A Time-Varying Factors Model for Interpreting Visually Induced Motion Sickness

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Abstract. For interpreting the process of visually induced motion sickness, we propose a time-varying factors model that consists of trigger and accumulation factors with different time-scales. As validation experiments, fifteen subjects viewed a 2-min-long first-person-view video image session five times (total 10-min) continuously. Measured biosignals were the RR interval, respiration, and blood pressure time-series to estimate the low-frequency (LF) and high-frequency (HF) power components. Then we determined the trigger points and the behavior of LF/HF. The results showed that time-distribution of trigger points showed the peak in the session and in trun the LF/HF, as the accumulation effect, increased in relation to the portions where the trigger points concentrated.

Introduction

Currently, video images taken from the first-person-viewpoint become popular especially in the CG movies, games, and applications of virtual environment (VE) to enhance presence sensation. These real or virtual images include vection-inducing or shakey scenes. Unfortunately, it has been reported that presence-enhanced images sometimes cause the visually induced motion sickness (VIMS) or cybersickness (McCauley and Sharkey, 1992) under some conditions. This type of sickness is caused by the mismatch between actual versus expected invariant patterns of vestibular, visual and kinaesthetic inputs (sensory conflict theory), according to the recent review (Golding, 2006). Researchers have generally studied the VIMS with subjective indices such as the simulator sickness questionnaire (SSQ) (Kennedy, *et al*., 1993) and objective indices regarding the autonomic nervous activity (Wood, *et al*., 2000; Holmes and Griffin 2001). In 2000, Nichols *et al*. studied the association between presence and sickness and showed the negative correlation between each subjective index (Nichols *et al*., 2000). They concluded that the association could be open to a number of interpretations, and presence is multifactorial and may be physiologically and psychologically displayed in different ways by different people. As a result, a model dealing with the association between presence and sickness is still uncompleted and it is important for interpreting the VIMS.

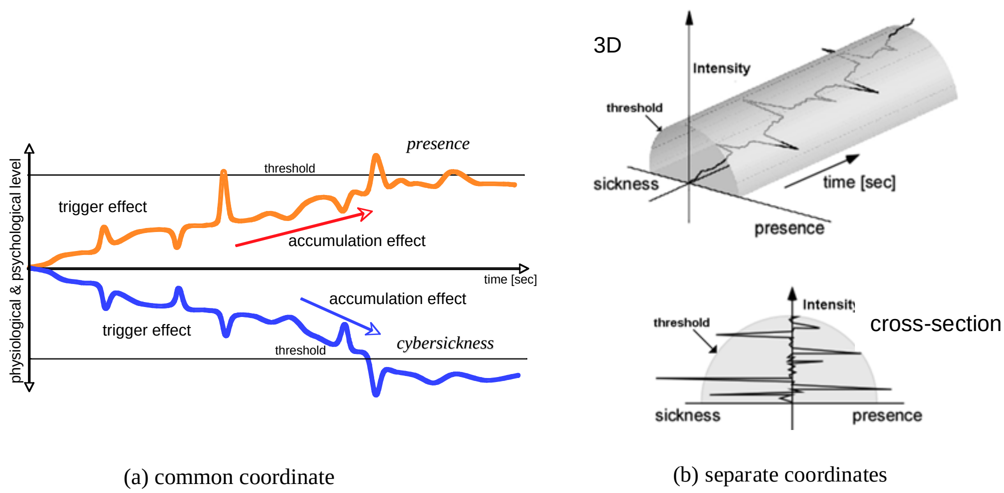


Fig. 1. Time-varying factors models.

We have objectively investigated the VIMS with the image motion vectors of real images, the visual characteristics, and the autonomic nervous regulation (Kiryu *et al*., 2005; Kiryu *et al*., 2007). The results demonstrated that specific camera motion could provoke some sensation including VIMS. In this paper, we propose a time-varying factors model for interpreting the emerging process of VIMS. The time-varying factors model with different time-scales describes VIMS with the effects by trigger and accumulation factors. The trigger factors have a short time scale and could be related to display devises and images, and sensory and cognitive systems. On the other hand, the accumulation factors have a long time scale and could be partly evaluated by the autonomic nervous regulation after specific visual stimuli.

Methods

Time-Varying Factors Model. Referring to the experimental results, we propose two types of the models representing the time-varying factors with different time-scales (Fig. 1). We assumed that presence or VIMS is caused by the relationship between accumulation factors and trigger factors in time. Accumulation factors have a long time scale because it relates to background activity, while trigger factors have a short time scale because of direct effects on vision or brain. Major trigger factors from outside could be the change in the luminance and the camera motion of video images. Accumulation factors include the changes in the autonomic-nervous-activity (ANA) and consciousness. The emerging process of unpleasant sensation has been assessed by the ANA-related indices estimated from biosignals after sensory stimuli. On the other hand, the emerging process of presence sensation is still hard to be evaluated. Like the subjective index of unpleasant sensation, there has been a presence questionnaire in VE (Witmer and Singer, 1998).

In Fig. 1(a), the trigger and accumulation effects have the same coordinate (Kiryu *et al*., 2007). The trigger effects are superimposed on the accumulation effect. A tight relation is assumed between two types of effects and it needs an appropriate time to shift the feeling between presence and VIMS. That is, we assumed positive and negative shifts evoked by the trigger factors and the different thresholds to the superimposed effects in relation to presence and VIMS, respectively. On the other hand, the trigger and accumulation effects have rather the individual coordinates in Fig. 1(b). Since the relationship is relatively independent, it is easy to switch the feeling between presence and VIMS. This model does not substantially include the effects of an elapsed time as the accumulation effect. We assumed the change in the thresholds depending on the level of accumulation effect. That is, the higher the level, the lower the threshold. Note that we set the thresholds to the trigger effects.

Experimental Protocol and Setup. Subjects volunteered for the experiments and viewed a 2-min-long mountain-bike video image session five times (total 10-min) continuously, with the 3-min rest period before and after the exposure. They were allowed to quit the experiment at any time during the visual exposure. To increase the movement sensation, the video images were taken from a first-person viewpoint: for example, the video camera attached at the bike produced shaken or off-centered vection-inducing camera motion. Note that we selected two sessions from ten different image sections in the first-person-view 18-min-long video image. The video images were back-projected onto a 70-inch screen by XGA video projectors with over 2500 ANSI lumens, and the illumination in the room was 10 lx. The distance between a subject and the screen was adjusted to near 1.7 meters for setting the horizontal and vertical view angle at 22 and 17 degree, respectively.

Measured ANA-related biosignals were ECG, blood pressure, and respiration. A subjective index, SSQ, was obtained before and after the exposure. Besides, we asked subjects to press the button at any time they felt unpleasant sensation.

Signal Processing. As trigger factors, both the property of video image and the vision characteristics should be treated. Although we have not enough data for the vision characteristics (Kiryu *et al*., 2007), we have analyzed the property of video images, which were reported as a high risk for the VIMS, with the camera motion (Kiryu *et al*., 2004; 2005). For presenting the accumulation effect, we practically estimated the time-varying behaviors of ANA-related indices: the level of consciousness is hard to be measured.

For quantifying the input visual stimulus, that is, the property of video images, we estimated the time-series of the zoom, pan, and tilt components of the image global motion vector (GMV) (Jinzenji *et al*., 1998) at a sampling frequency of 30 frame/s for an image size of 352×288 pixels. We measured biosignals at a sampling frequency of 1000 Hz with 12-bit resolution to evaluate the effects of the visual stimulus,. The focused frequency bands for ANA-related indices were 0.04–0.15 Hz (low-frequency (LF) power component; Mayer wave related frequency band) and 0.16–0.45 Hz (high-frequency (HF) power component; Respiratory Sinus Arrhythmia related frequency band) (Hayano *et al*., 1994). We estimated the time-series of the ANA-related indices every frame (30 frame/s) with a 10-s interval from the RR interval, respiration, and blood pressure time-series to adjust the sampling times with those of GMVs.

Short-Term Effects: Some Sensation Sections and Trigger Points. For evaluating the short-term effects, we determined the some sensation section (SSS) by ANA-related indices and then searched the onset of the trigger factors, tracing the time-series of the LF component backwards to find out the local minimum. Namely, after estimating the averaged LF and HF components during a preceding rest period, we determined the SSS based on the following ANA-related conditions (Kiryu *et al*., 2004; Kiryu *et al*., 2005): the LF component is greater than the 120% of the averaged LF component, the HF component is less than the 80% of the averaged HF component. Note that this condition was determined to highlight the peaks of trigger point in time. In practice, we used the LF and HF components from the RR interval, HF component from respiration (PS_{resp}), and LF component from blood pressure (PS_{bp}).

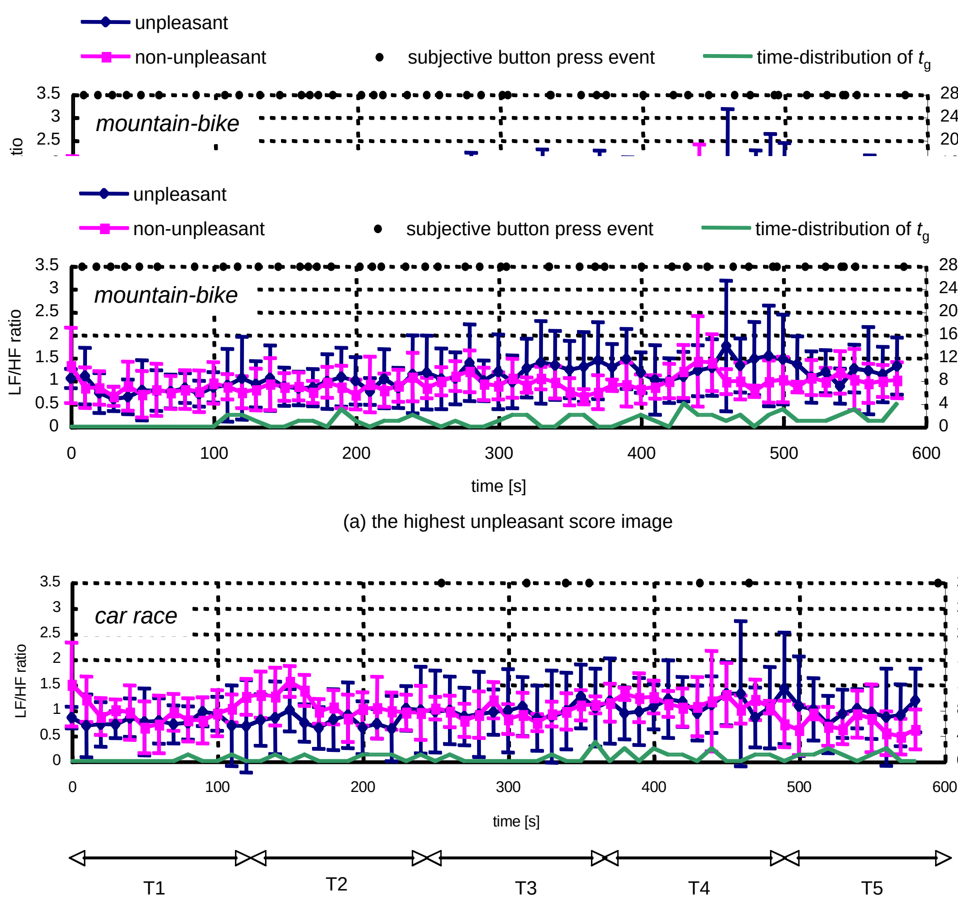
If the time-distribution of trigger points or SSS showed the peaks, the trigger factors would exist and they could be specified by the time-frequency structure of GMV.

Long-Term Effects: Autonomic Nervous Regulation and Consciousness. Long-term effects appear to be autonomic nervous regulation after visual stimuli and developing consciousness. They could be evaluated with the ANA-related indices and the well-designed questionnaire such as the SSQ. We estimated the autonomic nervous regulation with the LF/HF every 10-sec. If the accumulation effect was the function of the elapsed time, the time-varying behavior of LF/HF showed a monotonic change. Besides, the total severity of SSQ would change before and after the exposure.

Results

Subjects. Fifteen healthy young male subjects (21.9 ± 0.9 yrs. old) participated in the experiments. Nine subjects reported unpleasant sensations and six subjects did not, as determined by the number of subjective button press event. Incidentally, the nine subjects showed a large difference in the total severity of SSQ between before and after the visual exposure in order. We averaged the LF/HF time-series within each group and evaluated the time-varying behavior.

Objective and Subjective Indices. Fig. 2 shows the time-series of averaged LF/HF



(a) the highest unpleasant score image

(b) the lowest unpleasant score image

Fig. 2. Time-series of averaged LF/HF, subjective buttom press event, and trigger point.

for two groups and the subjective button press events in the unpleasant group. We compared the results between the highest unpleasant score image (mountain-bike) and the lowest unpleasant score image (car race) selected from the 18-min-long video image.

In the unpleasant group for the highest unpleasant score, the averaged LF/HF gradually increased with respect to the elapsed time and a significant difference ($p < 0.01$) with a long time interval appeared between two groups, especially in the 4th and 5th tasks (Fig. 2(a)). Almost all the subjective button press events located over the zones in which the averaged LF/HF in the unpleasant group significantly larger than that in the non-unpleasant group.

For the image session with the lowest unpleasant score, we observed the different time-varying behavior of the averaged LF/HF and the subjective button press events (Fig. 2(b)). Note that the number of trigger points per minute was the same as that in the image session with the highest unpleasant score (Kiryu *et al.*, 2005). Comparing to Fig. 2(a), the averaged LF/HF did not demonstrate steady increase. Besides, there were not a tight relationship between localization of trigger points and subjective button press events.

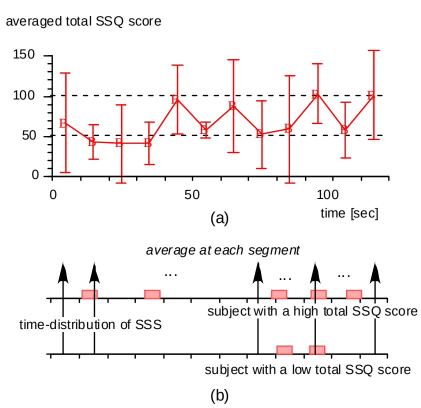


Fig. 4. (a) Time-distribution of total SSQ score averaged at each 10-s segment for 15 subjects; (b) average process with

Time-Distribution of Trigger Points. In Fig. 2(a), there were many trigger points and the trigger points showed the peak around subjective button press events in the unpleasant group. Evaluating the time-distribution of the 62 trigger points at each 10-sec segment for a 120-s task sowed that the trigger points concentrated around the 71–80-s segments in a task (Fig. 3).

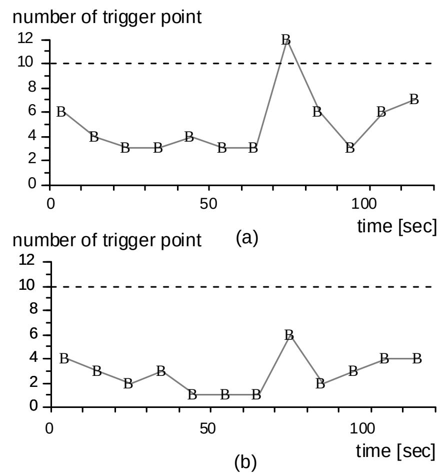


Fig. 3. Time-distributions of trigger points with (a) 120%LF and 80%HF; (b) 130%LF and 70%HF, for 15 subjects.

Note that the ANA-related conditions for SSS was determined so as to prominent the peaks in the time-distribution of trigger points, because the subjective button press events actually existed at the latter part in a task.

Using the time-distribution of trigger points, we further studied the relationship between the trigger effects and the total SSQ score averaged for the SSSs at each 10-s segment. This procedure practically revealed the time-distribution of the total SSQ score (Fig. 4): we estimated the mean and standard deviation of the total SSQ score among related subjects at each 10-s segment. The result demonstrated that the total SSQ score for the 61–120-s segment (the latter half) was significantly higher than that for the 1–60-s segment (the first half) (t-test, $p < 0.05$).

Discussion

According to the results of the repetitive visual exposure (five times), there was a noticeable time-distribution of trigger points estimated by the ANA-related conditions (Fig. 3) and in turn the LF/HF increased for unpleasant group (Fig. 2). For the 3rd and 4th tasks, unpleasant sensation was greatly expected due to the increase in the number of the subjective button press events and trigger points. Although the time-distribution of trigger points is affected by the ANA-related conditions, the relationship between the subjective button press events and trigger points supported the estimated time-distribution in Fig. 3. Besides, concentrated trigger points are most likely related to the increase in LF/HF: the less the localization of trigger points, the less the increase in LF/HF with respect to time. Hence, the specific behavior of image motion vectors could disturb the autonomic nervous regulation and produce the accumulation effect. We have presented the time-frequency structures of motion vectors in relation to VIMS in the previous literature (Kiryu *et al*., 2005): regarding the specific time-frequency structures of GMVs, it included low frequencies ranging 0.3–2.5 Hz in three GMV components. Although surveying the time-frequency structures of GMVs from high-risk real images is a practical approach, the simulation of camera motion by random-dot pattern (Ujike *et al*., 2004) and the special frequency estimated from CG movies are complementary approaches (So *et al*., 2001).

The LF/HF would be useful for evaluating the accumulation effect. However, the disturbance of autonomic nervous regulation was not always related to the unpleasant sensations (Yokota *et al*., 2005). According to the relationship between the unpleasant score and the number of trigger points per minute for ten different image sections in the first-person-view 18-min-long video image, there were image sections where the trigger points that did not cause VIMS (Kiryu *et al*., 2005).

Conventional studies with rotating drum and prolonged virtual environment exposure reported that sickness symptom increased as a function of time for more than several tens of minutes (Stanney *et al*., 2003; Howarth and Finch, 1999). Nevertheless, in the supplemental study, the accumulation effect did not occur for the 18-min-long video image that includes mountain bike and car race sections (Kiryu *et al*., 2007). Thus, the accumulation effect did not simply increase with respect to the elapsed time. The accumulation effect most likely links to specific trigger factors (Kiryu *et al*., 2005).

There might be different trigger factors or different accumulation effects for presence and VIMS. Besides, the ANA and consciousness, as the accumulation factors, might vary differently for presence and VIMS. These speculations should be further studied in terms of the features and timings of specific trigger factors that would produce a synergetic effect with the accumulation factors. Furthermore, other indices except LF/HF should be considered (Holmes and Griffin, 2001; Sugita *et al.*, 2005).

A dynamic threshold is assumed with respect to the level of consciousness and the capacity of autonomic nervous regulation in Fig. 1(b). The habituation training could reduce motion sickness susceptibility (Golding, 2006). By the habituation training, the level of consciousness would decreases and the capacity of autonomic nervous regulation would increase. Thus it seems sufficient that the dynamic threshold is designed like Fig. 1(b)).

Conclusions

We confirmed effects of trigger and accumulation factors of a time-varying factors model, studying VIMS with the image motion vectors and autonomic nervous regulation. The results showed that the VIMS would be first induced by the specific trigger factors and enlarged by the accumulation factors: the accumulation effect could be partly evaluated with the autonomic nervous activity.

The accumulation effect did not always depend on the elapsed time. Although the separate coordinates model (Fig. 1(b)) seems preferable, further study is required to interpret the relationship between presence and VIMS.

Acknowledgments

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