

Evaluation of Body Sway in a Seated Posture after Alcohol Ingestion with an Aim to Evaluate Motion Sickness Caused by Three-Dimensional Images

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Abstract

A few studies have evaluated swaying motion of the body in the seated posture; however, these studies did not evaluate motion sickness caused by watching movies, traveling, etc. This study aimed to analyze stabilograms recorded while the individuals were seated. Stabilometry was performed on 7 healthy male subjects (age, 21–22 years) in the seated position 5 min before, and at 5-min intervals from 5 to 60 min after alcohol load. Alcohol caused a decrease in the cerebellar equilibrium function that controls the vestibulospinal reflex. We adjusted the degree of simulative effect on the human equilibrium function. The stabilograms of the test subjects were analyzed according to the area of sway, total locus length, and total locus length per unit area. We found that significant alcohol-induced changes in the sway values in the seated posture were similar to those in the upright posture.

Keywords: Body sway; Alcohol load; Seated position; Stabilogram; Electrocardiogram (ECG)

Introduction

Stabilometry is useful to comprehensively investigate equilibrium function [1]. To increase the diagnostic value of stabilometry, stabilometric procedures and analytical indices of recorded body sway have been established with regard to the total locus length and locus length per unit area [2]. In particular, locus length per unit area is assumed to represent minute variations in postural control and is considered a scale for evaluation of spinal proprioceptive postural control [3]. Body sway is generally measured in a standing position, such as in Romberg's and Mann's postures, and fewer studies on body sway in a seated position have been performed. However, motion sickness that occurs in cars, trains, and ships, visually induced motion sickness that occurs while watching visual contents, and 3-dimensional (3D) sickness, which occurs while watching 3D video or playing 3D games, frequently occurs in a seated position. In addition, many jobs are performed in a seated position, such as Video Display Terminal (VDT) operation, office work, and driving, and fatigue accumulates while maintaining a seated position for a prolonged period. Moreover, an upright posture is difficult to maintain for some handicapped and elderly persons. However, there are few methods to objectively evaluate body sway in a seated position.

The mechanism of development of visually induced motion sickness, similarly to motion sickness, is explained with the sensory conflict theory [4], as follows: the equilibrium system receives information input from the visual, vestibular, and somatosensory systems. When the combination of this information concerning body movement is inconsistent with combinations previously established based on experience, spatial localization of self becomes unstable and produces discomfort. Input into the vestibular nuclei located in the brainstem from the visual and somatosensory systems and the cerebellum, in addition to the vestibular system, has been reported [5], suggesting that the nuclei physiologically integrate this sensory information. It is also known that there is a close relationship between the vestibular and autonomic nervous systems anatomically and electrophysiologically [6], which strongly suggests that the equilibrium system is associated with the symptoms of motion sickness, and providing a basis to quantitatively evaluate motion sickness based on body sway, an output of the equilibrium system. Furthermore, when

rotation sickness was induced in rats, the histamine level rose in the hypothalamus and brainstem, and this is probably associated with vomiting in motion sickness [7].

There are psychological measurement methods, such as subjective evaluation, and physiological measurement methods, such as measurement related to autonomic nerve activity used to evaluate the influence of visually induced motion sickness on the body. The best-known psychological method to evaluate visually induced motion sickness is the Simulator Sickness Questionnaire (SSQ) [8]. Evaluation of visually induced motion sickness employing measurement of physiological parameters, such as the heart rate and its variation (RR interval), low frequency of heart rate variability (LF), high frequency of heart rate variability (HF), LF/HF, blood pressure, respiratory rate, number of blinks, electrogastrography, skin resistance, and sweat rate has been attempted [9-11]. It has been reported that body sway (total locus length) significantly increased while watching a video in a wide-stance position (heels were 17 or 30 cm apart) in a high SSQ score group compared to a low score group [12].

The usefulness of analytical methods of stabilometry is evaluated based on a comparison of healthy subjects and patients with disequilibrium. Experiments involving these subjects are difficult with regard to availability of subjects and reproducibility. One way to overcome these problems is to artificially control disequilibrium and its severity by alcohol ingestion. Many investigators have reported the effects of alcohol on the oculomotor system [13-18] and on the vestibular system through positional nystagmus [19,20]. Postural instability is observed after alcohol ingestion because the cerebellar function controlling the vestibulo-spinal reflex (vestibulo-cerebellar

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system) is pharmacologically inhibited by alcohol. The change in the sway of the center of gravity induced by alcohol has been quantitatively evaluated by the correlation between the blood alcohol concentration (BAC) and body sway [17,21]. This instability induced by alcohol affects the mechanism that controls a seated posture. In this study, we verify the hypothesis that changes in the sway of the center of gravity can be detected in the seated position in subjects with high blood alcohol level.

To perform a basic investigation of body sway measurement in a seated position, we conducted an experiment with the artificial control of disequilibrium by alcohol loading and evaluated the sway of the center of gravity in the seated position.

Materials and Methods

Participants

The subjects were 7 young males (21-22 years of age) with no past medical history of ear or nervous system disease. The experiment was sufficiently explained to the subjects and written consent was obtained from the subjects. Participants also completed a questionnaire survey before the experiment. Physical information (height, body weight, and sitting height), frequency of alcohol use, and the presence or absence of cigarette smoking was noted.

Materials

Body sway measurement and electrocardiography were performed. A Wii Balance Board (Nintendo) was used as the stabilometer. The Wii Balance Board shows high temporal resolution, although the spatial resolution is not high compared to existing stabilometers. Existing stabilometers are triangular and large, and not well suited for measurement in a seated position. The coordinates of measurement points in this system are presented in cm, the temporal resolution was 0.01 sec, and the sampling frequency was 20 Hz. To investigate the influence of the alcohol load on the cardiovascular system, electrocardiograms were recorded during the experiment using a wireless biological sensor RF-ECG (Medical Electronic Science Institute). The degree of intoxication depends on the cerebral alcohol level, which is difficult to measure. Instead, the breath alcohol level, which is in equilibrium with the cerebral level, was measured using the AT-128 device (Akizuki Denship Tusho).

Design and procedure

In the experiment, a 1-cm thick plate was placed on a table with a 60-cm height, on which the stabilometer was placed in parallel with the ground. The subject sat up straight with both feet elevated and placed lightly clenched fists on the knees. An electrocardiography electrode was attached to the left chest. After 10 min resting, the sway of the center of gravity was recorded for 1 min each with open and closed eyes consecutively (seated position stabilometry). In the test with open eyes, the subject gazed at an optotype, a red gaze point that was set at a site 2-m anterior at eye level. The breath alcohol level was measured 2 times immediately before the test with open eyes, and the mean was recorded.

- (1) Without alcohol ingestion: Seated position stabilometry was performed, and stabilograms were recorded every 5 min 12 times after the initiation.
- (2) With alcohol ingestion: Seated position stabilometry was performed, and stabilograms were recorded every 5 min 12 times after alcohol ingestion.

The order of the above experiments was randomly selected, and the experiments were performed on different days.

Alcohol load

The volume of alcohol ingestion was set to raise the blood level to 0.6 mmEq following the standard equation of blood alcohol concentration, and the subject drank the undiluted distilled liquor within 30 s. This blood alcohol level is classified as an early phase of slight intoxication, in which the pulse and respiratory rates increase, talk becomes fluent, and behavioral self-restraint decreases [21]. The blood alcohol level, Cp, is determined by the following equation, in which 0.789 (g/ml) is the specific gravity of alcohol, and the numerator and denominator represent the amount (g) and volume of distribution of ingested alcohol, respectively:

$$C_p[\text{mmEq}] = \frac{(\text{alcohol concentration})[\%] \times (\text{amount of alcohol consumed})[\text{ml}] \times 0.789[\text{g/ml}]}{0.53[\text{l/kg}] \times (\text{Weight of subject})[\text{kg}]}$$

Data collection

The x-y coordinates were measured during the sampling time with open or closed eyes, saved as text files, and developed to calculate the parameters. The data obtained with open and closed eyes were converted into a time series of the position of the center of gravity with the rightward and forward directions as positive x and y directions, respectively, and the area of sway, locus length per unit area, and total locus length were evaluated. These analytical parameters of stabilometry were employed in previous studies, and we measured them following the definitional equation established by the Japan Society for Equilibrium Research [2].

Data analysis

The stabilograms of all subjects were recorded at each time point and divided into those with and without alcohol ingestion with open and closed eyes, and the area of sway, locus length per unit area, and total locus length were calculated to investigate differences due to alcohol ingestion.

The paired Wilcoxon signed rank test was employed to evaluate the absence of differences in the population means between the patterns with and without alcohol ingestion as a null hypothesis. In addition, two-way ANOVA comparing the presence or absence of alcohol ingestion and measurement time points as factors was performed to investigate whether the main effects accompanying the alcohol load and maintenance of the posture observed were significant. The significance level, p, was set at 0.05.

Since inter-individual variation of alcohol metabolism is large, the time course of the heart rate and the breath alcohol level were also investigated.

Results

Typical stabilograms with and without alcohol ingestion are shown in Figure 1. The sway increased in the locus pattern when alcohol was ingested, compared to that without ingestion.

The mean time course of the area of sway, locus length per unit area, and total locus length are shown in Figure 2-4, respectively. In addition, the mean time course breath alcohol level is shown in Figure 5. When the eyes were open, the area of sway with alcohol ingestion was about 2-fold greater than without ingestion, and it was not dependent on the measurement time point. When the eyes were closed, the value measured with alcohol ingestion at 20-35 min was slightly smaller than that without ingestion.

When the eyes were open, the locus length per unit area was shorter when alcohol was ingested compared to that without ingestion. When

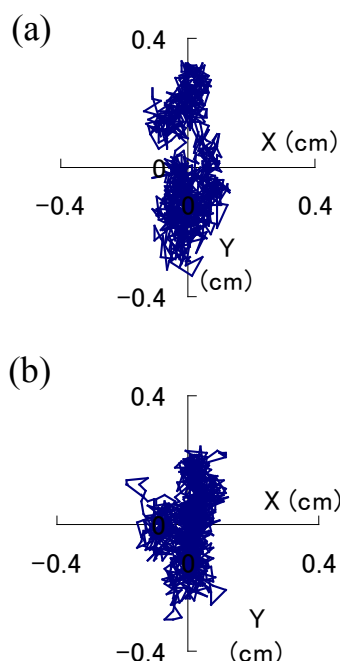


Figure 1: Typical stabilograms observed when subjects viewed the static circle (a), and with alcohol intake after 30 min (b).

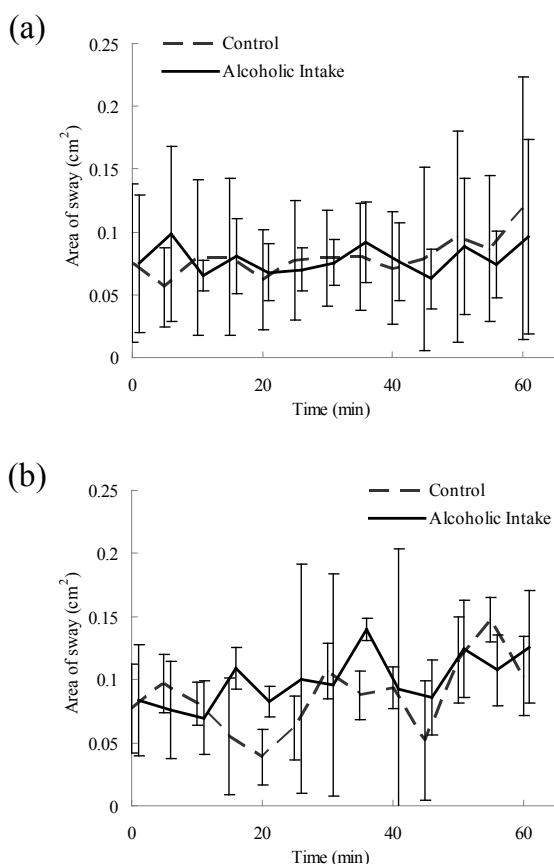


Figure 2: Mean time course of area of sway with alcohol intake vs. control: during open eye tests (a), and during closed eye tests (b).

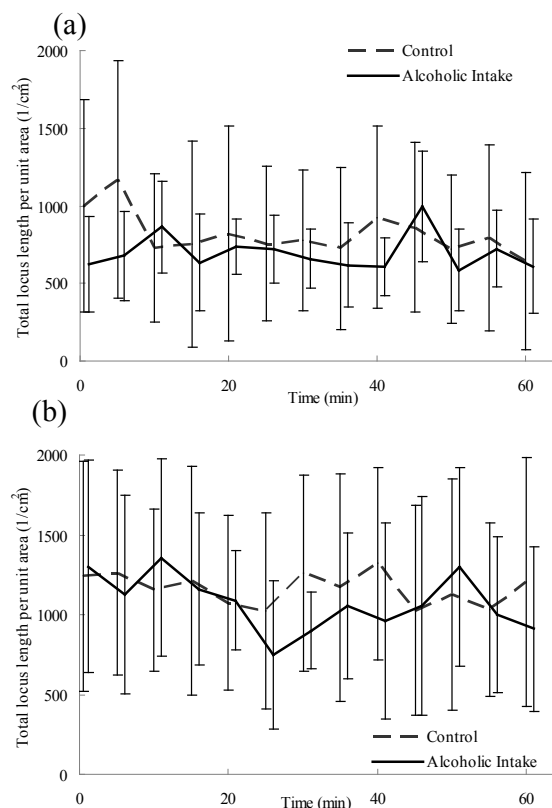


Figure 3: Mean time course of total locus length per unit area with alcohol intake vs. control during open eye tests (a), and during closed eye tests (b).

the eyes were closed, the level at 20-40 min was shorter when alcohol was ingested compared to that without ingestion.

In contrast, no marked difference due to alcohol ingestion was noted in the total locus length when the eyes were open, but the value at 15-30 min was greater when alcohol was ingested vs. without ingestion.

The breath alcohol level rapidly increased for 5 min from immediately after experiment initiation, followed by a moderate rise until 30 min, and then the level started to decrease at 35 min.

The data from all subjects were divided by open and closed eyes, and the data of each measurement period were analyzed using the Wilcoxon signed rank test. A difference was noted in the population mean of the total locus length between the conditions ($p < 0.05$) but no difference was noted in the population mean of the area of sway or locus length per unit area between the conditions. A significant alcohol ingestion-induced increase in the total locus length was noted in 3 and 6 analytical periods with open and closed eyes, respectively.

Two-way ANOVA with repeated measures was performed regarding the presence or absence of alcohol ingestion and measurement time point as factors. No interaction was observed among these factors. The main effect of alcohol ingestion on the locus length per unit area was noted when the eyes were open ($p < 0.05$). A significant effect of alcohol ingestion was noted in the total locus length in tests with both open and closed eyes ($p < 0.01$).

Discussion

The analytical parameters of stabilometry in a standing position were used to evaluate sway in a seated position. When the Wii Balance

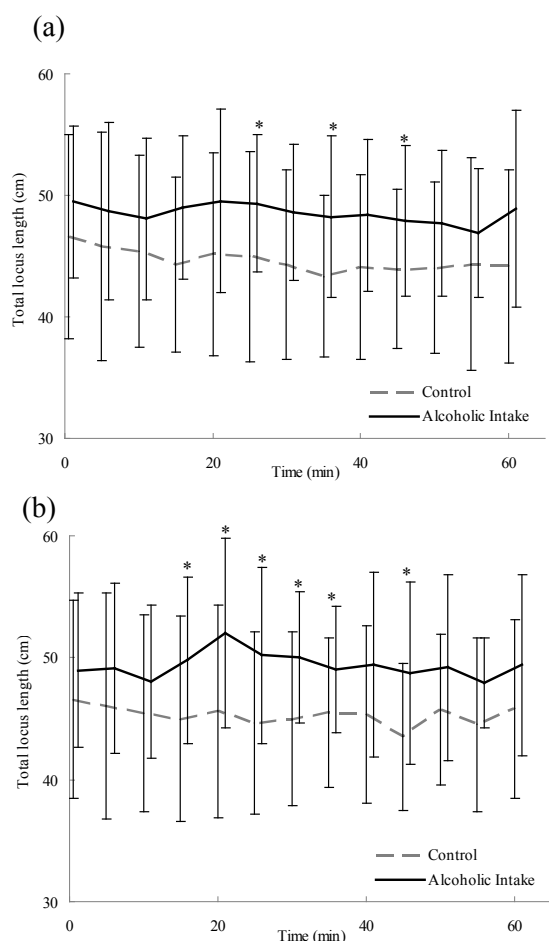


Figure 4: Mean time course of total locus length with alcohol intake vs. control: during open eye tests (a), and closed eye tests (b) (* $p < 0.05$).

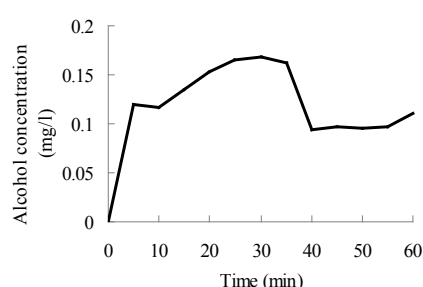


Figure 5: Mean time course of breath alcohol concentration.

Board is used as a stabilometer, the total locus length is useful to detect alcohol ingestion. It also facilitates stabilometry-based non-linear analysis of the human dynamic system to retain and control postures in a seated position [7].

The sway of the center of gravity measured in this study is termed a multicentric pattern [22], showing several minimal points in the time-averaged potential [7] of a mathematical model describing body sway (Appendix). The distance between the minimal points of the time-averaged potential estimated from the stabilogram measured in the seated position tended to increase when alcohol was ingested

compared to that without ingestion, and this may have been due to alcohol ingestion-induced changes in the coefficient of the time-averaged potential of a mathematical model describing the body sway. We have already clarified deformation of the time-averaged potential of a mathematical model describing body sway based on the stabilogram while watching a 3-dimensional film [23].

On analysis of the area of sway and total locus length, the Romberg rate (Romberg rate = values with closed eyes/values with open eyes) was reduced to less than 1 by alcohol ingestion, being judged as a Romberg sign (-). In cerebellar disorders, sway is severe even when the eyes are open [2], and the Romberg rate is less than 1, suggesting that alcohol ingestion does not influence the vestibular function or positional sense of the joints, and that the increase in sway is due to temporary functional inhibition of the cerebellum. This is different from the mechanism of motion sickness caused by watching 3-dimensional video clips. Accordingly, the pattern of structural changes in the time-averaged potential of the above mathematical model of body sway is different.

The locus length per unit area is viewed as a scale to evaluate the function of spinal proprioceptive postural control [1], representing minute variations in postural control. Regarding this parameter, the main effect of alcohol ingestion was noted on two-way ANOVA ($p < 0.05$) when the eyes were open, indicating that the cerebellar function was temporarily inhibited by alcohol ingestion.

Preceding studies have investigated the influence of alcohol ingestion on body sway in a standing position. It has been statistically demonstrated that it is generally difficult to classify patterns of stabilograms with and without alcohol ingestion employing existing parameters, such as the area of sway, effective area, total locus length, and locus length per unit area in either condition with open or closed eyes [24]. However, differences have been observed between the patterns before alcohol ingestion and at 20-35 min after ingestion in a test with closed eyes [24], supporting the possibility of a different pattern in the sway measured at 15-40 min with closed eyes vs. that without alcohol ingestion in this study. The breath alcohol level exceeded 0.15 mg/l during these measurement periods (Figure 5), suggesting the presence of a lower limit of intoxication for the detection of alcohol ingestion by seated position stabilometry. Changes in the extent of sway in an upright posture induced by the ingestion of alcohol causing a specific level of drunkenness have been observed. Changes may also be noted in a seated position.

Conclusion

Stabilometry in a standing position has been established, but measurement of body sway in a seated position has not been established. Thus, sway for which measurement in a seated position is desirable, such as that while watching a film, has to be measured in a standing position, and stabilometry cannot be performed in individuals who cannot maintain a standing position. If body sway measurement in a seated position becomes possible, stabilometry could be performed in these individuals. Furthermore, differences between sway in standing and seated positions could be evaluated, and motion sickness in a simulator could be detected, through which new information could be obtained. In addition, using stabilometry in a seated posture may be significant with regard to public health, as it is possible to assist with the measurement of mental load and fatigue at welfare, health care, and work sites, and broad application and development can be expected. To achieve this potential, an accumulation of basic studies and establishment of a standard evaluation method are necessary. For

the next step, it is necessary to further investigate the reliability of a measurement method by increasing the number of subjects.

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