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Refractive Intervention

The Potential of Self-Controlled Focus for Myopia Prevention: A Pilot Study Using a Mobile Phone

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Purpose: The purpose of this study was to determine the short-term impacts of reading through self-controlled focus.

Methods: Thirteen near-emmetropes performed a 30-minute reading task under unrestricted working distance on a mobile phone while wearing either (1) a self-adjusted eyeglass (SAG) or (2) a plano eyeglass (PE), equipped with an integrated Time of Flight (ToF) distance sensor. The ocular impacts of the self-controlled focus on spherical equivalent refraction (SER), axial length (AxL), and choroidal thickness (ChT) were tested before and after reading. Temporal dynamics of dioptric correction, reading distance, and speed were tracked to assess the behavioral impact of the defocus correction.

Results: Our results show a significant reduction in hyperopic retinal defocus (mean difference = −1.12 diopter [D] ± 1.00 D, $P < 0.005$) accompanied by larger working distance (mean difference = 75.96 mm ± 33.88 mm, $P < 0.05$) under self-adjusted focus, as compared with the healthy controls. This behavioral change showed no significant influence on reading performance, as estimated by reading speed, but affected ocular responses: as expected, reduced hyperopic retinal defocus in SAG resulted in reduced AxL elongation (mean difference: 9 µm ± 4 µm, $P < 0.05$) and SER (mean difference = −0.17 D ± 0.078 D, $P < 0.05$). On the other hand, ChT exhibited a significant association with dioptric dynamics ($P < 0.001$), but not lens correction, suggesting the potential role of visual dynamics.

Conclusions: Self-controlled defocus has a significant impact on short-term eye changes under reading. Further work is necessary to understand the long-term impact of this solution and its interaction with individual behavioral responses.

Translational Relevance: Self-controlled defocus has the potential to reduce hyperopic retinal defocus for myopia prevention and control in schoolchildren.

Introduction

Myopia – the common manifestation of an over elongation of the eyeball – enables clear near vision but at the expense of blurred distance vision. The myopia boom[1] observed in the past decades has raised important concerns in the scientific community, as one of the ocular problems that affect most people in the world. It is particularly elevated in East Asian regions, like Hong Kong, where a large proportion of schoolchildren start wearing spectacle lenses in primary school.[2–4] Although myopia can be corrected with permanent eyeglasses, myopia can have deleterious impacts on psychology/behavior,[5,6] and when severe, is associated with important sight-threatening conditions.[7] On a neural level, research has also shown that individuals with myopia exhibit altered

brain activity[8] and visuospatial attention.[9] Although the etiology of myopia is still under investigation, studies suggest that environmental factors,[10] including outdoor time and near work, play a key role in myopia. In particular, the dioptric properties of the visual environment have been recognized as important external cues influencing the development and control of myopia.[10–16] In this respect, cumulated studies have shown that sustained optically imposed defocus triggers automatic ocular compensatory responses to minimize retinal defocus.[17] Exploiting this exogenous compensatory mechanism, myopic control lenses[13] have been invented that project onto the eye peripheral myopic blur to impel the eye to shorten its length. Optical interventions, such as the defocus incorporated multiple segment (DIMS) spectacle lens, have demonstrated satisfactory results in reducing the progression of myopia in patients with early-onset myopia[17–20] and are commonly implemented in the treatment of myopia. However, potential concerns with the use of myopic control lens in non-myopic eye, including the generation of blurry visual signals, had long restricted their use to participants diagnosed with pre-myopia[21] and they are often prescribed too late to prevent myopia onset. Thus, to date, there is no definitive optical preventive method that has emerged from the concept of lens-induced ocular compensation,[22] which can protect the most highly vulnerable populations against the onset of myopia at school (e.g. children with very close reading distance or/and parents with myopia).[23] Given the triggering role of retinal defocus on the myopia response,[17] a controlled removal of blur produced by near work could be a beneficial method to prevent myopia in children the most at risk of developing myopia. Although blur reduction is naturally performed by the eye via ocular accommodation and body/head adjustment provided accurate sensing of defocus, this process can be impaired under intensive, stressful near work by physiological[24] and attentional[25] costs, which could favor an external focus control. Notwithstanding, a system that adaptively corrects retinal defocus by accounting for accommodation and viewing distance remains technically challenging. Hence, the question of whether an external focus adjustment, using the eye's defocus detection, could successfully reduce myopiagenic blurs caused by ocular responses or/and near work. To address this question, we investigated the ocular effect of self-adjusted focus during reading on a mobile phone using a distance sensor-integrated adjustable eyeglass. The distance sensor-integrated adjustable eyeglass ensured adjustment of visual focus without the positional restraints imposed by traditional optical bench-based tunable focus[26–29] and the optical performance limits of deformable lens-based eyeglass.[30] Our purpose was to determine whether self-adjustment of defocus can effectively reduce the environmental myopiagenic defocus during reading using self-adjustable focus eyeglasses, preventing the elongation of the eye and myopia development. To test this hypothesis, emmetropic participants completed a 30-minute reading task at a free reading distance, both with and without adjustable eyeglasses, using a repeated-measures crossover design. Throughout the task, their behavioral responses (reading distance and reading speed) and were continuously recorded during the task, and ocular measurements (axial length [AxL] and accommodation, and choroidal thickness [ChT]) were taken before and after reading. Our results demonstrated that distance and retinal dioptric are only partially minimized by self-focus adjustment under condition of reading with unrestricted reading distance, in spite of the absence of biofeedback signal, translating into a reduction of accommodation and axial elongation over short-term simulated reading, which could be potentially harnessed for myopia prevention and control.

Methods

Participants

A total of 13 near-emmetropes Chinese adults (20–35 years old) were recruited to match the following inclusion criteria: (1) best-corrected distance visual acuity of logMAR 0.00 or better in both eyes; (2) |spherical-equivalent error| < ±1.00 diopter (D). The exclusion criteria were as follows: (1) astigmatism ≤−0.75 diopter cylinder (DC); (2) anisometropia ≥1.50 D; (3) binocular vision or accommodation problems; (4) any type of eye disease; (5) ocular trauma, or (6) surgery; (7) a history of myopia control intervention; or (8) prescription of medication. Based on the previously observed change of 10 µm ± 8 µm of AxL in response to 3D of defocus change,[31] a power analysis using G*Power 3.1 estimated that a sample size of 13 participants would achieve over 90% power to detect a significant change in AxL, given a 2-tailed paired *t*-test at a 0.05 significance level. The clinical characteristics of the participants are listed in the Table.

The experimental procedures were approved by the Institutional Review Board of The Hong Kong Polytechnic University, and the research was conducted according to the principles expressed in the Declaration of Helsinki. Informed consent was obtained from each participant.

Table. Clinical Characteristics of the Participants

Subject	Age	Gender	SER, RE, D	SER, LE, D	Character Size, H/V, mm	Lens Power, RE (D), Mean + SD	Lens Power, LE (D), Mean + SD
1	21	M	−0.625	−0.625	2.26/1.70	0.7419 ± 0.5450	0.9073 ± 0.2976
2	21	F	0.9375	0.8125	2.35/1.70	0.5484 ± 0.1490	0.5484 ± 0.1490
3	23	F	0	0.1875	2.35/1.70	1.0806 ± 0.4289	1.1613 ± 0.3897
4	22	F	−0.125	−0.0625	2.07/1.51	0.7097 ± 0.3766	0.7339 ± 0.4020
5	23	F	−0.0625	0.1875	1.88/1.41	0.5242 ± 0.0745	1 ± 0
6	30	F	−0.1875	−0.3125	1.98/1.41	0.5444 ± 0.0963	0.5444 ± 0.0963
7	22	M	−0.75	0.1875	2.35/1.70	0.6089 ± 0.1846	0.6089 ± 0.1846
8	29	M	0.125	−0.125	1.98/1.41	0.9839 ± 0.0891	0.9839 ± 0.0891
9	29	M	−0.0625	0.5	1.79/1.32	0.5202 ± 0.0686	0.5 ± 0
10	19	F	0.3125	−0.625	2.16/1.60	0.5202 ± 0.0686	0.5202 ± 0.0686
11	32	F	0.1875	0.25	1.69/1.22	0.5 ± 0	0.5081 ± 0.0445
12	21	F	0.25	0.125	1.88/1.41	0.5161 ± 0.0619	0.5 ± 0
13	21	F	0.0625	−0.3125	2.07/1.51	0.5202 ± 0.0686	0.5202 ± 0.0686

Apparatus

Participants engaged in binocular reading tasks on a mobile phone (IPS LCD, Nokia 2.4) featuring a 6.5-inch diagonal screen and a resolution of 720 × 1600 pixels, resulting in a pixel density of approximately 270 pixels per inch. A white-on-black (white: 60 cd/m^2, 100% contrast) text written in Chinese (font = Yahei Microsoft) was used in photopic light conditions (room luminance = ∼ 25 cd/m^2). Each participant attended a total of three sessions (total duration = 3 hours), each set on a separate day in the morning between 9 AM and 12 PM to minimize diurnal-related ChT variations and ensure no carry-over effect between sessions.

Experimental Protocol

Pre-Measurement

On the first visit, each participant underwent a phase of pre-measurement screening, including dry objective and subjective refraction, routine visual acuity measurement, and binocular acuity reading threshold assessment.

Acuity Reading Threshold Assessment. The binocular acuity reading threshold assessment was performed using visual texts presented on a mobile phone to determine the smallest font size for which the participant could read at its maximum speed. Throughout reading, participants rested on a chin-rest positioned at a distance of 33 cm from the mobile phone, which was fixed vertically on a stand. During the task, participants were instructed to read aloud each character as fast as possible without pauses/correction in the case of errors or uncertainty. Text presented on the mobile phone were controlled by custom software developed using the Psychophysics Toolbox version 3[32,33] in MATLAB (version 2022a). To allow text control, participants maintained in their hand a mouse, that they were instructed to press immediately after reading aloud the last character of each line. This permitted recording the reading speed for each tested font size, while triggering the automatic update of the size of the visual text for the next line to be read.[34] For each participant, the relationship between reading speed and font size was determined by fitting the data with a two-order polynomial curve, after exclusion of the plateau of intermediate character sizes and/or decline in reading speed for very large characters. The critical reading font size was determined by selecting the smallest font size for which the participant could read at its maximum speed.

Experimental Tasks

Following the pre-assessment, participants were invited to attend two additional visits. In each visit, participants performed a sustained reading task (reading time = 30 minutes) using visual texts presented on the same mobile phone. Texts used during the task had a fixed size, comprising 80 characters per rows with 31 rows of characters, which were presented as one full page document on the display. Sentences were presented horizontally, using the largest side of the screen. Given a nominal reading distance of 33 cm, the text subtended about 26 degrees × 12 degrees. To ensure that the same number of characters appeared on each row, sentence punctuation was removed from the text. The text font size was set near the critical reading

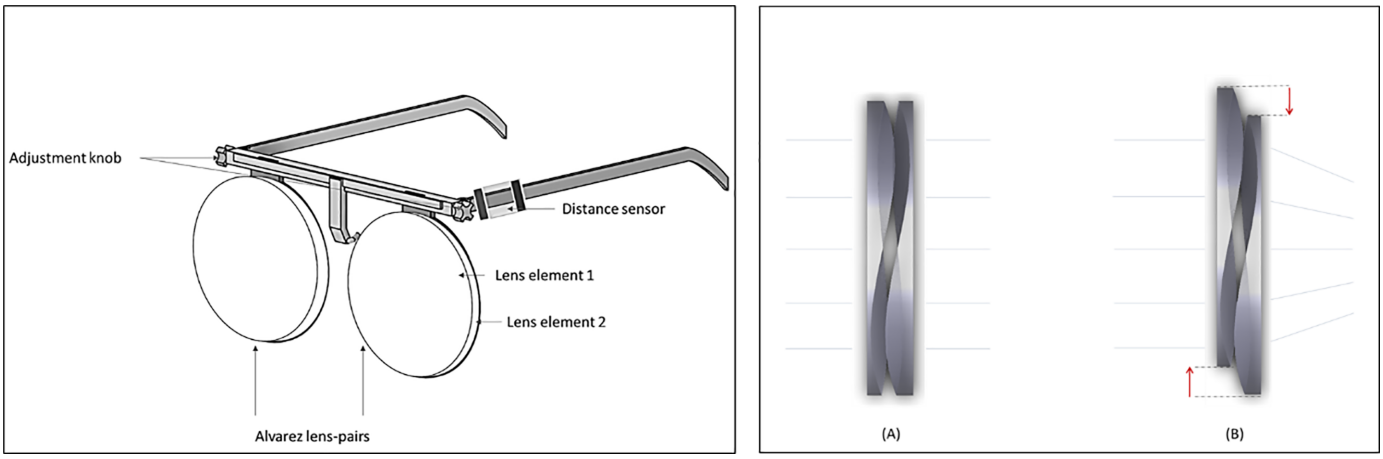

Figure 1. Distance sensor-based adjustable eyeglass. (*Left*) Diagram of the eyeglass highlighting the essential optomechanical components, including the Alvarez lens pair, adjustment knob, and distance sensor. (*Right*) Operating principle of the Alvarez lens. In configuration (**A**), the two complementary cubic lens elements are perfectly aligned, resulting in a constant optical path difference across the lens surface, and thus the lens behaves like a flat plate without optical power. In configuration (**B**), a horizontal lateral shift between the two lens elements is introduced, causing a quadratic variation in the optical path length.

font size during the pre-measurement session. The selected size ensures participants actively focus on the text, as it simulated a level of reading that was moderately intense. During the reading simulation, participants were submitted to the same reading rule, as in the threshold assessment text, but no chin rest was used, enabling participants to adopt a natural, preferred reading posture while seated. The mobile phone was placed horizontally on a table at close distance from the participant, ensuring that the distance sensor consistently pointed to the same surface (i.e. the surface belonging to the plane of the mobile phone).

Lens Adjustment. Each participant completed the reading task in a separate visit once with an Alvarez-based adjustable-focus eyeglass (Eyejuster; Dioptric range = +0.50 to +4.00 D) and once with plano eyeglass (control). As depicted in Figure 1, the Alvarez-based adjustable-focus eyeglasses consist of two complementary cubic optical elements separated by a small air gap[35]; spherical power changes are achieved by laterally shifting the two lens elements relative to each other, with the magnitude of the power change proportional to the degree of displacement. Evaluation of the optical performance of commercial Alvarez eyeglasses have demonstrated that Alvarez-based adjustable-focus eyeglasses provide precise correction with relatively uniform spherical and cylindrical refractive power adjustments across central and peripheral visual field.[36,37] Their potential for visual correction has also been confirmed by various studies.[36–41] Visits were set on a separate day to minimize carry-over effects, and the order of lens administration was randomized across the two experimental visits and counterbalanced across participants. In the control condition, no optical correction was applied. In the self-controlled focus condition, participants adjusted their visual focus by rotating a knob located on the inner side of each eyeglass frame near the hinges. This knob controls the lateral translation between the 2 lens elements, featuring 24 grooves, each groove corresponding to an incremental dioptric step of approximately 0.15 D, enabling an accuracy of measurement better than 0.5 D. To ensure active focus adjustment, participants were instructed to adjust the knob of the eyeglass to the position that provided the clearest image so as to optimize their vision. Every 30 seconds, a clock ringing sound signaled them to stop adjusting, allowing their current diopter setting to be recorded using visual recording of the graduated knob of the adjustable eyeglass.

Behavioral Measurement. During the reading task, including the adjustment phase, the real-time near reading distance, estimated as the distance between the eyeglass and the plane of the mobile phone, was tracked using a Time of Flight (ToF) distance sensor (25 readings/second, resolution = 1 mm, minimum distance range = 20 cm; TeraRanger Neo ES, Terabee) attached to one of the temples of the eyeglass frame. The distance sensor allowed monitoring of the individual dioptric dynamics, and their effect on ocular biometrics during reading. Reading speed, calculated as the number of characters read per second for each line, was simultaneously recorded.

Biometric Measurements. At the beginning of the sessions, each participant underwent a 10-minute washout period, during which participants were asked to navigate inside a large room and engage in varying visual activities to ensure no prior visual adaptation from sustained retinal stimulation. The luminance in the testing environment was matched to that of the background used during the washout period. After washout, pre-reading ocular biometric measurements were performed, including AxL measurement (duration test = <10 seconds) with a commercial partial coherence interferometer (Lenstar LS900; Haag-Streit) and ChT measurement (duration test = <20 seconds) with swept-source optical coherence tomography (SS-OCT; DRI OCT Triton, Topcon) for both eyes, systematically starting with the right eye first, followed by the left eye, for each measurement. In addition, objective refraction was performed binocularly using a Maltese cross target, situated at 3 meters via an open-field autorefractor (Shin-Nippon NVision-K 5001, Rexxam Co.). Immediately after measurements, the participants performed the reading task for a duration of 30 minutes, and then the post-reading ocular biometric measurements. A radial scan pattern (9.0 mm diameter, 1024 A-scans × 12 lines) was used to measure central choroidal thickness at nine subfield of the Early Treatment Diabetic Retinopathy Study (ETDRS) grid, utilizing the SS-OCT device's built-in software. Following the approach adopted in previous studies,[42–45] five consecutive measurements were taken and averaged for each AxL measurement to overcome the limited precision of the Lenstar LS900 (resolution = 10 µm).

Analysis

All statistical analyses were carried out using IBM SPSS Statistics version 21 (Armonk, NY). To test the effect of reading on short-term eye responses, linear mixed model analyses with maximum likelihood estimation were performed to account for individual differences and accommodate missing data due to poor measurements and outlier exclusion.

Linear mixed model analyses of spherical equivalent refraction (SER; model 1) and AxL (model 2), respectively, were performed to test the effect of reading time (i.e. pre/post) and lens type (i.e. plano eyeglass [PE]/self-adjusted eyeglass [SAG]), assuming an unstructured variance structure. Reading time, lens type, and ocular side (left/right), along with all pairwise

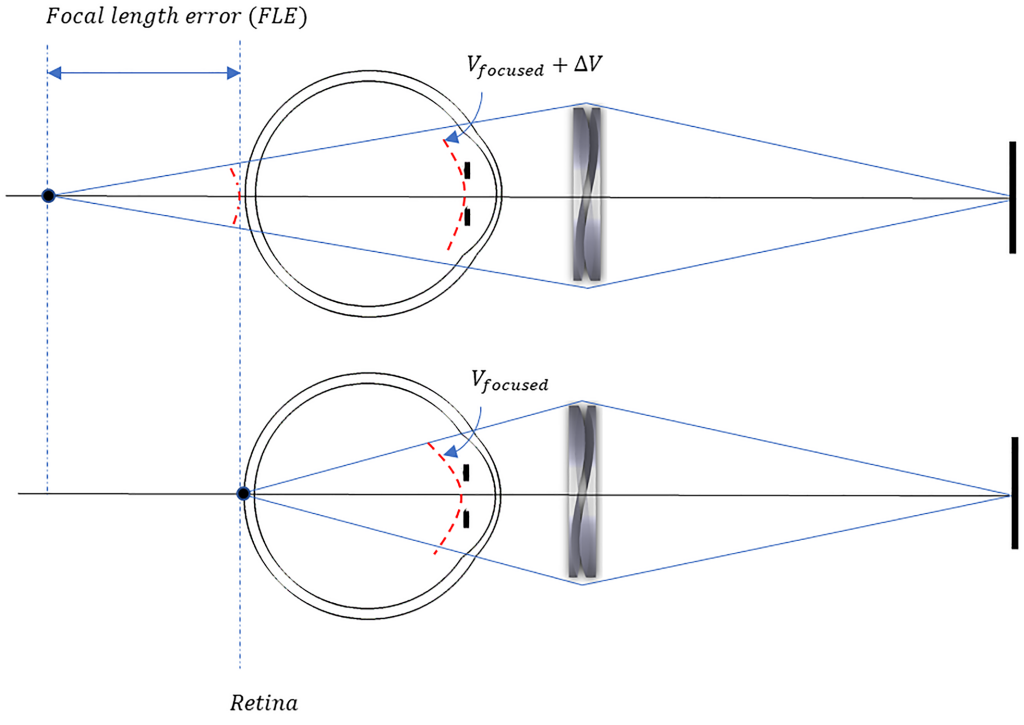

Figure 2. Retinal dioptric estimate. This diagram illustrates a perfectly focusing eye compared to one exhibiting retinal blur due to focal length error (FLE). The FLE quantifies the amount of blur on the retina and is estimated by the retinal dioptric estimate $\Delta V = Rx + F + L$, where $\Delta V \sim fle/V^2_{focused}$ assuming the FLE is small. In this context, $V_{focused}$ represents the vergence of the light in a perfectly focusing eye after refraction by the Alvarez lens and the eye, Rx denotes the participants' refractive errors, F is the optical power applied on the adjustable lens during the adjustment task, and L is the environmental dioptric demand. It is important to note that this estimate does not consider the accommodation response, which was not monitored during reading, and therefore differs from accommodation lag.

interactions, were set as fixed factors. To examine the global changes in ChT, a similar analysis evaluated the effects of reading time, lens type, and retinal location, with fixed factors including these variables and their pairwise interactions.

A second set of linear mixed models quantified changes in SER (or, equivalently, changes in accommodation; model 4), AxL (model 5), and ChT (post and pre values; model 6). Lens type, ocular side, and central ETDRS subfields (for model 6), along with all pairwise interaction, were set as fixed factors, assuming an unstructured variance structure.

In all models, participants were modeled as random effects using an identity covariance structure. Main effects and interactions were tested via least significant differences for post hoc tests. For each tested condition, individual outlier data were identified as data deviating by more than ±3.5 median absolute deviation from the group median for each condition.[46] Results are reported as means with standard errors.

In addition, paired *t*-tests were performed to assess the impact of self-focus adjustment on behavioral measures, including the mean reading speed, mean and standard deviation (SD) of the environmental dioptric distances recorded continuously over the 30-minute reading session, as well as mean and SD of the retinal dioptric estimate. The SD of the environmental dioptric distance and retinal dioptric estimate were used as a measure of the dioptric dynamics.

The dioptric distance was calculated as the inverse of the real-time distance between the mobile phone and the eye. As illustrated in Figure 2, The retinal dioptric estimate measured the total dioptric errors[10] relative to a perfectly focusing eye (with zero dioptric error) and was computed as the dioptric sum of: (a) the environmental dioptric demand (1/object distance), (b) the optical power applied on the adjustable lens during the adjustment task, and (c) the participants' refractive errors (estimated as the mean of pre- and post-refractive measurements).

Negative values denote hyperopic defocus (e.g. environmental dioptric) whereas positive values represent myopic defocus (e.g. lens power).

Results

Question 1. Does Self-Adjustable Focus Affect Behavioral Responses?

Dioptric Measures

Reading distance was affected by lens type with a significant increase of the mean reading distance (Paired sample *t*-test: mean difference PE-SAG = −75.96 mm ± 33.88 mm, t(10) = −2.24, $P = 0.49$) and decrease of the SD of the reading distance (mean difference PE–SAG = 0.77 mm ± 0.27 mm, t(8) = −2.831, $P = 0.020$) for self-controlled focus, as compared to the control. This resulted in a modest, although nonsignificant, reduction in mean dioptric distance (0.46 D ± 0.34 D, $P > 0.1$). On the other hand, a significantly larger mean retinal dioptric estimate was observed in the control condition (Fig. 3; −3.11 D ± 0.32 D) as compared to the self-controlled focus condition (see Fig. 3; −2.00 D ± 0.34 D, t(10) = −3.70, $P = 0.004$), allowing for a decrease myopiagenic response in the self-controlled focus condition. Importantly, the mean retinal dioptric estimate was significantly hyperopic for both the self-controlled focus (one sample *t*-test: t(12) = −5.95, $P < 0.001$) and control (one sample *t*-test: t(10) = −11.57, $P < 0.001$), indicating that participants only partially compensate for the environmental dioptric distance under self-controlled focus (see the Table, lens power adjustment, right eye [RE] = +0.64 D ± 0.069 D; left eye [LE] = +0.70 D ± 0.065 D).

Reading Performance

Despite its impact on dioptric measures, self-controlled focus did not cause altered reading performance: no significant effect of lens type on the mean (see Fig. 3; paired sample *t*-test: mean difference PE-SAG = 51.62 ms ± 206.44 ms, t(12) = 0.25, $P = 0.81$) and SD (paired sample *t*-test: mean difference = 39.65 ms ± 48.29 ms, t(10) = −0.82, $P = 0.43$) of the reading speed was found, suggesting a limited influence of the self-adjustable focus on reading performance, as compared with the control condition.

Question 2. Is Self-Controlled Defocus Protective Against Myopic Shift?

Spherical Equivalent Refraction

As anticipated, model 1 shows a significant interaction of reading time by lens type (model 1: akaike information criterion, corrected (AICc) = 92.04, $F(1, 26.00) = 4.90$, $P < 0.036$) on SER. A significant increase in accommodation was found with reading (Fig. 4; mean difference [SER post - SER pre] = 0.12 D ± 0.52 D, $P = 0.035$) in the control lens condition. Conversely, in the self-controlled focus condition, a small decrease in accommodation was observed, although it did not reach significance (mean difference [SER post - SER pre] = 0.058 D ± 0.058 D, $P > 0.05$). Ocular side ($F(1, 13.72) = 2.53$, $P > 0.1$), and its interaction with reading time ($F(1, 26.000) = 0.14$, $P > 0.1$) were not significant. Model 4 confirmed the significant effect of lens type (AICc = 34.51, $F(1,$

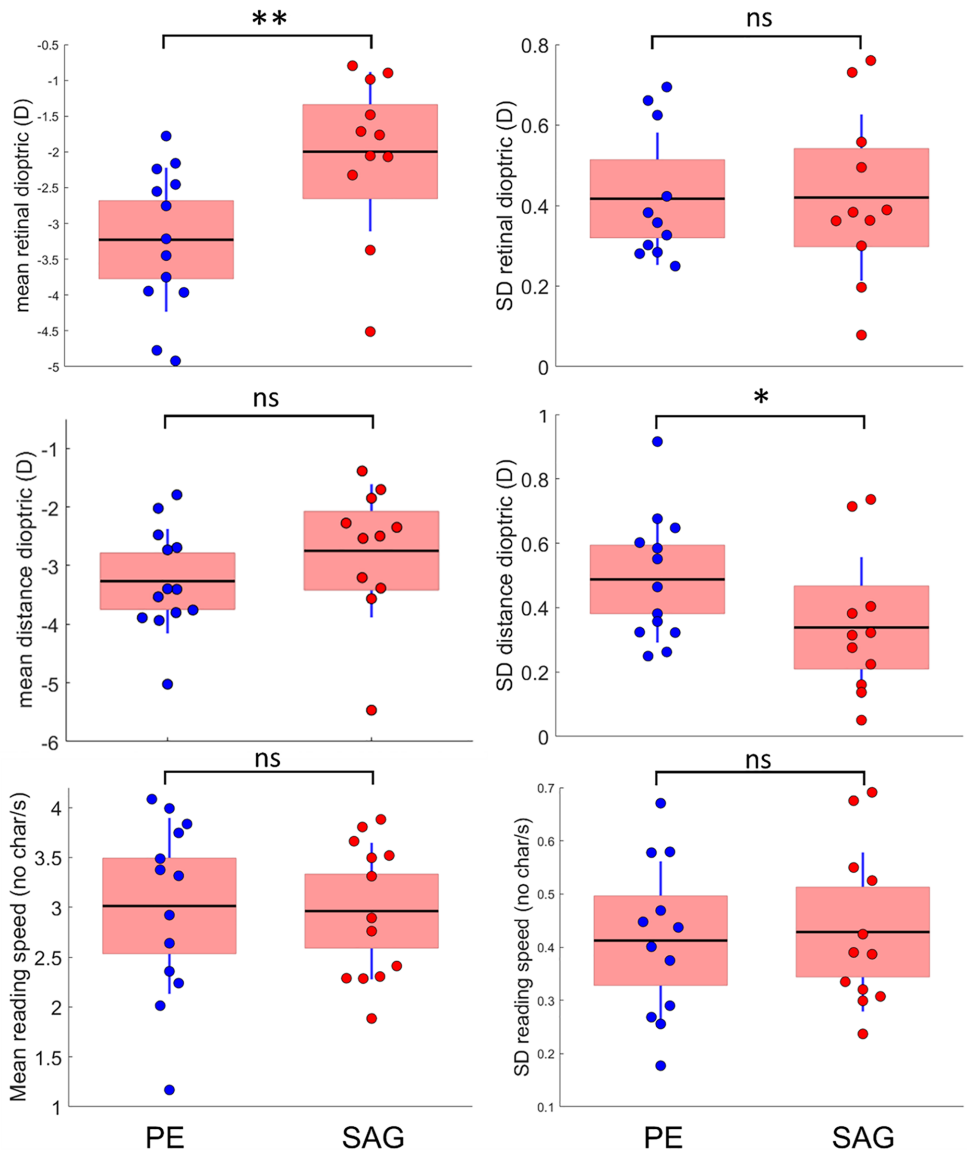

Figure 3. Behavioral and reading performance changes. (**A, B**) Behavioral changes including (mean and SD) retinal dioptric estimate and environmental distance dioptric. (**C**) Reading performance changes including mean and SD reading speed, obtained with self-adjusted eyeglass (SAG; *red circle*) and plano eyeglasses (PE; *blue circle*), simulating self-controlled and uncorrected focus conditions. Error bar represents the standard error.

26.00) = 4.90, mean difference: - 0.173 D ± 0.078 D, $P < 0.036$).

Axial Length

Similarly, model 2 shows a significant interaction of reading time by lens type (AICc = −317.28, $F(1, 26.45) = 5.53$, $P < 0.026$), confirming the influence of lens correction on AxL. Ocular side ($F(1, 13.492) = 0.122$, $P > 0.05$), and its interaction with reading time ($F(1, 26.17) = 1.28$, $P > 0.05$) were not significant. Model 5 confirmed the significant effect of lens type (AICc = −256.14, $F(1, 26.26) = 5.41$, P =0.028) on AxL changes. In the control lens condition, AxL elongated (Fig. 5; estimated mean = +8 µm ± 2 µm) whereas, in the SAG type, AxL slightly shortened (see Fig. 5; mean difference = −1 µm ± 3 µm). Again, no significant effect of ocular side ($F(1, 26.22) = 1.27$, $P > 0.05$), nor its interaction ($F(1, 26.26) = 2.55$, $P > 0.05$) was found.

ChT ETDRS

Model 3 shows a significant interaction between reading time and the ETDRS subfields (AICc = 7428.25, $F(8, 227.22) = 2.30$, $P < 0.022$), but no significant change in the central ETDRS subfield ($P > 0.1$). Surprisingly, no significant effect of reading time by

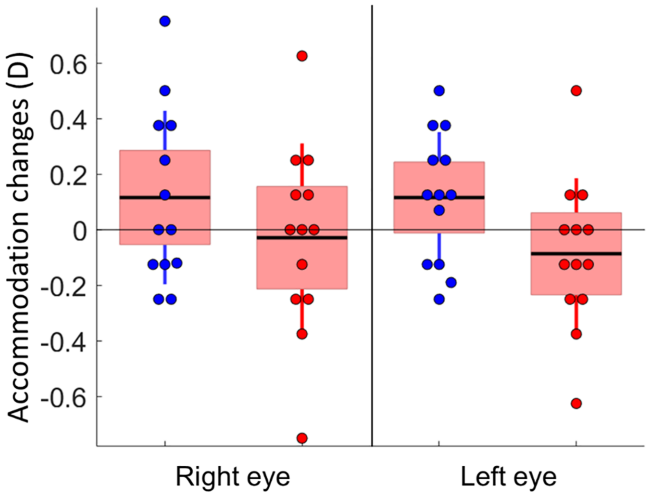

Figure 4. Accommodation change. Accommodation changes in left and right eyes, measured as spherical equivalent refraction (SER) difference just before and after reading, using self-adjusted eyeglasses (SAG; *red circle*) and plano eyeglasses (PE; *blue circle*), simulating self-controlled and uncorrected focus conditions. Error bar represents the standard error.

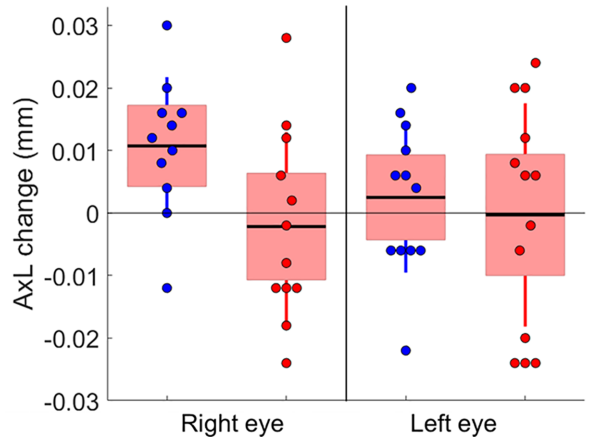

Figure 5. AxL change. AxL changes in the left and right eyes obtained with the self-adjusted eyeglasses (SAG; *red circle*) and the plano eyeglasses (PE; *blue circle*), simulating self-controlled and uncorrected focus conditions. Error bar represents the standard error.

lens type interaction ($F(1, 229.79) = 1.81$, $P > 0.05$) on ChT changes was found, suggesting the absence of a generalized ChT changes in response to the environmental dioptric induced by the near reading. Model 6 also confirmed the nonsignificant influence of lens type and its interactions (AICc = 3381.61, $P > 0.1$). On the other hand, adjusting for dioptric measures in model 6, unlike in models 4 and 5, highlighted a significant effect of the SD of distance (Fig. 6; AICc = 3218.86, F (1, 133.00) = 23.98, $\beta = -17.91 \pm 3.66$, $P < 0.001$) and retinal dioptric estimate (AICc = 3107.96, F (1, 95.68) = 14.67, $\beta = -13.07 \pm 3.41$, $P < 0.001$), which indicated a preferential influence of dioptric variations on ChT under unrestricted viewing distance, consistent with earlier animal findings on the role of defocus dynamics.[10,47,48]

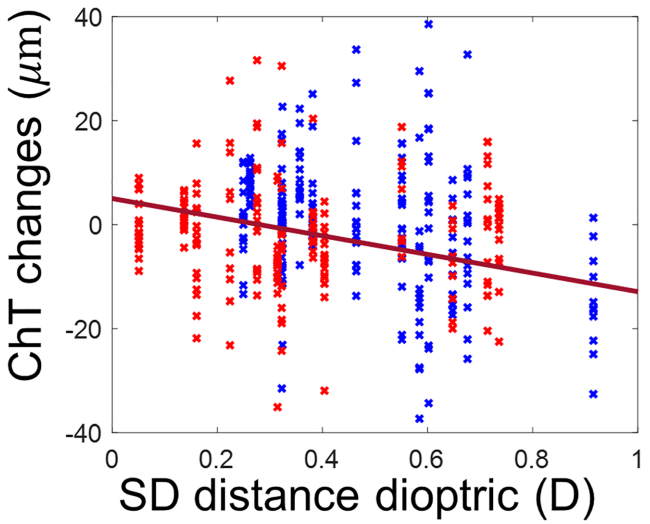

Figure 6. Effect of dioptric dynamics on ChT. Changes in ChT are shown as a function of the dioptric dynamics quantified as the SD environmental dioptric distance for the self-adjusted eyeglasses (SAG; *red cross*) and the plano eyeglasses (PE; *blue cross*), across all retinal and ocular sides. The *solid line* represents the linear mixed model (LMM) fit to the data.

Discussion

This study examined for the first time the effects of reading on a mobile phone with unrestricted reading distance on short-term eye changes, as well as the potential of self-focus adjustment for the control of eye growth and reading performance.

Our results demonstrated a significant impact of reading on a mobile phone on the eye, with an increase of AxL elongation and accommodation after reading with uncorrected vision, indicating that dioptric blurs are influential even when projected over a small region of the visual field with unrestricted reading distance.

Our results also demonstrate the capability of focus adjustment to provide significant reduction of the hyperopic retinal dioptric estimate during reading. This finding complements previous works showing effective correction of refractive errors via adjustable eyeglasses under subjective refraction,[38–41] an untimed, static task. Of note, the correction of retinal blur by self-controlled focus is only partial under reading on a mobile phone, which might be due to the difficulty of an accurate judgment of image sharpness

during reading with rapid eye movements. Because the subjects were young emmetropes, their natural accommodation could minimize any changes in reading acuity afforded by the adjustable-focus eyeglasses, as demonstrated in a separate study, making perceived blur the most reliable cue for adjusting the lens. It is thus possible that a full correction of the hyperopic retinal defocus might necessitate (bio-feedback) training to be effective under reading tasks, and may depend on individual reading patterns. Whether a full correction of hyperopic retinal defocus would present an advantage for myopia control over a partial correction of hyperopic retinal defocus though needs to be determined.

Indeed, control of defocus with self-adjustable lenses may be an effective solution to minimize the blur-related effects of reading. This is confirmed by our observation that, under self-controlled focus, both ocular accommodation and AxL elongation are significantly reduced during reading, as compared to the uncorrected control condition, attenuating the effect of near distance on eye changes. Indeed, the optical compensation of hyperopic defocus afforded by the self-adjustable eyeglasses might not be the sole factor underlying the observed ocular changes. An increase in adopted reading distance — potentially driven by lens-induced magnification that allows finer details to be resolved at greater distances — could contribute, but the associated decrease in mean distance dioptric, only modest and not statistically significant, suggested a minor effect in our study. When considered alongside the maintained reading performance with self-controlled focus, these findings indicate that the system could be effective both in facilitating a more relaxed ocular state and in supporting functional visual tasks. Unlike some myopia-control lenses,[49,50] self-adjusted focus applies a uniform, compensatory defocus lens power across the field, preserving peripheral clarity, making it a potential asset for myopia prevention without introduction of extrafoveal blurs.

These findings are, however, mitigated by the observation that self-controlled focus had no significant thickening effect on ChT, as compared with the uncorrected control. Such a decoupling between AxL and ChT has been observed in several studies,[51–54] highlighting the possibility that different ocular components may be under the control of distinct influences[55] with distinct dynamics.[56] Consistent with the former hypothesis, ChT was found correlated with reading dioptric dynamics, but not AxL and accommodation. This finding is interesting because previous studies manipulating ChT/AxL have used fixed distance (using a chin rest), discarding the possible influence of reading and defocus dynamics. It is, however, well known that the modulation of defocus can have drastic impact on the influence of defocus on eye growth.[11,47,48] For instance, transient episodes of clear vision or myopic defocus are known to cancel the myopiagenic effect of hyperopic defocus. Thus, it could be valuable to consider individual dynamics in the susceptibility of eye changes and for myopia-control strategy. Indeed, additional ocular biometric parameters, including the sclera,[57] retinal and choroidal vascularization[58] may provide further insights into short-term ocular responses to self-adjusted focus and thus warrant investigation in future studies.

In summary, our results revealed that self-adjustable eyeglasses can be an efficient method to minimize hyperopic retinal defocus under near work, even in the context of a complex, dynamic tasks like reading. Although this solution may not be able to reverse the development of myopia, as does myopic control lenses, it could be a valuable preventive solution for the control of myopia in participants with high likelihood of developing myopia at school. This solution may be particularly useful for emmetropic participants that would not receive standard myopia control due to its (peripheral) treatment effects, but have heightened likelihood of developing myopia because of near reading distance.

This study has limitations. First, the adjustable-focus lens utilized in our experiment, like other currently available adjustable lenses, introduces residual, although a clinically negligible level of cylindrical blur and prism. Second, the match between frame PD and individual pupillary distances could not be fully controlled, which limited the control of residual prism. Third, our estimate of the retinal dioptric measurements was limited by the accuracy of the dioptric measurement and the absence of real-time recording of accommodation during reading. Fourth, the myopiagenic effect of reading from a mobile phone, and its control, might not fully apply to other forms of reading, such as printed text, standard monitor, or large display. These formats typically engage a wider retinal area, which matters because the eye's response to defocus depends on both the stimulus's spatial pattern and its retinal location.[45] In particular, a "sweet spot" for defocus detection has been reported in the near-peripheral retina (8–30 degrees), making it more likely to be recruited during larger-format reading. By contrast, our mobile-phone stimulus covered only a narrow field (approximately ±5.5 degrees vertically), primarily stimulating the parafovea and thereby limiting near-peripheral engagement. Fifth, because of the limited compensatory range of focus in self-adjustable eyeglasses based on Alvarez principles,[59] we only recruited near-emmetropes for this study. However, progressing myopes could also benefit from

a self-controlled focus. Further research might thus be necessary to explore the potential advantages of self-adjusted eyeglasses for myopic individuals. Future work should be carried to integrate biofeedback training to help subjects determine an optimal eyeglass adjustment that cancels hyperopic environmental defocus, thereby enhancing their capacity to regulate accommodation and optimize defocus correction. Understanding the potential of self-controlled focus for myopes could pave the way for novel optical solutions of myopia control. It will be interesting to develop high quality self-adjustable eyeglasses covering a wider range of refraction or adjusted for different refractive status.

Conclusions

This study presented the first implementation of a distance sensor-based adjustable eyeglass in adult emmetropes, demonstrating the potential of self-controlled focus for controlled short-term eye responses during reading. It is highlighted that self-adjustable lenses provide a feasible defocus control during reading without affecting reading performance. A key question remaining is whether self-controlled focus can reduce the risk of near distance-related myopic eye changes and to what extent. Future studies may concentrate on the effectiveness of self-controlled focus for longer period of use and young children with different refractive errors. This study may open the path for the novel development of adjustable eyeglass for myopia prevention and more generally the control of accommodation-related visual problems.

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