Reduction of asthenopia related to accommodative relaxation by means of far point stimuli

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ABSTRACT.

Purpose: To conduct an experimental investigation of the effect of accommodative relaxation using far point shift stimuli for the reduction of asthenopia.

Methods: Twenty-two female students accommodated to a far point shift stimuli during a 2-min period immediately after a 15-min sustained task on a three-dimensional display. Before and after the trial, their accommodative step response and symptoms were assessed. The far point shift stimuli in the optical system, which were presented on a refractometer, were created by moving the target scenery images from far to near, linearly centred about the far point position of each eye. During 2 min of fixating on the far point shift stimuli, changes in refraction were recorded in the same eye.

Results: While looking at the far point shift stimuli, 10 of 22 subjects had changes in refraction that showed a hypermetropic shift, and the other 12 subjects had changes in refraction that showed a myopic shift. The time taken for the accommodative step response from far to near post-trial in the myopic shift group was markedly prolonged, and the accommodative lag at the far target in the optometer was significantly increased. In the myopic shift group, the symptoms of 'eye fatigue', 'eye pain', 'eye heaviness', and 'eye dryness' also increased after the trial. In the hyperopic shift group, however, only the symptom of 'eye dryness' increased, with no reduction of accommodation function.

Conclusions: We suggest that accommodative relaxation by accommodative far point shift stimuli is effective in the reduction of asthenopia.

Key words: accommodation – accommodative relaxation – asthenopia – far point shift stimuli – refraction – three-dimensional display

Introduction

The spread of new electronic devices, such as mobile computers, cellular phones, the Internet and interactive digital satellite broadcasting, has fuelled the progress of information technology (IT) in recent years and has introduced new elements to the visual environment. It is widely accepted that changes in environmental factors easily induce symptoms of asthenopia (Duke-Elder & Abrams 1970; Suzumura 1972), and many recent reports have documented the relationship between the visual display terminal (VDT) work environment and asthenopia. As the range of visual stimuli expands with the progress of IT, asthenopia may be reported more frequently.

Duke-Elder & Abrams (1970) proposed six factors of visual function as causes of asthenopia: uncorrected ametropia, accommodative difficulties, heterophoria, convergence difficulties, fusional inadequacy, and aniseikonia. In particular, accommodative difficulties are considered to be among the main causes of asthenopia. After subjects have performed visual work, or in asthenopic patients, the following changes in accommodation were confirmed: reduction of accommodative power (Gur & Ron 1992; Gur et al. 1994); recession of the near point of accommodation (Gur et al. 1994; Wolska & Switula 1999); delay of accommodative response velocity and accommodative response time (Iwasaki & Kurimoto 1987, 1988; Iwasaki et al. 1989); increase in the low frequency component of accommodative microfluctuations (Saito et al. 1994), and inward or myopic shift of the dark focus (DF) (Pigion & Miller 1985; Jaschinski-Kruza 1989; Miwa & Tokoro 1994).
Nakamura (1996) asserts that the inward shift of the DF is the result of excitation of the parasympathetic nervous system, and that the cause of asthenopia is abnormal excitation of the parasympathetic nervous system. These conclusions imply that one of the causes of asthenopia is accommodative contraction. In VDT workers with asthenopic symptoms, or after VDT work, accommodative contraction is induced; that is, an inward shift of the accommodative far point and a myopic shift occurs (Gratton et al. 1990; Ishikawa 1990; Saito et al. 1994; Piccoli et al. 1996). There is a strong possibility that this accommodative contraction is related to asthenopia. Therefore, we examined the accommodative contraction in subjects clearly perceived the stereoscopic images of the random-dot stereogram used in this experiment (details described later), without diplopia. Informed consent was obtained from all subjects after the nature of the procedures had been fully explained.

Methods

Protocol timeline

The flow of the experiment is shown in Fig.1. Accommodative step response measurements were carried out following investigation of the symptoms of asthenopia. These inspection results were made into a pre-value. Then, a visual task was conducted for 15 min, immediately followed by far point shift stimuli for a further 2 min. After the trial, accommodation was measured and symptoms were investigated, and these values were made into a post-value.

Subjects

Twenty-two female university students, aged 20–22 years (mean ± SD: 20.8 ± 0.9 years) were recruited. We chose one gender only to reduce the influence of gender differences. No subject had a dominant eye refractive error outside the range of −1.5D to 0D spherical (mean ± SD: −0.76 ± 0.63D) or greater than −0.5D cylinder or measured by autorefractometer (AR1100; NIDEK, Aichi, Japan). Subjects were free of other ophthalmological anomalies. They had normal accommodative amplitude by Donders’ method. All subjects carefully perceived the stereoscopic images of the random-dot stereogram used in this experiment (details described later), without diplopia. Informed consent was obtained from all subjects after the nature of the procedures had been fully explained.

Method of accommodative relaxation

The target was presented on an open-field refractometer (Speedy-1; Nikon, Tokyo, Japan) based on the Badal optical system (Fig.2). The target scenery image set up in the optical system showed an image of a tree in the centre, and the sky and a field on the periphery. Target component luminances were 4 cd/m², 40 cd/m² and 8 cd/m², respectively (Fig.3). The targets for both eyes, which were moving linearly from near to far, were viewed binocularly under orthoposition through a dichroic mirror system. The target presenting system was connected to a computer (PC SOLO5300; Gateway, Irvine, CA, USA), which controlled target movement and recorded refractive values from the Speedy-1 every 200 ms.

The dioptric distance of the scenery target was set as follows. First, the refraction of each eye of each subject was measured using the Speedy-1 to determine the dioptric distance of both eyes’ accommodative far point. The target was placed at a position 0.5D hyperopic to the far point and moved toward a position of 0.5D myopic to the far point at a velocity of 0.5D/second. The target stopped at this position for 1 second and then moved back to the distant position, which was now shifted outward by 0.5D from the far point, with the same dioptric velocity and stopped at that position for 2.5 seconds. This motion of the target was defined as one cycle. The subjects, who were instructed to maintain a clear gaze at the target, experienced 16 cycles while gazing at the moving target for 2 min. During this period, changes in refraction in each subject’s dominant eye were measured by the Speedy-1 by sampling at a rate of one recording per 200 ms. The mean refractive value for each cycle was then calculated by the PC. When the mean refractive value in the nth cycle of the stimulus changed on the plus shift more than in the (n − 1)th cycle, the target in the (n + 1)th cycle was moved to the distance to which the amount of plus shift was added in the nth cycle. The target movement did not change when the refractive value did not change, nor when the refractive value changed in the myopic direction. The subject’s accommodative far point was thus extended optically by feedback corresponding to the change in plus shift of the subject’s refractive value, and the ciliary smooth muscle was made to relax. This movement of the target was named the far point shift stimuli.
Division of the subjects into two groups by the far point shift stimuli

The changes in the refractive values of the subjects, which were recorded during the far point shift stimuli for 2 min at a rate of one point per 200 ms, could be approximated by a linear equation. The refractive values of a starting point and an ending point, the former being the point at which the target in the far point shift stimuli was started and the latter being the point at which the target was located after 2 min, were calculated from this regression line, and the change in the far point of each subject produced by the far point shift stimuli was represented as a refractive value. When this refractive value became positive, or, in other words, when the slope of the line was positive, the far point shifted outward, meaning that the accommodative effect was relaxed. Conversely, when the refractive value became negative, or when the slope was negative, the accommodative effect remained. The subjects were divided into two groups: those who changed in the former manner, the so-called hyperopic shift group, and those who changed in the latter manner, the so-called myopic shift group. The changes in accommodative function and symptoms were compared in both groups before and after a trial which involved completing a visual task and the far point shift stimuli.

Visual task

A visual task in which accommodative dysfunction and an increase of asthenopic symptoms had been previously reported (Iwasaki & Tawara 2000) was given to the subjects in accordance with the following procedure. The subjects perceived the monochrome random dots stereogram (RDS) as the stereoscopic images on a 26 cm parallax barrier system three-dimensional display (THD-10 PN3; Sanyo, Osaka, Japan). The RDS images in the visual task were a circle, a square and an equilateral triangle with a 4.5-degree horizontal visual angle. Each image was presented in the centre of the display as a stereoscopic image generated with a 60-min arc binocular crossed disparity for 5 seconds; the presentations were performed alternately for 15 consecutive minutes based on the results of previous experiments showing accommodative dysfunction. The

Fig. 2. Diagram of an optical far point shift stimuli system. A = part of the far point shift stimulus, a target presenting system; B = open-field autorefractometer (Speedy-1, Nikon); C = personal computer (SOLO, Gateway); T = a target scenery image; L = Badal lens system; Dm = dichroic mirror. The broken line represents visible rays from the target scenery image. The dotted line represents infrared rays from the Speedy-1 which measure the subject’s refractive error. The refractive values obtained from the Speedy-1 were processed, and the computer that connected the target presenting system with the Speedy-1 controlled the movement of the target. The targets were viewed under binocular vision, and the measurement of the refractive value was conducted from the dominant eye.

Fig. 3. The target scenery image used in the far point shift stimulation with a visual angle of 32.5 degrees. The colours of the tree, the sky and the field were green, approximately blue, and green, respectively. The illuminations were about 4 cd/m², about 40 cd/m² and about 8 cd/m², respectively.
Measurements of accommodation
Before and after the trial during which the visual task and the far point shift stimuli were presented, subjects had their accommodative step response measured using an infrared optometer (AR-3SV6; Nidek, Aichi, Japan). The subjects were asked to make accommodative changes to target positions, and to always keep the starburst target (visual angle, 3 degrees) in the optometer as sharply in focus as possible. The dynamics of the accommodative response to stepwise modulations with three-dimensional accommodative stimuli were measured; the mean accommodation distance of the near target was 4.25D (SD 0.41D), and the mean far target position was 1.25D (SD 0.41 D). The step response of the dominant eye was observed five times at 5-second intervals.

Changes in the accommodation responses and the stimulus position were recorded by a microcomputer (PC 9801BX2; NEC, Tokyo, Japan) as analogue signals. The analogue signals obtained were converted to digital signals at a rate of one point per 80 ms by an A/D board in the computer. To analyse the waveform, the digital signals of five accommodative responses were superimposed on the monitor and averaged, and the differences in accommodation response time and accommodative lag were calculated before and after the trial.

Temporal characteristics of the response were quantified in terms of response time (Tucker & Charman 1979; Iwasaki 1993; Culhane & Winn 1999). From the averaged waveform, the far-to-near response time (t1) was taken as the time between presentation of the near visual target and completion of the response. The near-to-far response time (t2) was taken as the time between presentation of the far visual target and completion of the response (Fig. 4). Spatial characteristics of the response were quantified in terms of lag. The lag of accommodation to the target stimulated in the optometer was calculated during the latter 2.5-second period of the target presentation time (Fig. 4). For the near target, the lag of accommodation was called the positive lag (Δd1), and for the far target, the lag of accommodation was called the negative lag (Δd2).

Asthenopic symptoms
The symptoms of asthenopia were examined by the self-rating method (Jaschinski-Kruza 1991; Feldman et al. 1992). We selected the following 15 characteristics from the symptoms for discrimination diagnosis of asthenopia outlined by Suzumura (1981) and The New Handbook of Industrial Fatigue (Japan Society for Occupational Health 1995) to evaluate asthenopic complaints:

1. eye fatigue;
2. eye pain;
3. eye heaviness;
4. unfocused eye;
5. blurred vision;
6. double vision;
7. burning sensation;
8. eye dryness;
9. excess tearing;
10. foreign body sensation;
11. itching;
12. spasm of eyelid;
13. sensitivity to bright light;
14. different colour sensation, and
15. headache.

Subjects responded on paper using a 7-point rating scale where 1 = never feel, 2 = minimally feel, 3 = mildly feel, 4 = moderately feel, 5 = ordinarily feel, 6 = very often feel, and 7 = extremely often feel. Before and after the trial, the above 15 characteristics on the subjects’ visual strain were assessed sequentially, and the mean score for each question was calculated.

Statistical analyses
Measurements for each item – accommodation time, accommodative lag and the scores of symptoms before (pre-value) and after (post-value) the trial – were analysed using a paired t-test (two-tailed). The significance level was set at p < 0.05. An unpaired t-test (two-tailed) was used to confirm the absence of significant differences among the pre-values.

Results
Hyperopic shift and myopic shift groups
An example of a subject showing a hyperopic shift with the far point shift stimulus is shown in Fig. 5A. The change in refractive value during the stimulus period was approximated by the linear equation, y = 0.0033x - 0.0153. From this regression line, the starting and ending points of the refractive values were calculated as -0.015 D and +0.402 D, respectively, and the difference between these values, +0.417 D, meant that a relaxation of accommodation resulted from an hyperopic shift of the accommodative far point. In contrast, in Fig. 5B, the

![Fig. 4](image-url)
linear equation was approximated by 
\[ y = -0.0017 \times -0.7092. \]
The difference between the refractive values of the 
starting point, \(-0.709\, \text{D}\), and the ending point, \(-0.909\, \text{D}\), was \(-0.199\, \text{D}\). 
Thus, the accommodative far point was shifted in a myopic direction by 
the stimuli, and accommodation did not relax. Ten of the 22 subjects showed 
a hyperopic shift while observing the 
far point shift stimuli and the other 12 
subjects showed a myopic shift.

Changes in accommodative functions

The accommodative step response for 
one of the 22 subjects in the non-
relaxed group before and after the 
trial is shown in Fig. 6. The near-to-far 
response did not change following the

![Fig. 5. Change in the refractive value during far point shift stimuli in one subject. (A) The refractive value of the hyperopic shift was approximated by the linear equation \( y = +0.0033 \times -0.0153 \). (B) The refractive value of the myopic shift was regressed by the linear equation \( y = -0.0017 \times -0.7092 \). The sinusoidal line indicates the position of the target, which is the same as T in Fig. 2; the far point shift stimuli system is the same as A in Fig. 2, and the dotted line indicates the change in refractive value of the subject.](image)
trial, but the far-to-near response became markedly delayed. The far response lag of accommodation was increased after the trial.

Table 1 lists the changes in response times of accommodation for far-to-near and near-to-far observed in the two groups. The hyperopic shift group demonstrated a longer response time for far-to-near after the trial than before it, although the change was not statistically significant. In the myopic shift group, however, the mean value before the trial was 0.96 seconds, which was significantly increased to 1.15 seconds after the trial (p = 0.0002) in the myopic shift group (Table 2).

Neither group exhibited any change in the positive lag of accommodation after the trial. While no change was noted in the negative lag of accommodation from 0.139 D to 0.197 D in the hyperopic shift group, the lag was significantly increased after the trial from 0.105 D to 0.208 D (p = 0.0024) in the myopic shift group (Table 2).

Changes in the scores in symptoms
Table 3 presents the symptoms and mean scores that changed significantly after the trial in both groups. The frequency of four of the 15 symptoms, ‘eye fatigue’, ‘eye heaviness’ and ‘eye dryness’, increased after the trial. In the myopic shift group, the scores of all four symptoms markedly increased after the trial. ‘Eye fatigue’ increased from 1.00 to 2.67 points (p = 0.0015), ‘eye pain’ increased from 1.00 to 1.58 points (p = 0.0271), ‘eye heaviness’ increased from 1.00 to 1.75 points (p = 0.0210), and ‘eye dryness’ increased from 1.20 to 2.17 points (p = 0.0081). In the hyperopic shift group, however, only the score of ‘eye dryness’ increased from 1.20 to 1.90 points (p = 0.0445).

Discussion
In the myopic shift group, the accommodative dysfunction remained after the trial, resulting in the prolongation of the far-to-near accommodation time and the increase in the negative lag for the far target in the optometer. The symptoms of ‘eye fatigue’, ‘eye heaviness’ and ‘eye dryness’ also increased. In the hyperopic shift group, no accommodative dysfunction was observed, and only one symptom increased after the trial (‘eye dryness’). From these results, we suggest that accommodative relaxation by accommodative far point shift stimuli is effective in the reduction of asthenopia.

It has been indicated that accommodative anomalies and functional decline influence asthenopia very strongly, and asthenopia may resolve after therapeutic intervention. According to Duke-Elder & Abrams (1970), training the eyes to look from far to near and near to far alternately is effective in reducing asthenopia. Daum (1983, 1984) reported that if accommodative power was at least recovered, 88% of asthenopic patients improved. Other research has shown that systematic and programmed monocular accommodative training to increase accommodative power can be used to increase accommodative amplitudes and reduce asthenopia in patients with accommodative deficiencies (Liu et al. 1979; Cooper et al. 1987). In addition, a low concentration (0.025–0.05%) of cyclopentolate-HCl applied to asthenopic patients before sleep for 1–2 months can relax accommodation (Ohmi & Kinoshita 1989; Atsumi 1990; Ohmi et al. 1991). These three papers do not make it clear whether the cyclopentolate-HCl was directly responsible for relief of asthenopia because there were no control groups; thus, it is possible that asthenopia-inducing factors in the patient’s everyday environment may have been eliminated naturally during the 1–2-month period. The effect, however, of a
Table 2. Changes of accommodation lag (mean ± SD) in both groups. Positive lag indicates the lag of accommodation for the near target in the optometer and negative lag indicates the same for the far target.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Positive lag (D)</th>
<th>Negative lag (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Hyperopic</td>
<td>0.840 ± 0.359</td>
<td>0.891 ± 0.266*</td>
</tr>
<tr>
<td>(n = 10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myopic</td>
<td>1.015 ± 0.305</td>
<td>1.044 ± 0.314*</td>
</tr>
<tr>
<td>(n = 12)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Not significant (by t-test for the pre-value).
† p = 0.0024.

parasympathetic block of the ciliary smooth muscle is equivalent to the far point shift stimuli in relaxation of accommodation. Our finding that reductio of asthenopia was induced by far point shift stimuli supports the results of these pharmacological studies, and implies that asthenopia may be caused simultaneously by accommodative contraction.

The results generated by 10 of our 22 subjects gave good agreement with the experimental hypothesis in which the far point shift stimuli relaxed accommodation by extending the subjects' accommodative far point, while 12 subjects failed to exhibit accommodative relaxation. As one of the important causes of asthenopia is accommodative contraction, the causes of the myopic shift of the far points in those 12 subjects must be considered.

One of the most common stimuli to induce accommodation is the blur of the retinal image. Blur thresholds have been shown to vary according to refractive error, standing at ±0.11 D for emmetropes and ±0.18 D for myopes (Rosenfield 1998). Randle (1988) performed an experiment to explore the feasibility of using biofeedback training of accommodation to extend the far points of low myopes. In this experiment, when the visual target was moved outward by 0.1 D or 0.2 D, the far point recession was successfully achieved. Randle (1988) reported that increments of 0.3 D or more resulted in frequent failure, and that this may have been due to the tendency of accommodation to revert to its resting position when not actively and clearly focused on a target of interest. In our experiment, 12 subjects showed a myopic shift of the far point that could clearly be seen to respond to the target movement in a myopic direction of 0.5 D. However, when accommodation was not pursued, the moving target resulted in an over-threshold blur of beyond 0.3 D, and the stimulus of blur induced accommodation to shift inward. In the hyperopic shift group, however, when the target scenery image was at the farthest position in the optical system, the difference in refractive value was beyond 0.3 D (Fig. 5A). Thus, we are not able to confirm that the cause of the myopic shift in the myopic shift group was solely due to blur of the target image.

According to the experiment of accommodative hysteresis or adaptation, this accommodative adaptation is a factor in inducing myopia. Several studies (McBrien & Millodot 1987; Gilmartin & Bultimore 1991; Ciuffreda & Wallis 1998; Culhane & Winn 1999; Hung & Ciuffreda 1999) have examined accommodative adaptation in different refractive groups. They observed that late-onset myopes (i.e. those with myopic onset at 15 years of age or later) are most susceptible to accommodative adaptation, followed by early onset myopes, emmetropes and hypermetropes. In our experiment, although we did not capture the time of myopic onset in the subjects, there was no difference in refractive error between the groups, resulting in the mean refractive values of −0.77 D (SD ± 0.71 D) and −0.70 D (SD ± 0.62 D). We do not believe that the cause of the myopic shift by the far point shift stimuli is related to refractive error.

In another report investigating the relationship between accommodative adaptation and myopia, 18 subjects, all of whom were either emmetropes (n = 8) or myopes (n = 10), performed a continuous 10-min binocular near-vision task at a viewing distance of 33 cm with full correction and were divided into two groups consisting of those with adaptation and those with non-adaptation in accommodation (Rosenfield & Gilmartin 1999). The reduction in lag in the 11 subjects in the adapting group was significant, whereas no significant change in lag was observed in the seven subjects in the non-adapting group. The relatively small number of emmetropes and myopes in each group precludes useful analysis of refractive error within each type of response, so no evidence was found for a causal relationship between accommodative adaptation and refractive error. We are presuming, however, that if there are relationships between

Table 3. Changes in scores (mean ± SD) for symptoms in both groups. Complaints of four out of 15 symptoms increased after the trial, but the other 11 symptoms did not change markedly.

<table>
<thead>
<tr>
<th>Eye fatigue</th>
<th>Eye pain</th>
<th>Eye heaviness</th>
<th>Eye dryness</th>
</tr>
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<tbody>
<tr>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Hyperopic</td>
<td>1.00 ± 0.00</td>
<td>1.70 ± 1.06*</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>(n = 10)</td>
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<td></td>
<td></td>
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<tr>
<td>Myopic</td>
<td>1.00 ± 0.00</td>
<td>2.67 ± 1.37‡</td>
<td>1.00 ± 0.00</td>
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<td>(n = 12)</td>
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* Not significant (by t-test for the pre-value).
† p = 0.0445; † p = 0.0015; § p = 0.0271; ** p = 0.0210; †† p = 0.0081.
accommodative adaptation and the difference in compensation of the accommodative lag, one of the causes of the myopic shift by the optical far point shift stimuli would be the difference in compensation of the accommodative lag in each individual.

We cannot identify a definite cause in the subjects whose refractive value shifted in the myopic direction in our experiment after the far point shift stimuli. However, we conclude at least that relaxed accommodation using optical far point shift stimuli is effective in reducing, or achieving recovery from, asthenopia.

References


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