A Study on Within-Subject Factors for Visually Induced Motion Sickness by Using 8K Display

Through Measurement of Body Sway Induced by Vection While Viewing Images

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Abstract. Visually induced self-motion perception (vection) is one of the phenomena related to human vision. It often emerges as a precursory symptom of motion sickness while viewing moving images. Employing a large number of subjects in a wide range of age groups and using a large-scale 8 K display, we investigated within-subject factors which can influence a sense of vection. We report some results of statistical analyses of vection-induced body sway which occurred when the subjects viewed rotating images on the display. Then we find that our fundamental study may provide useful information in order to set safety guidelines for large-scale ultra-high-definition displays such as 4K and 8K which are becoming popular in public use.

Keywords: Within-subject factor · Visually induced motion sickness · 8K display · Body sway · Vection

1 Introduction

Recent advances in image transmission and presentation technologies have brought us the benefit of increase in size and resolution of displays such as ultra-high-definition (UHD) 4 K (3840 × 2160) and 8 K (7680 × 4320). As a result, we have more and more opportunities to be exposed to virtually created but ultra-realistic environments [1]. The advantage is that those displays can present more dynamic and exciting information to

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viewers. On the other hand, the disadvantage is that one of the problems arising from such situations is visually induced motion sickness (VIMS). It is considered that, the larger the display size becomes and the more moving images of higher resolution are involved, the more easily VIMS arises. Symptoms of VIMS are in general (i) head spins, body sway, headache, sense of fatigue, feeling of drowsiness, facial pallor, etc. in the early stage, (ii) cold sweats, hypothermia, increased saliva production, stomach discomfort, etc. in the middle stage, and (iii) nausea, vomiting, etc. in the severe stage. Since the appearances of VIMS are similar to carsickness, seasickness, etc., VIMS is classified as kinesia [2].

The mechanism of kinesia is not yet fully understood in detail although several hypotheses are suggested. Let us refer to the most common hypotheses for the cause of motion sickness here. First is the "sensory discrepancy" hypothesis that the primary factor which develops motion sickness is the visual global motion which contradicts the actually static body, causing a sensory integrative discrepancy between visual and balance information [3]. Second is the "toxic" hypothesis that the presence of nausea is a part of our defensive function against intoxication [4, 5]. In the case that we have swallowed (ingested) poisons by mistake, we unconsciously make the functional interrelation in our visual and vestibular systems incommensurate each other in the brain, resulting in head spins, body sway, etc. leading to vomiting for forceful expulsion of contents of the stomach. It is considered that humans have acquired such physiological function to survive in the evolutionary process. Once we obtained the function, incommensurate functional interrelation induced for our visual and vestibular systems can cause head spins, body sway, etc. leading to vomiting not only when poisons are detected but also for any reason such as motion sickness. Third is the "postural instability" hypothesis that putting ourselves in an unfamiliar environment to keep our postural stability is the cause of motion sickness [6]. Naturally, we unconsciously keep ourselves in a stable position by using various kinds of sensory information. However, when we happen to put ourselves in an unstable situation and have difficulty keeping ourselves in a stable position, then we suffer from motion sickness. Unfortunately, there exist evidences both for and against each of the three hypotheses described above. They are merely hypotheses and there has been no definite proof provided for any of them so far.

Regardless of our poor understanding of the mechanism of motion sickness, there is an urgent need for safety evaluation in viewing moving images as is described at the beginning of this section. However, there is not so much progress not only in setting safety guidelines on VIMS [7, 8] but also in finding a standard method for safety evaluation from the viewpoint of prevention of VIMS [2, 9] or even identifying incentive factors [10].

Visually induced self-motion perception known as vection [11] is one of the phenomena related to human vision. In particular, rotational and translational self-motion perception is called circular and linear vection, respectively [11]. The vection is induced in the following way: When stationary observers are exposed to large-field one-way visual flow stimulating the retina with corresponding optic flow uniformly and continuously in one direction, they often experience an illusory perception of self-motion in the opposite direction to the visual stimulus. It means that visual information has a significantly crucial influence on self-motion perception [12, 13].

Vection is deeply related with VIMS and often emerges as a precursory symptom of VIMS. Therefore, it has been used as a clue to verify and elucidate occurrence factors and mechanisms of VIMS in the past studies. Most of such studies are on VIMS-influencing "information factors" such as velocity [14–16], acceleration (vestibular sensory information supposed to be integrated with visual information) [17–19], direction (i.e., retinal, body, head and/or world coordinates) [20], frequency [21], depth feel [22], view angle [23, 24], etc. However, because of experimental difficulties, very little research has been done on "within-subject factors" so far except a report verifying a difference between children and adults [25, 26]. Vection is supposed to become prominent when we use a display of larder size with higher resolution because of the enhancement of reality of the presented image.

In this study, employing a large number of subjects in a wide range of age groups and using a large-scale 8 K display, we examined within-subject factors which might influence a sense of vection while viewing moving images. We evaluated the effect of vection through measurement of body sway. Candidates of within-subject factors for the verification experiment in this study are sex (SX), age (AG), physical condition (PC) of the day, pupil distance (PD), average cylindrical power (CYL) indicating the degree of astigmatism and average spherical power (SPH) indicating the degree of nearsightedness or farsightedness.

2 Method

2.1 Stimuli

Moving images used in the experiment were produced by using a digital 4 K video camera recorder (Sony FDR-AX100). Each of them consisted of small beads with different colors. Those beads were densely distributed at random on the frame. The images have two types in speed, i.e., slow moving (SM) and fast moving (FM): SM and FM images were produced such that they rotate clockwise at a constant angular velocity of 3 and 6 degrees per second around its own center, respectively. We also produced a green monochrome (GM) image by computer graphics as a static reference.

2.2 Apparatuses

The images were presented on an 8 K tiled-display of 185-inch (4 × 4 Sumsung UD46C, total 16 commercial FullHD LED-backlit LCD flat panels of 46-inch 1920 × 1080). It was operated by a supercomputer (SGI UV 2000 with 20 TB RAM and 4 GPU enabling to present 8 K images on the display) and installed as a part of the High-Definition Visualization System in Information Technology Center, Nagoya University. On the display, the luminance at the position of beads in the SM and FM images was an average of 235 cd/cm^2 while that of the GS image was 20.4 cd/cm^2.

The experiment was conducted in a dark chamber. At the position of subjects, the illuminance toward the display and overhead was an average of 110.2 lx and 42.2 lx, respectively, for the SM and FM images while 65.4 lx and 35.4 lx, respectively, for the GM image.

Body sway of each subject was measured by using Wii Balance Board (Nintendo) [27–29] together with a head-mounted three-axis acceleration sensor. The Balance Board plays the role of a stabilometer and can record the center of pressure (COP) displacement on the two-dimensional surface of the board (x and y-axis for horizontally parallel and perpendicular direction to the display surface, respectively, in the experiment). In the analyses below, we only used data collected by the Balance Board.

2.3 Participants

Total 88 naive volunteers, 43 males and 45 females, participated in this experiment. Their ages range from 18 to 76 years old. We classified the ages into four groups, i.e., young (Y) for ages 18−29 years, young-middle (YM) for ages 30−44 years, middle (M) for 45−64 years and elder (E) for more than equal 65 years. All the subjects reported either normal vision or vision corrected with glasses or contact lenses. They also reported no particular history of vestibular system disease and no fatigue at the beginning of the experiment. None of them was aware of the purpose of the experiment.

We obtained informed consent from all the subjects and the experiment in this study was approved by the Ethics Review Board in Graduate School of Information Science, Nagoya University.

2.4 Procedure

In advance, we carried out questionnaire investigation (SX, AG, PC, hours and quality of sleep, previous experience of motion sickness, etc.) as well as examination of visual functions (PD, visual acuity including SPH, refractivity including CYL, etc.) for each subject. Then the subject was asked to stand still on the Balance Board placed 2 m in front of the display, facing straight the display and maintaining the posture with the bilateral toes and heels together (Romberg's posture [30]). Stabilometry is generally performed in the Romberg's posture. It is because the posture with a small support area is unstable and body sway increases in inverse proportion to the area of the supporting base. Therefore, the Romberg's posture is appropriate to measure the degree of disequilibrium [31]. We should note that the SM and FM images correspond to so-called "roll" rotations around the front-to-back axis for the subject. Among roll, pitch and yaw, roll is considered to have the largest influence on VIMS [32]. We should also note that the length of the narrow side of each image (i.e., height of the screen of the display) is nearly equal to the width (diameter) of the field of view (FOV) of the subject because the central visual field (CVF) of Japanese people on average is within about 30 degrees (conical angle) around the direction of the line of sight [33, 34], so that the width (diameter) of CFV is about 2.3 m which nearly coincide with the height of the 185-inch screen of the display with aspect ratio 16:9. In the estimation, we ignored the peripheral visual field since it is considered to have much lower ability to perceive than the central visual field [33, 34].

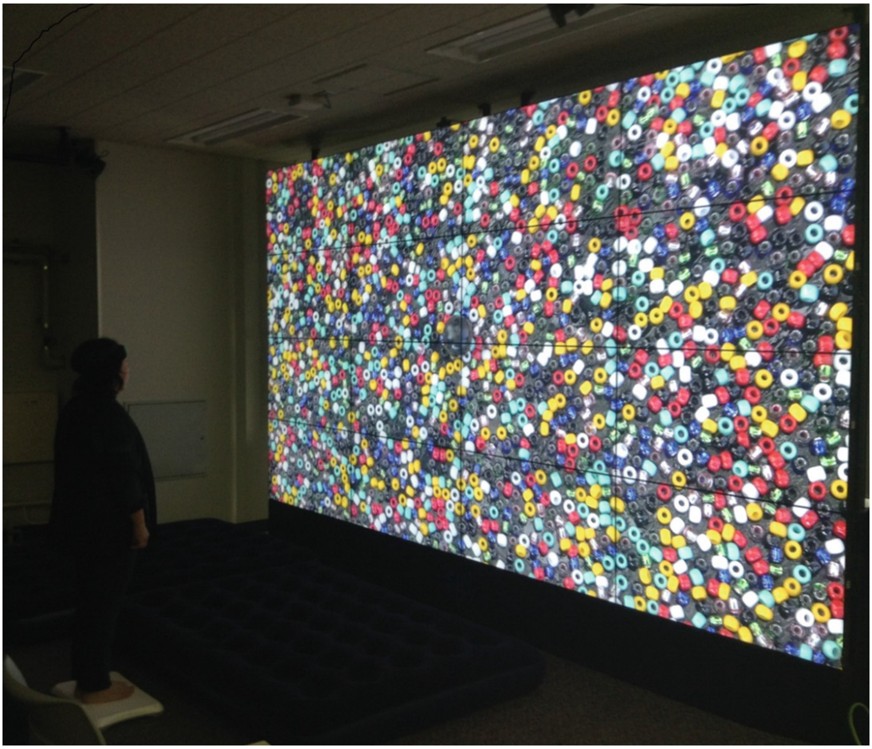

Fig. 1. Actual condition of the experiments

Protocol of the experiments was the following:

1. First, as a pre-test, each subject was instructed to concentrate on the central part of the GM image presented on the display and the body sway (i.e., center of gravity) was recorded for 60 s. Succeedingly, the subject was instructed to close the eyes and the body sway was recorded again for 60 s. Afterwards, the subject was required to answer Simulator Sickness Questionnaire (SSQ) [35] as a standard method for subjective evaluation of the degree of VIMS.
2. Next, as a 1st main test, the subject was instructed to concentrate on the central part of the SM image presented on the display and the body sway was recorded for 30 s. Then suddenly the rotation of the image was suspended. The subject was instructed to continue to keep the eyes open and the body sway was recorded for 60 s. Succeedingly, the subject was instructed to close the eyes and the body sway was recorded again for 60 s. Afterwards, the subject was required to answer SSQ.
3. Finally, as a 2nd main test, we repeat the same first main test but with the FM image.

The actual condition and sequence of the experiments are shown in Fig. 1 and Fig. 2, respectively.

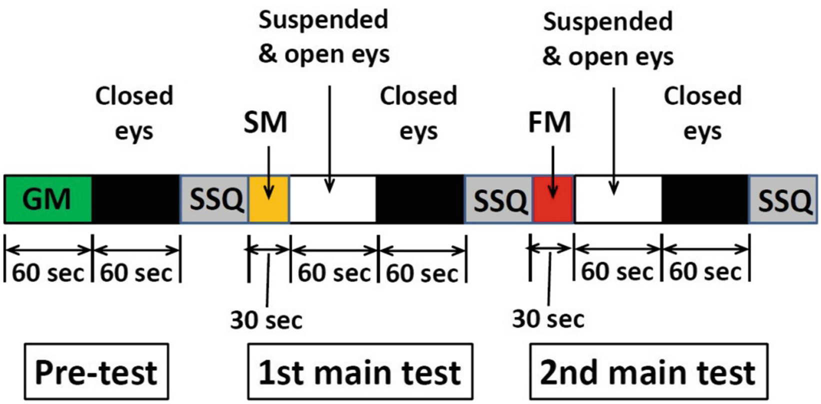

Fig. 2. Sequence of the experiments

3 Results

We first calculated average value (AV) and standard deviation (SD) of x and y components of COP for the entire subjects as statistical analyses in terms of time steps of the data in each task shown in Fig. 2. Then we have found that, especially while the subjects were gazing at the SM and FM images, the AV of x significantly deviates rightward, i.e., the bodies of the subjects were swaying toward the direction of rotation of the images before suspension while, after suspension, the value deviates leftward opposite to the rotation of the images. Correspondingly, SD of x was enhanced in both cases. On the other hand, AV and SD of y did not have much change in a series of the tasks. These effects are rather known in the past literatures. The braking of symmetry in the results may attribute to the Romberg's posture the subjects were forced to take. With the posture it is more difficult to keep their balance in the x-direction than in the y-direction [36]. Therefore, it is strongly recommended that, for safe viewing of moving images, we should take a posture more stable in the direction of x-axis.

We further investigated statistics on the AV and the SD. We considered each of them as an index of vection and hence an objective variable. Then, using a multiple regression analysis, we estimated factors (explanatory variables) which may have largest influences on the objective variable. Candidates of such factors in this study were SX, AG, PG, PD, CYL and SPH. We carried out a reliability test of the estimation by t-test, where we say that the explanatory variable with its significance probability (p-value) less than 0.05 has a significant relation to the objective variable. According to our calculation, p-value for each explanatory variable was around 0.05 or larger so that we report almost no statistically significant difference between the explanatory variables we chose. Only exception was that, while viewing the FM images, SX has a stronger significant relation with SD of both x and y: SD of x, $t = 2.0$ ($p = 0.05$); SD of y, $t = 1.9$ ($p = 0.06$). This means that males have larger SD of both x and y than females, which contradicts a belief that females are more "unsteady" than males. We need more detailed investigations to solve this contradiction.

We also carried out a multiple regression analysis to find any significant relation between the speed of rotation (i.e., SM and FM) and the effect of vection (i.e., AV and SD), however, we could not find any relation there.

Finally, in the same way as described above, we investigated any significant relation between the responses to the SSQ and the effect of vection (i.e., AV and SD). The SSQ has been used as the standard methods for measuring responses of subjects in the study of VIMS, however, many of the observed SSQ variables are highly correlated so that it is not clear which ones are appropriate to use as a basis for building an explanatory model [37]. Again, we could not find any relation here.

4 Discussion

In the work, we reported some results of statistical analyses of vection-induced body sway while viewing the rotating images on the 8 K display and discuss an effect of vection on motion sickness. Although our trials using a multiple regression analysis were not so successful, we find that our fundamental but pioneering study may provide useful information in order to set safety guidelines for large-scale UHD displays such as 4 K and 8 K which are becoming popular in public use. That is, our study may serve as a proof to say that it seems safe to show on such a display a rotating image of 6 degrees per second to people in wide range of generations. In the experiment, no one complained of headache, etc. as a symptom of VIMS. In this context, identification of a maximum speed limit value of rotation for preventing VIMS, if it exists, may be a future issue to be solved.

Another issue to be examined in detail is that, in the case of circular vection, it is not certain but said that the sense of vection increases in proportional to the speed of rotation until 10 degrees per seconds and then saturates.

As for statistical analysis of COP, we can further study stabilogram indices such as area of sway, total locus length, velocity of COP, etc. We can also apply a FFT analysis to the motion of COP.

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