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Accommodation Training in Foreign Workers*

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***Abstract*— By relaxing the contracted focus-adjustment muscles around the eyeball, known as the ciliary and extraocular muscles, the degree of pseudomyopia can be reduced. This understanding has led to accommodation training in which a visual target is presented in stereoscopic video clips. However, it has been pointed out that motion sickness can be induced by viewing stereoscopic video clips. In Measurement 1 of the present study, we verified whether the new 3D technology reduced the severity of motion sickness in accordance with stabilometry. We then evaluated the short-term effects of accommodation training using new stereoscopic video clips on foreign workers (11 females) suffering from eye fatigue in Measurement 2. The foreign workers were trained for three days. As a result, visual acuity was statistically improved by continuous accommodation training, which will help promote ciliary muscle stretching.**

I. Introduction

With the development of computers and widespread use of the Internet, close-up visual tasks, such as visual display terminal (VDT) activities, have increased in young to elderly persons causing social problems. Close-up visual tasks for a prolonged time strain the ciliary muscles, which may cause abnormalities in the accommodative function of the lens. This condition is known as pseudomyopia, and is considered to be a part of refractive myopia. Prolonged close-up 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 the 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 reduce or prevent these 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 m 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. To solve the abovementioned problems, we suggest that accommodation training is best accomplished by gazing at an image in a 3D video that simulates back-and-forth motion in a stereoscopic space by using a computer and a liquid crystal display (LCD).

For alleviating pseudomyopia, a stretching exercise of the ciliary muscle, which is 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 video clips displayed on a CRT or LCD [3], [4].

Stereoscopic videos using binocular stereoscopic vision often cause unpleasant symptoms of asthenopia, such as headache and vomiting, depending on the audiovisual condition [5]. Ataxia has been reported in simulator-induced motion sickness. The influence of video-induced motion sickness on the body has been studied by employing subjective scales such as the Simulator Sickness Questionnaire (SSQ) [6] and by quantitatively investigating the relationship between external factors and internal conditions using physiological indices [7]–[10] such as a respiratory function, electro-cardiogram, skin electrical activity, electrogastrogram, and body sway.

Mathematically, the sway in the center of pressure (COP) is described by a stochastic process [11]–[13]. We examined the adequacy of using a stochastic differential equation and investigated the most appropriate equation for our research. $G(\mathbf{x})$, the distribution of the observed point $\mathbf{x}$, is related in the following manner to $U(\mathbf{x})$, the time-averaged potential function, in the following stochastic differential equation (SDE):

$$\frac{\partial x}{\partial t} = -\frac{\partial}{\partial x} U_x(x) + w_x(t), \qquad (1.1)$$

$$\frac{\partial y}{\partial t} = -\frac{\partial}{\partial y} U_y(y) + w_y(t), \qquad (1.2)$$

which has been considered as a mathematical model of sway:

$$U(\mathbf{x}) = -\frac{1}{2} \ln G(\mathbf{x}) + const. \qquad (2)$$

Actually, $G(\mathbf{x})$ is estimated by the histogram of the time series data. The nonlinear property of SDEs is important [14]. There were several minimal points of the potential. In the vicinity of these points, local stable movement with a high-frequency component can be generated as a numerical solution to the SDE. We can therefore expect a high density of observed COP in this area on the stabilogram.

A new 3D video construction method has recently been

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TABLE I. Result of Measurement 1 (mean ± standard deviation)

	(I)	(II)	(III)
SSQ-Nausea	-	14.31 ± 14.31	8.56 ± 7.92
SSQ-Oculomotor Discomfort	-	16.68 ± 12.13	17.43 ± 10.20
SSQ-Disorientation	-	22.72 ± 27.98	16.70 ± 18.47
SSQ-Total Score	-	19.82 ± 17.39	16.46 ± 11.24
Area of sway	0.92 ± 0.52	1.41 ± 0.68	1.86 ± 1.03
Total locus length	38.26 ± 14.50	49.47 ± 11.99	46.20 ± 10.64
Total locus length per unit area	51.69 ± 27.70	50.03 ± 43.08	36.90 ± 23.52
S_2	1.23 ± 0.09	1.32 ± 0.11	1.33 ± 0.12

developed to prevent video-induced motion sickness [15, 16]. Humans perceive 3D objects by simultaneous convergence and by accommodation of the lens, but stereoscopic video clips generally consist of unnatural images perceived at a fixed distance, negating such convergence and accommodation. To reduce inconsistency between experience and the actual senses, we prepared a 3D video clip that was created by the POWER3D method (Olympus Visual Communications Co., Ltd.) [17] and focused on stereoscopic videos prepared using this method. An LCD displaying the stereoscopic videos and a visual acuity recovery device using liquid crystal shutter eyeglasses (DR.REX Eye Care Program [17]) were used to present various stereoscopic video content, which simulated close-up and distant visual conditions. The alternating presentation of these with appropriate intervals is expected to reduce and prevent myopia and presbyopia.

In Measurement 1 of the present study, we verified whether the abovementioned 3D technology reduced the severity of motion sickness. Then, using the new stereoscopic video clips, we evaluated the short-term effects of the accommodation training on foreign workers suffering from eye fatigue in Measurement 2.

II. Material & Method

The objective and contents of the study and the 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 260 lx) air-conditioned at 25°C.

A. Measurement 1

There were 10 healthy subjects (age, 23.6 ± 2.2 years) who voluntarily participated in the study. The subjects stood without moving on the detection stand of a stabilometer (G5500; Anima Co., Ltd.) with their feet together. The subjects were positioned facing an LCD monitor (S1911-SABK, NANAO Co., Ltd.) on which three types of video clips were presented in no particular order: (I) a visual target (circle) with a diameter of 3 cm; (II) a conventional 3D video that showed a sphere approaching and moving away from subjects irregularly; and (III) a new 3D video clip that shows the same sphere in motion as in (II). The new stereoscopic video clip (III) was constructed by the Olympus Power 3D method [17]. The distance between the wall and the subjects was 57 cm.

The subjects stood on the detection stand in the Romberg posture for 2 min before their sway was recorded. Each sway of the COP was then recorded at a sampling frequency of 20 Hz during the measurement; subjects were instructed to maintain the Romberg posture for the first 120 s and a wider stance (with the midlines of heels 20 cm apart) for the next 60 s. The subjects viewed one of the video clips, i.e., (I), (II), or (III), on the LCD from the beginning till the end. The SSQ was filled out before and after stabilometry.

We calculated several indices that are commonly used in the clinical field [18] for obtaining stabilograms such as “area of sway,” “total locus length,” and “total locus length per unit area.” In addition, new quantification indices that were termed “SPD” were also estimated.

B. Measurement 2

The subjects of this experiment were 11 female foreign workers. These subjects were also divided into two groups. One group (accommodation training group) underwent the accommodation training in which they viewed a stereoscopic video clip for 6 min after their visual inspection work, and the other group (control group) was not given any task to perform during the first three days. Thereafter, the groups switched tasks, and the experiment was performed in a similar manner to collect data without the influence of task order.

Before the visual inspection work on the morning of the first day (Pre) and after the task on every experimental day (Post) the following tests were conducted (1) an SSQ, (2) a visual analog scale (VAS) to measure the severity of eye strain, (3) an objective refractometry test, (4) a binocular visual acuity test (distant vision), and (5) a binocular visual acuity test (near vision). The tests were conducted in the order mentioned above.

An auto visual acuity meter NV-300 (NIDEK) was used for the visual acuity tests of binocular and monocular visions. Time-course changes in the VAS, the best visual acuity (BVA) at a distance, and that from close-up were investigated. The findings for Pre and Post values were compared using Friedman’s test, setting the significance level to 0.05.

III. Results

A. Measurement 1

The results of the SSQ include the scores for nausea (N), oculomotor discomfort (OD), disorientation (D) subscale, and total score (TS) of the SSQ. No statistical differences were seen in these scores among video clips presented to subjects. However, increases were seen in the scores for SSQ-N and

TABLE II. Results of Measurement 2 (mean ± standard deviation)

	Pre	Post 1	Post 2	Post 3
Control group				
BVA at a distance	1.12 ± 0.38	1.05 ± 0.45	1.10 ± 0.41	1.06 ± 0.42
BVA from close-up	0.80 ± 0.43	0.90 ± 0.43	0.92 ± 0.35	0.87 ± 0.46
Accommodation training group				
BVA at a distance	-	1.07 ± 0.39	1.14 ± 0.40	1.12 ± 0.41
BVA from close-up	-	0.75 ± 0.45	0.89 ± 0.42	0.90 ± 0.43

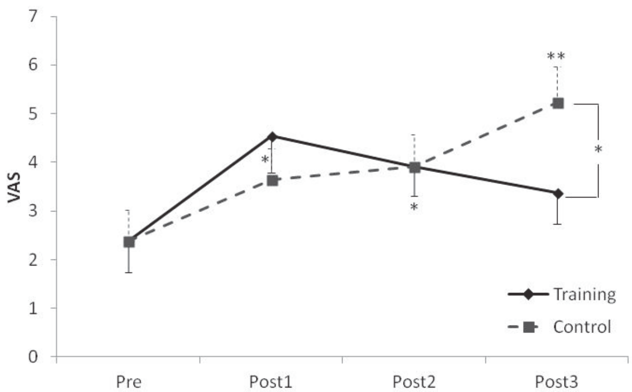

Figure 1. Time course of the VAS for measuring the severity of asthenopia. Subjects' replies the category 7, owing to the serious case in their asthenopia.

SSQ-D after exposure to the conventional 3D video clip (II).

In the stabilograms, the COP was not isotropically dispersed but characterized by much movement in the anterior-posterior (*y*) direction. The amplitudes of the sway observed during exposure to the video clips tended to be larger than those of the control sway. In that time (II)/(III), the diffusion of COP was also large in the lateral (*x*) direction. Although a high density of COP was observed in the stabilograms, the density decreased in stabilograms during exposure to the conventional clip (II).

Except for the total locus length per unit area, a main effect was seen in the exposure factors (Table 1) in accordance with the Freedman's tests ($p < 0.01$). As a result of the *post hoc* test, area of sway, total locus length, and SPD S_2 in the stabilogram observed during exposure to the conventional 3D video (II) were significantly larger than those during exposure to a static circle ($p < 0.05$). There was no significant difference between indicators except for the total locus length in the stabilogram observed during exposure to the new 3D video (III) and those during exposure to a static circle.

B. *Measurement 2*

Although the other subjective indices (SSQ sub scores) did not significantly increase, the VAS for the evaluation of the visual fatigue increased after their work (Post 1–3). Moreover, the VAS decreased with the time course of the accommodation training, and there was significant difference between the VAS in the control group and that in the accommodation training group, as shown in Fig.1.

The variations in the BVA of the 22 subjects at a distance and from close-up with the experimental dates are listed in Table 2. Irrespective of the subjects undergoing the accommodation training, there was no significant difference in the visual acuity according to Friedman's test. The dioptric mean also did not increase throughout this period. However, the gravitational mean BVA from close-up increased with the date. According to Wilcoxon's signed-rank test, the BVA of the control group was significantly greater than that of the accommodation group after the first experimental day ($p < 0.05$). The order was switched in the 3rd experimental day ($p < 0.10$).

IV. Discussion

In the present study, we presented video clips on an LCD and showed that the POWER 3D method could reduce the severity of the VIMS in Measurement 1. The 3D video clip for the accommodation training was then created by the POWER 3D method. In Measurement 2, a short-term effect of the accommodation training was investigated in foreign workers suffering from eye fatigue. The myopic tendency had increased owing to their close-up visual inspection work. It took at least three days to reduce their eye strain.

In Measurement 1, sickness symptoms seemed to appear more often with the conventional video clip (II), although there were large individual differences in results of the subjective tests, SSQ. However, a theory has been proposed to obtain SDEs (1) as a mathematical model for body sway on the basis of the stabilogram. The variance in the stabilogram depends on the form of the potential function in the SDE; therefore, the SPD is regarded as an index for its measurement. The video clips decreased the gradient of the potential function [20]. The new 3D video clip (III) reduced body sway owing to the consistency between convergence and visual accommodation. The reduction could be evaluated by the SPD during exposure to the video clip (III) on an LCD screen. By using Friedman's test for a posture with a wide stance, we succeeded in estimating the decrease in the gradient of the potential function by using the SPD, as indicated by Table 1 ($p < 0.05$). However, the total locus length could not evaluate the change of form in the potential function to control the standing posture.

In Measurement 2, we showed that the foreign workers suffered from eye fatigue after their work, as shown in Fig. 1. The subjects might have become skilled in the visual acuity test. This is why the binocular BVA increased considerably, as indicated by Table 2. In our previous study on visual inspection workers in Japan, the visual acuity of the control group without the accommodation training also showed an improvement [21]. However, the results showed that the distant visual acuity in the training group had increased significantly compared to that in the control group on the 3rd experimental day ($p < 0.05$). In this study, remarkable improvement in the distant visual acuity was not seen for the foreign workers, because they had good eyesight originally. However, the BVA of the training group was statistically higher than that of the control group after the 3rd experimental day ($p < 0.10$).

There seemed to be not only visual acuity improvement but also a reduction in visual fatigue by accommodation training for more than three consecutive days. The VAS in the control group had increased significantly after the 3rd experimental day as compared to that in the training group ($p < 0.05$).

The authors have verified a middle-term effect of accommodation training that uses the strategy of presenting a stereoscopic video clip to 32 myopic youth (20 ± 1 years) for 2 weeks. The video clip consisted of 1–5 balls moving back and forth against a stereoscopic sky background. At a viewing distance of 60 cm, the stereoscopic ball appeared 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 visual acuity increased in 17 of the 32 subjects (53.1%) participating in this study. Although there were some variations, the visual acuity improved in the accommodation training group, but not in the control group. We found that the visual acuity on the 11th experimental day was considerably higher in the accommodation group than in the control group ($p < 0.05$). This result suggests that accommodation training using a stereoscopic video clip had a cumulative positive effect on eyesight and prevented deterioration in visual acuity. Although the myopic tendency decreased slightly in the accommodation training group, there was only slight progress in the control group. These results suggested that accommodation training using the stereoscopic video clip did not deform the lens, and thus did not alleviate myopia fundamentally [19]. This tendency was also seen in the present Measurement 2.

We assume that these effects of accommodation training were temporary, but the findings suggest that the continuous accommodation training will promote a ciliary-muscle-stretching effect, leading to an improvement in visual acuity. The accommodation reflex for close-up vision may be defined as the mechanism of working the ciliary muscle. This may also inhibit a reduction in visual acuity.

V. Conclusion

In this study, we showed that the new 3D technology reduced the severity of motion sickness according to stabilometry. The effect of accommodation training using the new 3D video clip was investigated with foreign workers suffering from eye fatigue, and their eye strain was reduced by continuous accommodation training for a short period. We are planning to investigate the effect of the device over a prolonged period.

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References

[1] T. Nakazawa, Y. Okubo, Y. Suwazono, E. Kobayashi, S. Komine, N. Kato, and K. Nogawa, “Association between duration of daily VDT use and subjective symptoms,” *Am. J. Ind. Med.,* vol. 42, pp. 421–426, 2002.

[2] S. Kobayashi, “Eye sight recovering apparatus,” Japan Patent H6 - 339501, Dec 13, 1994.

[3] M. Miyao, S. Ishihara, S. Saito T. A. Kondo, H. Sakakibara, and H. Toyoshima, ” Visual accommodation and subject performance during a stereoscopic object task using liquid crystal shutters,” *Ergonomics,* vol. 39, no. 11, pp. 1294–1309, 1996.

[4] M. Omori, T. Watanabe, J. Takai, H. Takada, and M. Miyao, “A trial for preventing asthenopia among VDT workers,” *Int. J. Occupational Safety and Ergonomics,* vol. 9, no. 4, pp. 453–462, 2003.

[5] K. Ukai, P. A. Howarth, “Visual fatigue caused by viewing stereoscopic motion images,” *Displays,* vol. 29, pp. 106–116, 2008.

[6] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, “Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness,” *Int. J. Aviation Psychology*, vol. 3, pp. 203–220, 1993.

[7] S. R. Holomes and M. J. Griffin, “Correlation Between Heart Rate and the Severity of Motion Sickness Caused by Optokinetic Stimulation,” *J. Psychophysiology*, vol. 15, pp. 35–42, 2001.

[8] N. Himi, T. Koga, E. Nakamura, M. Kobashi, M. Yamane, and K. Tsujioka, “Differences in autonomic responses between subjects with and without nausea while watching an irregularly oscillating video,” *Autonomic Neuroscience: Basic and Clinical*, vol. 116, pp. 46–53, 2004.

[9] Y. Yokota, M. Aoki, and K. Mizuta, “Motion sickness susceptibility associated with visually induced postural instability and cardiac autonomic responses in healthy subjects,” *Acta Otolaryngologia*, vol. 125, pp. 280–285, 2005.

[10] L. M. Scibora, S. Villard, B. Bardy, and T. A. Stoffregen, “Wider stance reduces body sway and motion sickness. in *Proc. the First International Symposium on Visually Induced Motion Sickness, Fatigue, and Photosensitive Epileptic Seizures*, Hong Kong, 2007, pp. 18–23.

[11] J. J. Collins and C. J. De Luca, “Open-loop and closed-loop control of posture: A random-walk analysis of center of pressure trajectories,” *Exp. Brain Res.*, vol. 95, pp. 308–318, 1993.

[12] R. E. A. Emmerrik, R. L. Van Sprague, and K. M. Newell, “Assessment of sway dynamics in tardive dyskinesia and developmental disability: sway profile orientation and stereotypy,” *Moving Disorders*, vol. 8, pp. 305–314, 1993.

[13] K. M. Newell, S. M. Slobounov, E. S. Slobounova, and P. C. Molenaar, “Stochastic processes in postural center-of-pressure profiles,” Exp. Brain Res., vol. 113, pp. 158–164, 1997.

[14] H. Takada, Y. Kitaoka, and Y. Shimizu, “Mathematical Index and Model in Stabilometry,” *Forma*, vol. 16 (1), pp. 17–46, 2001.

[15] R. Yasui, I. Matsuda, and H. Kakeya, “Combining volumetric edge display and multiview display for expression of natural 3D images,” in *Proc. SPIE 6055*, San Jose, 2006, pp. 0Y1–0Y9.

[16] H. Kakeya, “MOEVision: simple multiview display with clear floating image,” in *Proc. SPIE 6490*, San Jose, 2007, pp. 64900J.1–64900J.8.

[17] T. Nishihara, H. Tahara, “Apparatus for recovering eyesight utilizing stereoscopic video and method for displaying stereoscopic video,” US Patent 7404639, 2008

[18] J. Suzuki, T. Matsunaga, K. Tokumatsu, K. Taguchi, and Y. Watanabe, ”Q&A and a manual in Stabilometry,” *Equilibrium Res.*, vol. 55(1), pp. 64–77, 1996.

[19] A. Sugiura, M. Miyao, T. Yamamoto, and H. Takada, “Effect of strategic accommodation training by wide stereoscopic movie presentation on myopic young people of visual acuity and asthenopia,” *Displays*, vol. 32, no. 4, pp. 219–224, 2011.

[20] H. Takada, K. Fujikake, and M. Miyao, “Metamorphism in potential function while maintaining upright posture during exposure to blurred images,” *Proceedings of 2009 International Symposium on Nonlinear Theory and its Applications*, pp. 344–347, 2009.

[21] M. Takada, M. Miyao, M. Satoh, K. Yoshikawa, Y. Matsuura, and H. Takada, “Effect of accommodation training on visual function of visual inspection workers and middle-aged people,” *Journal of Sports Medicine & Doping Studies*, vol. 2, no. 3, 2012, doi: 10.4172/2161–0673. 1000112.