.5 D steps while the subjects binocularly fused the target and attempted to keep both dichoptic letters simultaneously clear. All lenses were introduced in the spectacle plane. The lens series began with ±0.50 D and continued up to ±3.00 D, in 0.5 D steps, unless the subject experienced suppression of one of the dichoptic letters or could no longer fuse the target, at which point the session was terminated. The lenses were introduced monocularly before each eye in an alternating sequence to present aniso-accommodative stimuli and then binocularly to present iso-accommodative stimuli.

The binocular presentation of the lenses allowed a constant calibration of the subject's iso-accommodative response to which all aniso-accommodative responses were referenced. The subject's response to the iso-accommodative stimuli of the binocularly worn lenses in the lens series were subtracted from their response to the aniso-accommodative stimuli of the monocularly worn lens of the same power. This allowed for any fluctuations in anisometropic refractive error (or tonic aniso-accommodation) over the course of the experiment. It also served to correct any uncorrected anisometropic refractive error of the subject's current refraction that was worn during the experiment. This analysis technique was preferred over trying to correct any anisometropia because of the sensitivity of the stigmascope measurements (0.12 D) and potential tonic effects mentioned above.

For the 1 m and 50 cm target conditions, concave or minus lenses were used for the lens series. Convex or plus lenses were used for the lens series of the remaining conditions, the 33.3, 25 and 20 cm conditions. The use of concave or convex lenses does not differentially affect the aniso-accommodative response (Marran and Schor, 1998).

General analysis techniques

Uncorrected refractive error. Subjects wore their current refractive correction during the experiments plus any cylinder correction that was discovered by our subjective refraction. This cylinder correction was found to be necessary for reliable and consistent haploscopic settings. A final correction for any uncorrected spherical refraction (the difference between our subjective refraction and the subjects current refractive correction) was made in the data analysis. This difference did not exceed 0.75 D and thus the most distant stimuli of the experiment (1 m) was always within subject's far point.

Comparison of conditions. In Experiment I, each Experimental condition was compared to a Reference condition which served as a benchmark for the gain of the aniso-accommodative response for that individual subject for that given day (see Marran and Schor, 1998). The methods and stimulus conditions of the Reference Condition was the 20 cm target condition, as described in Experiment I. In Experiment II, Conditions A & B, C & D, B & C, and A & D were compared.

For analytical comparative purposes, for all experiments, aniso-accommodative responses were plotted as a function of aniso-accommodative stimuli. The gain of the response (slope (m) of the response function) and r^2 values were fitted to the results of each condition and appear in the upper left hand corner of each graph. To test for significant differences in these slopes between conditions, the responses of one condition were subtracted from the responses of the comparison condition to matched aniso-accommodative stimuli of the lens series. Regression analysis was then used to determine if this difference slope was significantly different from zero; p-values less than 0.05 and 0.01 are represented by * and **, respectively, and appear in the upper right hand corner of each graph.

Specific experiments

Experiment I. Comparison of lens induced aniso-accommodation for targets at varying distances

Methods. The distance dependent effect demonstrated earlier (Marran and Schor, 1998) was confirmed and extended by measuring individual's aniso-accommodative response to identical aniso-accommodative stimuli at varying target distances: 100, 50.0, 33.3, 25.0 and 20.0 cm. (This is equivalent to varying the accommodative stimulus level from 1.0 to 5.0 D in 1.0 D steps.) Both accommodative level and target proximity were changing concurrently with changes in target distance. Absolute disparity of the target was held constant at 5 MA for all viewing distances. Retinal image size also was held constant. (See Standard target). Henceforth, these conditions will be referred to by their physical target distance since this terminology accounts for both the dioptric demand and the proximal stimuli of these conditions.

Results. As demonstrated earlier (Marran and Schor, 1998), most subjects showed a distance dependent effect. In *Figure 1*. the aniso-accommodation response slopes for each target viewing distance were averaged across subjects and plotted as a function of the inverse of target distance, the dioptric level of the target. Regression analysis of the group data averages reveals a significant effect of target distance on the aniso-accommodative response (m = 0.036, r^2 = 0.76, p < 0.05). In this analysis, the slope chosen to represent the 20 cm distance Reference Condition was the one which served as a Reference Condition for the 1 m Exper-

Table 1. Summary of target distance where facilitation of aniso-accommodation occurs for each subject

Subject	Target distance where aniso gain equals gain at 20 cm (p>0.05)
JM	1 m
CG	1 m
DL	33 cm
JA	33 cm
JS	25 cm
MR	20 cm

imental Condition. This method allowed equivalent comparison of standard error bars across distances.

The effects of target distance on individual subjects' aniso-accommodative responses are summarized in *Table 1*. The left column identifies the subject by initials. The right column identifies the farthest target distance for each subject in which the gain of the aniso-accommodative response was equivalent to the 20 cm Reference condition ($p > 0.05$). This distance may indicate the operating range for the facilitation of aniso-accommodation by distance cues.

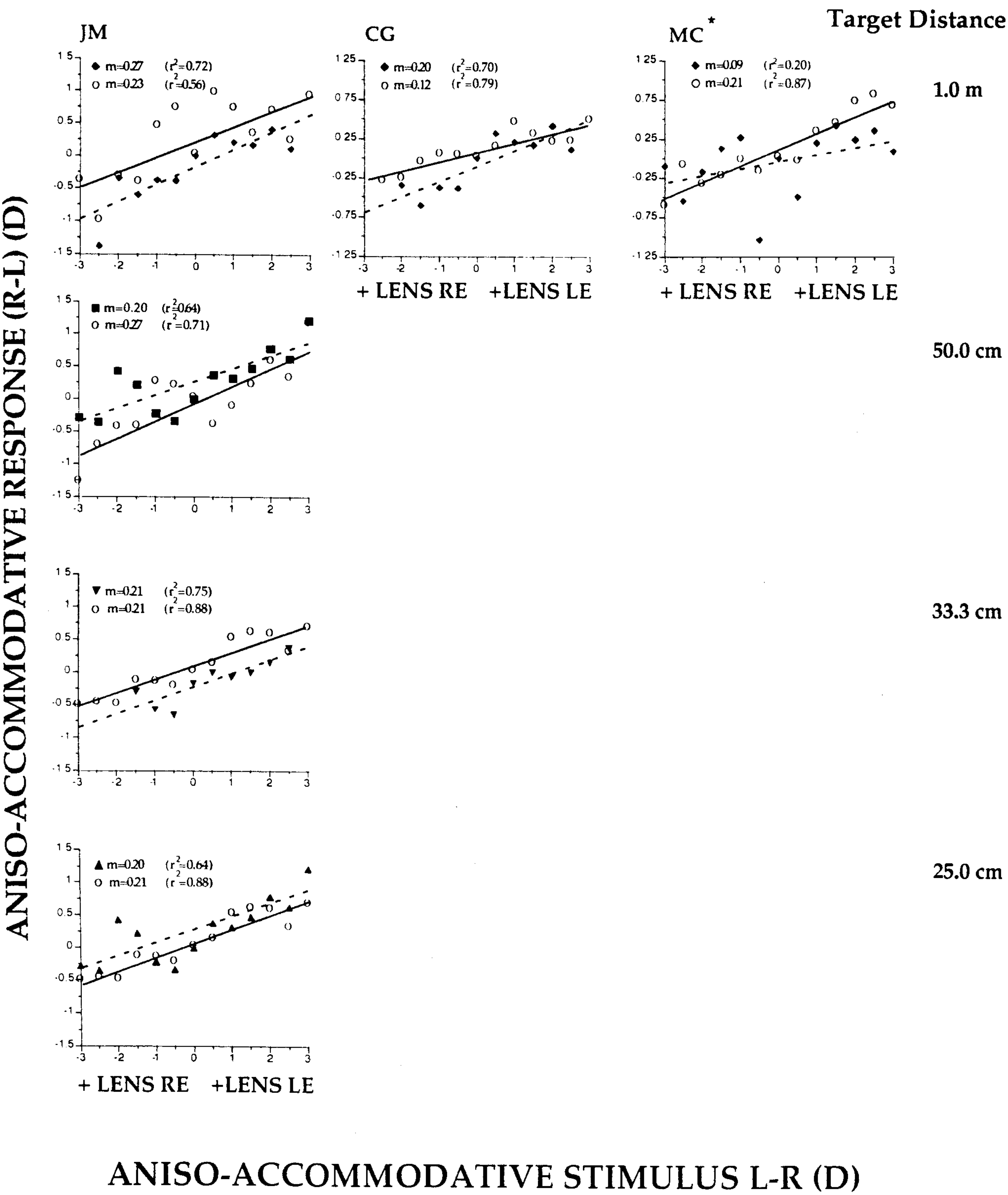
Figures 2–4 illustrate *individual* subjects aniso-accommodative responses to the four target distances. The open symbols and solid lines represent the Reference Condition (20 cm) and the closed symbols and dashed lines, the Experimental Conditions. Each subject's data is in a vertical column with each row representing a different viewing distance, noted at the far right. Two of the seven subjects (CG & JM) showed no difference in the aniso-accommodative response to the target distances of 20 cm and 1 m ($p > 0.05$) (*Figure 2*). Upon further testing of all target distances, JM continued to show no dependency on target distance for the aniso-accommodative response ($p > 0.05$). CG was not tested further at the other viewing distances.

The other five subjects demonstrated a distance dependent effect. For those subjects whose response was measured at all testing distances, all showed significantly reduced aniso-accommodative responses at 50 and 100 cm, compared to the 20 cm Reference condition. The target distance for which aniso-accommodation was first facilitated varied among these subjects. As illustrated in *Figures 3* and *4*, and summarized in *Table 1*, this occurred at target distances of 33 cm for two subjects (DL & JA), 25 cm for one subject (JS) and 20 cm for another subject (MR). The remaining subject, MC showed a facilitated response at 20 cm compared to the 1 m target but was not tested at other viewing distances (*Figure 4*).

Experiment II. Comparison of target proximity effects vs accommodative level effects on the aniso-accommodative response

In Experiment I, accommodative level and target proximity were changing concurrently with changes in target distance. The gain of the aniso-accommodative response was reduced in the 1 m and 50 cm target conditions compared to the 20 cm target condition for all subjects who showed a distance dependent effect. This reduced gain may have been a result of low accommodative level, low target proximity or a combination of both. In Experiment II, four experimental conditions were created to isolate the influence of accommodative level and target proximity on the aniso-accommodative response. Absolute disparity (5 MA) and retinal image size of the target were held constant across all four conditions. (See Standard target). Target proximity and accommodative level were manipulated independently by changing the physical distance of the target while subjects binocularly wore plus or minus lenses. *Table 2* summarizes the accommodative and proximity stimulus levels and the experimental results (the aniso-accommodative gain measured under of each of these four conditions).

Figure 2. This figure illustrates the results of Experiment I, the effect of target distance on the aniso-accommodative response function for *individual* subjects. Each subject's data is in a vertical column while each row represents a different viewing distance. JM was tested at all experimental target distances (1 m ◆, 50 cm ■, 33 cm ▼ and 25 cm ▲) while CG and MC were tested only at 1 m. Each Experimental Condition at each distance, closed symbols and dashed lines, was compared to a same day Reference Condition for a target at 20 cm, open symbols, solid lines. The *x*-axis represents the aniso-accommodative stimulus; positive values indicate a higher accommodative stimulus for the right eye relative to the left eye; negative values indicate a higher accommodative stimulus for the left eye relative to the right eye. The *y*-axis represents the aniso-accommodative response, Reye-Leye, where plus indicates a greater relative accommodative response by the right eye and minus indicates a greater relative accommodation response by the left eye. Slope and values from Regression Analysis of the aniso-accommodative response for the Experimental and Reference condition appear in the upper left hand corner of each graph. Asterisks indicate that the slope of the Experimental Condition was significantly different than that of the Reference Condition (*$p < 0.05$ and **$p < 0.01$).



JM
CG
MC*
Target Distance
1.0 m
50.0 cm
33.3 cm
25.0 cm
m=0.27 (r²=0.72)
m=0.23 (r²=0.56)
m=0.20 (r²=0.70)
m=0.12 (r²=0.79)
m=0.09 (r²=0.20)
m=0.21 (r²=0.87)
m=0.20 (r²=0.64)
m=0.27 (r²=0.71)
m=0.21 (r²=0.75)
m=0.21 (r²=0.88)
m=0.20 (r²=0.64)
m=0.21 (r²=0.88)
+ LENS RE +LENS LE
ANISO-ACCOMMODATIVE RESPONSE (R-L) (D)
ANISO-ACCOMMODATIVE STIMULUS L-R (D)

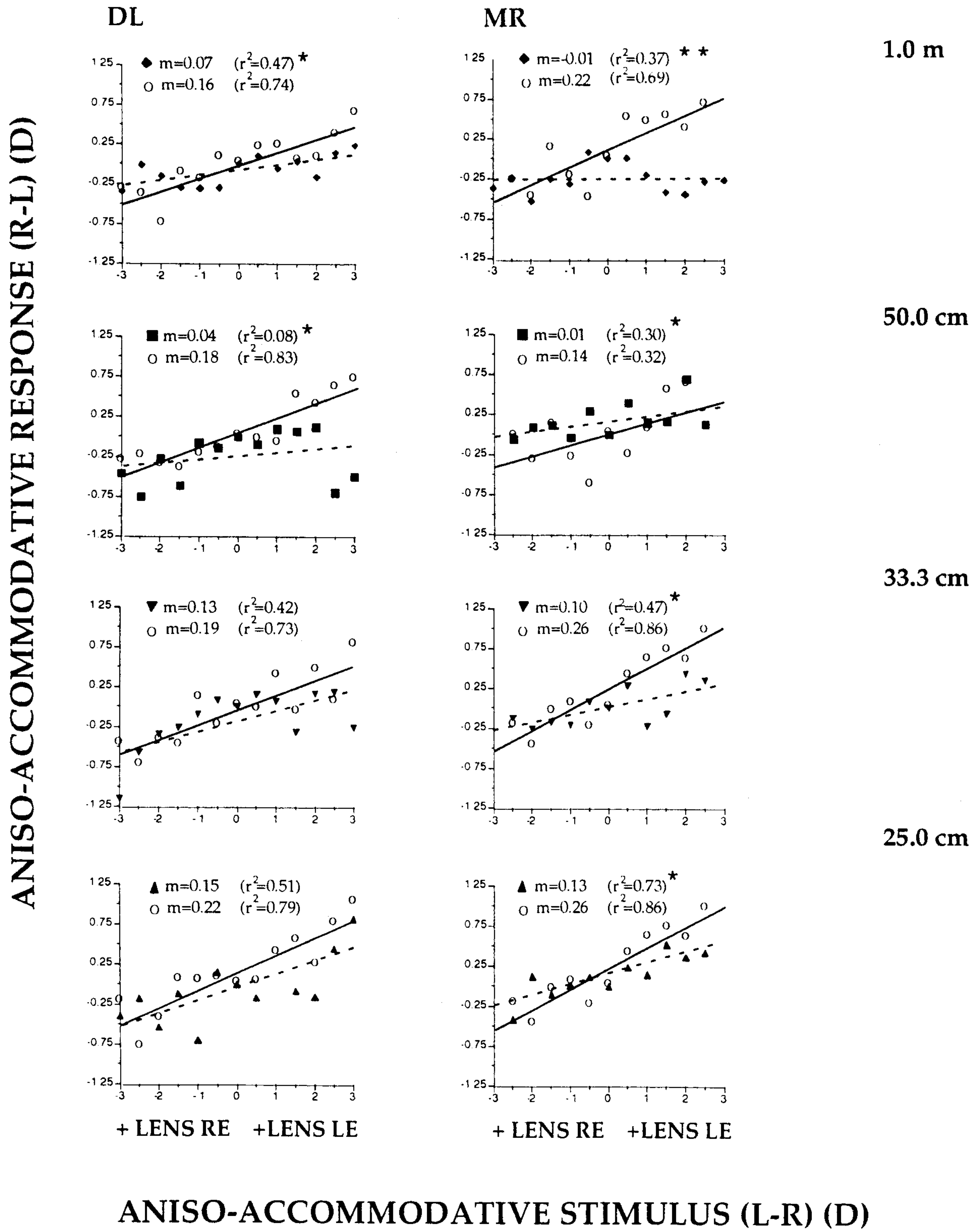


Figure 3. This figure illustrates individual subjects' (DL & MR) aniso-accommodative responses to four target distances: (1 m ◆, 50 cm ■, 33 cm ▼ and 25 cm ▲). The *x*-axis represents the aniso-accommodative stimulus. The *y*-axis represents the aniso-accommodative response. Each experimental target distance condition, closed symbols, was compared to a same day Reference Condition, open symbols. Sign conventions and notations are the same as in *Figure 2*.

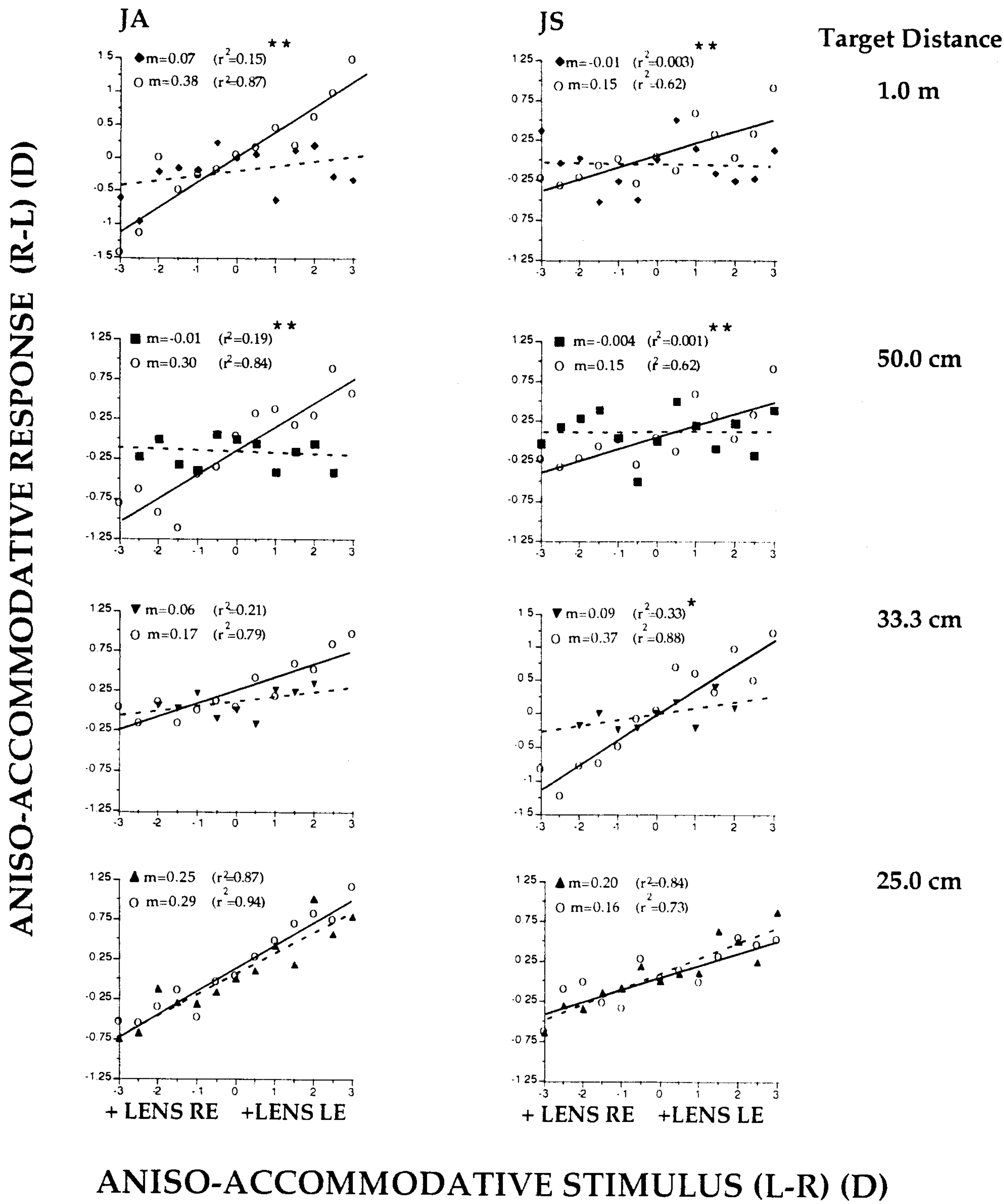


Figure 4. This figure illustrates individual subjects' (JA & JS) aniso-accommodative responses to four target distances: (1 m ◆, 50 cm ■, 33 cm ▼ and 25 cm ▲). The *x*-axis represents the aniso-accommodative stimulus. The *y*-axis represents the aniso-accommodative response. Each experimental target distance condition, closed symbols, was compared to a same day Reference Condition, open symbols. Sign conventions and notations are the same as in *Figure 2*.

Table 2. Summary of conditions and results of Experiment II

Condition	Experimental condition Accomm High = 5 D Low = 1 D	 Proximity High = 20 cm Low =1 m	Results Aniso-accom gain Experimental results
A	HIGH	LOW	LOW
B	HIGH	HIGH	HIGH
C	LOW	HIGH	HIGH
D	LOW	LOW	LOW

Note: Absolute disparity = 5 MA across all conditions

Role of target proximity on the aniso-accommodative response: accommodation level constant, target proximity manipulated

High accommodation conditions with low proximity (condition A) or high proximity (condition B).

Methods

This experiment investigated the effect of proximity on the aniso-accommodative response when accommodative level was high. In both conditions (A and B) accommodation was high (5 D). However, in Condition A, the concurrent target proximity was low (1 m) while in Condition B, the concurrent target proximity was high (20 cm). If the gain was equivalent in both conditions, this would suggest that target proximity did not affect the response. If the gain was higher in Condition B, this would suggest two possibilities: (1) both high accommodative level and high target proximity were required; or (2) high proximity alone could drive the response.

In Condition A, the target was viewed at 1 m while accommodative stimulus levels of 20 cm were created by beginning the lens series with binocularly worn −4.00 D lenses. The minus lens power was then reduced monocularly in 0.5 D steps in an alternating sequence to present aniso-accommodative stimuli and binocularly to present iso-accommodative stimuli.

In Condition B, the target was viewed at 20 cm while plus lenses were introduced in 0.5 D steps in an alternating sequence to present aniso-accommodative stimuli and then binocularly to present iso-accommodative stimuli.

Results

As would be expected, subjects who showed no distance dependent effect (JM and CG) also showed no proximity dependent effect at the testing distances used in these experiments ($p > 0.05$), *Figure 5*, Column 1. Of the remaining five subjects, four showed a significant reduction in their aniso-accommodative response in Condition A compared to Condition B (*Figures 5* and *6*, Column 1). The fifth subject's (MR) response was also reduced in Condition A and just failed to reach significance ($p = 0.09$). In a paired t-test comparison of the response slopes *across subjects*, the slope of the aniso-accommodative response in the Condition A was significantly lower than the response in Condition B ($x = 0.11$, $x = 0.21$, respectively, $p < 0.05$), see the upper histogram of *Figure 7*. These results suggest two possibilities, either both accommodative level and target proximity need to be high or a high proximal stimulus alone can drive the response.

Low accommodation conditions with low proximity (condition D) or high proximity (condition C)

Methods

This experiment addressed the question of whether a high proximal stimulus alone could drive the aniso-accommodative response. In both conditions (C and D) accommodation was low (1 D). However, in Condition C, the concurrent target proximity was high (20 cm) while in Condition D, the concurrent target proximity was low (1 m). If the aniso-accommodative response was found to be equivalent in Conditions C and D, then target proximity did not affect the response. If the aniso-accommodative response was found to be significantly higher in Condition C (low accommodation & high target proximity), this would suggest that target proximity alone can drive the response.

In Condition C, the target was viewed at 20 cm while the accommodative stimulus levels of 1 m were created by beginning the lens series with binocularly worn +4.00 D lenses. The plus lens power was then reduced monocularly in 0.5 D steps in an alternating sequence to present aniso-accommodative stimuli and then binocularly to present iso-accommodative stimuli.

In Condition D, the target was viewed at 1 m while minus lenses were introduced in 0.5 D steps in an alternating sequence to present aniso-accommodative

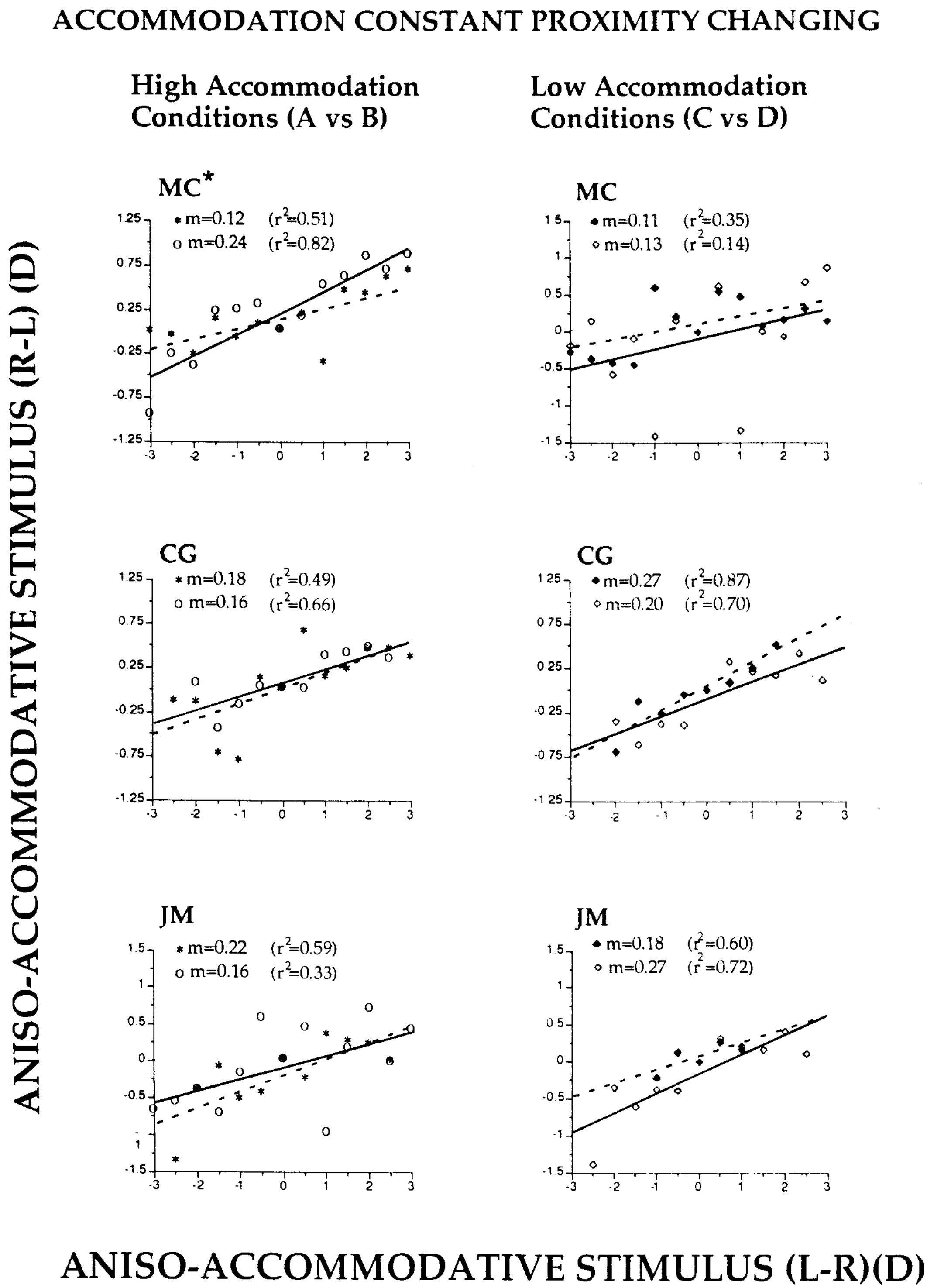


Figure 5. This figure illustrates individual subject's (MC, CG & JM) aniso-accommodative responses when accommodative level is held constant and proximity is manipulated. High Accommodative Level with Low Proximity (Condition A, closed symbols and a dashed line) is compared to High Accommodative Level with High Proximity (Condition B, open symbols and a solid line) in the left column. Low Accommodative Level with Low Proximity (Condition C, closed symbols and a dashed line) is compared to Low Accommodative Level with High Proximity (Condition D, open symbols and a solid line) in the right column. The *x*-axis represents the aniso-accommodative stimulus. The *y*-axis represents the aniso-accommodative response. Sign conventions and notations are the same as in *Figure 2*.

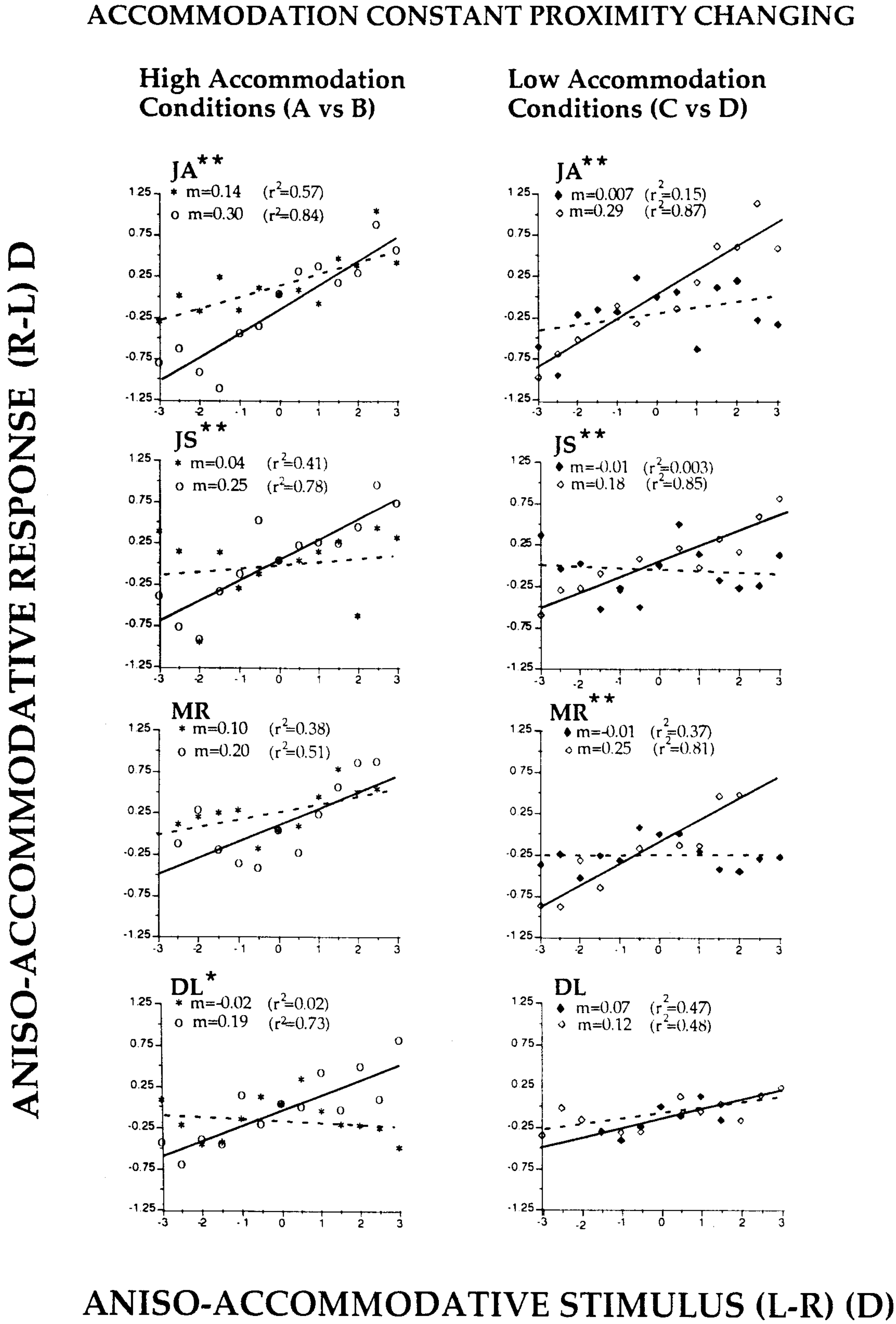


Figure 6. This figure illustrates individual subjects' (JA, JS, MR & DL) aniso-accommodative responses to Conditions A & B (Left Column) and Conditions C & D (Right Column) as described in *Figure 5*. Sign conventions and notations are the same as in *Figure 2*.

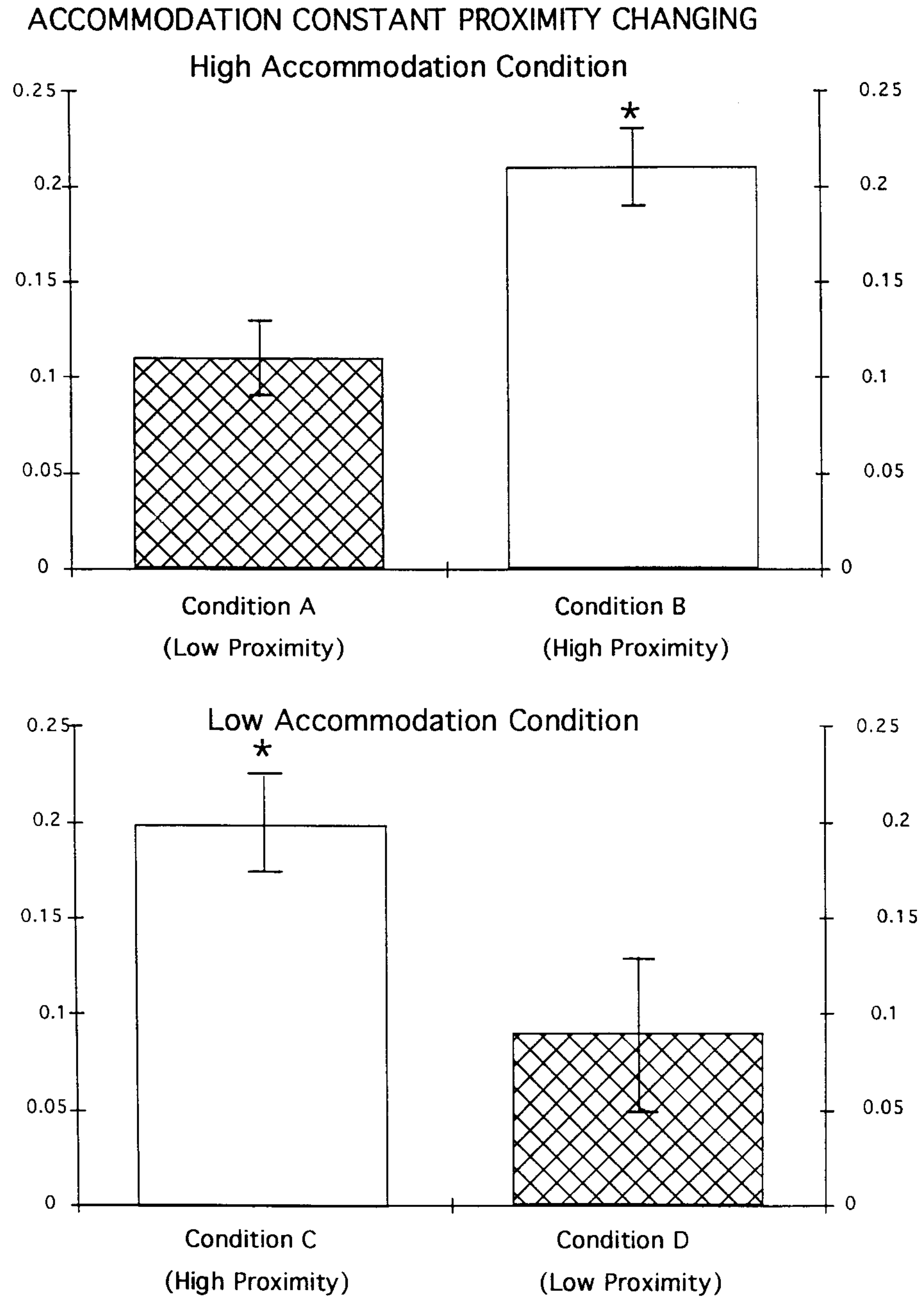


Figure 7. This figure illustrates the slopes of the aniso-accommodative response averaged across subjects while accommodative level is held constant and proximity is varied. Accommodation is high in the upper half of the figure and low in the lower half of the figure. Proximity is concurrently low in Conditions A and D (cross-hatched rectangles) & high in Conditions B & C (open rectangle).

stimuli and then binocularly to present iso-accommodative stimuli.

Results

Again, those subjects (CG & JM) who showed no distance dependent effect showed no effect of target proximity, (*Figure 5*, Column 2). Of the five remaining subjects who showed a distance dependent effect, three subjects (JA, JS, & MR) showed a significantly augmented aniso-accommodative response in Condition C compared to Condition D ($p < 0.01$), *Figure 6*, Column 2. In a paired t-test comparison of the response slopes *across subjects*, the slope of the aniso-accommodative response in Condition C was signifi-

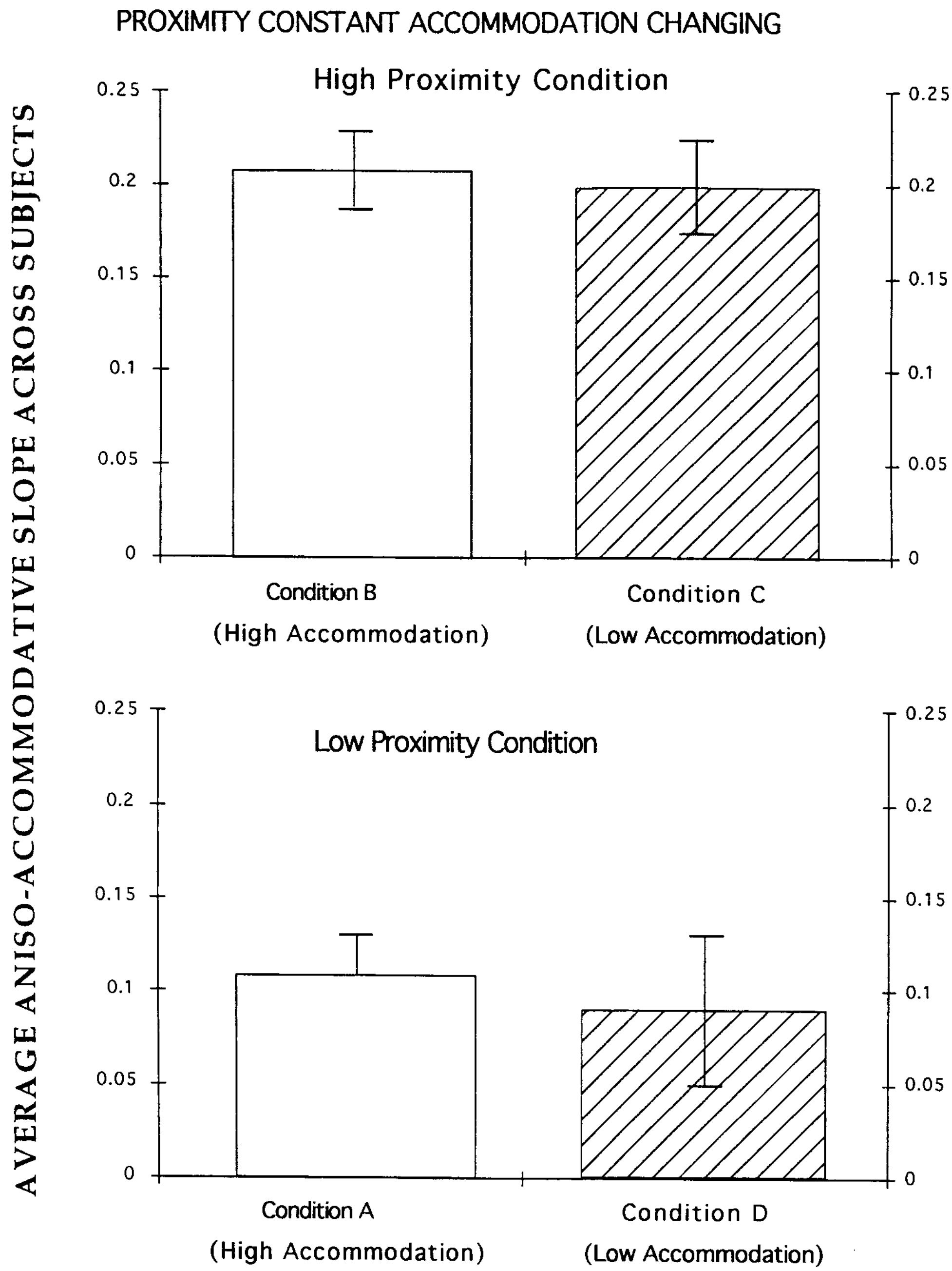


Figure 8. This figure illustrates the slopes of the aniso-accommodative response averaged across subjects while proximity is held constant and accommodative level is varied. Proximity is high in the upper half of the figure and low in the lower half of the figure. Accommodation is concurrently low in Conditions C & D (oblique hatched rectangle) and high Conditions A & D (open rectangle).

cantly greater than the response in Condition D ($x = 0.20$, $x = 0.09$, $p < 0.05$) (see lower histograms of Fig. 9). This suggests that target proximity alone provided the requisite visual conditions to elicit the aniso-accommodative response to aniso-accommodative stimuli in those subjects characterized as showing a distance dependent effect. Additionally, this result reconfirms that the low gain demonstrated in the 1 m condition of Experiment I is not a result of the accommodative vergence mismatch of this condition (1 D and 5 MA) because the same accommodative level and absolute disparity level were used in Condition C, which resulted in a high response gain. The only difference between these two conditions was the proximal stimulus of the target, 1 m in Experiment I and 20 cm in Condition C.

Role of accommodative level on the aniso-accommodative response: target proximity constant while accommodation was manipulated

Without conducting further experiments, cross comparisons can be utilized to access the effect of accommodative level on the gain of the aniso-accommodative response.

High proximity conditions with high accommodation (condition B) or low accommodation (condition C).

Methods

This cross comparison investigated the role of accommodative level on the aniso-accommodative response when proximity was high. In both conditions (B and C) proximity was high (20 cm). However, in Condition C, the concurrent accommodative level was low (1 D) while in Condition B, the concurrent target accommodative level was high (5 D). If the gain was equivalent in both conditions, this would suggest that accommodative level did not affect the response. If the gain was higher in Condition B, this would suggest two possibilities: (1) both high accommodative level and high target proximity were required; or (2) high accommodative level alone could drive the response.

Results

In a paired t-test comparison, there was no significant difference between Condition B and Condition C ($x = 0.21$, $x = 0.20$, respectively, $p = 0.33$); (see Upper Histograms of *Figure 8*). Since the response in Condition B was not greater than in Condition C, *both* high proximity and high accommodative level are not needed for a high aniso-accommodative response. Since both conditions were equivalent, this suggests that accommodative level does not affect the response.

Low proximity conditions with high accommodation (condition A) or low accommodation (condition D).

Methods

This comparison addressed the question of whether a high accommodative level alone could drive the aniso-accommodative response. In both conditions (A and D) target proximity was low (1 m). However, in Condition A, the concurrent accommodative level was high (5 D) while in Condition D, the concurrent accommodative level was low (1 D). If the aniso-accommodative response was found to be equivalent in Conditions A and D, then accommodative level did not affect the response. If the aniso-accommodative response was found to be significantly higher in Condition A (high accommodative level & low target proximity), this would suggest that high accommodative level alone could drive the response.

Results

In a paired t-test comparison, there was no significant difference in Condition A (high accommodation) compared to Condition D (low accommodation), $x = 0.11$, $x = 0.09$, respectively, $p = 0.30$; (see Lower Histograms of *Figure 8*.) Since the response in Condition A was not greater than in Condition D, high accommodative level alone cannot drive the response. In fact, the equivalent response in the two condition confirms the above comparison, that accommodative level does not affect the response.

Discussion

Target proximity

The effect of distance on the aniso-accommodative response reported by Marran and Schor (1998) was replicated, with the majority of subjects (5 of 7) showing reduced aniso-accommodation for the 1 m target compared to the 20 cm target. Furthermore, when tested at a range of target distances between these two distances, the group average gains of the aniso-accommodative response fell off with target distance ($m = 0.038$, $r^2 = 0.76$, $p < 0.05$.) This represents a 2.2-fold difference in the gain of the aniso-accommodative response when the target is at 20 cm vs 1 m. If only distance dependent subjects are used in this analysis, a 5.3-fold gain is seen between the 20 cm and 1 m target distances. This response fall-off, as illustrated in *Figure 1*, may either be described as a linear trend of increasing aniso-accommodative gain with target proximity or as a threshold function in which response facilitation occurs once a target is nearer than the threshold distance.

The results of Experiment II strongly suggest that this fall-off in the aniso-accommodative response with increasing target distance was directly related to the associated decline in target proximity alone, rather than the decline in the accommodative level or a combination of the two. As illustrated in *Figure 8*, when accommodative level was low (Conditions C and D), the aniso-accommodative response was high when concurrent target proximity was high (Condition C) but low when concurrent target proximity was low (Condition D). Thus target proximity alone could drive the response. In contrast, when target proximity was held low (Conditions A and D), and accommodative level was manipulated, the response was equally low in both conditions. High accommodative level alone could not drive the response. In fact, accommodative level had no effect on the aniso-accommodative response as shown by the additional cross experiment comparison where proximity was matched and accommodative level differed, Condition B vs Condition C.

Two subjects (CG, JM) showed no difference in the gain of their aniso-accommodative response when tested at 1 m and 20 cm. When one of these subjects (JM) was further tested at the other target distances, he continued to demonstrate invariability in his aniso-accommodative response as a function of target distance. These two subjects whose response was independent of target distance also demonstrated equivalent aniso-accommodation in the high and low target proximity conditions of these experiments.

Experience/training

In the previous investigation (Marran and Schor, 1998) it was found that the aniso-accommodative response is strengthened with training (by the monocular blur feedback in the target subjects viewed) and by practice (subjects typically demonstrated lower gains after a long break between experimental sessions). Thus it may be possible that if given sufficient experience with aniso-accommodative stimuli, the near bias could be eliminated. Indeed two subjects (CG & JM), who showed equivalent aniso-accommodative responses at 20 cm and 1 m, had more experience with aniso-accommodative stimuli than the other subjects. CG was an uncorrected anisometrope, –0.75 D in one eye and plano in the other, who had never been corrected. Thus, he was constantly presenting his visual system with aniso-accommodative stimuli when viewing targets within the far point of his myopic eye (anything within 1.3 m). JM was a lab assistant who served as a subject on a daily basis, and thus participated in numerous pilot experiments with aniso-accommodative stimuli under a great variety of viewing conditions. If the typical visual environment of the adult viewer reinforces a greater ability for aniso-accommodation for more proximal stimuli, it seems this bias may be reduced by greater exposure to aniso-accommodative stimuli in more distant viewing conditions.

In the earlier investigation, it was hypothesized that aniso-accommodation could be used during refractive error development as a directional cue for eye growth, particularly isometropization (attainment of equal refractive error) from developmental anisometropia. If this were true, it is possible that during refractive error development, the aniso-accommodative response would be equally robust at near and far viewing distances since an aniso-accommodative stimulus would be constantly present in an infant anisometrope (since most infants are hyperopic). Once the eyes had emmetropized (attained zero refractive error) from the hyperopia, the greater functional advantage of aniso-accommodative responses at near (e.g. to preserve fine stereoacuity) could then bias the response to higher gains at near (less than 1 m), as demonstrated in most adult viewers of this investigation. Target proximity could still be the primary cue driving the aniso-accommodative response if this response occurred in infants, since infants as young as 7 months show sensitivity to familiar size (Ganrud, 1998; Yonas *et al*., 1982). Emmetropization and isometropization occur over the first 6 years of life (Hirsch and Weymouth, 1991; Laird, 1991).

Volitional responses

Another possible explanation of the proximal effect on aniso-accommodation is that it is controlled by a volitional response. Since the targets used in these experiments provided subjects with visual feedback of the relative blur of the dichoptically viewed letters, subjects had access to perceptual blur information cues. Subjects could have used voluntary efforts to change their binocular accommodative state until aniso-accommodation was accomplished and the perceived monocular blur minimized. Target proximity, or knowledge of nearness of the target, could facilitate this response in some subjects more than in others. Subjects who showed equivalent aniso-accommodative responses for all conditions of this investigation may either have aniso-accommodative responses which are independent of target proximity or may simply have lower thresholds to target proximity. To test this latter hypothesis, subjects showing the distance invariant response should be tested for proximal effects at *more* distal target viewing distances than the 1 m used in these experiments. If their responses were reduced under such viewing conditions, this would suggest that proximity drives the response in all subjects. The group differences in these experiments could then be explained by differences in subjects' threshold to object proximity. Unfortunately, time limitations prevented us from testing this hypothesis.

One subject, (JS) showed distance invariance in Experiment II of the earlier investigation (Marran and Schor, 1998), but then demonstrated a distance dependent response in this series of experiments. There was about a 3-month time period between her participation in the two sets of experiments. It seems that within that time period, that either her threshold to proximity changed or that she lost access to the cues that were independent of target proximity which she was using earlier in the 1 m viewing condition.

Dependence on perceptual cues suggests that the aniso-accommodative response is not a reflex blur response. Reflex blur is a low level accommodative cue which can elicit an appropriate accommodative response even when it falls within the depth of focus of the eye, and is thus inaccessible to perceptual processing (Kotulak and Schor, 1986).

Response time characteristics

If subjects were using volitional efforts to control the aniso-accommodative response, this may help explain both the long total response time and the importance of training or practice on the response amplitude. The reaction time and total response time (onset of stimulus to attainment of final response level) of the aniso-accommodative response was, on average, 11 and 15 s, respectively (Marran and Schor, 1998), compared to consensual accommodative reaction and total response times of 350 ms and 1.0 s, respectively (Campbell and Westheimer, 1960; Tucker and Charman, 1979).

If consideration is made of the natural conditions in which aniso-accommodative stimuli occur, the long response time does not seem incongruous from an evolutionary perspective. Unlike the frequent rapid changes of consensual accommodative stimuli, most naturally occurring aniso-accommodative stimuli is static. Naturally occurring aniso-accommodative stimuli may occur in at least three ways: by uncorrected anisometropia, by unequal lens sclerosis, and by asymmetrical viewing of near objects. Anisometropic stimuli created by anisometropic refractive error or unequal lens sclerosis would develop over a long time period, so that for any given time period, a constant aniso-accommodative stimulus would be present.

Only in asymmetrical viewing of a near object would aniso-accommodative stimuli be presented *dynamically*. The first response to such stimuli would most likely be to turn one's head toward the object. This would eliminate the anisometropic stimuli and the need for a rapid aniso-accommodative response. The long latency of the aniso-accommodative response would allow the opportunity for the head to turn. Without this latency, the aniso-accommodative response, which would have occurred *before* the head turn, would have to be corrected once the head turn eliminated the aniso-accommodative stimulus. However, if for some reason this head turn response did not occur within a time period of a few seconds, as in a habitual headturn to compensate for extraocular muscle imbalance or paresis, the aniso-accommodative response could be available to reduce or eliminate the anisometropic blur.

Gain

Just as naturally occurring anisometropic stimuli occur slowly over time, they are also relatively small in magnitude. This may explain the difference in the gain of the consensual and aniso-accommodation systems, 0.98 vs 0.27, respectively.

For instance, in asymmetrical viewing, the aniso-accommodative stimulus increases with increasing eccentricity and decreasing viewing distance of the target. Significant aniso-accommodative stimuli occur only at very eccentric and very near target viewing conditions. For instance, a 0.75 D aniso-accommodative stimulus is not attained until the target is viewed with 30° of eccentricity at a distance of 20 cm.

In symmetrical viewing, naturally occurring aniso-accommodative stimuli is also limited in magnitude. In a general clinical population, about 10% of the patients have anisometropia, as defined by an interocular difference of 1.0 D or more. This prevalence is reduced to 2.5% if a criteria of an interocular difference of 2.0 D or more is used to define anisometropia (Laird, 1991). Thus, about 75% of all clinically defined anisometropia (e.g. interocular difference of 1.0 D or more) is between 1.00 and 2.00 D. With this in mind, the gain of aniso-accommodation may be adequate for the majority of anisometropes. For instance, for an interocular difference of 1.50 D and a typical gain of 0.25, the aniso-accommodative response would be 0.375 D, leaving about 1.0 D of interocular blur. If this blur is split evenly between the two eyes, 0.50 D of consensual accommodative blur remains. This may be within the depth of focus of the eye, as demonstrated by the average 0.50 D lag of the accommodative response to a target subtending 7.5 min of arc at 40 cm (Scheiman and Wick, 1995). The letter size used in the target used in all of our experiments subtended 30.0 minutes of arc. It is possible that slightly higher aniso-accommodative gains would have been measured if smaller letters were used since spatial frequency content can affect the consensual accommodative response (Ciuffreda and Hokoda, 1985).

Conclusion

This set of experiments demonstrate a linear fall off in the gain of the aniso-accommodative response with increasing target distance for those subjects (5 of 7) who show a distance dependent effect. Cues such as absolute disparity and image size were held constant while target proximity and accommodation were independently manipulated. Target proximity alone rather than accommodative level, or a combination of the two, was responsible for the distance dependent effect demonstrated by these subjects. These results suggest that a perceptual cue and possibly a volitional response, rather than a reflex blur response, is involved in aniso-accommodation. This conclusion is strengthened by the previous finding of a long reaction and response time, 11 and 15 s respectively, to step aniso-accommodative stimuli[1]. Those subjects showing a distance invariant aniso-accommodative response (2 of 7) may have been able to use perceived aniso-accommodative blur alone and their ability to disregard proximal cues may have resulted from greater experience with the aniso-accommodative stimuli. Alternatively, these subjects may have had a lower threshold to proximal stimuli and experienced target proximity at the more distant (1 m) viewing condition.

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