CLINICAL TRIAL

Effects of Progressive Addition Lens Wear on Digital Work in Pre-presbyopes

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SIGNIFICANCE: Growing popularity of handheld digital devices imposes significant challenges to our visual system and clinical management. This study aimed to determine the effects of lens design on parameters that may influence the refractive management of pre-presbyopic adult computer users.

PURPOSE: To determine the effects of wearing conventional single-vision lenses (SVL) versus progressive addition lenses (PAL) on the working distance and refractive status.

METHODS: Adult computer users, recruited from two age cohorts (18 to 25 years, n = 19; 30 to 40 years, n = 45), were prescribed SVLs and PALs designed for use with handheld digital devices. For each lens type, the working distance and refractive shift (post-task – pre-task) were measured immediately after lens delivery (T0) and after 1 month of lens wear (T1). Working distances were recorded with an automatic ultrasound device while the participants were playing a video game. Refractive status through the subjects' glasses was measured before (pre-task) and after playing the game (post-task). Questionnaires assessing the frequencies of 10 digital work–related visual symptoms were conducted for both lens types at T1.

RESULTS: Switching from SVL to PAL increased the working distance in both cohorts (mean ± SEM = 1.88 ± 0.60 cm; $P = .002$) and induced a small but significant positive refractive shift (+0.08 ± 0.04 D, $P = .021$) in the older cohort at T1. In the younger cohort, the changes in working distance due to the switching lens design were correlated with myopic error ($r = +0.66$, $P = .002$). In the older cohort, the changes in refractive shift due to switching lens design were correlated with amplitude of accommodation at both time points (r for T0 and T1 = –0.32 and –0.30, respectively; both $P < .05$). Progressive addition lens was rated as causing less "increased sensitivity to light" compared with SVL.

CONCLUSIONS: Switching from SVL to PAL increased the working distance and induced a positive refractive shift in the majority of pre-presbyopic adults.

Optom Vis Sci 2018;95:457–467. doi:10.1097/OPX.0000000000001211

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Prolonged computer usage leads to a series of clinical symptoms commonly known as "computer vision syndrome."[1] These symptoms include both visual (asthenopia, blurred vision, dry eye, irritated eye, eye pain) and physical discomforts (headache, neck pain, back pain, shoulder pain), significantly affecting the quality of life.[1,2] Factors associated with computer vision syndrome may be grouped into three[3]: the physical nature of visual targets presented on the monitor (e.g., contrast, color), the setting of the computer workstation (e.g., height, ambient light), and the working habits of the computer users (e.g., blinking rate, frequency of breaks). However, earlier studies typically assessed the visual discomforts encountered by computer users at intermediate working distances (50 to 70 cm), a working range corresponding to a lower accommodative demand when compared with near work (e.g., reading). Recently, the availability of handheld digital display devices (e.g., tablet computers and smartphones) provides not only static reading contents, but also streaming graphic videos. Furthermore, their accessibility to the digital network has made them handy and irresistible tools for all ages. Of particular concern are the findings that reading using a tablet computer was more likely to cause visual fatigue compared with reading a paper book[4] and that smartphone users appeared to view the device at a distance closer than normal working distance (<40 cm).[5]

In addition to visual fatigue, prolonged computer usage can induce a refractive shift in the minus direction.[3,6] Although the magnitudes of prolonged computer usage induced negative refractive shift were quite low (–0.036 to –0.19 D), they were statistically significant[7–9] and higher than those induced by equivalent durations of paper work.[7,9] It should be noted that because the working distances during computer usage in these studies were adjustable by the participants and were typically quite long (about 60 cm), the low magnitudes of negative refractive shift may be related to the low accommodative demands. More recent studies, reporting a higher-magnitude (~0.3 D) transient myopia induced by a much shorter working distance (20 to 25 cm), have questioned the potential linkage of this refractive shift to myopia development,[10] although studies from different animal models have provided evidence that only brief episodes of unrestricted vision could effectively counteract experimentally induced myopia.[11–13] Nevertheless, to alleviate the accommodative demands for prolonged computer work in presbyopic office workers, a variety of "occupational lenses" (a branch of progressive addition lens type) have been designed to offer positive correcting powers (addition powers, "ADD") for intermediate and near working distances, with the powers for distance vision either not provided or occupying only a small area on the lens surface. With the increasing reliance on tablet computers and smartphones in all ages, it is important to determine the impact of prolonged usage of these handheld digital devices on working habit and refractive status. The primary purpose of this study was to compare the effects of wearing a conventional single-vision lens type versus wearing a new occupational lens type designed for handheld digital devices on the outcomes (working distance and refractive status) of playing an interactive computer game for 30 minutes in two pre-presbyopic adult age groups. The secondary purpose was to study whether the impacts of each lens type would vary over a period of 1 month. A questionnaire assessing the frequencies of 10 digital work–related visual symptoms during the 1-month period was also conducted.

METHODS

Subjects

Sixty-four healthy computer users (computer usage >2 hours per day) were recruited from young (18 to 25 years, n = 19) and pre-presbyopic (30 to 40 years, n = 45) cohorts via advertisements posted on the campus or the Web site of the Hong Kong Polytechnic University. Mainly due to the short recruitment period, there were fewer participants in the younger cohort. Because the clinical population in Hong Kong are typically myopic and astigmatic,[14] only participants with spherical-equivalent refractive errors between plano and −9.00 D and cylindrical power 2.50 D or less were included in this study. The exclusion criteria were any subject with visual acuity worse than 0 logMAR, anisometropia more than 2.00 D, abnormal accommodative function, wearing rigid contact lens, and a history of ocular surgery and pathology. Soft contact lens wearers were asked to stop wearing their contact lenses for at least 12 hours before the experiment. All experimental procedures were approved by the human subject ethics committee of The Hong Kong Polytechnic University (HSEARS20140808001) and were conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Written informed consent was collected from all participants after the purpose and procedure of the study had been explained. The procedure was carried out by experienced optometrists (KK, CHIL, and TWL) at the optometry research clinic of The Hong Kong Polytechnic University (described below). To complete the project according to schedule, the participant recruitment and the data collection period were between September 2014 and April 2015. This study was registered at the US National Institutes of Health (ClinicalTrials.gov), registration no. NCT02775396.

Procedures

Data were collected from five visits by adopting a crossover experimental design (Fig. 1). On visit 1, a comprehensive optometry eye examination was conducted to collect baseline data.[15] These data included demographic information, amplitude of accommodation by Royal Air Force rule, gradient AC/A by Maddox Wing with +1.00 D spherical lens, and near phoria by Maddox Wing. The amplitude of accommodation and AC/A measurements were repeated thrice, and the averaged values were used for analyses. The refractive status was measured by noncycloplegic subjective refraction using the maximum-plus-maximum-acuity as the endpoint. Spherical-equivalent refractive errors of both eyes were averaged for statistical analysis. Based on the result of subjective refraction, two pairs of spectacle lenses, that is, the conventional single-vision lenses (Zeiss Clarity aspheric lens, n = 1.67) and the progressive addition lenses designed for digital devices (Zeiss Digital lens, n = 1.67, addition power = +0.75 D), were delivered in random order on visits 2 and 4. On visit 2, each successive participant was allocated to receive the alternate lens type from a previous participant, resulting in similar number of participants for each lens type. Each participant used the same spectacle frame throughout the experiment. The frame was adjusted to align the participant's pupillary center with the optical center of the single-vision lens or the fitting cross of the digital lens. All participants were trained to use the addition portion when wearing the digital lenses for digital devices; the lower and upper portions of the lenses were covered to demonstrate clear zones for distance and near vision, respectively. This training usually took no more than 5 minutes.

From visits 2 to 5, the same set of measurements aimed at testing the effects of each lens design on working distance and refractive shift (described below) was carried out. Each visit was separated by 1 month, the measurements representing the effects immediately after spectacle deliveries (visits 2 and 4, referred to as "T0") and 1 month after each lens wear (visits 3 and 5, referred to as "T1"). Between visits 3 and 4, the participants were asked to wear their own spectacles, this serving as a washout period from the potential residual effects of the first pair of lenses. Questionnaire data, after wearing each lens type for 1 month, were collected on visits 3 and 5. This questionnaire asked the participants to rate the frequency of 10 digital work–related visual symptoms using Likert scales (blurred vision, eye fatigue, eye pain, excessive blinking, burning, double vision, eye strain, increased sensitivity to light, eye redness, and tearing; scoring from 1 [very frequent] to 5 [never]). Ocular aberrations data were also collected but are not presented in this study. All participants reported that the progressive addition lenses were used for digital work for more than 2 hours per day. At the end of the study, the participants were asked to choose their preferred lens type (single-vision lens, progressive addition lens, or no preference).

Working Distance

In order to determine the effects of lens design on natural working habits, we did not restrict the participants' preferred working distances while they were playing a 30-minute interactive video game (Candy Crush Saga) using a tablet computer (iPad Air, 9.7-inch monitor; Apple Store, Hong Kong). During the video-game play, the working distances of the participants were recorded using an automatic ultrasonic near work analyzer validated for its operating range and reliability.[16] In brief, the automatic near work analyzer was held firmly by a headband on the forehead of the participant, with the axis of the ultrasonic sensor aligned with the eye's fixation axis when looking at the center of the tablet computer at their preferred working distance. The device was set to record the working distances every 1.04 second over the period of video-game play. The accumulated data collected during this period were used to derive four parameters associated with the working habits of each participant:

- *mode = the working distance most frequently recorded during the period*

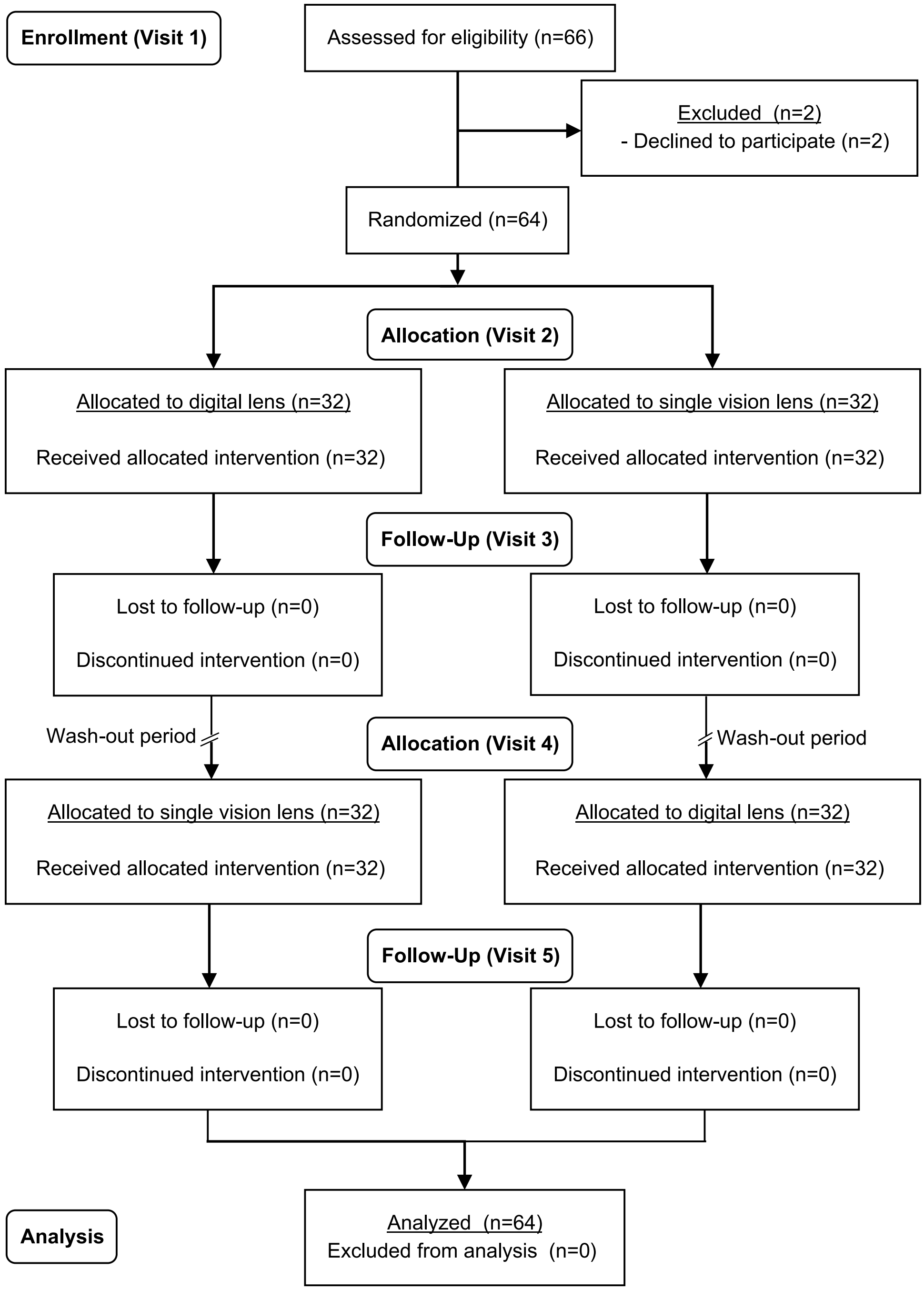

FIGURE 1. CONSORT flowchart. Participants visited the optometry clinic five times. Baseline data were collected at visit 1. In visits 2 and 4, either conventional single-vision lens or progressive addition lens was delivered to participants in random sequence, and measurements were taken. In visits 3 and 5, the same set of measurements was performed.

- $\textit{percentage of mode} = 100\% \times \frac{\textit{count of mode}}{\textit{total count}}$
- $\textit{percentage of short working distance: } 100\% \times \frac{\textit{count of shorter working distances}}{\textit{total count}}$
- $\textit{percentage of long working distance: } 100\% \times \frac{\textit{count of longer working distances}}{\textit{total count}}$

The short and long working distances were identified as working distances that were shorter and longer than the modal working distance by 0.50 D, respectively.

Refractive Shift

To calculate the shift in refractive status due to computer work, objective refractions over the spectacle lenses (overrefraction) were measured using an open-field autorefractor (NVision-K 5001; Shin-Nippon, Tokyo, Japan) immediately before and after playing the video game. Previous studies have demonstrated high reliability[17] (mean difference = 0.04 D; 95% limits of agreement = –0.38 to +0.47 D) and minimal measurement errors when using this autorefractor for myopic subjects.[18] All subjects were dark adapted for 5 minutes to relax their accommodation before playing the video game. To measure the objective refraction, the participant was instructed to look at a target (visual angle, 0.25°) 6 m away at eye level, the eye position of the participant was monitored through the instrument's display window, and the measurement was taken only if the eye was wide open and fixating at the distant target. Any measurement affected by a blink or a change in eye fixation was discarded. Because the primary purpose of our experimental protocol was to measure the transient change in refractive status before and after 30 minutes of computer work, to increase the likelihood that we would be able to capture these small refractive shifts, we limited the measurements to three per eye even though the three measurements per eye took approximately only 30 seconds. The averaged spherical-equivalent refractive errors of the pre-task value were subtracted from the post-task value (i.e., refractive shift = post-task spherical equivalent – pre-task spherical equivalent). Thus, a refractive shift in negative value would indicate a relative myopic shift, and a positive value would indicate a relative hyperopic shift. The measurements were always performed first on the right eye and then the left eye, the refractive shifts from both eyes being averaged.

Statistical Analysis

All statistical tests were performed using SPSS software (version 23; IBM Corp., Hong Kong). Two-sample *t* tests were used to compare the baseline ocular biometric parameters between the two cohorts. Linear mixed-effects model was used to test the effects of age (younger vs. older groups), duration of lens wear (lens wear immediately after delivery vs. after 1 month), and lens design (single-vision lens vs. progressive addition lens) on the working distance and refractive shift. Three covariance subtypes (diagonal, compound, or unstructured subtypes) of the linear mixed effects model were first tested, and the model that yielded the minimum Akaike information criteria among the three subtypes (indicating the best model among the three) was selected to test the main and interaction effects. For all covariance subtypes tested, subjects were treated as a random effect, whereas age, duration of lens wear, and lens design were treated as fixed effects; the dependent variables were the working distance and refractive shift. Based on the SD of 2 cm of the measuring device for working distance,[16] a sample size of 19 participants would generate 85% power for an intergroup difference of 2-cm working distance ($\alpha = 0.05$). At each time point, relative changes in working distance and refractive shift when switching from single-vision lens to progressive addition lens (progressive addition lens–single-vision lens) were tested against zero using one-sample *t* test. Pearson correlation analyses were performed for baseline parameters with the two outcome variables. Questionnaire data were analyzed by nonparametric Wilcoxon signed rank tests to compare the ratings of the two lens designs on each visual symptom and by Spearman correlation tests to determine the correlation between biometric parameters (including baseline parameters and the relative changes in outcome variables) and subjective ratings. The evaluation of each symptom was considered as an independent judgement; thus, a Bonferroni correction was not used.[19] Statistical significance for all tests was defined as $P < .05$.

RESULTS

Demographic Information

Of the total of 66 participants recruited, only two declined to participate in the study, the remaining 64 participants completing all five visits (Fig. 1). Table 1 shows the demographic information at the baseline visit and the outcome measures when wearing conventional single-vision lens at T0 for the two age cohorts (mean, 95% confidence interval in brackets). While the two cohorts had similar magnitudes of spherical-equivalent refractive error and AC/A ratio, the older cohort had lower amplitude of accommodation ($P < .001$) and was slightly more exophoric at near than the younger cohort ($P < .05$). Despite these differences, the working distance parameters (including mode and percentages) and the refractive shift, when they were wearing the single-vision lens for the 30 minutes of interactive video-game play, did not differ between these two cohorts.

Effects of Age, Duration of Lens Wear, and Lens Design

There were no interaction effects of age, duration of lens wear, and lens design on the working distance (all $P \geq .28$) or the refractive shift (all $P \geq .53$).

Working Distance

Neither age ($P = .19$) nor duration of lens wear ($P = .30$) had significant main effects on the modal working distance. In contrast, lens design had a significant impact on the working distance ($P = .002$); on average, wearing the progressive addition lens while playing the video game increased the working distance by 1.88 cm (standard error, 0.60 cm) compared with wearing single-vision lens. Using the averaged working distances measured when wearing single-vision lens (Table 1) to convert the working distance into dioptric distance, the 1.88-cm increase in working distance may be interpreted as 0.16 and 0.15 D of dioptric changes for the younger and older cohorts, respectively.

To determine the effects of switching lens design on individual participants, the changes in working distance (progressive addition lens – single-vision lens) were calculated for each time point (T0 and T1) and plotted as histogram and box plots (Fig. 2). In the younger (left) and older (right) cohorts, the changes at different time points were represented by white (T0) and gray (T1) bars. As shown, excluding the participants within the central two bars (representing bins covering the range within ±1.5 cm), there were more participants who had longer working distances (bars in the shaded area) than shorter working distances when switching to progressive addition lens in both cohorts at both time points. The magnitude of change in working distance due to a switch to progressive addition lens was significantly different from zero in the older cohort at T0 (mean ± standard error, 3.04 ± 1.17 cm; $P = .013$; Fig. 2): 29 of the 45 participants (64.4%) in this cohort had increased working distances greater than 0 cm (median, 5 cm) by changing from the single-vision lens to progressive addition lens.

Lens design ($P = .013$), but not age or duration of lens wear (both $P \geq .211$), also produced significant impacts on the working habits of participants during the video-game play; wearing progressive addition lens reduced the percentage of time spent on modal working distance by 2.48% compared with wearing single-vision lens. Fig. 3 plots the distributions of changes in the percentage of time spent on modal working distance due to different lens designs (progressive addition lens – single-vision lens) for the two cohorts. A similar plotting template as Fig. 2 was adopted. All distributions in Fig. 3 showed a general trend: more participants reduced their time spent on modal working distances (bars in the white area) after switching from single-vision lens to progressive addition lens. The magnitudes of reduction in time spent at modal working

TABLE 1. Demographic information at baseline visit and outcome measures when wearing the conventional single-vision lens

	18–25 y (n = 19, 57.9% Female)	30–40 y (n = 45, 57.8% Female)
Baseline parameters		
Age* (y)	20.2 [19.4 to 21.1]	33.6 [32.6 to 34.6]
SE (D)	–4.13 [–3.17 to –5.08]	–4.25 [–3.56 to –4.94]
AA (D)*	10.14 [9.54 to 10.74]	7.01 [6.55 to 7.47]
Horizontal phoria*	0.37 [–1.70 to 2.44]	3.47 [2.27 to 4.66]
Vertical phoria	–0.05 [–0.25 to 0.14]	0.06 [–0.09 to 0.20]
AC/A	2.34 [1.81 to 2.87]	2.24 [1.96 to 2.54]
Outcome measures when wearing SVL		
Working distance (mode) (cm)	33.63 [31.15 to 36.12]	34.96 [33.16 to 36.75]
Percentage of mode (%)	23.5 [20.4 to 26.6]	23.2 [21.2 to 25.1]
Percentage of short (%)	1.3 [–0.2 to 2.8]	2.6 [1.0 to 4.2]
Percentage of long (%)	8.8 [3.4 to 14.2]	5.0 [2.1 to 7.9]
Refractive shift (D)	–0.06 [–0.15 to 0.03]	–0.04 [–0.11 to 0.03]

The table shows mean and 95% confidence intervals (in brackets). Horizontal phoria: positive indicates exophoria; vertical phoria: positive indicates right hyperphoria. *Statistically significant difference between the two cohorts tested by a two-sample *t* test. AA = amplitude of accommodation; SE = spherical-equivalent refractive error; SVL = single-vision lens.

distances were significantly different from zero for both cohorts at T0 (18 to 25 years: −3.8 ± 1.6%, $P = .026$; 30 to 40 years: −2.7 ± 1.2%, $P = .037$). On the other hand, the increase in time spent at the shorter working distance (by 0.50 D) due to switching the lens design was also statistically significant in the older cohort at T0 (3.64% increase in time spent at shorter working distance when wearing the digital lenses, $P = .046$). No such effects were found on the percentages of longer working distances.

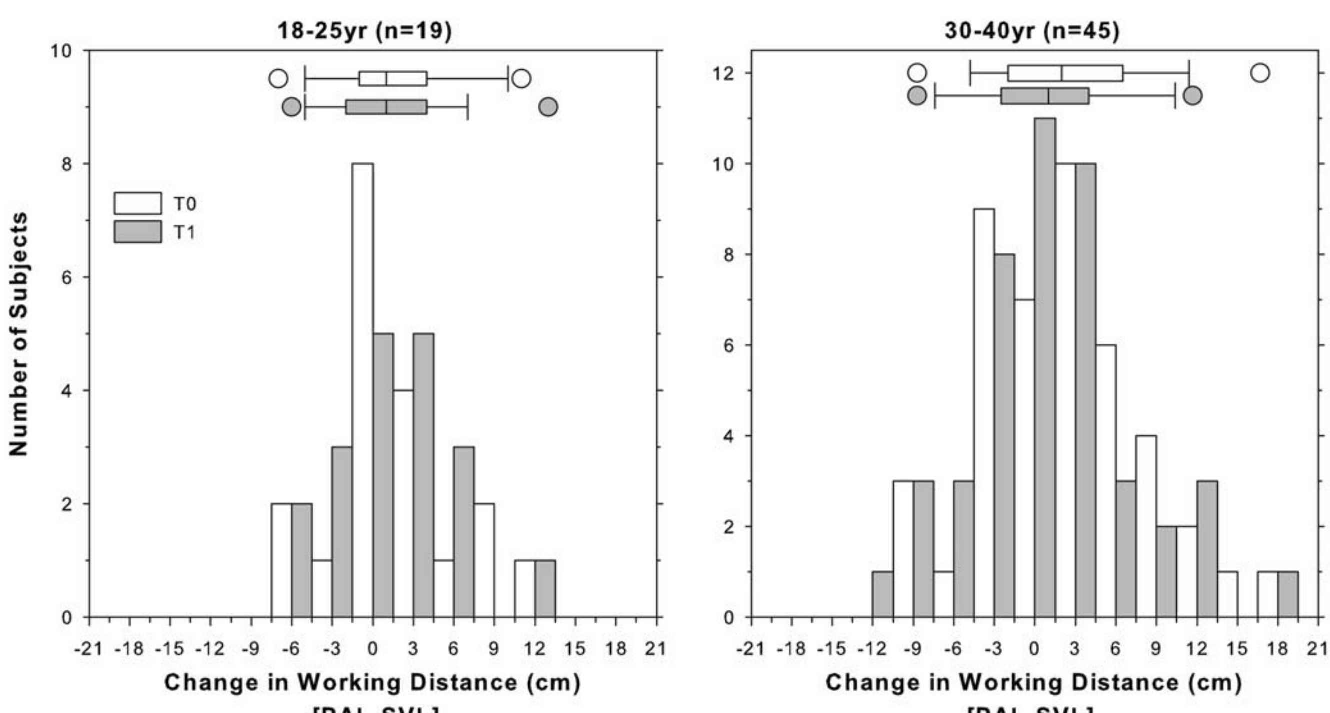

FIGURE 2. Effects of switching lens design on working distance. Histogram (bottom) and box plots (top) for the changes in working distance due to switching lens design (PAL-SVL) in younger (left) and older participants (right) at both time points (see legend). Lines within the boxes were medians, and the round symbols represent outliers beyond the 5th/95th percentile. The magnitude of increased working distance due to switching the lens design was significantly different from 0 at T0 for the older cohort (one-sample *t* test, $P = .013$). PAL = progressive addition lens; SVL = single-vision lens.

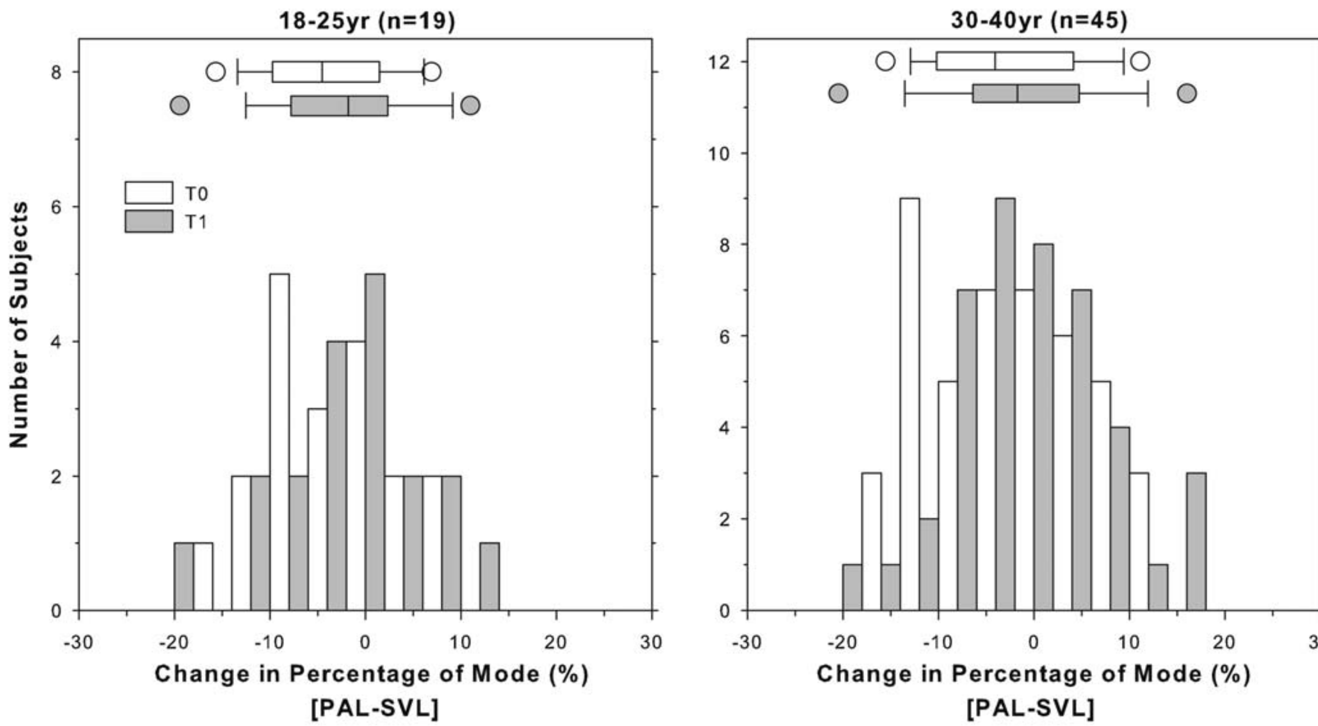

FIGURE 3. Effects of switching lens design on the percentage of time spent at modal working distance. Histogram (bottom) and box plots (top) of the changes in percentage of modal working distance after switching lens design (PAL-SVL) in younger (left) and older participants (right) at both time points (see legend). Lines within the boxes were medians, and the round symbols represent outliers beyond 5th/95th percentile. The reductions in percentage of time spent at modal working distance due to switching lens design were significantly different from 0 at T0 for both cohorts (one-sample *t* tests, $P \leq .037$). PAL = progressive addition lens; SVL = single-vision lens.

Refractive Shift

To show the impacts on refractive status by wearing single-vision lens for 30 minutes of video-game play, Fig. 4 shows the distributions of refractive shift for both age cohorts (white bars, 18 to 25 years; gray bars, 30 to 40 years) at T0. Although the average refractive shifts were not statistically significant in both cohorts (both $P \geq .17$; see also Table 1), it should be noted that the refractive shifts covered a wide range, and there were more participants showing negative than positive shifts (18 to 25 years: 63.2% vs. 36.8%; 30 to 40 years: 60% vs. 40%).

Fig. 5 illustrates the effects of lens design on the changes in refractive shift after switching lens design (progressive addition lens–single-vision lens) for individual participants. A similar plotting template as Figs. 2 and 3 is used. As observed from the distributions, both cohorts exhibited considerable ranges of changes in refractive shift after switching from single-vision lens to progressive addition lens. Although the proportions of participants showing opposite shifts were quite similar in the younger cohort at both time points and in the older cohort at T0, there were slightly more participants showing positive refractive shifts in the older cohort at T1, with the peak of this distribution occurring within the 0.06- to 0.18-D bin. The positive refractive shift after switching the lens design was significantly different from zero (mean ± standard error, +0.08 ± 0.04; $P = .021$) in the older cohort at T1: 64.4% of the participants in this cohort had more than 0-D positive refractive shift (median, 0.13 D). Cohen effect size value ($d = 0.36$) suggested a small to moderate practical significance for this small refractive shift. Assuming an SD of 0.22 D for refractive power measurement using Shin-Nippon autorefractor,[17] it requires a refractive shift of 0.04, 0.11, and 0.18 D, respectively, to achieve a small ($d = 0.2$), moderate ($d = 0.5$), and high effect size ($d = 0.8$). It should be noted that these participants did not overlap fully with the group of participants who had longer working distances when wearing progressive addition lens at T0 (see above).

Correlations between Baseline Ocular Parameters and Changes in Outcome Measures due to Switching Lens Design

Because lens design showed significant impacts on the two outcome measures, correlation analyses were focused on the changes in outcome measures due to switching lens design (progressive addition lens – single-vision lens) and parameters collected at the baseline visit (i.e., age, spherical equivalent, amplitude of accommodation, AC/A ratio, and near phoria). Table 2 presents the significant Pearson correlation coefficients found between these parameters in the two cohorts. In the younger cohort, spherical-equivalent refractive error and amplitude of accommodation were correlated with the changes in working habit due to switching lens design at T0; near horizontal phoria was correlated with the changes in both the percentage of short working distance and the refractive shift. In the older cohort, the amplitude of accommodation and near horizontal phoria were weakly but significantly correlated with the changes in refractive shift due to switching the lens design at different time points. Furthermore, the amplitude of accommodation in this older cohort was also negatively correlated

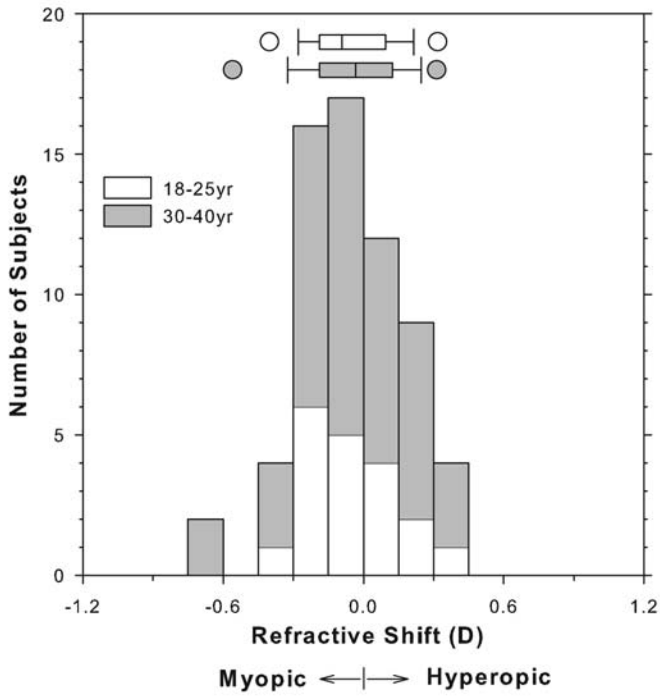

FIGURE 4. Effects of wearing the conventional SVL on refractive status. Histogram (bottom) and box plots (top) of the changes in refractive status (post-task – pre-task) for younger (white) and older (gray) cohorts after playing 30 minutes of video game with SVL. SVL = single-vision lens.

with age (Pearson $r = -0.62$, $P < .001$). All other parameters were not significantly correlated.

Comparisons of Ratings between the Two Lens Types

In the younger cohort, both lens designs scored similar ratings in all 10 digital work–related visual symptoms (range of mean ranks, 3.42 to 4.84; all $P \geq .06$). In the older cohort, both lens designs also scored similar ratings in nine visual symptoms (range of mean ranks, 3.07 to 4.64; all $P \geq .16$), but progressive addition lens scored significantly higher rating (less frequent) in "increased sensitivity to light" when compared with single-vision lens (mean rank, 4.58 vs. 4.33, respectively, $P = .012$). Mean ranks (±SD) for each visual symptom are presented in Table 3.

Table 4 summarizes the significant correlations found between the baseline parameters or the changes in working habits (rows) with the differential ratings of individual visual symptoms given to the two lens designs (columns) in the two age cohorts. The differences in ratings (progressive addition lens – single-vision lens) for the first four visual symptoms showed significant correlations with at least two parameters (range of Spearman $\rho = -0.31$ to $+0.52$), whereas "tearing" and "sum of rankings" were correlated with only one parameter.

Comparisons of the ratings between single-vision lens and progressive addition lens were further analyzed in the three subgroups divided by preferred lens type (single-vision lens: 37 [57.8%], progressive addition lens: 17 [26.6%], no preference: 10 [15.6%]). The rankings for the majority of symptoms were similar between the two lens designs in these three subgroups. However, those who preferred progressive addition lens ranked "eye pain" ($P = .03$)

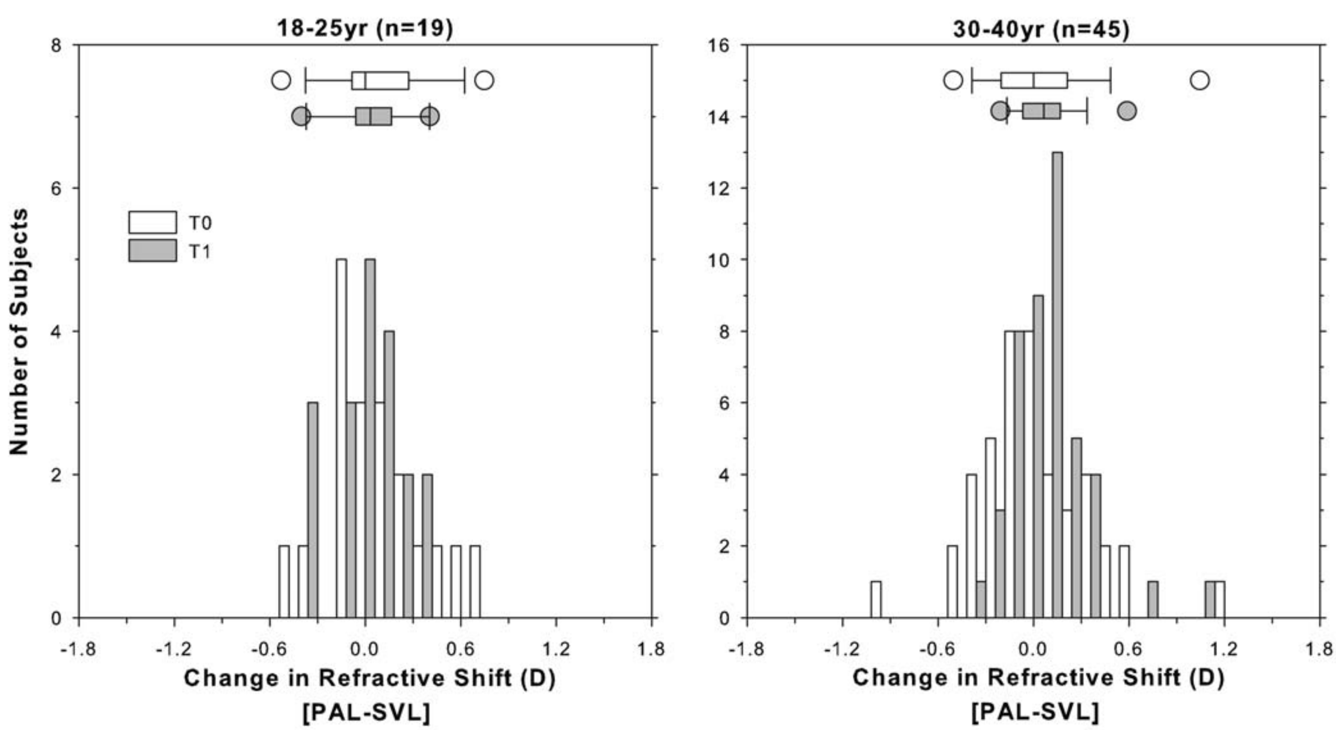

FIGURE 5. Effects of switching lens design on the refractive shift after playing interactive video game. Histogram (bottom) and box plots (top) of the changes in refractive shift after switching lens design (PAL-SVL) in younger (left) and older participants (right) at both time points (see legend). Lines within the boxes were medians, and the round symbols represent outliers beyond 5th/95th percentile. The positive refractive shift due to switching the lens design was significantly different from zero at T1 in the older cohort (one-sample *t* tests, $P = .021$). PAL = progressive addition lens; SVL = single-vision lens.

TABLE 2. Significant Pearson correlation coefficients found between the changes due to switching lens design and the spherical-equivalent (SE), amplitude of accommodation (AA), and horizontal phoria in the two cohorts

	Baseline biometric parameters		
Changes due to lens switch (PAL-SVL)	SE	AA	Horizontal phoria at near
18–25 y (n = 19)			
WD at T0	+0.66, $P = .002$	—	
% of mode WD at T0	–0.46, $P = .046$	—	
% of short WD at T0	—	–0.51, $P = .032$	+0.58, $P = .009$
% of long WD at T0	—	–0.48, $P = .043$	
Refractive shift at T0			+0.52, $P = .022$
30–40 y (n = 45)			
Refractive shift at T0	—	–0.32, $P = .034$	–0.35, $P = .017$
Refractive shift at T1	—	–0.30, $P = .048$	

PAL = progressive addition lens; SVL = single-vision lens; T0 = immediately after lens delivery; T1 = 1 month after lens delivery; WD = change in working distance.

and "eye redness" ($P = .02$) as less frequent when wearing progressive addition lens compared with wearing single-vision lens. Interestingly, those who preferred single-vision lens ranked "increased sensitivity to light" as less frequent when wearing progressive addition lens than when wearing single-vision lens ($P = .04$), suggesting that the frequency of this visual symptom might not be the key criterion when this group of participants chose their preferred lens type. There were no significant differences across the three subgroups in all other parameters tested (all $P \geq .07$).

DISCUSSION

Our results showed that (1) wearing the conventional single-vision lens for video-game play induced a wide range of refractive shifts between individual participants in both age groups; (2) the increase in working distance after switching to progressive addition lens was significant in the older cohort at T0; (3) a significant refractive shift in the plus direction after switching to progressive addition lens was observed in the older cohort at T1; (4) the changes in working distance and refractive shift due to the different lens designs were correlated with spherical equivalent, amplitude of accommodation, and near horizontal phoria in the two cohorts at different time points; (5) progressive addition lens was ranked higher (less frequent) in the occurrence of specific visual symptoms.

TABLE 3. Likert scales (mean ± SD; 1 = very frequent, 5 = never) for digital work–related visual symptoms given by participants after wearing SVL or PAL for 1 month

	18–25 y		30–40 y	
	(n = 19, 57.9% Female)		(n = 45, 57.8% Female)	
	SVL	PAL	SVL	PAL
Blurred vision	4.16 ± 0.83	4.37 ± 0.60	4.07 ± 1.03	4.02 ± 0.94
Eye fatigue	3.42 ± 1.12	3.53 ± 0.91	3.24 ± 1.03	3.07 ± 1.03
Eye pain	4.58 ± 0.77	4.68 ± 0.58	4.51 ± 0.76	4.64 ± 0.77
Excessive blinking	4.26 ± 0.99	4.47 ± 0.70	4.22 ± 0.85	4.20 ± 0.82
Burning	4.37 ± 1.07	4.68 ± 0.75	4.51 ± 0.90	4.64 ± 0.77
Double vision	4.56 ± 0.71	4.68 ± 0.67	4.53 ± 0.84	4.58 ± 0.69
Eye strain	4.11 ± 0.99	4.26 ± 0.87	4.07 ± 0.86	4.18 ± 0.98
Increased sensitivity to light	4.63 ± 0.68	4.84 ± 0.38	4.33 ± 0.98	4.58 ± 0.89
Eye redness	4.37 ± 1.07	4.63 ± 0.68	4.31 ± 0.90	4.51 ± 0.76
Tearing	4.53 ± 0.84	4.68 ± 0.75	4.27 ± 0.94	4.24 ± 0.91

PAL = progressive addition lens; SVL = single-vision lens.

Wearing the conventional single-vision lens for a short period of interactive video-game play induced a range of refractive shifts, with more participants showing negative shifts in both cohorts at T0 (Table 1, Fig. 4). The average refractive shifts in both cohorts were negative in value, but small in magnitude (Table 1), similar to the magnitudes induced by computer work in earlier studies: Yeow and Taylor[7] reported a significant negative shift of –0.11 D after 2.4 hours of computer work in 105 computer users, whereas no significant refractive shift was found after 2 hours of non-computer work in 61 typists. Similarly, Gratton et al.[8] and Piccoli et al.[9] reported computer work–induced negative shifts of –0.19 D (6 hours' computer work) and –0.036 D (~6 hours' computer work), respectively, using much smaller sample sizes (n = 7 and 14, respectively). The negative shift induced by computer work resembles the transient myopia induced by near tasks—commonly referred to as "near work–induced transient myopia."[10] However, instead of performing computer work, the participants in near work–induced transient myopia studies were requested to read continuously (10 minutes to a few hours) at a very short working distance of 20 to 25 cm. Consequently, at least 0.3 D of negative refractive shift after reading was observed, but it reverted rapidly to the baseline refractive status usually within a few minutes.[10] In our study, although the average magnitudes of negative shift (Table 1) induced by wearing single-vision lens were less than 20% of the typical near work–induced transient myopia values, it should be noted that we did not restrict our participants' working distances during the video-game play. The longer working distances observed in our participants (approximately 10 cm longer than those used in near work–induced transient myopia experiments; Table 1) could have contributed to smaller accommodative demands and therefore smaller refractive shift in the minus direction. Nonetheless, even with these longer working distances, playing a video game for only

TABLE 4. Significant Spearman correlation coefficients found between the changes due to switching lens design and the differential rankings given to the two lens types

Baseline biometric parameters or changes due to lens switch (PAL-SVL)	Differences in rankings (PAL-SVL)					
	Eye pain	Excessive blinking	Eye strain	Increased sensitivity to light	Tearing	Sum of ranks
18–25 y (n = 19)						
Spherical equivalent				–0.47*		
Vertical phoria	–0.48*					
WD at T0		+0.46†				
WD at T1						+0.51*
30–40 y (n = 45)						
Horizontal phoria			–0.31*			
ACA	+0.30*		+0.40‡			
WD at T1				–0.32*		
% of mode WD at T0		+0.52§				
% of short WD at T0		–0.41‡			–0.30*	

*$P < .05$, †$P = .05$, ‡$P < .01$, §$P < .001$. PAL = progressive addition lens; SVL = single-vision lens; T0 = immediately after lens delivery; T1 = 1 month after lens delivery; WD = change in working distance.

30 minutes (vs. 2 to 6 hours in previous studies) with conventional single-vision lens induced a wide range of refractive shifts in these pre-presbyopic adults (Fig. 4), indicating a potential impact on vision after prolonged digital work.

The changes in working distance and refractive status due to switching lens design were correlated with the degree of myopic refractive error, amplitude of accommodation, and near horizontal phoria. In the younger cohort, the low myopes tended to use longer working distances, but spent less time at modal working distances when wearing progressive addition lens at T0 (Table 2, Fig. 6). Also at this time point, the younger participants with low amplitudes of accommodation tended to spend more time at shorter or longer working distances, and more exophoria at near was correlated with increased time spent on shorter working distance and positive refractive shifts when wearing progressive addition lens than when wearing single-vision lens (Table 2). All these significant correlations observed in the younger cohort at T0 disappeared at T1. We speculate that the relatively higher amplitudes of accommodation and less exophoria at near in this younger cohort (Table 1) may have given more flexibility for this cohort to undergo adaptive changes in working habits (e.g., longer working distances or longer times spent at other working distances) over the 1-month lens wearing period, leading to the disappearance of interactions at T1 as observed at T0. In contrast, the older cohort showed low but significant negative correlations between the amplitude of accommodation and refractive shift at both T0 and T1 and between the horizontal phoria and refractive shift at T0; in other words, the older participants with lower amplitudes of accommodation and less exophoria tended to show more positive refractive shift when playing the video game with progressive addition lens. However, it should be noted that not all subjects showed this positive shift after switching to progressive addition lens. Indeed, switching from conventional single-vision lens to a new progressive addition lens produced a wide range of changes in working distance and refractive shift, and these changes may vary over time (Figs. 2 to 5, Table 2), although what causes this variability remains unclear. Nonetheless, in terms of alleviating the negative refractive shift related to computer work, these results suggest that the prescription of +0.75 D addition power for handheld digital displays is more likely to benefit those individuals who are constantly encountering higher accommodative demands (e.g., low myopes would have higher accommodative demands than high myopes, according to effective power calculation), but having lower amplitude of accommodation. Further studies are in need to longitudinally follow up the refractive shift due to lens design and whether and how this refractive shift is related to myopia development.

To the best of our knowledge, this is the first study that surveyed the frequencies of digital work–related vision symptoms after wearing the single-vision lens and progressive addition lens for 1 month in pre-presbyopic adult computer users. Although the ratings for both lens designs were similar for the majority of visual syndromes, wearing progressive addition lens was rated as causing less "increased sensitivity to light" compared with wearing single-vision lens. Interestingly, those who preferred progressive addition lens or single-vision lens at the end of the wearing period also rated progressive addition lens as causing less "eye pain," "eye redness," and "increased sensitivity to light" (see RESULTS for details). However, these ratings should be interpreted carefully when prescribing spectacle lenses in ophthalmic practice, because higher subjective ratings for progressive addition lens are associated with different sets of biometric parameters in the two age cohorts (Table 4). Nevertheless, it should be noted that the highest correlations with subjective ratings were associated with the changes in working distances due to switching the lens type in both age groups (Table 4: younger, $\rho = +0.51$; older, $\rho = +0.52$), indicating the importance of assessing the working habits of potential lens wearers.

In this study, the results derived by comparing the treatment effects of two lenses on the same individuals removed the potential intersubject variation that may arise if the effects of the two lens designs were compared between two subject groups. However, there are two limitations in this study that warrant consideration when planning for future studies. First, the progressive addition lens design did not take into account the potential influence of peripheral optics in subjects with different levels of ametropia.

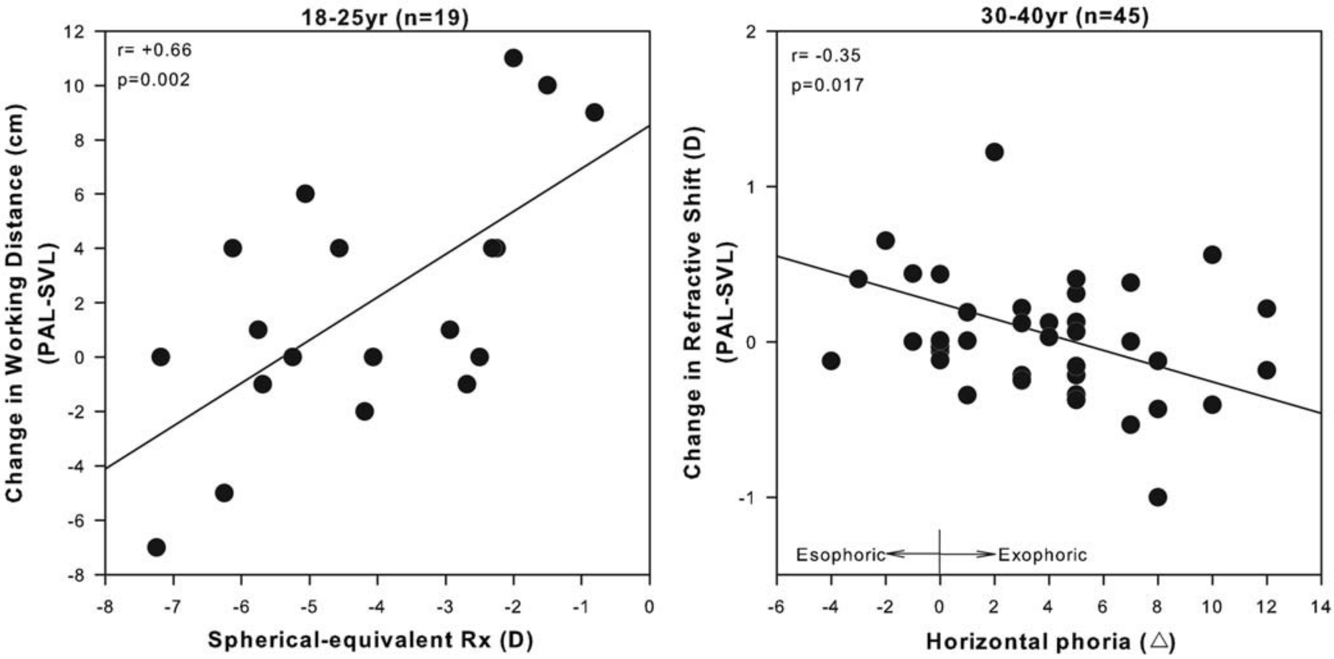

FIGURE 6. Correlations of baseline parameters with the changes in outcome measures due to switching the lens design in younger (left) and older participants (right). Only significant correlations showing the highest Pearson *r* in each group are plotted here. Refer to Table 2 for details. Linear regression lines are inserted in each plot.

Although the progressive lens design and the positive power imposed (+0.75 D addition power) were consistent among all participants, we could not exclude the possible influences of individual refractive profiles across the visual field[20–22] on the working behavior and in creating optical error signals on the peripheral retina. An uncertainty related to this optical effect was the effective use of addition portion for digital work over time, even though a training session to demonstrate the progressive addition lens design was provided to all participants in lens delivery visit. The second was the different sample sizes of the two cohorts in this study, which was mainly due to a short recruitment period for this study. A larger sample size for the younger cohort might generate clearer patterns of change in working distance and refractive shift.

CONCLUSIONS

Compared with use of the conventional single-vision lens, wearing a new progressive addition lens designed for handheld digital devices increased the working distance for both non–presbyopic-age cohorts and induced a small positive refractive shift. The changes in working distance and refractive shift due to the different lens designs were correlated with the spherical-equivalent refractive error in the younger cohort and the amplitude of accommodation in both cohorts at different time points. Whether these impacts of lens design could interfere with the effectiveness of optical intervention on myopia development should be investigated.

ARTICLE INFORMATION

Submitted: February 7, 2017

Accepted: February 18, 2018

Funding/Support: Carl Zeiss Far East (P14-0085; to CK) and Centre for Myopia Research, School of Optometry, The Hong Kong Polytechnic University (J-BB7P; to CK).

ClinicalTrials.gov Registration: NCT02775396 (registered May 17, 2016).

Conflict of Interest Disclosure: None of the authors have reported a financial conflict of interest.

Author Contributions and Acknowledgments: Conceptualization: CK, TWL, KK, CHIL; Data Curation: TWL, KK, CHIL; Formal Analysis: CK, TWL, KK, CHIL; Funding Acquisition: CK, TWL; Investigation: CK, TWL, KK, CHIL; Methodology: CK, TWL, KK, CHIL; Project Administration: CK, TWL, KK, CHIL; Software: KK, CHIL; Supervision: TWL, CHIL; Writing – Original Draft: CK, KK; Writing – Review & Editing: CK, TWL, KK, CHIL.

Part of the results of this study were presented at the second Chinese Myopia Conference, Shenzhen, China, July 2016.

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