A Study of Accommodation Training by Stereoscopic Film Presentation

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Abstract. By relaxing the contracted focus-adjustment muscles around the eyeball, such as the ciliary and extraocular muscles, improvement of the pseudo-myopia is expected. This understanding has led to the accommodation training in which the visual target is given by stereoscopic video clips. In this study, we verify short-term effects of the accommodation training on eyesight of visual inspection workers (22 females) suffering from eye fatigue and 12 middle-aged persons. In the Measurement 1, the workers were trained in 3 days. Moreover, the middle-aged were investigated on several trials of the eyesight recovering apparatus in the Measurement 2. In the Measurement 3, we verify the effects of the accommodation training on eyesight and asthenopia of the young. The accommodation training is compared with close work on VDTs. As a result, the visual acuity was statistically improved by continuous accommodation training which will promote a ciliary muscle-stretching effect.

Keywords: Myopia, Presbyopia, Spherical Diopter (SPH), Visual Acuity (VA), Stereoscopic Images, Ciliary Muscle, Accommodation.

1 Introduction

With the development of computers and widespread use of the internet, near visual tasks, such as visual display terminal (VDT) activities, have increased in young to elderly persons, causing social problems. Near visual tasks for a prolonged time strain the ciliary muscle, which may cause abnormalities in the accommodative function of the lens. This condition is called pseudomyopia, considered to be a part of refractive myopia. Prolonged near visual tasks have been reported to possibly induce cervico-omo-brachial syndrome and psychoneurotic symptoms [1]. The main cause of these vision problems is an accommodative function error. Therefore, we assume that it is possible to improve an abnormal accommodative function of the lens by activating the muscles by alternately repeating negative and positive accommodation. By improving the abnormal accommodative function, we can improve or prevent these

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vision problems. We call this operation "accommodation training." In Japan, an apparatus called MD-SS was developed [2]. This apparatus works by using a Landolt ring drawn on a flat plate that moves back and forth over a distance of 2 meter in order to encourage alternately repeating negative and positive accommodation in the observers. However, the moving distance of the target object is very short. Therefore, the back-and-forth motion of the objects might have no effect on the observers. In order to solve the abovementioned problems, we suggest that the accommodation training is accomplished by gazing at an image in 3D movies, which simulate the back-and-forth motion in a stereoscopic space by using a computer and a liquid crystal display (LCD).

For pseudomyopia, stretching exercise of the ciliary muscle, involved in accommodation of the lens, by alternately repeating negative and positive accommodation alleviates strain of the ciliary muscle. Miyao et al. experimentally showed that the lens was accommodated by following stereoscopic images when gazing at them displayed on a CRT or LCD [3], [4].

Presbyopia represents senile impairment of near vision due to a reduced accommodative function of the lens with aging. The major cause of the reduction of accommodative function is thickening of the lens with aging, increasing the radius of the frontal curvature of the lens. In addition to this increase in lens volume, the elasticity of the lens capsule decreases, which results in an insufficient increase in the lens curvature even when the ciliary zonule is relaxed by ciliary muscle contraction, reducing the amplitude of accommodation [5].

Stereoscopic videos utilizing binocular stereoscopic vision often cause unpleasant symptoms of asthenopia, such as headache and vomiting, depending on the audiovisual condition [6]. Ataxia in simulator-induced sickness has been reported. The influence of video-induced motion sickness on the body has been measured employing subjective scales, such as the Simulator Sickness Questionnaire (SSQ) [7], and by quantitatively investigating the relationship between external factors and internal conditions using physiological indices [8]-[11], such as respiratory function, electrocardiogram, skin electrical activity, and fluctuation of the center of gravity.

A new 3D video construction method has recently been developed to prevent video-induced motion sickness [12], [13]. Humans perceive 3-dimensional objects by simultaneous convergence and accommodation of the lens, but stereoscopic videos generally consist of unnatural images perceived along a fixed visual line, negating such convergence and accommodation. Stereoscopic images using the POWER3D method (Olympus Visual Communications Co., Ltd.) prepared in order to reduce inconsistency between experience and the actual senses [14]. Some preceding studies showed that the degree of sickness was reduced by viewing stereoscopic videos prepared using this method [15], [16]. We focused on stereoscopic videos prepared using this method. An LCD displaying the stereoscopic videos and visual acuity (VA) recovery device utilizing liquid crystal shutter eyeglasses (Dr.REX Eye Care Program [14]) include several stereoscopic video contents (Figs.1), which induce near and distant visual conditions. The alternating presentation of these with appropriate intervals is expected to improve and prevent myopia and presbyopia.

In this study, we investigated the short-term effect of the accommodation training with the device utilizing stereoscopic videos on visual inspection workers suffering from eye fatigue, middle-aged subjects becoming aware of presbyopia, and young myopic person.

2 Material and Methods

The objective and contents of the study and consideration of protection of personal information were explained to all subjects before the experiment, and written informed consent was obtained. The measurement was performed in a dimly lit room (about 250 lx) air-conditioned at 25°C. Before (Pre) and after (Post) the accommodation training of measurement 1 and 2 stated below, the tests:

(1) Simulator Sickness Questionnaire (SSQ)
(2) Visual analog scale (VAS)
(3) Objective refractometry
(4) VA test (distant vision)
(5) VA test (near vision)

were performed in this order. The auto VA meter NV-300 (NIDEK) was used for the VA tests that were employed for binocular and monocular visions. Time-course changes in the VAS, the best VA (BVA) at a distance, and that from near were investigated. Findings on Pre and Post values were compared employing the Wilcoxon signed-rank test, setting the significance level to 0.05.

2.1 Measurement 1

The subjects of the experiment were 22 female visual inspection workers, aged 37 ± 6 years. These subjects were also divided into two groups. One group underwent the accommodation training, in which they viewed a stereoscopic video (Fig.1a) for 6 min after the visual inspection work, and the other group was not given any task to perform during the first three consecutive days. Thereafter, the groups switched tasks, and the experiment was performed in a similar manner to collect data without the influence of task order. The above -mentioned items (1)-(5) were performed before the visual inspection work on the first day morning and after the task every experimental day.

2.2 Measurement 2

The subjects of the experiment were were 12 middle-aged persons, aged 46.6 ± 3.5 years (6 males and 6 females). The accommodation training was performed, in which the subjects viewed 4 contents of the Dr.REX Eye Care Program (Figs.1) for 6 minutes each in a random order. Before the accommodation training and after viewing each contents, the tests (1)-(5) were performed in this order. The subjects then viewed the 4 contents in the same order for 6 minutes each, and the above-mentioned tests (1)-(5) were repeated.

2.3 Measurement 3

The subjects of the experiment were 32 young myopic persons, aged 20 ± 1.0 years (16 males & 16 females). The study participants were divided into two groups. Far-vision tests were carried out by using auto optometer NV-300 (NIDEK) to test vision

from the right eye and vision from the left eye before the study commenced. In this case, measured eyesight was under 0.1, measurement of eyesight was circumstantially carried out by using a Landolt ring posted on a wall due to the difficulty of measurement with the optometer. The study schedule and processes is shown in Table.1. One group used the Dr.REX apparatus for 6 min, and the other group carried out simple close work on VDTs, which required a steady gaze for the same amount of time. Each group carried out their assigned tasks every day for 11 days. Far-vision tests and entry on degree of eyestrain in visual analogue scale (VAS) were carried out immediately after loading the works. On days 5 and 11 (the final day), we made an addition to previous far-vision tests and asked the participants to fill out a simulator sickness questionnaire [7] (SSQ) before and after each assignment in the foregoing tests.

When the study was completed, each group took a two-week break in order to recover from the effects of the study. Then the groups switched assignments and the study was resumed on the same schedule.

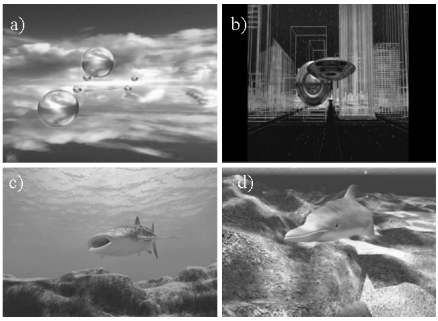

Fig. 1. Dr.REX Eye Care Program [14] includes several stereoscopic video contents: Sky vision a), Cyber vision b), Under the sea c), Dolphin d)

Table 1. This table is a study schedule. One group is taken as Measure 1 and the other group is taken as Measure 2. This schedule was carried out twice, with each group switching assignments.

Schedule [day]	1-4	5	6-10	11
Processes	Measure1* or Measure2**	SSQ**** Far-vision tests	Measure1 or Measure2	SSQ Far-vision tests
	VAS*** Far-vision tests	Measure1 or Measure2	VAS Far-vision tests	Measure1 or Measure2
		SSQ VAS Far-vision tests		SSQ VAS Far-vision tests

*Measure1: Close work using a recent VDT system
**Measure2: Carrying out the eyesight recorvering apparatus
***Visual Analogue Scale
****Simulator Sickness Questionnaire

3 Results

3.1 Measurement 1

The VAS for the evaluation of the visual fatigue significantly increased after their work although the other subjective indices (SSQ sub scores) did not significantly increase. However, the VAS after the accommodation training was significauntly lower than that of the control group on the 3rd experimental day.

Variations in the BVA at a distance and from near with the experimental dates are shown in Table 1. The gravitational mean BVA of the 22 subjects increased with the date. Irrespective of the subjects undergoing the accommodation training, when the Wilcoxon signed-rank test was used to compare the BVA before and after the initiation of this experiment, a significant difference in the VA was observed ($p<0.05$). The monocular vision test yielded a similar statistical significance. Although in comparison to the values obtained from the previous test, the VA after the visual inspection work increased significantly on the experimental days ($p<0.05$), the dioptric mean did not increase throughout this period.

Table 2. Results of Measurement 1 (mean ± standard deviation)

Index	Pre	Post1	Post2	Post3
Control group				
BVA at a distance (binocular)	1.01 ± 0.38	1.03 ± 0.41	1.07 ± 0.38	1.03 ± 0.37
BVA at a distance (monocular)	0.80 ± 0.39	0.76 ± 0.48	0.79 ± 0.40	0.86 ± 0.43
BVA from near	0.94 ± 0.36	1.01 ± 0.37	1.01 ± 0.31	0.99 ± 0.40
VAS	1.72 ± 1.74	3.49 ± 1.94**	3.81 ± 1.99**	4.46 ± 2.33**
Accommodation training group				
BVA at a distance (binocular)	1.01 ± 0.38	1.10 ± 0.33	1.15 ± 0.35	1.13 ± 0.37
BVA at a distance (monocular)	0.77 ± 0.39	0.81 ± 0.43	0.89 ± 0.44	0.87 ± 0.44
BVA from near	0.94 ± 0.36	0.97 ± 0.40	1.00 ± 0.37	1.07 ± 0.34
VAS	-	4.01 ± 2.54**	3.59 ± 1.91**	3.10 ± 1.89**

The VAS was enhanced significantly by the accommodation training. (** $p< 0.01$)

3.2 Measurement 2

Subjective indices did not significantly increase with viewing frequency. The time-course changes in the VAS were shown in Table.3. The degree of asthenopia tended to decrease at 5th and 7th Post viewing than that measured at Pre viewing ($p<0.10$).

Changes in the binocular near and distant visual acuities with the frequency of video viewing are shown in Table.3. The gravitational mean binocular near and distant visual acuities of the 12 subjects increased with the viewing frequency from the 1st to the 8th viewing, although there was some variation. On comparison of the uncorrected near VA between the Pre and after the 7th video viewing employing the Wilcoxon signed-rank test , a significant difference was noted ($p<0.05$).

Table 3. Typical Results of Measurement 2 (mean ± standard deviation)

Index	Pre	Post3	Post5	Post7
Control group				
BVA at a distance (binocular)	0.23 ± 0.17	0.30 ± 0.17	0.33 ± 0.17	0.31 ± 0.16
BVA at a distance (monocular)	0.13 ± 0.17	0.15 ± 0.14	0.17 ± 0.15	0.17 ± 0.13
BVA from near (binocular)	0.95 ± 0.14	0.93 ± 0.13	0.95 ± 0.14	1.03 ± 0.15
VAS	-	-	-	-
Accommodation training group				
BVA at a distance (binocular)	0.87 ± 0.15	0.84 ± 0.13	0.95 ± 0.12	0.92 ± 0.11
BVA at a distance (monocular)	0.67 ± 0.11	0.79 ± 0.12	1.06 ± 0.43	0.78 ± 0.06
BVA from near (binocular)	1.03 ± 0.10	1.06 ± 0.08	1.13 ± 0.08	1.20 ± 0.09*
VAS	5.14 ± 0.82	4.60 ± 0.63	4.30 ± 0.72#	4.32 ± 0.72#

The visual acuity was enhanced significantly by the accommodation training. (# $p<0.10$; * $p< 0.05$)

3.3 Measurement 3

The geometrical mean of eyesight before and after carrying out Dr.REX on days 5 and 11 is shown in Table 2 in order to verify short-range effects. The far-eyesight on both days 5 and 11 improved slightly (day 5; both vision: 0.015, right vision: 0.009, left vision: 0.017), (day 11; both vision: 0.033, right vision: 0.012, left vision: 0.019). Although the eyesight before and after carrying out Dr.REX was compared for statistical significance by using the Wilcoxon matched-pairs signed test, the increase of statistical significance was found on both vision on day 5 and left vision on both days 5 and 11. ($p<0.05$)

The geometrical mean of eyesight after carrying out Dr.REX is calculated in order to verify middle-range effects [19]. All the geometrical mean of eyesight is higher than in the pre-far-vision test (both vision: 0.037, right vision: 0.055, left vision: 0.043). When eyesight was compared for statistical significance using the Friedman test, the increase of statistical significance is found on all the eyesight. ($p< 0.01$) In addition, when carrying out the multiple comparison (Scheffe's test), the increase of statistical significance compared with pre-vision is found on right vision on days 8, 9 and 11 and left vision on 8,10 and 11. ($p< 0.05$ or 0.01)

The adding mean value of VAS after carrying out Dr.REX and the close work were 3.63 ± 1.80 and 4.57 ± 2.18, respectively. The mean value after carrying out Dr.REX is lower than the mean value after carrying out the close work (Close work: 4.57, Dr.REX: 3.63). When each type of work was compared for statistical significance using paired t-test, a significant difference is found for each work type. ($p<0.01$)

The mean asthenopic score calculated SSQ before and after carrying out Dr.REX and the close work on days 5 and 11 is shown in Table 4. All of the scores after each work type on both days are shown to increase slightly. When the eyestrain before and after carrying out the each work was compared for statistical significance by paired t-test, a significant difference is found only close work on day 5. ($p<0.01$)

Table 4. This table shows the change of eyesight after carrying out Dr.REX on days 5 and 11. The eyesight on both days 5 and 11 increased slightly. (* $p<0.05$)

Index	Pre5	Post5	Pre11	Post11
Control group				
VA at a distance (binocular)	0.13 ± 0.25	0.15 ± 0.28	0.15 ± 0.23	0.15 ± 0.29
VA at a distance (Right vision)	0.11 ± 0.20	0.12 ± 0.22	0.11 ± 0.23	0.12 ± 0.23
VA at a distance (Left vision)	0.09 ± 0.16	0.10 ± 0.15	0.09 ± 0.13	0.10 ± 0.22
Accommodation training group				
VA at a distance (binocular)	0.14 ± 0.30	0.16 ± 0.29	0.14 ± 0.27	0.17 ± 0.33*
VA at a distance (Right vision)	0.11 ± 0.28	0.12 ± 0.24	0.13 ± 0.26	0.14 ± 0.24
VA at a distance (Left vision)	0.09 ± 0.18	0.11 ± 0.20*	0.10 ± 0.19	0.12 ± 0.21*

4 Discussion

In this study, we presented a movie using the POWER 3D method as the movie for the accommodation training, and a short-term effect of the accommodation training was investigated in visual inspection workers suffering from eye fatigue and middle-aged people. In both measurements, the motion sickness could not be induced by viewing 3D video clips in accordance with subjective tests, and the VA was improved by continuous training.

In measurement 1, we showed that the visual inspection workers suffered from eye fatigue after their work. Although the dioptric comparison between the control and the training groups showed that there was no significant difference between the values for the groups ($p<0.05$), the binocular BVA increased in 13 of the 22 visual inspection workers (59.1%) [17].

The VA of the control group without the accommodation training showed an improvement. The myopic tendency had increased due to the visual inspection work. Moreover, it was possible that the subjects became skilled in the vision test. However, the results obtained from the Wilcoxon signed-rank test showed that the distant VA in the training group had increased considerably compared to that in the control group ($p<0.05$). As compared to the near VA in the control group, that in the training group had increased significantly on day 3 ($p<0.05$).

The VAS in the control group had also increased significantly on day 3 as compared to that in the training group. There seemed to be not only VA improving effect but also reduction of the visual fatigue by the accommodation training for more than 3 consecutive days.

The authors have verified a middle-term effect of accommodation training that uses the strategy of presenting a stereoscopic movie to 32 myopic youth (20 ± 1 years). The movie consists of one to five balls moving back and forth in the stereoscopic sky background. At a viewing distance of 60 cm, the stereoscopic ball is viewed to move from 30 cm (forward) to infinity (backward). This ball completes a round-trip movement more than 25 times in 3 min. The uncorrected distant VA increased in 17 of the 32 subjects (53.1%) participating in this study. Although there were some variations, the VA improved in the accommodation training group and not in the

control group. Upon comparing the value obtained on each measurement day using the Wilcoxon signed ranks test, we found that the VA on day 11 was considerably higher in the accommodation group than in the control group ($p<0.05$). This result suggests that the accommodation training using a stereoscopic movie has a cumulative positive effect on eyesight and prevents the deterioration of VA. Although the myopic tendency improved slightly in the accommodation training group, there was only slight progress in the control group. These results suggested that the accommodation training using the stereoscopic movie did not deform the lens, thus not improving myopia fundamentally [18].

We assumed that these effects of the accommodation training was temporary, but the findings suggest that the continuous accommodation training will promote a ciliary-muscle-stretching effect, leading to an improvement in VA. Accommodation reflex for near vision may be defined as the mechanism of working the ciliary muscle. This may also inhibit a reduction in the VA.

In measurement 2, both the binocular near and distant visual acuities were improved, suggesting that the viewing of the stereoscopic video reduced strain and increased the flexibility of the ciliary muscle, which temporarily recovered the VA. In contrast, findings on objective refractometry at Pre and post viewing stereoscopic videos were compared employing the Wilcoxon signed-rank test, setting the significance level to 0.05 [19]. The spherical diopter of individual eyes with the frequency of video viewing was also measured. The mean SPH was about –3 diopters in both eyes, showing no significant changes with the viewing frequency. Therefore, diopteric measurements did not change in either eye. The duration of the accommodation training may have been too short to modify the eyeball (lens) structure. It was suggested that the short-term repeated use of the accommodation training increased the near VA, for which the improvement and prevention of presbyopia may be expected.

The effect of short-range recovering eyesight was verified by the results of the far-vision test on days 5 and 11. The effect of recovering eyesight was noted so that the mean value of eyesight was increased. However, the constant increase of statistical significance was not found. One of the reasons for this was the measurement interval of the far-vision tests. In this study, when measured eyesight is under 0.1, the result is obtained at 0.01 intervals. On the other hand, when measured eyesight is over 0.1, the result is obtained at 0.1 intervals due to our use of an auto optometer. The other reason for this was the status of the subjects' eyes. Subjects who abused their eyes before measurements obtained the largest effects of recovering eyesight; their focus-adjustment muscles around the eyeballs were strongly contracted. In contrast, the subjects whose muscles were relaxed obtained hardly any improvement.

The degree of asthenopia from using the Dr.REX apparatus and the close work was verified by VAS and the asthenopic score calculated with SSQ. In the VAS, the mean value from carrying out the close work was statistically more significant than the value from using the Dr.REX. In the SSQ, although the mean value for carrying out the close work indicated higher than the value of using the Dr.REX, a significant difference is not found between each work. We consider that these results depend on the each subject's psychological state or their eye condition due to subjective assessment.

The manufacturer of the Dr.REX apparatus suggests the use of this apparatus within 10 minutes each time. Thus, in this study, we expected the subjects to obtain hardly any asthenopia while using the apparatus in the recommended time. Dr.REX had the effect of relaxing the subjects and also the effect of semi-compulsory stretches. We consider that these effects gave the subjects a temporary pseudo-asthenopia. On the other hand, the close work in this study was designed to induce asthenopia compulsorily. We consider that the close work certainly gave the subjects asthenopia. Thus, we estimated that asthenopia from the close work was relatively heavier than that from the Dr.REX due to the results of study. This conclusion, however, needs to be verified continuously.

5 Conclusion

The VA-improving effect of the VA recovery device utilizing stereoscopic videos was investigated in visual inspection workers suffering from eye fatigue and middle-aged subjects becoming aware of presbyopia, and the VA was improved by the continuous accommodation training for a short-term period. We are planning to investigate the effect of the device employed for a prolonged period.

In this study, it became clear that pseudo-myopia could be improved by relaxing contracted focus-adjustment muscles around the eyeball, such as ciliary body and extraocular muscles, by using a stereoscopic movie shown on LCD. On the other hand, a feature of the Dr.REX apparatus was inexpensive and unlimited of installation space as previously indicated. Using the apparatus freely, a trainee might interrupt the training in terms of his/her negligence. Therefore, we came to a conclusion that the apparatus was used for improvement of eyesight due to relaxing the contracted muscles continuously.

The effects of asthenopia from close work were more pronounced than it is from Dr.REX. A tangible result in terms of asthenopia, however, was not obtained by the asthenopic scores due to the lack of significant difference. These results need to be verified continuously by using the other index of asthenopia.

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