MAR Ophthalmology (2023) 6:1

Research Article

Accommodation Responses in Myopes with Multifocal Contact Lenses

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Received: 26 June 2023

Published: 10 July 2023

Abstract

Objectives: *To measure accommodation responses (ARs) in single vision contact lenses (SVCLs) and multifocal contact lenses (MFCLs) under blur (B), blur and light (BL), and blur, light, illuminance, and size (BLIS) conditions in two directions: distance to near (D-N) and near to distance (N-D).*

Methods: *Five myopic participants wore two lenses under each condition. Accommodation step responses were measured to obtain baseline over-refraction values with 6-m distance fixations and ARs to 33-cm near distances. The refraction and accommodation responses produced an average of 10 continuous refractometer readings over seven cycles.*

Results: *The mean AR for SVCLs under the BL condition was 1.57±0.55 for N-D and 1.56±0.54 for D-N. The corresponding values under the B and BLIS conditions were, respectively, 1.59±0.57 and 1.57±0.57 and 1.51±0.46 and 1.45±0.51. For MFCLs, the mean AR under the BL condition was 0.85±0.61 for N-D and 0.83±0.61 for D-N. The corresponding values under the B and BLIS conditions were, respectively, 0.99±0.64 and 1.00±0.61 and 0.86±0.57 and 0.89±0.53.*

Conclusions: *The near AR amplitudes differed between SVCLs and MFCLs under the BL and B conditions, while distance differed under BLIS. However, the lenses showed no significant difference in the accommodation step response under all three conditions.*

Keywords: *Accommodation response, Myopia progression, Multifocal contact lenses, Single vision contact lenses*

Introduction

Near-work is a prominent environmental factor that increases the risk of myopia progression, especially in schoolchildren.[1] Harb et al.[1] found a significantly longer accommodation lag in myopes compared to in emmetropes during near work. Due to the inaccuracy of accommodation systems, an accommodation lag occurs when the eyes focus on a near target, whereas an accommodation lead occurs when the eyes shift from near to distant targets, resulting in leftover accommodation. Accommodation lag is suspected to cause myopia progression due to the effect of hyperopic defocus stimulation on axial elongation. [1,2]

Gwiazda et al. [3] investigated the function of the accommodation response at near distances for real targets between myopic and emmetropic children, and they found that myopic children with full correction errors accommodated significantly less than emmetropic children. Both groups presented with accommodation lags for near targets. [3,4] Additionally, the study by Harb et al. [1] showed that accommodation responses in young myopic children showed significantly greater changeability than in young emmetropes and involved larger accommodative lags at near work. Therefore, greater accommodation lags in myopic children could possibly lead to a hyperopic shift in the eyes, thus facilitating myopia progression.

Anstice and Phillips[5] measured the effects of dual-focus (DF) contact lenses (CLs) on reducing myopia progression in children between 11 and 14 years of age. In their study, the accommodation response was measured when participants in two groups (a group with DF CLs in one eye and single vision distance (SVD) CLs in the other and another group with DF lenses in one eye and single vision near (SVN) CLs +2.50 D in the other) viewed near targets at 40 cm at a static 2.50 D. Measurements were taken at baseline and at two separate occasions (10 and 20 months). Those fitted with SVD and DF lenses showed a 2.07 D accommodation response when viewing the near target at 40 cm, which usually requires an accommodation demand of 2.50 D, as seen in Figure 1. However, when participants wore DF lenses with SVN lenses, the accommodation was 1.78 D. The study suggested that with a correction of +2.00 D, the DF lenses were able to produce a sufficient 0.43 D myopic defocus during near work, as demonstrated in the group wearing DF and SVD lenses. With the incorporation of myopic defocus as a preventive measure against axial elongation, eyes wearing DF lenses showed a 54% decrease in myopia progression and up to 80% reduction in axial elongation over the course of 20 months in comparison with control eyes wearing SVD lenses.

Therefore, DF lenses were suggested to be successful in retarding myopia progression by providing sustained myopic defocus in the eyes, unlike SVD lenses, which are imposed during near work to achieve hyperopic defocus on the peripheral retina.

Another similar study on the effect of myopic defocus in myopia progression was conducted by assessing the effect of bifocal contact lenses (BFCLs) on accommodation errors and responses.6 The study involved 35 young adult participants, of which 10 were emmetropic and 15 were myopic. The accommodation response was measured at four distances (100, 50, 33, and 25 cm) using three different types of single: SVD, SVN (+1.50 D add), and BF (+1.50 D). The study found that both myopes and emmetropes with SVD lenses experienced accommodation lag at all four distance targets, and when both groups wore BFCLs, the accommodation response diverted to accommodation lead.

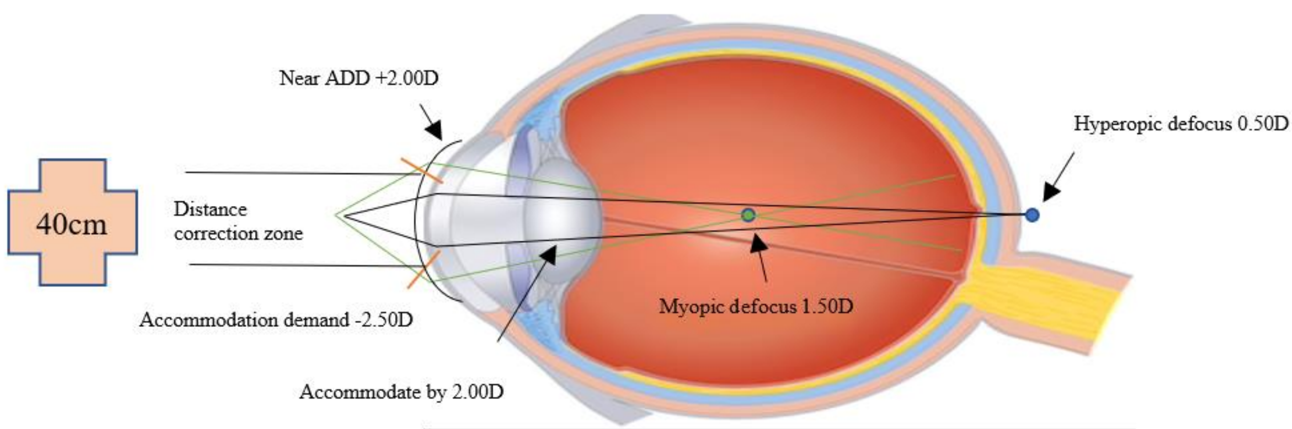

Figure 1: Schematic eye of DF CL. Plane schematic eye from (Peter, 2007).

In the above-mentioned study, myopic participants were more exposed to accommodation lag with the four distance targets when using SVN lenses (+1.50 D). However, the accommodation was significantly greater in the myopic participants than in the emmetropic participants when looking at 1-D and 2-D targets. In contrast, the emmetropic participants showed an accommodation lag when looking at 1-D and 2-D targets and an accommodation lead with the 3-D and 4-D targets. Tarrant et al. [6] showed a significant difference in the accommodation responses between both groups. When the participants wore BFCLs, as seen in Figure 2, with correction of distance and near (+1.50 D) and the eye accommodated by 1.50 D at near, a hyperopic defocus was produced by the distance correction zone of about 1.50 D, while the near (+1.50 D) produced no change with a myopic defocus of 0 D. However, when the participants wore SVN lenses (+1.50 D) and viewed a near target at 33 cm, the eye accommodated by 2.50 D and remained 0.50 D behind the retina, which represents a hyperopic defocus, and with a near addition (+1.50 D), the rays were in front of the retina (1.00 D), which is a sign of myopic defocus. Tarrant et al.[6] provided a myopic defocus of 1.1 D by using SVN lenses, but this was not a good option because it affected distance viewing despite improving accommodation at near targets. Therefore, BFCLs are a better option because the lenses consist of distance and near additions that can provide clear vision for distance and near targets. In addition, BFCLs can help reduce the accommodation lag, thus providing sufficient myopic defocus to prevent myopia progression.[6]

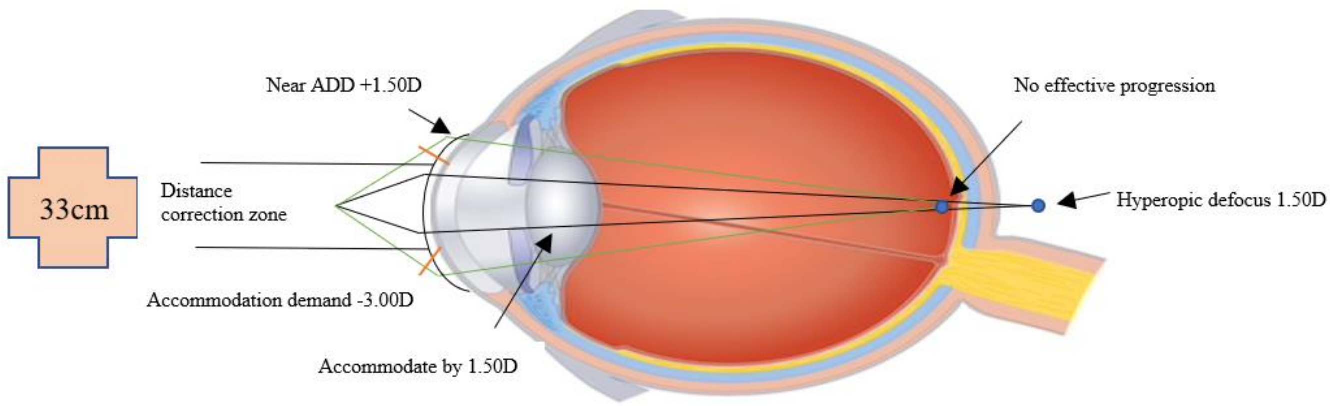

Figure 2: Schematic eye of BF CL. Plane schematic eye from (Peter, 2007).

The use of multifocal CLs for patients with presbyopia has reduced recently, and there is more research suggesting the use of multifocal CLs for myopia control in children. Therefore, an investigation of accommodation responses with participants looking through MFCLs is essential to establish how this factor influences myopia progression. Pettersson et al.[7] aimed to investigate accommodative behavior in young adults fitted with MFCLs (centered distance) while decreasing the level of blur on the retina, assessing whether these lenses can be used as an alternative treatment. They found that, when wearing multifocal center-distance CLs, accommodation did not relax in young adults. This was determined by the fact that the lag remained constant with and without the CLs, suggesting that the use of MFCLs in young adults with the ability to accommodate was not a suitable approach to decrease blur.[7] This finding was similar to the result of another study by Montés-Micó et al.,[8] which showed no significant difference between SVCLs and MFCLs in terms of accommodation lag when worn by young adults.

Of these previous studies, one study used the distance part of CLs,[5] and another used a mixture of the distance and near parts of CLs.[6] Therefore, it remains unclear which CL design is useful in alleviating myopia progression.

Considering the conflicting results described above, further research in this area is needed. It is important to know which part of the CL the eye is using because if it is using the near part of the CL, there is no protective effect and no reason to explain why these CLs are involved in reducing myopia progression.

In this study, accommodation steps were studied because no previous study has measured step responses in these CLs and because accommodation steps are a major part of how the eyes function in real life. However, accommodation step responses may differ between different refractive groups. As shown in the study by Strang et al.,**[**9**]** the accommodation step responses are different between emmetropes and myopes. Myopes appear to show larger accommodation errors when presented with 2-D and 3-D accommodation stimuli, whereas emmetropes can initiate a normal accommodation step response.**[**9**]** Interestingly, when presented with smaller (less than 2-D) or larger (more than 3-D) steps, both emmetropes and myopes show no difference in the accommodation step response.**[**9**]**

This study aimed to determine how multifocal CLs with +2.50 D influence accommodation responses in the eyes. This study will help to verify the need for multifocal lenses as an alternative treatment for myopia progression by providing myopic defocus protection against axial elongation. Additionally, this study was conducted under three different stimulus conditions to determine changes in the accommodation responses under stimulation with proximal cues. The accommodation response was measured under dynamic conditions to mimic the natural everyday viewing interchange between distance and near targets.

Methods

Ethical approval

This research complies with the tenets of the Declaration of Helsinki. Ethical approval was provided by the School of Health and Life Sciences Ethics Department (HLS/LS/A18/039). Participant information remained confidential throughout the study. Only the researchers involved in the study could access the collected data.

Experiments

The experiments in this study were performed in myopic participants by using two types of CLs (SVCLs and MFCLs) under three conditions (blur **[**B**]**, blur and light **[**BL**]**, and blur, light, illumination, and size **[**BLIS**]**) from two step directions (near to distance **[**N-D**]** and distance to near **[**D-N**]**). The accommodation step responses were measured using the Shin-Nippon SRW-5000 autorefractor (Tokyo, Japan). Five healthy students from Glasgow Caledonian University were selected as the study participants. All the participants were female adults between 25 and 35 years of age, had astigmatism less than 0.75 D, had a corrected monocular visual acuity of 20/20, and showed no history of ocular pathology or systemic disease.

The participants were asked to disclose current and past refractive information and related family history. Prior to the start of the experiment, each participant received an explanation regarding the concept of the experiment along with detailed instructions. Subsequently, a baseline refraction measurement of both eyes was taken with the autorefractor. For each condition, 10 measurements were averaged, and the mean spherical equivalent (MSE) was calculated.

Measurements

The autorefractor was used to obtain baseline refraction measurements with a distance fixation of 6 m, and the accommodation response was determined at both 6 m and 33 cm. Ten static refractometer readings were taken for each distance and near target over 10 accommodation step cycles, where each step cycle was performed from D-N and N-D. By using a specially modified, commercial, open-field, infrared autorefractor (that is, the Shin-Nippon SRW-5000), accommodation steps were recorded. The autorefractor uses infrared light to record the response and has the advantage of using an open binocular field.

The recording was set in static mode at a sampling rate of 52 Hz. The instrument was calibrated according to each participant while they were viewing 0.0 logMAR at 6 m. Before beginning, the equipment was cleaned with alcohol swabs, and the participant was set in a comfortable position. The autorefractor and computer were then turned on. Refraction measurements of the right and left eyes were then taken and used as the participant's refractive error.

Stimulus conditions

In an initial pilot, two participants were instructed to look at the targets and make them clear. The participants were not told about the distance and near targets. The room lights were turned off, and the targets had the same apparent size. This provided a blur-only stimulus without proximal cues. These two participants did not show step responses, so the set-up was used in subsequent assessments. Subsequently, the participants received verbal instructions indicating the rough location of the target they were viewing.

For example, "now you are viewing the distance target" or "now you are viewing the near target."

Three different set-ups related to the volume of proximal information on the target were used. The three different conditions were:

1. Blur (B) condition. The room lights were off, and the targets were of the same apparent size and had the same illuminance.

2. Blur and light (BL) condition. The room lights were on, and the targets were of the same apparent size and had the same illuminance. This increased the presence of proximal cues since light provides the participant with a general idea of where the new target is placed.

3. Blur, light, illuminance, and size (BLIS) condition. The room lights were on. This condition yielded the most proximal cues because the participant could observe a difference in target size and illumination between the near and distance targets. The near target size was larger and brighter. This was done by placing a neural density filter of 0.8 in front of the distance stimulus condition to reduce the amount of light coming from this target and therefore entering the right eye.

Stimuli

Maltese cross target

Throughout the experiment, a high-contrast (80%) Maltese cross target was observed monocularly using the right eye. This target was chosen since it is formed of different spatial frequencies at various orientations and has been used in several previous accommodation experiments.9 The distance fixation target was at 16 cm vertically (V) and 15.4 cm horizontally (H), and the Maltese cross target equivalent was single 6/60 (0.1) Snellen visual acuity (angular subtense: 15°; average luminance: ×2 lux).

The near accommodative target was a high-contrast test and had equal V and H values of 1.14 cm, with a Maltese cross target equivalent of 6/6 (1.0). Two types of near targets were used. In the B and BL conditions, the angular subtense and luminance were the same as the distance target (angular subtense: 15°; average luminance: ×2 lux) However, in the BLIS condition, the near target was larger and brighter (angular subtense: 15°; average luminance: ×2 lux).

In the experimental set-up, the near target was arranged straight in front of the right eye, and a physical septum, which was an infrared filter, allowed visible light to pass through, so autorefractometer measurements could still be performed. This was done because the right eye was the measurement eye and the left eye converged with the stimuli. A mirror was used to reflect the distance target from 6 m.

With the room lights on, the participants could see both targets simultaneously, and the two Maltese cross targets (distance and near targets) were then aligned with each other using the mirror. Before examination, the alignment of the system was double-checked to ensure that both targets were aligned in the participant's central view with no displacement of the targets.

Subsequently, the participant removed the CL from the right eye (measurement eye), as measurements through the multifocal lens were not possible since the optic zone of the multifocal lens interfered with the zone used by the autorefractor. As a result, the participant needed to view the target with one eye (which had the CL in) and record through the other (which did not have a CL in). We did not obtain recordings through multifocal or single vision lenses in order to make a perfect comparison.

An initial calibration was performed whereby the lights were turned on and an average of 10 continuous refractometer readings for seven cycles from the right eye were taken while the participant viewed the distance target. The dimensions of the measurement rings in pixels were measured 10 times, and the average was used as the calibration value.

During the experiment, only one of the two targets was lit up at any point in time. The participant waited for a response, and the second target lit up 8 s later so that the participant completed an accommodation step. This procedure was repeated 10 times.

We instructed the participant to focus on two crosses at different distances from the eye (near and far targets), of which one was lit up, followed by the other before the former was lit once again. The participant was asked to focus on the cross and maintain a clear vision of the target regardless of the different distances it was presented at. They were instructed to blink whenever they had to and before the target change in order to keep their vision clear. The experiment was paused if the participant's eye felt dry since this would compromise the accuracy of the measurements.

Contact lenses

This study was conducted using two types of CLs (SVCLs and MFCLs) with a +2.50 add. The participants wore the lenses randomly, so they did not know whether they wore the SVCL or MFCL first. Upon first wearing the MFCLs, the participants were allowed 20 min to adapt. In the meantime, a team member would chat with the participant or ask them to read. The participants were not allowed to use a phone to stimulate the motion. They were fitted with clear multifocal CLs (CooperVision Ltd, Hamble, UK).

Data analysis

Ten readings of seven cycles for each condition were obtained, and then the average of the 10 readings in each cycle was calculated and recorded separately for both distance (D) and near (N). Subsequently, the seven steps for each participant for each condition were averaged, giving an accommodation response value for the D and N targets. The standard deviations of these were also calculated. The amplitude of each accommodation step response was calculated using the total distance average minus (-) the total near average for each condition, providing an amplitude for the N-D and D-N for each condition for each participant. Statistical analysis of these values was conducted using repeated measures ANOVA tests using version 24 of SPSS. Values were compared in the SVCLs and MFCLs individually under the three stimulus conditions to determine if there was any difference between the conditions or between each CL. Differences were considered statistically significant when the p-value was less than 0.05.

Results

Mean accommodation response at distance and near targets

Figure 3 shows that the mean accommodation response was significantly greater in the near condition ($p < 0.05$). There was no significant difference in the accommodation response among the three stimulus conditions ($p = 0.389$). However, there was a significant difference in the accommodation response between SVCLs and MFCLs in the B condition with near (2.48±0.55 D vs. 1.68±0.48 D, $p < 0.05$), in the BL condition with near (2.43±0.54 D vs. 1.47±0.52 D, $p < 0.05$), and in the BLIS with distance (0.89±0.78 D vs. 0.72±0.77 D, $p < 0.05$).

Amplitude of the accommodation step response

The mean±SD amplitudes of the accommodation step responses between D-N and N-D for the SVCLs and MFCLs under the three conditions are shown in Figure 4. With the MFCLs, the amplitude of the step accommodation response was not significantly reduced compared to that of the SVCLs ($F = 5.717$, $p = 0.075$). In addition, no significant difference in accommodation step responses was observed between the

MFCLs and SVCLs in the three viewing conditions (B, BL, and BLIS; F = 2.295, p = 0.175). Likewise, the accommodation step responses between the MFCLs and SVCLs in each condition (B, BL, and BLIS) from D-N and N-D were not significant (F = 1.252, p = 0.336).

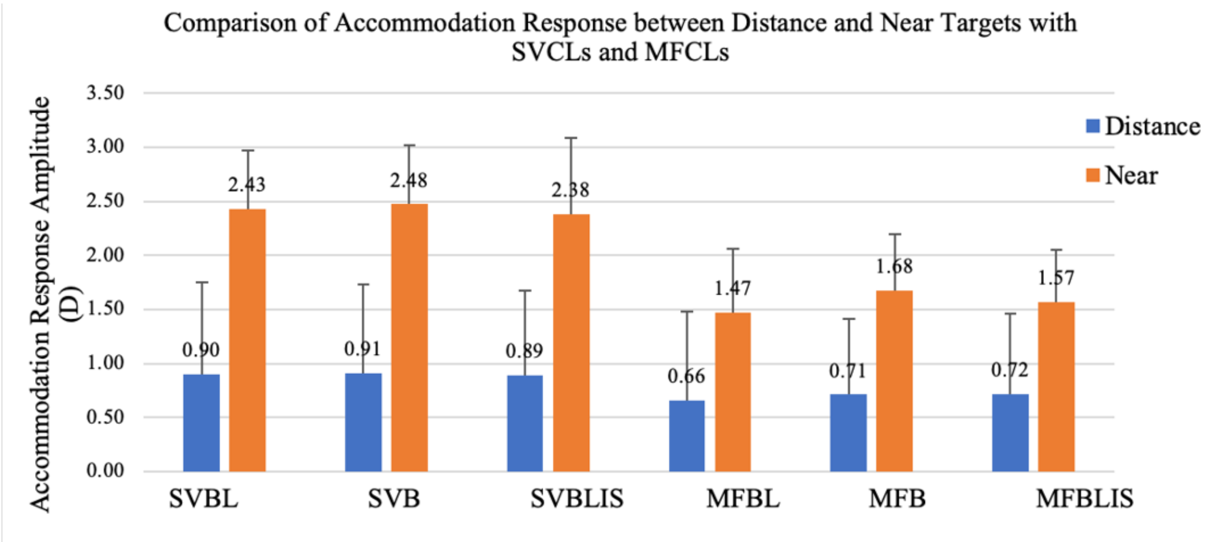

Figure 3: Mean accommodation response in distance and near conditions with the two lenses (single vision contact lenses **[**SVCLs**]** and multifocal contact lenses **[**MFCLs**]**) under the three conditions (blur **[**B**]**, blur and light **[**BL**]**, and blur, light, illuminance, and size **[**BLIS**]**).

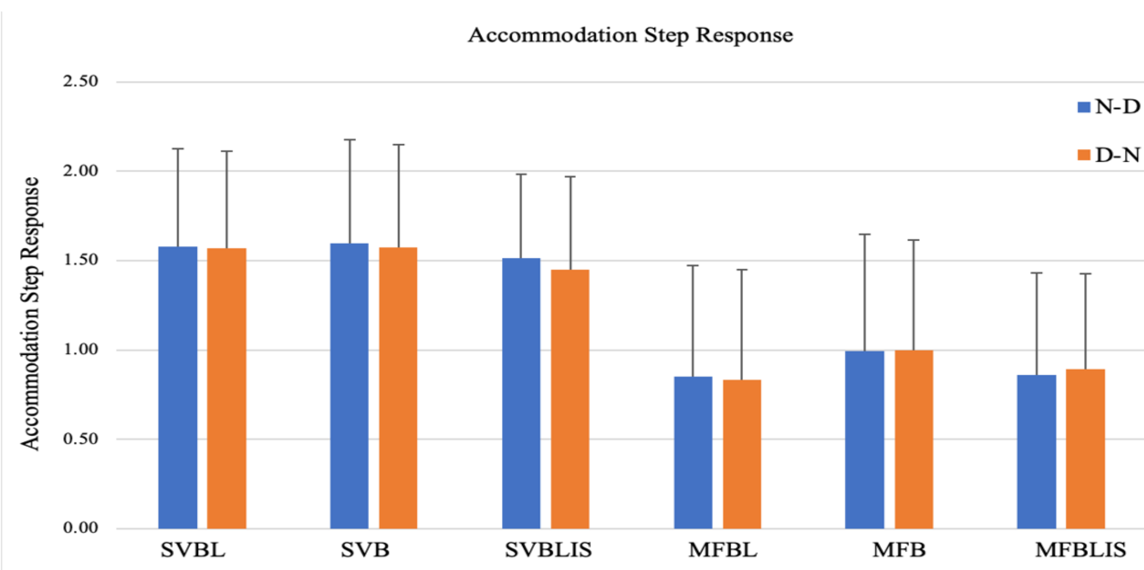

Figure 4: Accommodation step responses for the two lenses (single vision contact lenses **[**SVCLs**]** and multifocal contact lenses **[**MFCLs**]**) under the three conditions (blur **[**B**]**, blur and light **[**BL**]**, and blur, light, illuminance, and size **[**BLIS**]**) between near to distance (N-D) and distance to near (D-N) conditions.

Discussion

Effects of stimulus conditions

As described previously, the effects of various stimulus conditions were not certain when we conducted the pilot study to assess accommodation step responses under the blur condition with the same illuminance and size of near and far targets, as the participants found it difficult to accommodate the stimuli accordingly. With additional proximal cues and verbal instruction, the participants were able to provide proper accommodation step responses. In addition, the fact that our study showed no significant difference in accommodation responses under the three different conditions could be due to the effect of verbal instruction on the voluntary accommodation response.

Mean accommodation response of MFCLs

Given our results, we can argue that this study agrees with the hypothesis of MFCLs half distance and half near, which is in accordance to the study by Anstice and Phillips.**[**5**]** The numerical results showed the extent to which the CL is accommodated. For example, SVCLs are accommodated by 2.50 D when viewing the near target and 0.9 D when viewing the distance target. When using SVCLs as distance CLs in the experimental set-up, the participants were able to accommodate normally. Immediately after the target was changed, once they saw from near to distance, the reading showed a slightly higher lead compared to that in other studies that wait for the participant before taking the measurement. An accommodation response of 1.50 D occurs with MFCLs when viewing a near target. The rays traveling through the distance part of the CL produce hyperopic defocus 1.50 D, as shown in Figure 5. The rays traveling through the near part of the CL produce 1.00 D of myopic defocus.

If the participants were using the near part of the CLs alone, we would expect them to accommodate by around 0 D (the near target has a vergence of 3 D, and the add is 2.50 D, which would make the target clear). The results show that the participants were accommodated by a sizable amount (1.50 D), so they were not solely using the near section of the MFCLs. If participants were using the distance part of the CLs alone, we would expect them to accommodate by around 2.50 D (this is what they accommodated with the SVCLs). The results show significantly reduced accommodation responses while participants were viewing the MFCLs compared to the SVCLs, so they were not solely using the distance part of the lenses. Thus, the participants were using information from both the distance and near sections of the CLs.

The presence of 1.00 D myopic defocus produced in this set of conditions is likely to provide the protective part of the MFCL to reduce the progression of myopia.

Conversely, a study by Montés-Micó et al.**[**8**]** did not agree with our study; it reported that there was no significant difference in the lag of accommodation between SVCLs and MFCLs worn by young adults. Furthermore, they stated that in the young adult group, there was a statistically significant difference in the lag of the accommodation response comparable to the accommodative stimulus of 0.25 D on patients with myopia ($p = 0.002$).

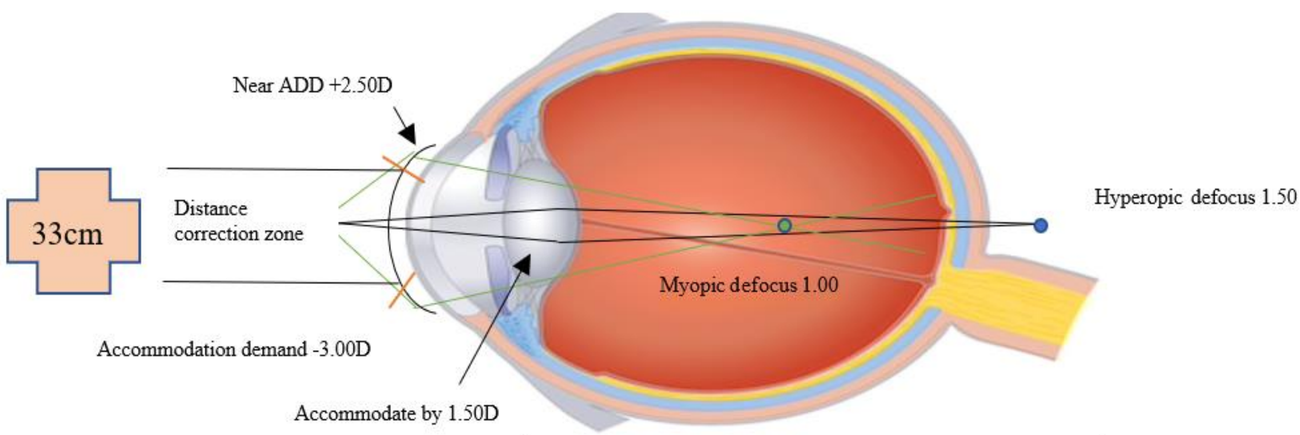

Figure 5: Schematic eye wearing a multifocal contact lens (MFCL). Plane schematic eye.11

Contact Lens Design

Although the CLs used in the study by Anstice and Phillips **[**5**]** were DF lenses instead of multifocal lenses, their study drew results similar to ours. This could possibly be due to the lens design of the Biofinity multifocal lenses used in this study, which use center distance correction instead of center near design. The lens design of the multifocal lenses used in myopia treatment could possibly have a different result. In the study by Montés-Micó et al.,**[**8**]** a multifocal lens with a center near design failed to establish any changes in the accommodation response. Therefore, multifocal lenses with a center distance lens design would provide a better protective mechanism against myopia progression than multifocal lenses with a center near design.

Future study

This study showed that future studies do not need to focus on what stimulus conditions to use, as none of the three conditions had a significant effect on accommodation responses. Additionally, this study found that it was vital that the participants were given clear instructions and descriptions such as "this is the near target" and "this is the distance target." However, future studies might want to increase the adaptation period for multifocal CLs. Instead of young adults, it would be more interesting to study young children wearing MFCLs over a longer period to establish the actual effect of the MFCLs on myopia progression. Due to time limitations, this study was only able to assess five participants. Future studies should consider including 19 participants to determine the significance of accommodation step responses, as recommended by the G*power. Thus, they would be able to provide better information on the effect of MFCLs on accommodation response.

Conclusion

This study yielded three main findings. First, MFCLs with a +2.50 D add center distance design could produce adequate myopic defocus in myopic participants. Second, there was no accommodation response difference between different condition set-ups as long as verbal instructions were given. Third, MFCLs with a +2.50 D add did not affect accommodation step response.

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