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Quantification of accommodative response and visual performance in non-presbyopes wearing low-add contact lenses

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ABSTRACT

Purpose: Digital eye strain encompasses a range of ocular and visual symptoms across all age groups. Recently, symptoms associated with accommodative or binocular vision stress have become a major problem, especially in young individuals. The purpose of this prospective, single-blinded study was to objectively quantify the accommodative response and visual performance of low-add soft contact lenses (CLs) in young non-presbyopic individuals.

Methods: A daily disposable low-add bifocal design lens (low-add CL) was tested. It employs a centre-distance optical zone and peripheral zone with the added power of +0.50 D to support near vision. Sixteen subjects aged 20–39 years were enrolled in the study. Refractive state and accommodation were measured using an open-field autorefractor with three target vergences, namely, −0.20 D, −2.5 D, and −4.0 D. Binocular visual acuity at high (100%) and low (40%, 20%) contrast and reading ability were assessed. Monofocal soft CLs were used as controls.

Results: Accommodative response with low-add CLs was significantly smaller than those with two monofocal CL wearing conditions, i.e., at 40 cm (2.5 D of stimulus) and 25 cm (4.0 D of stimulus) (all $p < 0.05$). The 20% contrast visual acuity at distance was significantly better with low-add CLs and second-time monofocal CLs compared to first-time monofocal CLs (all $p < 0.05$). The reading ability was not significantly different.

Conclusions: Quantification of accommodative response and visual performance demonstrated that using low-add CLs alleviated the accommodation under the near-vision condition, without sacrificing distance vision, in non-presbyopes.

1. Introduction

In recent years, a remarkable increase in digital device usage has been observed across all age groups for both social and professional purposes. Digital eye strain encompasses a range of ocular and visual symptoms, and its prevalence is reported to be 50% or more among computer users. [1] Digital eye strain symptoms can be classified into those associated with dry eye or those related to accommodation [1–3]. Devices such as smartphones, tablets, and small computers are commonly held at closer viewing distances than conventional printed materials. The small size of some portable screens may necessitate the use of reduced font sizes. Staring at the tiny screen of a smartphone for long hours can also create a need for close-distance viewing, which makes high demands upon ocular accommodation. Socially, it has been a very common problem that an increasing number of people in their 20 s and 30 s are reporting symptoms associated with accommodative or binocular vision stress similar to presbyopia. Individuals who wear contact lenses (CLs) in their 20 s and 30 s are generally wearing monofocal CLs; therefore, accommodation is needed for near vision. Prolonged use of digital devices at closer viewing distances with the CLs corrected for distance vision may cause symptoms due to accommodative stress in aged non-presbyopic individuals.

For aged presbyopic CL users, purely CL correction, including monovision and bifocal or multifocal CLs, is available. Use of multifocal CLs or monofocal CLs with reduced correction can reduce accommodative fatigue in some cases for non-presbyopes. However, the main

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disadvantage is the unwarranted decrease in distant vision. In recent years, a wide variety of add powers have been commercially available for multifocal CLs including the lower-add power. Regarding lenses with an additional power less than +0.75 dioptre (D), CLs with a very low-add power such as +0.50 D have been introduced to reduce the accommodative or binocular vision stress without sacrificing distance vision in non-presbyopic populations who engage in prolonged use of digital devices. The purpose of this study was to objectively quantify the accommodative response and visual performance of low-add soft CLs in young non-presbyopic individuals.

2. Methods

This prospective, single-blinded study was reviewed and approved by the institutional review board of Osaka University Hospital. The study adhered to the tenets of the Declaration of Helsinki. All subjects provided written informed consent after receiving an explanation of the nature and possible consequences of the study.

2.1. Subjects

Experienced soft CL wearers, who had been wearing spherical disposable CLs in both eyes, between 20–39 years of age were eligible to participate if they met the following criteria: (1) refractive error between +0.00 D and −6.00 D; (2) astigmatism less than 1.50 D; (3) best corrected visual acuity of 20/20 or better in each eye; (4) able to wear CLs more than 8 h per day and more than 5 days per week; (5) use of digital devices such as smartphones, tablets, or small computers more than 3 h per day.

Exclusion criteria were extended CL usage; toric CLs, multifocal CLs, or hard CLs; manifest strabismus or dry eye; clinically significant anterior segment abnormalities or ocular and systemic diseases that would preclude CL wear; and pregnancy or lactation.

2.2. Tested lenses

A daily disposable low-add bifocal design lens (SEED 1dayPure moisture Flex; SEED CO., LTD., Tokyo, Japan) (low-add CL) was tested in this study. This lens is made from a copolymer of 2-hydroxyethylmethacrylate (2-HEMA) and methacrylate compounds containing ammonium, carboxyl, and methyl groups cross-linked by ethylene glycol dimethylacrylate (EDGMA). The material is zwitterionic, comprising both cations and anions with a water content of 58%. This lens has a diameter of 14.2 mm. It is classified by the U.S. Food and Drug Administration as a group IV lens. It employs a centre-distance optical zone and peripheral zone with an added power of +0.50 D to support near vision. (Fig. 1) According to the manufacturer, the widely designed centre-distance zone together with the gentle and progressive transition of lens refractive power between lens zones can provide natural vision of monofocal lens. As a control lens, a daily disposable monofocal lens (SEED 1dayPure moisture; SEED CO., LTD.) (monofocal CL) was used. Both lenses were identical in materials and the only difference was in their designs.

2.3. Experimental procedure

Fig. 2 details the outline of the study visits. Once trial suitability was established at the baseline visit, subjects were fitted bilaterally with the monofocal CLs for 2 weeks. The lens power was selected on the basis of the spherical equivalent of the subjective refraction. At the end of 2 weeks, the on-eye visual performance of the lens and accommodative response were evaluated. Subsequently, subjects were asked to wear low-add CLs for another 2 weeks, after which the same measurement procedure was repeated. Each subject then wore the monofocal CLs for another 2 weeks, after which the same measurement procedure was repeated. Subjects were masked to the type of each lens. Both lenses were worn bilaterally in a daily wear with daily disposable modality.

At each visit, subjects were assessed in the following order: 1) CL fitting examination using the slit-lamp, 2) binocular visual acuity evaluation at high and low contrast, 3) reading ability evaluation, 4) accommodative response evaluation, 5) slit-lamp examination of the ocular surface.

2.4. Measurements

Binocular visual performance test results, including distance visual acuity measurements at high (100%) and low (20%, 40%) contrast levels at 5 m, were obtained using the Landolt C chart. Near visual acuity measurements were also obtained for high (100%) and low (20%, 40%) contrast levels at 40 cm. These tests were performed using Binoptometer 4 P (Oculus Optikgeräte GmbH, Wetzlar, Germany).

Binocular reading ability was measured using the electronic version of the MNREAD-J, which is the Japanese version of the MNREAD acuity charts [4]. One sentence comprised 30 characters (3 printed lines of 10 characters per line), and the character contrast was approximately 85%. The patients were asked to read the sentences aloud on the tablet display screen. The distance for the measurements was 40 cm. The time required for reading and the frequency of mistakes were recorded. In accordance with the previous studies [5,6], the following parameters of the MNREAD-J were calculated: (1) maximum reading speed: the mean reading speed of the fixed value (i.e., level at which no further increase in reading speed occurs); (2) critical character size: the smallest character size with which the maximum reading speed is attained; (3) reading acuity: the smallest character size with which the patient can read (regardless of speed).

Objective refractive state and accommodation were measured using a Grand Seiko WAM-5500 open-field autorefractor (Grand Seiko Co., Hiroshima, Japan) under binocular viewing conditions. The principles and procedures involved in the use of the WAM-5500 open-field autorefractor have been described elsewhere. [7,8] While it allows binocular viewing, the measurements of this device are monocular. In this study, the CL of the non-dominant eye was taken off and the consensual response of the non-dominant eye was measured with the CL on the dominant eye. Ocular dominance was assessed by the hole-in-card test. This method was adopted since measuring accommodative response with an open-field auto-refractor through a multifocal contact lens can lead to errors. Moreover, the similarity of the accommodative state between the two eyes has been reported from previous studies that measured it using a binocular optometer under natural viewing conditions in the normal eye. [9–11] Dynamic accommodative responses were measured at three stimulus distances: at 5 m (0.20 D of stimulus), 40 cm (2.5 D of stimulus), and 25 cm (4.0 D of stimulus). The accommodation target was a high-contrast Maltese cross positioned on the subject's midline. Subjects were instructed to keep looking fixedly at the target. A total of 5 measurements were obtained at each of the stimulus levels and averaged.

Following the measurements mentioned above, ocular surface examination with the slit-lamp was performed by removing CLs from eyes and applying fluorescein.

2.5. Statistical analyses

Regarding sample size calculation, a 0.5 D difference in the accommodative response was considered as clinically meaningful when comparing low-add CL wear and monofocal CL wear. It was calculated that with a sample of 10 patients, the study would have 80% power to detect 0.5 D mean difference in the accommodative response, with a type I error of 5%. For power analysis, a standard deviation of 0.5 D in the accommodative response based on the data of a preliminary study was used.

Statistical analyses were performed using MedCalc for Windows, version 18.11 (MedCalc Software, Ostend, Belgium). Friedman

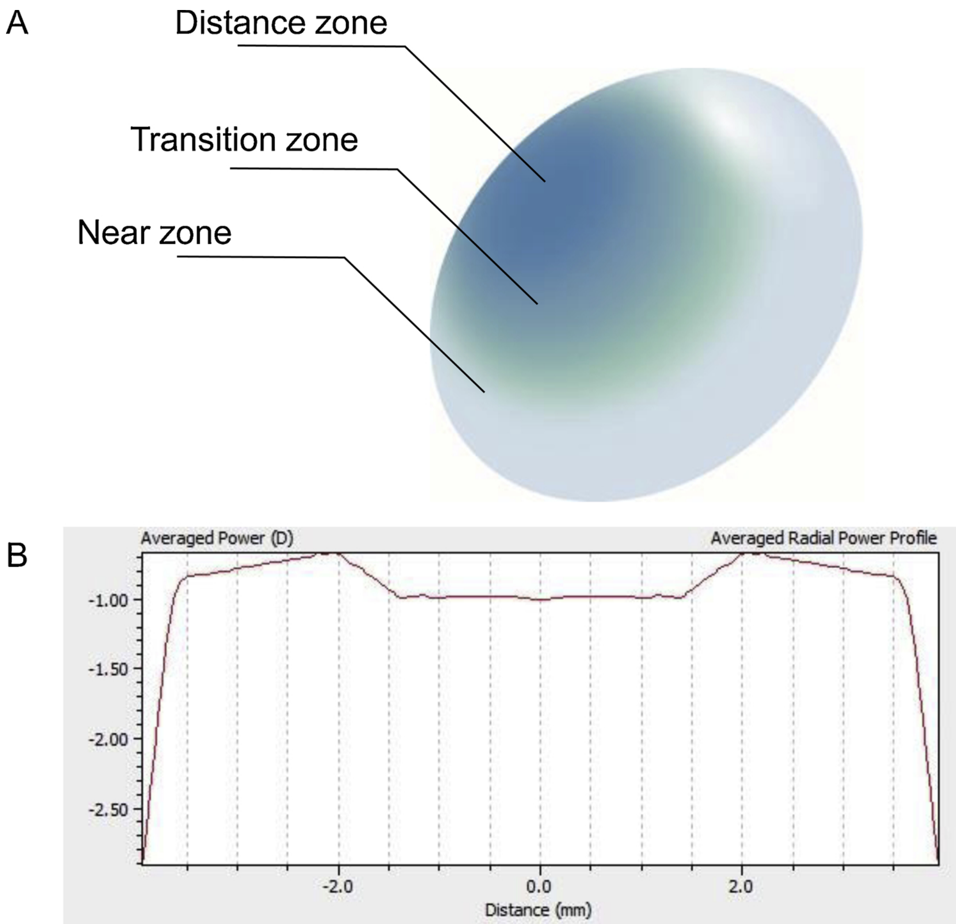

Fig. 1. Design of a daily disposable low-add progressive design lens and (B) power of the lens.

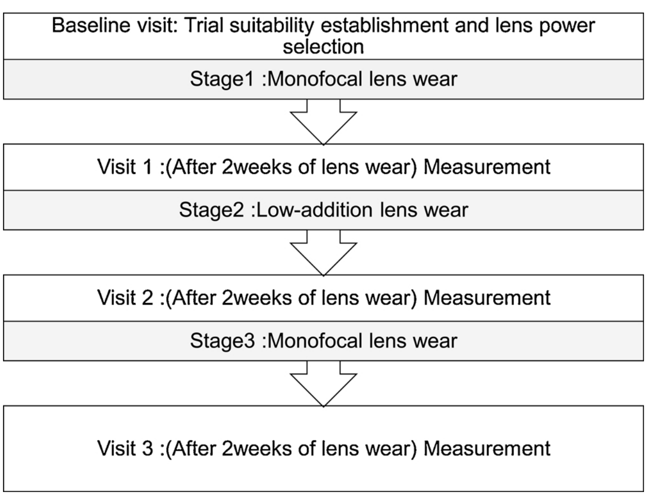

Fig. 2. Outline of the study visits.

repeated-measures ANOVA on ranks was used to compare the parameters of visual performance, reading ability, and accommodative response among the 3 conditions (first-time monofocal CL wear, low-add CL wear, and second-time monofocal CL wear).

3. Results

Sixteen subjects (6 men and 10 women; age 24.0 ± 2.2 years) were enrolled in the present study. The mean spherical equivalent refractive error was −4.02 D ± 1.64 D. All subjects completed the study.

Visual performance for high and low contrast visual acuity under distance- and near-vision conditions are demonstrated in Fig. 3. The 20% contrast visual acuity in the distance-vision condition was significantly better with low-add CLs and second-time monofocal CLs compared to first-time monofocal CLs (all $p < 0.05$). No significant differences (all $p > 0.05$) were found among the three conditions for both high and low near contrast visual acuity.

Measured parameters of the reading ability; maximum reading speed, critical character size, and reading acuity are shown in Table 1. The reading ability was not significantly different among the three conditions (all $p > 0.05$).

For all the three conditions, accommodative responses increased with increased target vergence, overall. Accommodative stimulus-responses for each condition are shown in Fig. 4. At 40 cm (2.5 D of stimulus) and 25 cm (4.0 D of stimulus), accommodative response with low-add CLs was significantly smaller than those with two monofocal CL wearing conditions (all $p < 0.05$). There was no significant difference among the three conditions in terms of accommodative response at 5 m (0.20 D of stimulus). No adverse events were noted during the study period. Although mild corneal fluorescein staining was observed in some patients, it was considered that they did not prevent CL wear and affect the results.

4. Discussion

There have been significant advancements in CL multifocal technology. Currently, there is no specific numerical definition for ‘low’, ‘mid’, or ‘high’ multifocal CLs. Although the classification of add power is varied among the CL manufacturers, +0.75 D–+1.50 D are generally considered as ‘low add’. There are a few CLs with + 0.50 D add power

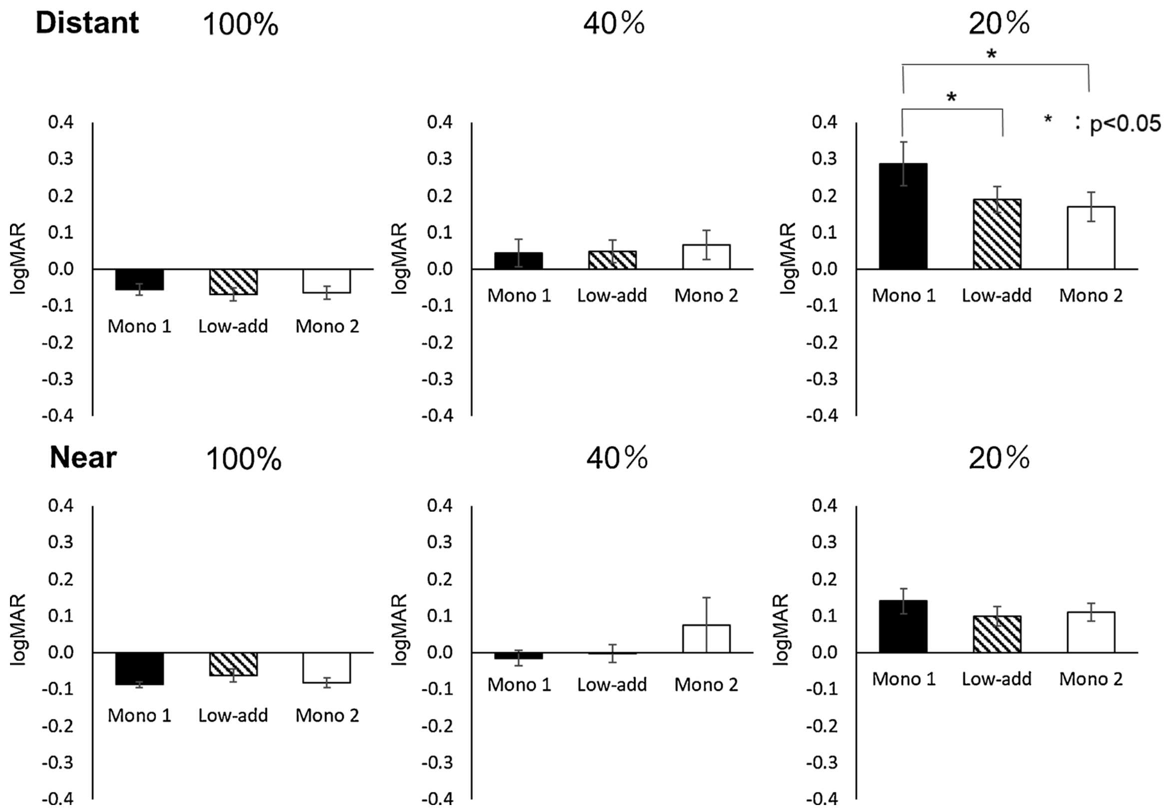

Fig. 3. Visual performance for high (100%) and low (40%, 20%) contrast visual acuity at distance and near are measured under 3 conditions (first-time monofocal CL wear, low-add CL wear, and second-time monofocal CL wear).
Mono 1: first-time monofocal CL wear, Low-add: low-add CL wear, Mono 2: second-time monofocal CL wear.

commercially available in Japan. Although these CLs have add power, the concept of these CLs is to alleviate the accommodative burden in non-presbyopic young individuals, rather than multifocal CLs for real presbyopia, according to the manufacturers. Comfilcon A CL with Digital Zone Optics lens design (Biofinity Energys, Coopervision Inc) is designed to ease accommodative burden, with multiple front-surface aspheric curves across the optical zone, resulting in more positive power in the centre of the lens. Information on the amount of plus power is not available. However, there have been no documented reports about the effect of low-add CLs on accommodation and visual performance.

In the current study, objective quantification of the accommodative response of low-add CLs and comparison with that of monofocal CLs in young non-presbyopic individuals (24.0 ± 2.2 years) were done. The open field autorefractor utilised in this study has been used in many studies of accommodation behaviour, [8,12,13] and it proved to be a useful tool for assessing the accommodative response of eyes with multifocal or multi-zone CLs [14–16]. Several studies have evaluated accommodative responses with multifocal CLs in non-presbyopic subjects using an open field autorefractor. [14,16–19] Anistice et al. have demonstrated children (age 11–14 years) accommodated normally through the multifocal CLs [17], while Gong et al. have shown that children (age 10–15 years) wearing +2.50 D multifocal CLs exhibited reduced accommodative responses [18]. According to Tarrant et al., young myopic adults (age 22.8 ± 2.5 years) wearing +1.50 D multifocal CLs showed leads of accommodation [19]. There are some other studies using wavefront analysis to investigate accommodative responses [14,16,20,21]. Kang et al. reported increased accommodative lag at near with +1.50 D and +3.00 D multifocal CLs in young adult population (age 18–28 years) [20], while Madrid-Costa D et al. reported no significant differences in accommodative response between single vision lens and multifocal CLs of simultaneous focus in adults (age 25–35 years) [21]. The differences in the results among these studies would be partly explained by differences in the device, method (including use of a consensual response method) and the design, and add power of multifocal CLs. In the current study, the dominant eye with CL was used to view targets and the consensual response of the non-dominant eye without CL was measured. However, the effect of the non-dominant eye could not be ignored. Ideal accommodative measurements with CLs way should be established in future.

Each measurement was performed after offering a sufficient adaption period of 2 weeks instead of performing measurements after limited adaption periods, such as 10–30 minutes. The benefit of the study design is that the evaluation of the reverse conditions was possible, i.e.,

Table 1
Reading ability results.

	Mono 1	Low-add	Mono 2
Maximum reading speed (cpm)	350 ± 21	348 ± 18	346 ± 16
Critical character size (logMAR)	−0.21 ± 0.05	−0.27 ± 0.05	−0.29 ± 0.05
Reading acuity (logMAR)	−0.29 ± 0.02	−0.31 ± 0.01	−0.31 ± 0.02

Mono 1: first-time monofocal contact lens wear, Low-add: low-add contact lens wear, Mono 2: second-time monofocal contact lens wear, cpm: characters per minute.

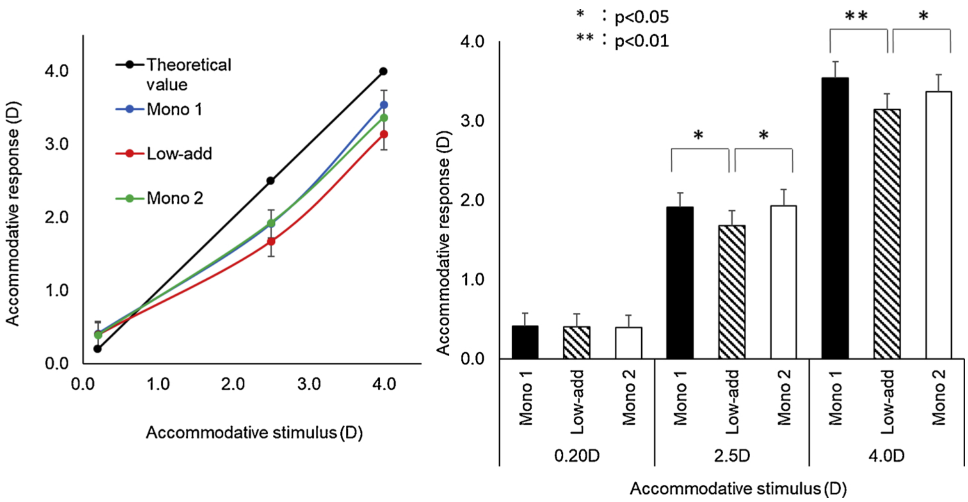

Fig. 4. Accommodative stimulus-responses at 5 m (0.20 D of stimulus), 40 cm (2.5 D of stimulus), and 25 cm (4.0 D of stimulus) measured under 3 conditions (first-time monofocal CL wear, low-add CL wear, and second-time monofocal CL wear).
Mono 1: First-time monofocal CL wear, Low-add: low-add CL wear, Mono 2: second-time monofocal CL wear.

by allowing the patients to wear monofocal CLs after wearing low-add CLs initially, because the additional power of the studied low-add CLs is +0.50 D and lower than those generally considered as 'low add'. Some subjects were refitted with lenses with slightly different power from those of their habitual lens based on the refraction examination at the first visit. Having a 2-week adaptation period might be appropriate for the comparison. However, eventual limitations should be noted. Randomisation would have required subjects to only have two conditions so that subjects were not forced to endure unnecessary intervention. The possibility of learning effect, may affect the results, and the need of a longer study period, may increase the number of subject drop out.

Previously, Bababekova et al. measured the viewing distances, while using a smartphone, and reported a viewing distance of 36.2 cm for reading text messages and 32.2 cm for viewing a web page on the internet, which were significantly closer than the typical near working distance of 40 cm when viewing hardcopy text. [22] A recent study from Australia reported that the mean viewing distance while using a smartphone over 60 min was 29.2 ± 7.3 cm [23]. According to a recent study from Japan [24] that measured the smartphone viewing distance among young people, the smartphone viewing distance was 20.3 ± 4.7 cm in the sitting position and 16.4 ± 2.7 cm in the lying position. It appears that smartphone viewing distances are decreasing compared to those reported in the past. Based on the aforementioned studies [22–24], both 25 cm and 40 cm were adopted as the viewing distances for smartphone and other digital screen devices, which can cover individual variations. Then, the measurements of the accommodative response at both distances were performed.

Similar to the prescription of multifocal CLs in daily CL practice, performing visual acuity assessment alone was thought to be a poor indicator for evaluation purposes. Therefore, binocular visual acuity and low-contrast visual acuity under distance- and near-vision conditions were measured. Moreover, reading ability, which is reported to approximate near visual acuity was measured. [6] The low-add CLs used in this study may not decrease visual acuity and low-contrast visual acuity under the distance-vision condition, at least. Interestingly, 20% contrast visual acuity under the distance-vision condition was significantly better with low-add CLs than with first-time monofocal CLs. In addition, there was a significant difference even between the two conditions with monofocal CL use. However, there was no difference in reading ability, although the critical character size and reading acuity tended to improve over time, which is likely partly due to learning effect.

This study has some limitations. First, the absence of manifest strabismus was confirmed at the baseline, but phorias and near point of convergence were not assessed with and without the study lenses objectively. In accordance with the previous study, [18] investigation of accommodative responses and phoria with low-add CLs would be interesting areas of research in future studies. Wavefront analysis would have been relevant to confirm the optical changes induced in the visual system. Subjective symptoms of the subjects were not evaluated because the focus was on the objective evaluation of the accommodative response with low-add CLs. It has been reported that acuity-based measurements alone may not give a true indication of visual performance in simultaneous-image CLs and that acuity-based measures of vision are insensitive indicators of performance compared to subjective alternatives. [25,26] Future studies with larger numbers of subjects should clarify the relationship between subjective symptoms and accommodative responses. Discomfort symptoms associated with accommodative or binocular vision stress caused by prolonged use of digital devices at closer viewing distances, is not an exception for CL wearers. Therefore, the introduction of low-add CLs and follow-up in such CL wearers would be helpful in preventing or improving abnormal accommodative behaviour.

Several recent articles [1,27,28] have described the multiple physiological and environmental factors contributing to digital eye strain. Recently, the relation of accommodative microfluctuation with dry eye symptoms in dry eyes with a short tear break-up time has been reported [29,30]. As mentioned previously, dry eye is one of the major factors for digital eye strain; thus, assessment of dry eye with the use of low-add CLs would be of interest.

In conclusion, the quantitative measurement of accommodative response and visual performance revealed that low-add CLs alleviated accommodation under the near-viewing condition, without sacrificing distance vision. Digital eye strain symptom is a very common problem across different age groups and will be more relevant over time. Generally, young individuals in their 20 s or 30 s may not think that CLs with added powers are necessary. The selection of low-add CLs from the viewpoint of accommodation and visual performance in the management of digital eye strain symptom in young non-presbyopic adults should be explored further.

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