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# Psycho-Physiological Response by 3D Image and Sound

Shuichi Satake[a]*, Hiroshi Hagiwara[b]

[a]*Graduate School of Information Science and Engineering, Ritsumeikan University, 1-1-1 Noji Higashi, Kusatsu, Shiga 525-8577, Japan*
[b] *College of Information Science and Engineering, Ritsumeikan University, 1-1-1 Noji Higashi, Kusatsu, Shiga 525-8577, Japan*

**Abstract**

Recently, advances in stereoscopicimaging technology have opened up opportunities to view three-dimensional (3D) images and itis expected that 3D imaging technology will be further utilized in medical facilities. In our study, we investigated the psycho-physiological effects induced by 3D imagery and sound combinations by using functional near infrared spectroscopy (fNIRS), electrocardiograms (ECG), and the Roken Arousal Scale (RAS). The following four image and sound conditions were comparedunder both 2D and 3D conditions: sound only, image only, synchronized image and sound combinations, and asynchronized image and sound combinations. In all tests, brain activity in the frontal cortex was measured by placing NIRS probes near the prefrontal cortex and in the vicinity of dorsolateral area 46. To evaluate any increase or decrease in oxygenated hemoglobin (oxyHb), we used δoxyHb. Briefly, oxyHb waveform data are passed through a differential filter, after which a sum of more than zero is defined as a positive component,and a sum less than zero is defined as a negative component. The δoxyHb value is defined as the positive component minus the negative component. It was found that δoxyHb values for sound and imageryalone under the 2D condition exceeded those under the corresponding 3D condition. Furthermore, δoxyHb values under synchronized and asynchronized 3D conditions were higher than those recorded under the corresponding 2D condition. These results suggest differences in brain activities between 2D and 3D imagery, or with or without sound. The highest δoxyHb value was recorded for 3D imagery with synchronized sound.High frequency component (HF)values for a synchronized image and sound under 3D conditions werethe lowest, and low frequencycomponent(LF) /HF values for the synchronized image and sound under 3D conditions werethe highest. These results indicate the predominance of the sympathetic nervous system during sound-synchronized 3D imagery.


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*Keywords:*fNIRS; oxyHb; 3D image and sound;prefrontal cortex;brain activation

* Corresponding author. Tel.: +81-77-561-5078; fax: +81-77-561-5078.
*E-mail address:*: is0118xh@ed.ritsumei.ac.jp


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## 1. Introduction

Recently, advances in stereoscopicimaging technology have opened up opportunities to view three-dimensional (3D) images, and it is expected that 3D imaging technology will be further utilized in medical facilities. Such 3D images give a realistic feeling but cause the problems of 3D sickness and eyestrain, and so studies on the faults of3D are being conducted. However, 3D images are associated withmany other unsolved questions. Therefore, more research on the psycho-physiological effect is needed in order to use 3D images safely, comfortably, and effectively.Such research needs not only a 3D visual stimulus but also stimuli of other senses. Accordingly, in our study, we considered a visual stimulus and an auditory stimulus. The purpose of this study was to reveal the effect of 3D and to obtain new knowledge on 3D ergonomics. In experiments, wetested the brain activity of subjects by using simple 3D images and sounds.

## 2. Experimental Method

### *2.1. Subjects*

Twelve healthy, non-medicated college students (10 men, 2 women; 21 or 22 years old) participated in the study. All subjects provided written informed consent prior to participation.The subjects refrained from excessive eating and drinking the night before the experiment. In addition, the subjects refrained from engaging in prolonged or strenuous exercise before the morning of the experiment. Blood hemoglobin concentrations in the brain were measured by using NIRStation (Shimadzu, Japan), a near-infrared imaging device. The measurement sites of the NIRS are shown in Fig.1. In this report we focused on the frontal probe and analyzed data from channel 1 (right frontal cortex), channel 10 (center frontal cortex), channel 19 (left frontal cortex), all three of which are involved in cognition or judgement, and channel 25 (dorsolateral prefrontal cortex, near Brodmann area 46), whichis involved in attention and control. In addition, electrocardiograms (ECG) were measured with a Polymate(Digitex Lab, Japan). The sites of the ECG electrodes were monitored by a 4-lead ECG. Before attaching the electrodes, skin cream was applied to the subject’s skin to reduce skin impedance.

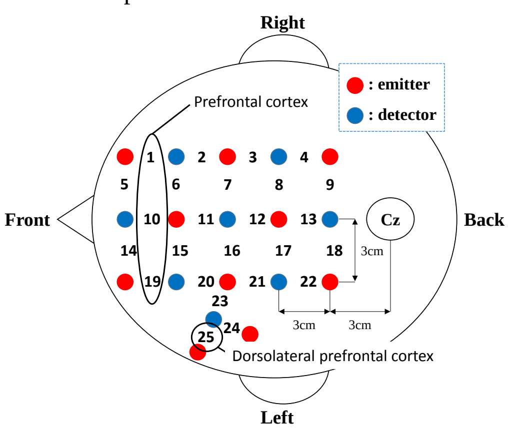



Fig. 1.Attachment of the probes.

### *2.2. Tasks*

We prepared eight image and sound conditions: image only, sound only, synchronized image and sound, and asynchronized image and sound under the2D and 3D conditions. We used a 27-inch LCD monitor (VG278HE, Asus) and active shutter glasses (3D Vision, NVIDIA). The experiment was conducted in adark room. Test subjects took a seat and put their chin on a fixed stand.

Test subjects viewed a stereoscopic image that moved in a circular motion for 3minutes (Fig.2 (a)). One rotation of the image was 5 s,and 1.0 degree of parallax was added. The viewing distance was 100 cm, whichwas three times larger than the height of the monitor (Fig.2 (b)). The stereoscopic image was seen atapproximately 23cm in the forward direction and approximately 37cm in the backward direction.

The sound stimulus was set at a base frequency of 500 Hz and then modified according to the image movement. In the 2D condition, only the frequency of the sound stimulus changed; in the 3D condition,the volume was changed as the image moved right and left. During testing of the asynchronized condition, the sound cycle was set at 4.3 seconds. Generally, human beings are more tolerant of a time lag in which the visual image isahead of the sound,rather than a time lag in which the sound isahead of the visual image[1, 2]. Therefore, in our experiments, the cycle of the asynchronized sound condition was set to be faster than a 5.0s cycle.

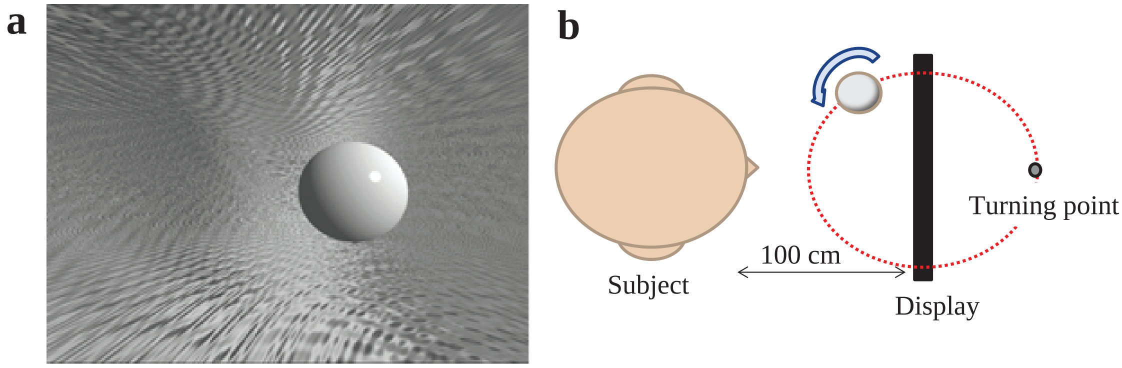



Fig. 2. (a) Presented visual target; (b) overview of the environment for this experiment.

## 2.3. Experimental Protocol

The experimental protocol is shown in Fig.3 and was as follows: 60s pre-task rest (eyes opened), 180stask (viewing image and sound), and 60s post-task rest (eyes opened). The Roken Arousal Scale (RAS) and Simulator Sickness Questionnaire (SSQ) were evaluated before and after each task.The subjects were given 5 minute breaks between each cycle. They put on active shutter glasses after filling out theRAS and SSQ, and took off the active shutter glasses after the NIRS and ECG measurements. The task was randomized inevery experiment to exclude an order effect.

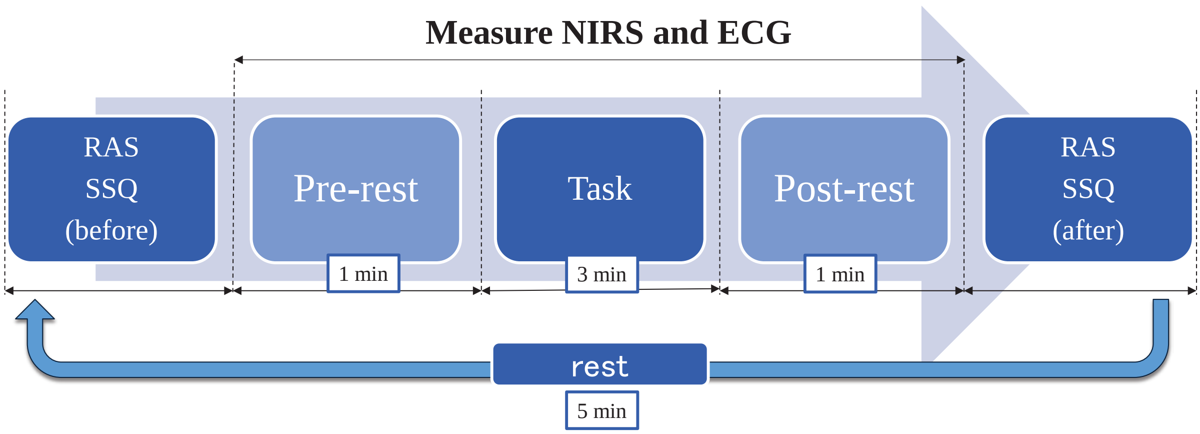



Fig. 3.Schematic of the experimental design.

## 3. Analysis

### *3.1. NIRS*

With NIRS it is possible to measure oxygenated hemoglobin concentration (oxyHb), deoxygenated hemoglobin concentration, and total hemoglobin concentration. In this study, we focused on oxyHb, because oxyHb correlates with changes in thecerebral blood flow. NIRS waveforms carry important information, because NIRS data arenot absolute but relative to baseline measures. Therefore, to assess NIRS waveforms, it is not enough just to calculate the average of oxyHb. Inour previous study[4], we defined $\delta_{oxyHb}$ to assess the NIRS waveform. First, we applied a bandpass filter (BPF; 0.001 Hz to 0.1 Hz) to oxyHb (Fig.4 (a)). After applying the BPF, we applied a differential filter to oxyHb (Fig.4 (b)). Following the application of the differential filter to oxyHb,we defineda positive component as a result greater than zeroanda negative component as a result less than zero. We defined $\delta_{oxyHb}$ as the positive component minus the negative component. By using the values of$\delta_{oxyHb}$, we can assess the changes in oxyHb during atask. A positive value of $\delta_{oxyHb}$ ($\delta_{oxyHb}>0$) indicates an overall increase in the oxyHb level, and a negative value of $\delta_{oxyHb}$ ($\delta_{oxyHb}<0$) indicates an overall decrease in the oxyHb level.

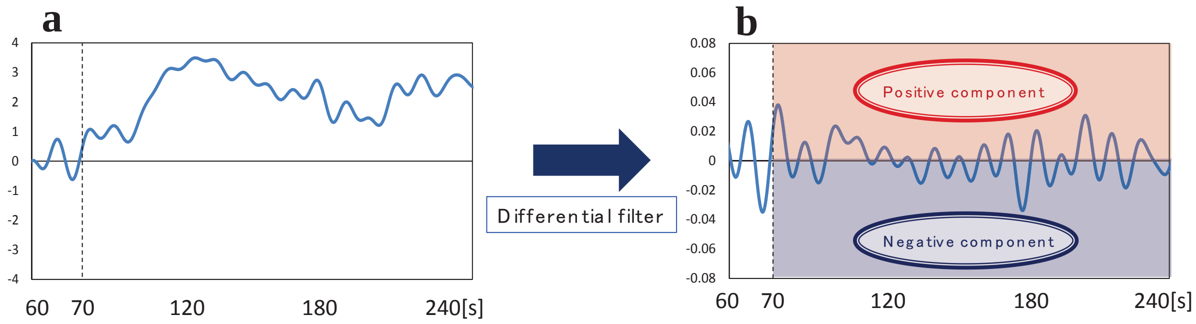



Fig. 4.(a) oxyHb data after applying BPF; (b)oxyHb data after applying a differential filter. The initial 10 s of a task was excluded in calculatingδoxyHb because the neurovascular coupling reaction takes 6 to 10 s.

### *3.2. Roken Arousal Scale (RAS)*

The RAS is a psychological evaluation method that quantitativelyratesthe psychological values of fatigue and alertness. The RAS providesa quantitative index of the following six states: Sleepiness; Activation; Relaxation; Strain (Tension); Difficulty of attention and concentration; and Lack of motivation. Two similar questions assess the six states. The average of the two similar questions was defined as the state value.

### *3.3. Simulator Sickness Questionnaire (SSQ)*

TheSSQ is anevaluation of visually induced motion sickness[3]. The SSQ consists of sixteen questions and provides indexes of nausea (N), oculomotor activity (O), and disorientation (D), as well as total score (TS). Which of the sixteen questions applies to each of the first three indexes is shown in Table 1.The questions were answered ona four-pointscale(0: not exactly to 3: exactly).Thefour indexes were calculated according to the following equations(1) through (4).

$$\text{Nausea(N)} = (\mathit{after\ task}\ \text{N}'\text{s total} - \text{befrore N}'\text{s total}) \times 9.54 \tag{1}$$

$$\text{Oculomotor (O)} = (\mathit{after\ task}\ \text{O}'\text{s total} - \text{before task O}'\text{s total}) \times 7.58 \tag{2}$$

$$\text{Disorientation (D)} = (\text{after task D}'\text{s total} - \text{before task D}'\text{s total}) \times 13.92 \tag{3}$$

$$\text{Total Score (TS)} = (\text{N} + \text{O} + \text{D}) \times 3.74 \tag{4}$$

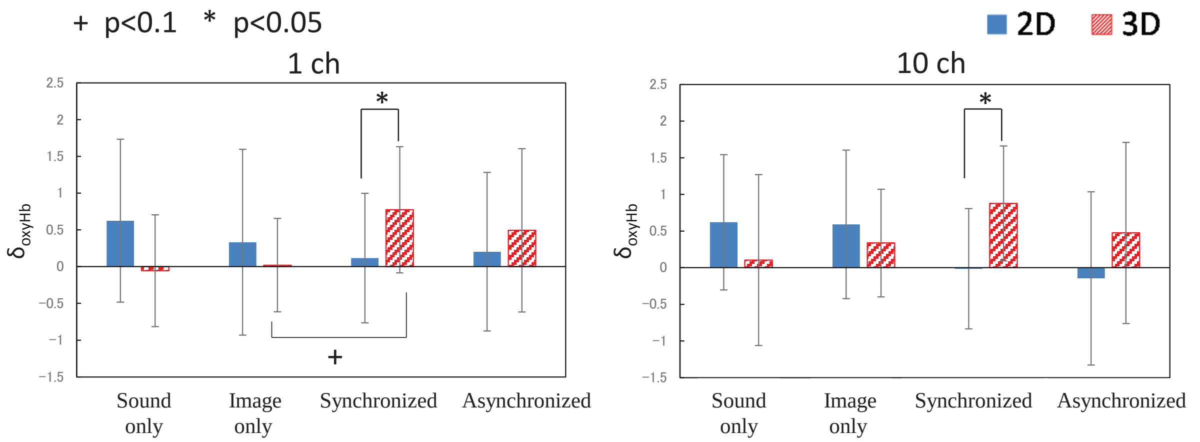
Table 1.Correspondence between the sixteen SSQ questions and three indexes.

| | (N) | (O) | (D) |
|---|---|---|---|
| General discomfort | ○ | ○ | |
| Fatigue | | ○ | |
| Headache | | ○ | |
| Eyestrain | | ○ | |
| Difficulty focusing | | ○ | ○ |
| Increased salivation | ○ | | |
| Sweating | ○ | | |
| Nausea | ○ | | ○ |
| Difficulty concentrating | ○ | ○ | |
| Fullness of head | | | ○ |
| Blurred vision | | ○ | ○ |
| Dizzy (eyes open) | | | ○ |
| Dizzy(eyes closed) | | | ○ |
| Vertigo | | | ○ |
| Stomach Awareness | ○ | | |
| Burping | ○ | | |

## 4. Results

### 4.1. NIRS

Fig.5 shows the $\delta_{oxyHb}$ values. At all channels (channels 1, 10, 19, and 25), the $\delta_{oxyHb}$values for soundand image alone under the 2D condition werehigher than those under the corresponding3Dcondition. On the other hand, at all channels, the $\delta_{oxyHb}$values under the synchronized and asynchronized 3D conditions were higher than those recorded under the corresponding2D conditions. In the synchronized condition, we obtained statistically significant differences at channels 1, 10 ($p < 0.05$), and 19 ($p < 0.1$). In the asynchronized condition, a marginallystatistically significant difference was foundat channel 25 ($p < 0.1$).



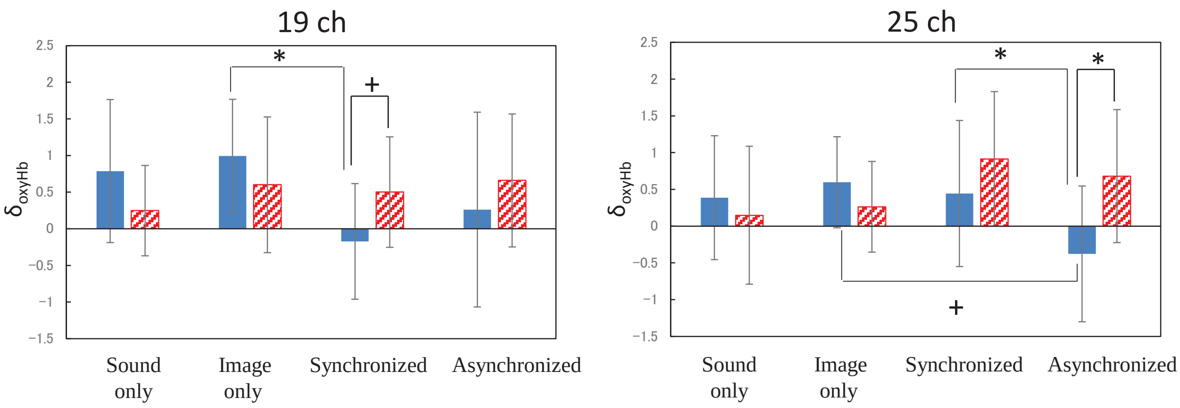



Fig. 5.δoxyHb values.

## 4.2. ECG(HF, LF/HF)

The left plot in Fig.6 shows the average HF values, andthe right plot in Fig.6 shows the average LF/HF values. Both plots were normalized foreach subject. The average ECG HF values in sound alone and synchronized under the 2D condition were higher than the corresponding valuesunderthe 3D condition. On the other hand, thevalues of image alone and asynchronized 3D conditions were higher than those ofthe corresponding 2D condition. In the comparison of 2D with 3D, statistically significant differences were found in image alone ($p < 0.05$) and synchronized ($p < 0.1$).Underthe 3D condition, marginally statistically significant differences were found between HF values in synchronized andasynchronized. The average ECG LF/HF values in sound and image alone and asynchronizedunderthe 2D condition were higher than those underthe corresponding 3D condition. On the other hand, the average ECG LF/HF values underthe synchronized 3D condition were higher than those under the corresponding2D condition. In the comparison of 2D with 3D, marginally statistically significant differences were found in asynchronized ($p < 0.1$).

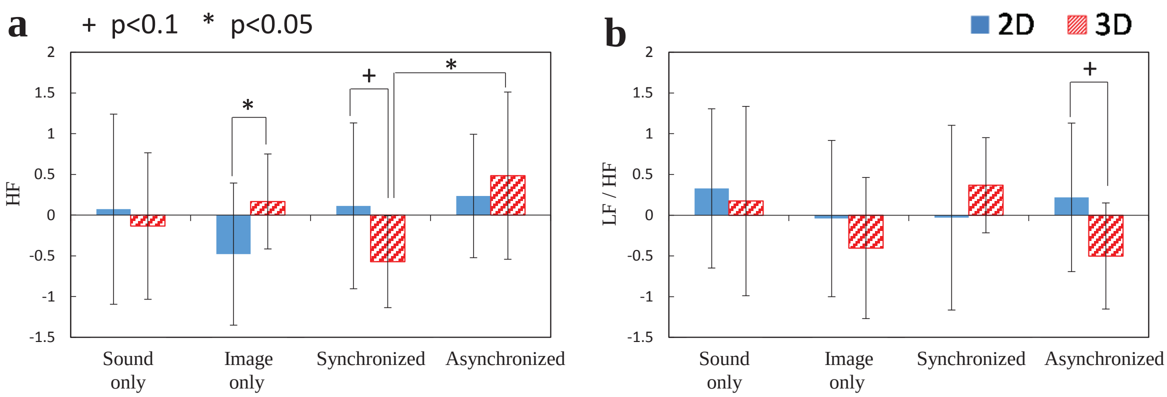



Fig. 6.(a) ECG HF (left); (b) ECG LF/HF.

## 4.3. RAS

From the results of the RAS, the average values of the six states were calculated. Comparing the differences between pre-task and post-taskstates showed a tendency for psychological changes in every task. Lack of motivation increased in all tasks. Strainshada relatively low score. Relaxation wasa relatively high score. Sleepiness and Difficulty of attention and concentration increased, and Activation decreased except for the synchronized 3D condition.

*4.4. SSQ*

Fig.7shows the SSQ results. TheNausea scores were smaller than those in the other states(Oculomotor, Disorientation, Total Score). Thescores under the 3D conditions were higher thanthose underthe corresponding 2D conditions in Oculomotor, Disorientation, and Total Score. Underthe 3D condition, the scores of Oculomotor, Disorientation, and Total Score insynchronized were smaller than those inimage alone and asynchronized.Underthe 2D condition, a similar tendency was shown. In the comparison of the 2D and 3D conditions for Disorientation and Total Score, marginally statistically significant differences were found in image alone ($p < 0.1$). In Disorientation, statistically significant differences appeared in synchronized ($p < 0.05$).

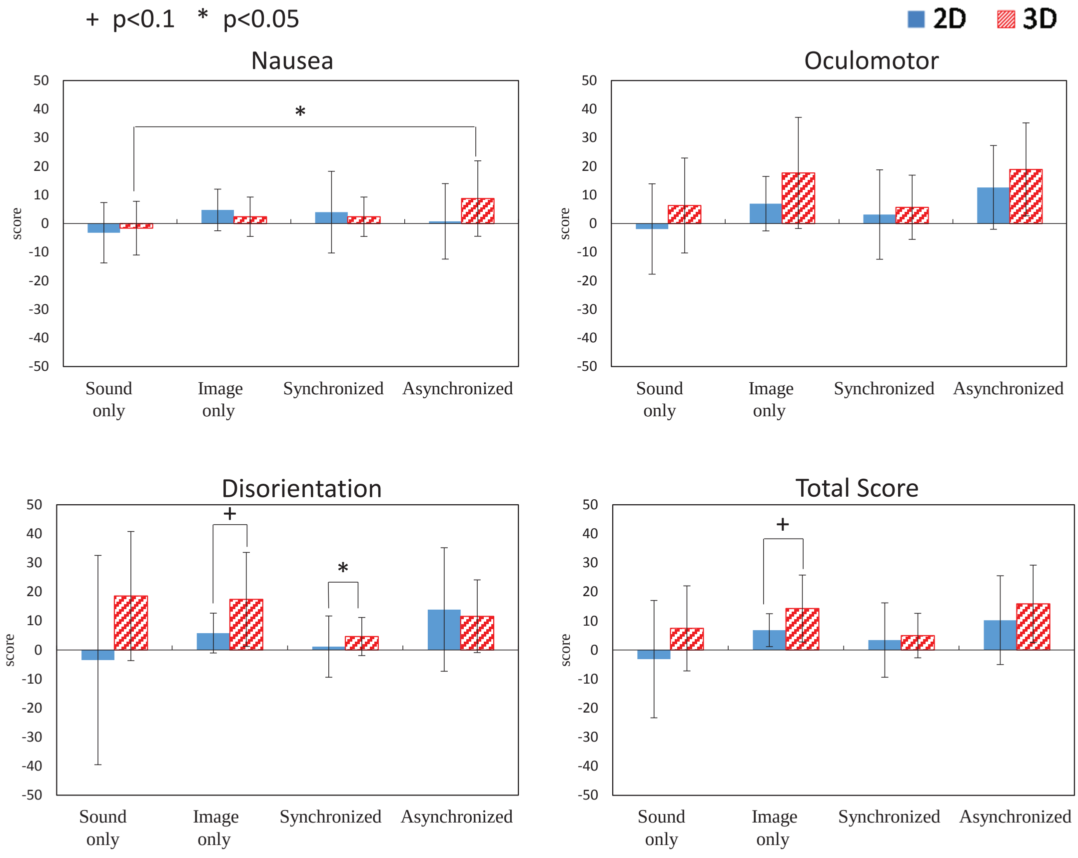



Fig. 7. SSQ score.

## 5. Discussion

In image only, $\delta_{oxyHb}$values from channels 1, 10, 19, and 25 underthe 2D condition were higher than those under the corresponding3D condition. This result means that the tendency to increase oxyHbunderthe 2D condition is stronger than that under the corresponding3D condition. In image only underthe 3D condition, there was little frontal cortex activity.Previous research shows that changes in the parietal oroccipital cortex blood flow increase when viewing the 3D image[5]. In this experiment, the parietal or occipital cortexcould be activated by the 3D image and the frontal cortexcould be made to be less active.In the synchronized and the asynchronized states, $\delta_{oxyHb}$values from channels 1, 10, 19, and 25 under the 3D condition were higher than those under the corresponding2D condition. This result suggests that the visual and auditory stimuli change brain activity.

The ECG HF values in image only and in asynchronized under the 3D condition were higher than those under the corresponding2D condition. Furthermore, the ECG LF/HF values in image only and in asynchronized under the 3D condition were lower than those under the corresponding2D condition. This result indicatesa predominance of the parasympathetic nervous system inimage only and in asynchronized under the 3D condition. The ECG HF values in synchronized under the 3D condition were lower than those under the corresponding2D condition.The ECG LF/HF values in synchronized under the 3D condition were higher than those under the corresponding2D condition. This result indicatesthe predominance of the sympathetic nervous system insynchronized under the 3D condition.

From the results of the RAS, Sleepiness andDifficulty of attention and concentration increased, and Activation decreased except insynchronized under the 3D condition. The reason for this result couldbe the possible influence of the monotonous task and the dark room.However, the synchronized 3D condition showed the opposite tendency.This result suggests that subjects might concentrate more under the synchronized 3D condition than under the other tasks. From the results of the SSQ,the scores in image only and asynchronized were higher than those in synchronized. This suggests that visual stimulus alone or the difference between the image and sound brought a sense of incongruity. Moreover, this tendency was particularly strong under the 3D condition.

Next, we consideredthe correlation between ECG HF, LF/HF, and SSQ.Generally, as motion sickness increased, ECG HF decreased or ECG LF/HF increased. However, in this study, as the SSQ scoresbecamehigher, ECG HF increased and ECG LF/HF decreasedunder the 3D condition. A possible influence is simply the task or the short time to carry out the task. As mentioned before, the visual stimulus alone or the difference between the image and soundbrought a sense of incongruity, and then the SSQ scores became high. We think that the SSQ scores in this study indicated a slightly vague state, not real motion sickness.

The $\delta_{oxyHb}$ values under the synchronized 3D condition were higher than thoseunderthe other conditions.The ECG HF values in synchronized under the 3D condition werethe lowest. The ECG LF/HF values in synchronized under the 3D condition werethe highest. Subjective evaluations of the RAS and the SSQ results showed that subjects were activated or in moderate tension. From the above results, we found that a synchronized 3D image with sound could decrease the faults in 3D comprehension and thus lead to brain activation.

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