Postural Sway with Illusory Motion Induced by Static Visual Stimuli in Migraineurs and Normal Controls

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Abstract: Illusory motion, in which observers can perceive static images to be moving, is an important graphic design concept. Although the mechanism of illusory motion is being uncovered, it is still unclear whether illusory motion can induce postural sway. Patients with migraine headaches (migraineurs) are likely to suffer from motion sickness and are more likely to perceive illusory motion than are individuals without chronic headaches. Since one of the causes of motion sickness is the conflict between visual and vestibular inputs, we hypothesized that migraineurs have an abnormal visuo-vestibular interaction. We measured postural sway during migraineurs' and normal controls' viewing of static visual stimuli with and without illusory motion. We used Kitaoka's artworks as both the illusory motion and control stimuli (Kitaoka, 2003, 2013). The participants stood on a stabilometer while they viewed one stimulus for 30 seconds. Immediately afterward (Experiment 1), or 30 seconds after viewing the stimuli (Experiment 2), the participants closed their eyes and stood on the stabilometer for 30 seconds. The results from Experiment 1 indicated that migraineurs swayed more than controls while their eyes were closed after viewing the illusory motion image. However, in Experiment 2, migraineurs swayed less than controls with their eyes closed following a 30-second interval after viewing the illusory motion. Taken together, these results suggest that static visual stimuli induce not only illusory motion but also postural sway, which may last for 30 seconds in migraineurs.

Keywords: Illusory Motion, Vision, Migraine, Postural Sway

1. INTRODUCTION

Optical illusion, such as illusory motion, is an important aspect of graphic design and art. In this artistic phenomenon, observers may actually perceive physically static images to be moving; for instance, *Op Art* employs geometrical patterns to introduce illusory motion into its brand of visual art in order to enhance the beauty of the relevant pieces. Optical illusion itself may induce beauty and/or preference (Noguchi, 2003). Actually, the magnitude of illusory motion in geometrical patterns has been known to contribute to people's reported preferences for these patterns (Stevanov et al., 2012). Although recent neuroscience studies have proposed a number of findings regarding the mechanism of illusory motion (e.g., Takemura et al., 2012), the mechanism by which illusory motion modulates human body movement has not been well explained. Although illusory motion has been found to induce illusory body movement (vection) in physically stationary observers (Seno et al., 2013), it is not known whether illusory motion can induce actual body movement—that is, postural sway.

Patients with chronic migraine headaches (migraineurs) are likely to suffer from motion sickness (Marcus et al., 2005) and are more likely to perceive visual discomfort (Marcus & Soso, 1989) and more illusory motion (Imaizumi et al., 2011) in visual stimuli such as grating patterns than are individuals who do not suffer from chronic headaches. About 8.4% of the total Japanese population is composed of migraineurs (Sakai & Igarashi, 1997). Some have visual hypersensitivity because the corresponding parts of their brains are easily excitable (Aurora et al., 1998). Since one of the causes of motion sickness is the conflict between visual and vestibular inputs (Reason & Brand, 1975), we hypothesized that migraineurs who are susceptible to motion sickness have an abnormal visuo-vestibular interaction. Although a recent study reported that some migraineurs showed greater postural sway than normal individuals (Carvalho et al., 2013), no study has of yet examined how visual stimuli modulate postural control in both migraineurs and controls.

In this study, we investigated whether illusory motion can influence postural sway and whether there are any distinguishing characteristics in migraineurs in terms of postural control. To accomplish our study goals, we attempted to measure the postural sway of both migraineurs and normal controls during their viewing of static visual stimuli with and without illusory motion.

2. EXPERIMENT 1

2.1. Methods

2.1.1. Participants

Eleven migraineurs (5 male and 6 female; mean age = 22.18 years, *SD* = 0.30) and nine non-chronic headache sufferer controls (7 male and 2 female; mean age = 22.22 years; *SD* = 0.40) participated in our study. We classified the participants into one of two groups—migraineurs or controls—by using a questionnaire based on the second edition of the International Classification of Headache Disorders (Headache Classification Subcommittee of the International Headache Society, 2004). This questionnaire included 18 items about the occurrence of chronic headaches, as well as characteristics, duration, frequency, and accompanying symptoms, among other things. All participants had normal visual acuity, and no one had visual deficits such as colour blindness.

Written informed consent was obtained from each participant. This study was approved by the ethical committee of the Graduate School of Engineering, Chiba University. The experiments were conducted according to the principles of the Declaration of Helsinki.

2.1.2. Stimuli

The static visual stimuli used in this experiment were grey plane and illusory motion images (Kitaoka, 2003; *Rotating Snakes.* See Figure 1, left). A red cross to be fixated on was presented in the centre of each stimulus. These stimuli had the same mean luminance. We refer to this illusory motion image as the 'snake image'. The smallest unit of the component for the snake image was an arrangement of 'black–blue–white–yellow' patches. In the illusory motion image, this order of colour patches was arranged in the same direction throughout, thus inducing an illusory rotational motion. The snake image is known to induce a strong illusory motion perception and has been used in a large number of studies investigating human motion perception (e.g., Conway et al., 2005; Kuriki et al., 2008).

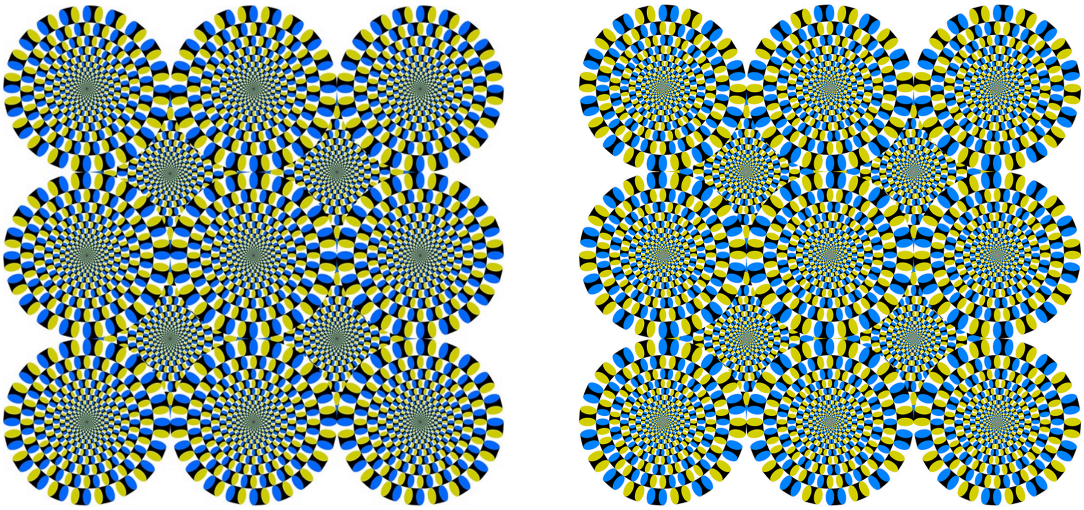

Figure 1: The snake image with illusory motion (Kitaoka, 2003) used in Experiments 1 and 2 is shown on the left side. The non-motion control image (Kitaoka, 2013) used in Experiment 2 is shown on the right side

2.1.3. Apparatus

Each of the stimuli was presented on a head-mounted display (HMD; HMZ-T1, Sony). All stimuli were subtended approximately 29 by 29 degrees on the HMD. We used a stabilometer (UM-BAR2, UNIMEC) to track the displacement of participants' centres of gravity (CoGs) and to sample fluctuations in the CoG at 60 Hz. The stabilometer was installed on the floor 60 cm away from the wall. An example of the experimental setup is shown in Figure 2.

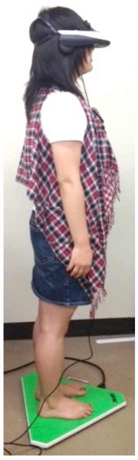

Figure 2: Apparatus used in Experiments 1 and 2

2.1.4. Procedure

The participants removed their shoes and stood erect on the stabilometer. During stabilometric measurement, they were asked to stand still with their knees straight and their hands down flat at their sides. First, the participants stood on the stabilometer without the HMD while viewing a fixation point on the wall in front of them for 30 seconds (Eyes Open condition; EO). Immediately afterward, they closed their eyes and kept standing for 30 seconds (Eyes Closed condition; EC). Next, the participants fitted the HMD on their heads. Following that, they stood on the stabilometer while fixating on the red cross in the centre of one of the stimuli for 30 seconds. Immediately afterward, the participants closed their eyes and kept standing on the stabilometer for 30 seconds. The stimuli were presented in a random order.

In these measurements, we recorded the stabilometric parameters of postural sway, total path length (TPL), rectangular area (REC), and Romberg ratio (RR). TPL refers to the total length of CoG displacement. REC refers to the area of the maximum amplitude of CoG displacement in the x and y coordinates. RR refers to ratio of the postural sway parameters measured with EC and EO. We calculated the RRs for both the TPL and the REC. RR assesses the stabilizing effect of vision in postural control (Diener et al., 1984).

2.1.5. Data Analysis

TPL (EO, EC, and RR) and REC (EO, EC, and RR) were independently analysed using repeated measured ANOVAs with a between-participant factor (migraineurs vs. controls) and a within-participant factor (stimulus type). Pair-wise comparisons with Bonferroni correction were used for post hoc testing.

2.2. Results

The measured TPL, REC, and RR of both the migraineurs and the controls are shown in Figure 3. The ANOVA revealed significant main effects of stimulus types on TPL under the EO and EC

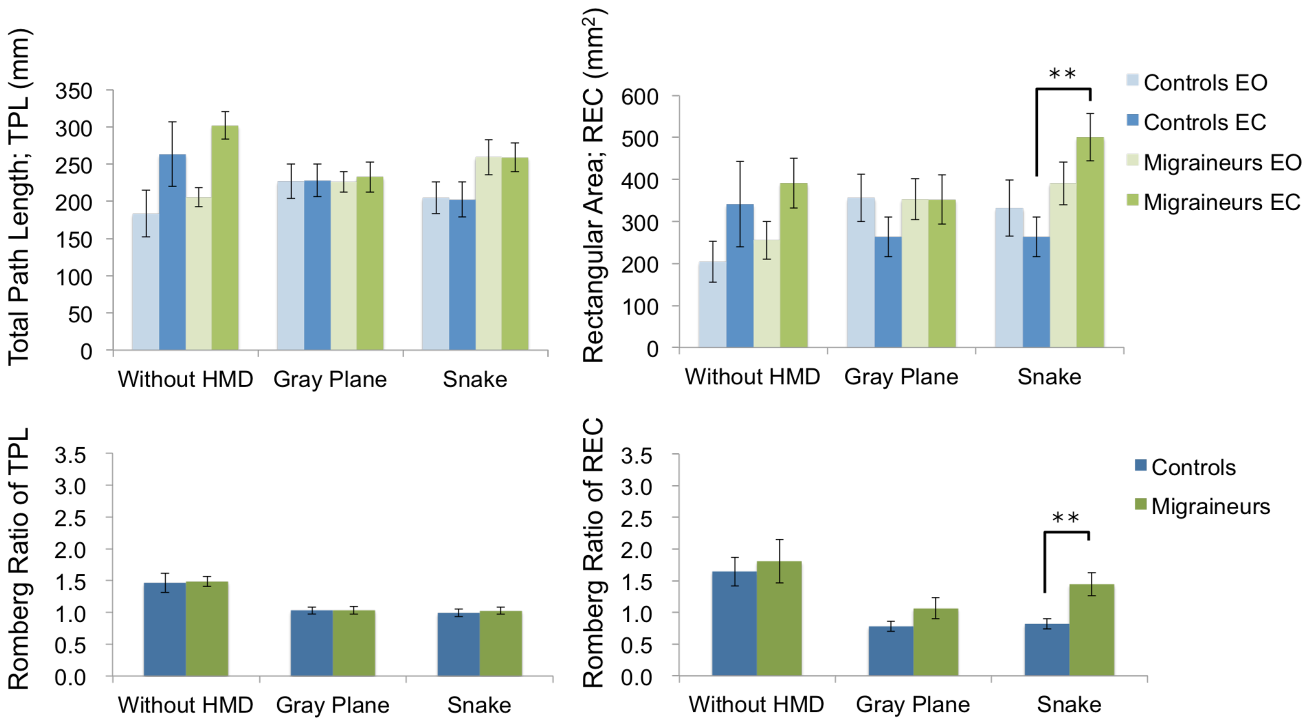

Figure 3: Results of Experiment 1. Error bars denote the standard error of the mean. Asterisks indicate the significant difference (** $p < 0.01$, Bonferroni correction)

conditions. Furthermore, the RR of the TPL was significant (EO: $F_{2, 36} = 4.48$, $p < 0.05$, $\eta^2 = 0.20$; EC: $F_{2, 36} = 7.16$, $p < 0.01$, $\eta^2 = 0.29$; RR: $F_{2, 36} = 19.69$, $p < 0.01$, $\eta^2 = 0.52$). No significant main effects or interaction effects were found for the between-participants factor. We found significant main effects of stimulus types on REC under the EO condition and the RR of REC (EO: $F_{2, 36} = 8.52$, $p < 0.01$, $\eta^2 = 0.32$; RR: $F_{2, 36} = 7.65$, $p < 0.01$, $\eta^2 = 0.30$). We also found a trend toward a main effect of the between-participants factor on the RR of REC ($F_{1, 18} = 4.17$, $p = 0.06$, $\eta^2 = 0.19$). No significant main effects or interaction effects were found for the between-participants factor. Multiple comparisons revealed a significantly larger REC in migraineurs in the EC condition after the observation of the snake image compared to the REC for the controls ($p < 0.01$). Consequently, there was a significantly increased RR of REC in the migraineurs for the snake image ($p < 0.01$).

2.3. Discussion

The results showed that no differences of TPLs existed between the grey plane and the snake image observations, and there were no differences between the migraineurs and the controls. As for REC, migraineurs showed larger postural sway while closing their eyes after viewing the illusory rotating snake image, whereas such differences were not found during the actual observation of the snake image. Given the fact that migraineurs perceive stronger motion aftereffects than do individuals who do not suffer from chronic headaches (Shepherd, 2006), we speculated that the motion aftereffect caused by the illusory motion increased the postural sway evidenced by the migraineurs. To investigate this speculation, we carried out another experiment designed to remove the motion aftereffect probably induced by illusory motion.

3. EXPERIMENT 2

To examine whether the aftereffect due to illusory motion can induce increased postural sway as observed in the EC condition for the migraineurs in Experiment 1, we provided an interval between the EO and EC conditions to decay the aftereffect caused by viewing illusory motion. If the aftereffect due to illusory motion increased postural sway, the removal of the aftereffect would decrease postural sway. Furthermore, we used a non-motion snake image (i.e., one that looked like *Rotating Snakes* but that did not have the rotating effect attached to it) as a control stimulus for a more detailed examination of the effect of the illusory motion induced by the snake image. If illusory motion is enough to modulate postural sway, then the control image should not have the same effect.

3.1. Methods

The method in Experiment 2 was identical to that in Experiment 1, except as noted below.

3.1.1. Participants

Eight migraineurs (4 male and 4 female; mean age = 21.29 years, *SD* = 3.09) and 14 non-chronic headache sufferer controls (7 male and 7 female; mean age = 22.36 years, *SD* = 2.24) who did not participate in Experiment 1 agreed to participate in this experiment.

3.1.2. Stimuli

In addition to the grey plane and the snake image (Figure 1, left), we used a non-motion control image (Kitaoka, 2013; see Figure 1, right). The order of colour patches that composed the control image was reversed between the adjacent units, so that the illusory motion signal would be nulled. All stimuli had the same mean luminance and were presented with a red cross as a fixation point.

3.1.3. Procedure

To prevent the aftereffect of illusory motion in the EO condition from modulating postural sway in the EC condition, we added intervals of 30 seconds between the EO and EC conditions for each measurement. During this interval, the participants who had their eyes open kept standing on the stabilometer while being exposed to a blank display for 30 seconds. They then closed their eyes and their bodily responses were measured under the EC conditions.

Directly after the stabilometric measurements, participants orally rated the magnitude of illusory motion for each stimulus using an 11-point Likert scale, where 0 meant ‘the image did not appear to move at all’ and 10 meant ‘the image appeared to move most strongly’.

3.1.4. Data Analysis

Along with TPL and REC, the ratings of illusory motion were analysed using repeated measures ANOVAs with a between-participants and a within-participants factor (stimulus type). Pair-wise comparisons with Bonferroni correction were used for post hoc testing.

3.2. Results

The measured TPL, REC, and RR of both the migraineurs and controls are shown in Figure 4. An ANOVA revealed significant main effects of stimulus types on TPL under the EO and EC conditions and for the RR of TPL (EO: $F_{3, 60} = 4.16$, $p < 0.05$, $\eta^2 = 0.17$; EC: $F_{3, 60} = 4.68$, $p < 0.01$, $\eta^2 = 0.19$; RR: $F_{3, 60} = 15.43$, $p < 0.01$, $\eta^2 = 0.44$). No significant main effects or interaction effects were found for the between-participants factor. We found significant main effects of stimulus types and between-factors on the RR of REC (stimulus type: $F_{3, 60} = 8.57$, $p < 0.01$, $\eta^2 = 0.30$; between-participants factor: $F_{1, 20} = 7.56$, $p < 0.05$, $\eta^2 = 0.27$), but no significant interaction between these factors. Multiple comparisons revealed significantly larger TPLs for the controls in the EC

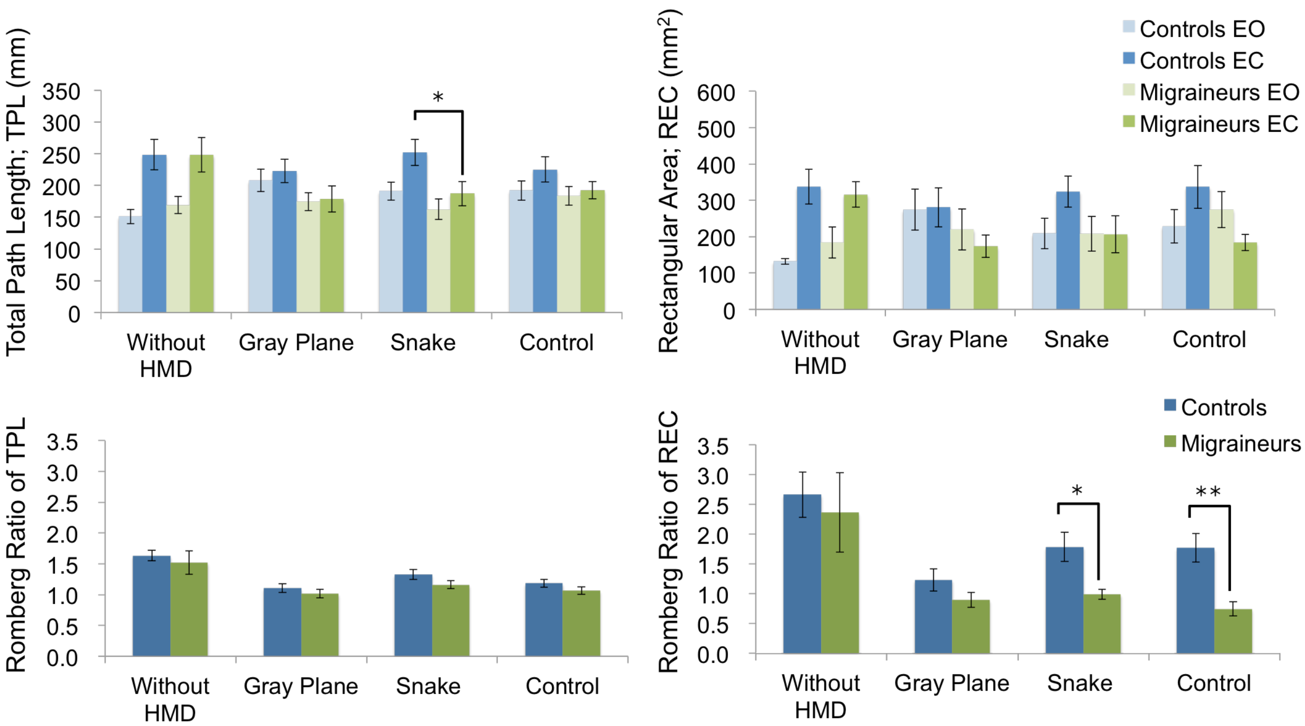

Figure 4: Results of Experiment 2. Error bars denote the standard error of the mean. Asterisks indicate the significant differences (* $p < 0.05$, ** $p < 0.01$, Bonferroni correction)

condition after the observation of the snake image in comparison to the migraineurs ($p < 0.05$).

Contrary to the results from Experiment 1, the RR of REC significantly decreased in migraineurs relative to controls when they observed both the snake image ($p < 0.05$) and the control image ($p < 0.01$).

The subjective magnitude of illusory motion in both the migraineurs and controls are depicted in Figure 5. An ANOVA revealed significant main effects of stimulus types ($F_{2, 40} = 24.53$, $p < 0.01$, $\eta^2 = 0.55$. No significant main effects or interaction effects were found for the between-participants factor. Multiple comparisons revealed that illusory motion significantly increased for the snake image relative to both the grey plane and the control image ($p < 0.01$).

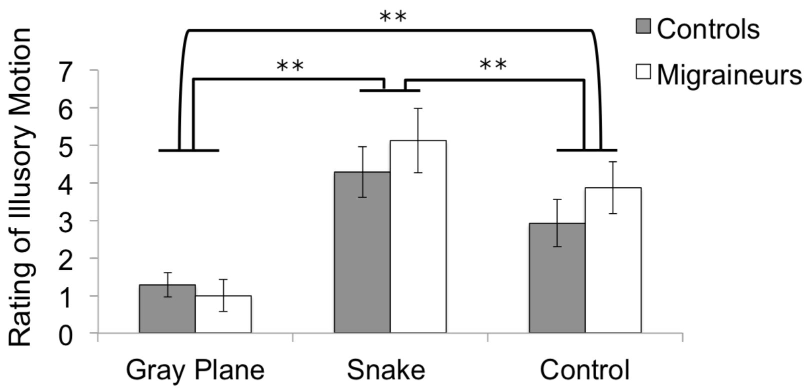

Figure 5: Subjective rating of the magnitude of illusory motion in Experiment 2. Error bars denote the standard error of the mean. Asterisks indicate the significant differences (** $p < 0.01$, Bonferroni correction)

3.3. Discussion

The results showed no differences of TPLs between the grey plane, the snake image, and the control image observations, and there were no differences between migraineurs and controls, except for longer TPL for the controls in the EC condition after the observation of the snake image. On the other hand, as for REC, migraineurs showed decreased postural sway in the EC condition after viewing both snake and control images, contrary to the results in Experiment 1. This suggests that the aftereffect of illusory motion may induce increased postural sway, especially in migraineurs.

Rating the magnitude of illusory motion confirmed that the snake image presented stronger illusory motion than the control image as far as both the migraineurs and controls were concerned. Given the absence of differences between the sway measured by using the snake and the control images, the stronger illusory motion from the snake image did not necessarily increase postural sway. Not only the magnitude of illusory motion, but also other spatial properties (e.g., spatial frequency, colour) may be involved in visually inducing postural sway.

4. GENERAL DISCUSSION

The present study suggests that postural sway can be modulated by static visual stimuli, especially when the stimuli can induce illusory motion perception. In our experiments, migraineurs showed larger sway while closing their eyes after viewing the illusory motion (Experiment 1). However, they showed decreased sway while closing their eyes after a 30-second interval following their viewing of the illusory motion (Experiment 2). Thus, we speculate that static visual stimuli induce not only illusory motion, but also postural sway, and that this effect may last for at least 30 seconds in migraineurs.

In this study, we focused on the relationship between illusory motion and postural sway. However, to more thoroughly understand visuo-vestibular interaction, the influence of emotional processes on the interactions should not be ignored, given the previous findings that postural sway can be modulated by visually evoked emotions, especially negative ones (Stins & Beek, 2007), and by a preference for visual objects (Brunye et al., 2013). In our experiment, since the high contrast of the geometrical pattern can easily induce visual discomfort in observers (Wilkins et al., 1984), the snake image consisting of high contrast geometrical patterns may have induced not only illusory motion but also visual discomfort in our participants, especially in migraineurs (Imaizumi et al., 2011; Marcus & Soso, 1989). If so, postural sway may have been affected by visual discomfort as well as by negative emotion.

Stabilometric measurement may provide a quantitative and objective measure to investigate the interactions between visual perception and cognition, such as optical illusion and emotion (e.g., Stins & Beek, 2007). This type of measurement can be beneficial in advancing Kansei Engineering, which quantitatively assesses the interactions between Kansei and multisensory processing. Recent studies have demonstrated that the relatively inexpensive stabilometric device, the Nintendo Wii Balance Board, can accurately assess postural sway (Bartlett et al., 2014; Clark et al., 2010). It would, therefore, not be so difficult to introduce stabilometric studies into the field of Kansei Engineering.

Our study has at least two limitations regarding the experimental design. First, the weight of HMD fundamentally affected the difficulty to control posture, consequently increasing postural sway. Second, the design of our experiment did not allow for ensuring whether the illusory-motion aftereffect appeared in the participants' visual fields. Further investigations overcoming these limitations should extend the present findings.

ACKNOWLEDGMENTS

We would like to thank an anonymous reviewer who provided valuable comments on this paper and Haruka Lee for her help with the data collection. A Grant-in-Aid for Scientific Research (B) to SK (23330218) and a Grant-in-Aid for JSPS Fellows to SI (13J00943) from the Japan Society for the Promotion of Science supported this work.

REFERENCES

Aurora, S. K., Ahmad, B. K., Welch, K. M., Bhardhwaj, P., & Ramadan, N. M. (1998). Transcranial magnetic stimulation confirms hyperexcitability of occipital cortex in migraine. Neurology, 50(4), 1111-1114.

Bartlett, H. L., Ting, L. H., & Bingham, J. T. (2014). Accuracy of force and center of pressure measures of the Wii Balance Board. Gait & Posture, 39(1), 224-228.

Brunye, T. T., Hayes, J. F., Mahoney, C. R., Gardony, A. L., Taylor, H. A., & Kanarek, R. B. (2013, August). Get in my belly: food preferences trigger approach and avoidant postural asymmetries. PLoS One, 8(8). Retrieved January 26, 2014, from http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0072432

Carvalho, G. F., Chaves, T. C., Dach, F., Pinheiro, C. F., Goncalves, M. C., Florencio, L. L., Ferreira, K. S., Bigal, M. E., & Bevilaqua-Grossi, D. (2013). Influence of migraine and of migraine aura on balance and mobility - a controlled study. Headache, 53(7), 1116-1122.

Clark, R. A., Bryant, A. L., Pua, Y., McCrory, P., Bennell, K., & Hunt, M. (2010). Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. Gait & Posture, 31(3), 307-310.

Conway, B. R., Kitaoka, A., Yazdanbakhsh, A., Pack, C. C., & Livingstone, M. S. (2005). Neural basis for a powerful static motion illusion. Journal of Neuroscience, 25(23), 5651-5656.

Diener, H. C., Dichgans, J., Bacher, M., & Gompf, B. (1984). Quantification of postural sway in normals and patients with cerebellar diseases. Electroencephalography and Clinical Neurophysiology, 57(2), 134-142.

Headache Classification Subcommittee of the International Headache Society. (2004). The international classification of headache disorders, 2nd edition. Cephalalgia, 24(Suppl.), 9–160.

Imaizumi, S., Koyama, S., & Hibino, H. (2011). A quantitative evaluation of stripe and grid patterns by migraine patients and normal controls. Bulletin of Japanese Society for Science of Design, 58(3), 69-74.

Kitaoka, A. (2003). “Rotating snakes.” Retrieved January 15, 2014, from Akiyoshi's illusion pages: http://www.ritsumei.ac.jp/~akitaoka/index-e.html

Kitaoka, A. (2013). “Rotating snakes: test and control stimuli.” Retrieved January 15, 2014, from Akiyoshi's illusion pages: http://www.psy.ritsumei.ac.jp/~akitaoka/illnews11e.html

Kuriki, I., Ashida, H., Murakami, I., & Kitaoka, A. (2008). Functional brain imaging of the Rotating Snakes illusion by fMRI. Journal of Vision, 8(10), 16, 1-10.

Marcus, D. A., Furman, J. M., & Balaban, C. D. (2005). Motion sickness in migraine sufferers. Expert Opinion in Pharmacotherapy, 6(15), 2691-2697.

Marcus, D. A., & Soso, M. J. (1989). Migraine and stripe-induced visual discomfort. Archives of Neurology, 46(10), 1129-1132.

Noguchi, K. (2003). The relationship between visual illusion and aesthetic preference–An attempt to unify experimental phenomenology and empirical aesthetics. Axiomathes, 13(3-4), 261-281.

Reason, J. T., & Brand, J. J. (1975). Motion sickness. London, UK: Academic Press.

Sakai, F., & Igarashi, H. (1997). Prevalence of migraine in Japan: A nationwide survey. Cephalalgia, 17(1), 15-22.

Seno, T., Kitaoka, A., & Palmisano, S. (2013). Vection induced by illusory motion in a stationary image. Perception, 42(9), 1001-1005.

Shepherd, A. J. (2006). Local and global motion after-effects are both enhanced in migraine, and the underlying mechanisms differ across cortical areas. Brain, 129, 1833-1843.

Stevanov, J., Spehar, B., Ashida, H., & Kitaoka, A. (2012, November). Anomalous motion illusion contributes to visual preference. Frontiers in Psychology, 3, 528. Retrieved January 26, 2014, from http://www.frontiersin.org/perception_science/10.3389/fpsyg.2012.00528/abstract

Stins, J. F., & Beek, P. J. (2007, October). Effects of affective picture viewing on postural control. BMC Neuroscience, 8, 83. Retrieved January 26, 2014, from http://www.biomedcentral.com/1471-2202/8/83/

Takemura, H., Ashida, H., Amano, K., Kitaoka, A., & Murakami, I. (2012). Neural correlates of induced motion perception in the human brain. Journal of Neuroscience, 32(41), 14344-14354.

Wilkins, A., Nimmo-Smith, I., Tait, A., McManus, C., Della Sala, S., Tilley, A., Arnold, K., Barrie, M., & Scott, S. (1984). A neurological basis for visual discomfort. Brain, 107, 989-1017.

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