World Journal of Neuroscience, 2022, 12, 68-81
https://www.scirp.org/journal/wjns
ISSN Online: 2162-2019
ISSN Print: 2162-2000

Effects of Image Presentation Using a Head-Mounted Display on Muscle and Brain Activity during Swallowing

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How to cite this paper: Hoyano, K. and Ogoshi, Y. (2022) Effects of Image Presentation Using a Head-Mounted Display on Muscle and Brain Activity during Swallowing. *World Journal of Neuroscience*, **12**, 68-81.
https://doi.org/10.4236/wjns.2022.122008

Received: March 3, 2022
Accepted: May 9, 2022
Published: May 12, 2022

Abstract

Introduction: It is well known that humans have an increased sense of taste and consume more food when eating with others. This effect is called social facilitation of eating. We previously reported that self-images also have the effect of social facilitation of eating. In the present study, we investigated the effect of a head-mounted display (HMD) as a means of presenting self-images. **Methods:** Fourteen healthy adults (7 females and 7 males) were included in the study. The mean age of the participants was 20.4 years. The experimental conditions were as follows: the presentation conditions include the SG condition, in which an image was projected on the smart glasses, and the MT condition, in which an image was projected on the monitor. The stimulation conditions include the self-image condition (Self condition), in which the participant's own image was projected, and the background image condition (Background condition), in which the background image was projected. Participants were asked to consume green tea jelly three times under the four conditions, which consisted of combinations of the presentation and stimulation conditions. Electromyography (EMG) and electroencephalography (EEG) were used to measure the muscle activity of the suprahyoid muscle group and brain activity, respectively. **Results:** The EMG of the "SG-Self" condition was significantly higher than that of "SG-Background" and "MT-Background" conditions. The EMG of the "MT-Self" condition was significantly higher than that of the "MT-Background" condition. In the EEG before the start of swallowing, "SG-Self" was significantly lower in the alpha band and higher in the beta band than "MT-Background". The beta-alpha ratio was significantly higher for "SG-Self" than for "SG-Background" and "MT-Background" and higher for "MT-Self" than for "MT-Background". **Conclusion:** These results suggest that self-images influence muscle and brain activities during swallowing, regardless of the presentation conditions, such as HMD or monitor.

Keywords

Social Facilitation, Swallowing, Electroencephalography (EEG), Electromyography (EMG), Diet Modification for Dysphagia

1. Introduction

Many factors are involved in human eating behavior. The surrounding environment is considered one factor that affects eating behavior and is an environmental factor associated with eating behavior is the presence of people who eat together [1]. Eating with others increases food intake [2]. de Castro reported that food intake increased by 40% - 50% on average when eating with others than when eating alone [3]. Lumeg *et al.* reported that food intake also increased in young children when the group size was larger [4]. Berry *et al.* reported that the amount of ice cream consumed was higher when eating in small groups than when eating alone [5]. These reports indicate social facilitation as the reason for the increased intake. Social facilitation is a phenomenon in which an individual's behavior is facilitated by the presence of others [6] [7]. Social facilitation is also observed in eating [8] [9] [10] [11]. This effect is called the social facilitation of eating. The social facilitation of eating requires the presence of others. For example, chocolate was judged to be more palatable and flavorful when consumed with a stranger, even without communication [12].

Social facilitation of eating requires the presence of others, but it also occurs even when others are not directly present. Roth *et al.* examined whether information about the cookie intake of hypothetical participants influenced female college students' actual cookie intake [13]. In this experiment, the intake of cookies decreased when the participants were informed that the hypothetical participants consumed minimal cookies than when there was no information and increased when they were informed that the hypothetical participants consumed numerous cookies than when there was no information. These results suggest that the perception of the presence of a person, even a hypothetical one, influences people's eating behavior. Nakata *et al.* conducted an experiment in which participants consumed popcorn under two conditions: one in which they viewed themselves mirrored and the other in which they viewed a wallpaper projected on a monitor. As a result, the rate of consumption and the liking for popcorn were higher in the condition in which participants viewed themselves in the mirror [14]. We reported that the condition in which the participants viewed themselves on a monitor improved the rate of consumption of a modified diet for dysphagia and subjective evaluation of food compared to the condition in which a wallpaper was displayed on a monitor [15]. We also investigated brain activity and muscle activity of swallowing-related muscle groups during ingestion of a modified diet for dysphagia in the condition in which the participants' self-images were presented, and we observed increased muscle and brain activities associated with social facilitation compared to the condition in which the background image was presented. Our previous findings suggested that consuming a modified diet for dysphagia with a self-image presented on the monitor may influence muscle activity in the suprahyoid muscle group and brain activity. Alternatively, there was a possibility that the effect of self-image presentation would be difficult to view if the eyes were diverted from the monitor due to eating and other movements. In the current study, we investigated brain activity and muscle activity of the swallowing-related muscle groups during ingestion of a modified diet for dysphagia using smart glasses that can present image stimuli without being affected by posture or movement.

2. Methods

2.1. Participants

Fourteen healthy adults (7 females and 7 males) with a mean age of 20.36 years participated in this study. Participants had no special dietary restrictions, food allergies, or history of eating disorders. Participants were informed of the experiment in writing and orally, and their consent was obtained.

2.2. Procedure

Participants participated in the experiment 3 hours after lunch. In a questionnaire, the participants confirmed that they were neither hungry nor full. They were instructed to consume green tea jelly after a signal from the examiner.

Participants were asked to consume green tea jelly three times in one session and that they should swallow without chewing as much as possible. They were instructed to sit in a chair in front of a desk in the room while wearing smart glasses (EPSON MOVERIO BT-30E). There was a 22-inch LED monitor (DELL; P2213) with a webcam (ELECOM; UCAM-C0220FBNBK) on top of the desk. The distance between the monitor and the participant was approximately 70 cm.

The experimental conditions were as follows: the presentation conditions included the SG condition, in which the image was projected on the smart glasses (SG condition), and the MT condition, in which the image was projected on the monitor (MT condition), and the stimulation conditions include the self-image condition (self condition), in which the participant him or herself was projected, and the background-image condition (background condition), in which the background image was projected. The presentation and stimulation conditions were combined to create four conditions: SG-Self, SG-Background, MT-Self, and MT-Background. The order of presentation of these four conditions was determined using a random number table. For the self-image condition, the webcam was adjusted so that the participant's upper body was projected on the monitor. To avoid discomfort while watching the image caused by wearing smart glasses, we presented the participant's own image captured by the webcam on the monitor for approximately 3 minutes and asked the participant to become accustomed to watching the image. Next, we confirmed that there was no sense of discomfort in watching the image with the smart glasses. The background image condition was defined as a control condition using the background image of the laboratory.

The green tea jelly presented to participants was made by adding 3 g of gelator (Healthy Food; Tromismile) to 100 ml of green tea (Suntory; Iemon). Three plastic spoons containing 10 ml of green tea jelly each were placed on a stainless steel tray in front of the participant.

2.3. Equipment

Surface electromyography (EMG) and electroencephalography (EEG) were used to measure the muscle activity of the suprahyoid muscle group and brain activity, respectively. BITalino(r)evolution (PLUX, hereinafter referred to as BITalino) was used to measure EMG and EEG. For the EMG and EEG sensors, the electrode cable and sensor cable were plugged into both sides of the sensor. The other end of the sensor cable was connected to the analog port of the BITalino. We used disposable electrodes (Covidien Arbo TM H124SG) with a diameter of 24 mm, a thickness of 1 mm, a gel dimension of 201 mm^2, and a sensor area of 80 mm^2. The electrodes for EMG were applied at the anterior 1/3 of the distance between the left and right molar and mandibular angles [16]. EEG electrodes were placed in the frontal plane (near Fpz in the extended 10 - 20 system).

EMG and EEG records

EMG bandwidth was set to 10 - 400 Hz and EEG bandwidth to 0.8 - 49 Hz, and the sampling rate was set to 1000 Hz. EMG and EEG data were recorded on a PC that was connected to BITalino via Bluetooth using Opensignals (PLUX) (**Figure 1**). The EEG and EMG data were measured after ingestion of green tea jelly three times under each condition.

Waveform processing

The EMG-recorded text files were converted to Excel CSV files and the EMG waveform components of the suprahyoid muscle during swallowing were extracted using MATLAB (MathWorks). The EMG data were processed by Root Mean Square (RMS) after absolute value processing. The range of analysis was defined as the mean +2SD of resting EMG action potential as the onset of muscle activity and up to 400 ms from there (**Figure 2**). The average RMS value of the three tests was defined as the activity level of the suprahyoid muscle.

The EEG waveform was extracted using the EMG of the suprahyoid muscle during swallowing as an index and was used as the EEG during swallowing. The EEG was extracted 1000 ms before the start of the swallowing motion (EEG before start of swallowing) and 500 ms after the start of the swallowing motion (EEG after start of swallowing) (**Figure 2**). The extracted EEG data were fast Fourier transformed (FFT) into power spectra of alpha (8 - 13 Hz) and beta (14 - 30 Hz) waves. The average of the three power spectra of the EEG before and after the start of swallowing was calculated and used as the values of alpha and beta waves for each participant.

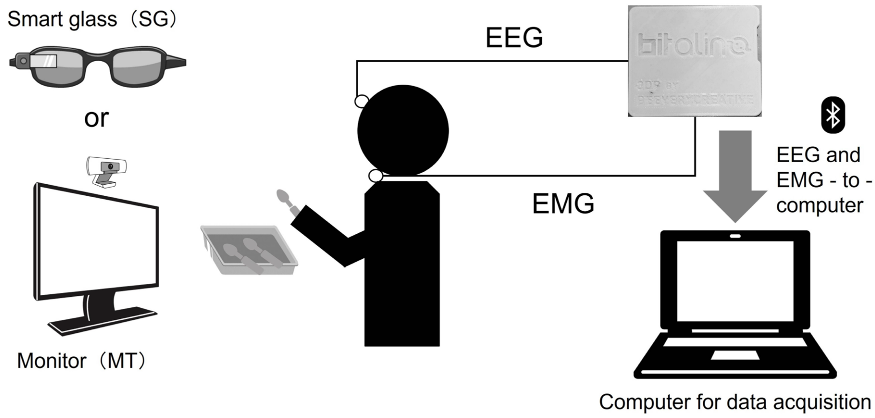

Figure 1. Data collection method.

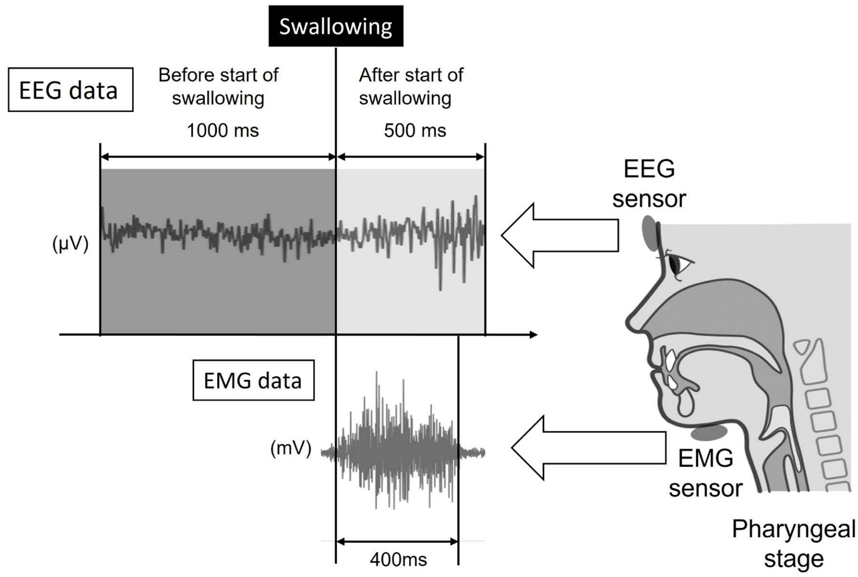

Figure 2. Waveform processing of EMS and EGG.

2.4. Statistical Analyses

A one-way analysis of variance (ANOVA) was performed on the EEG levels during swallowing, before and after the start of swallowing under the combined conditions of presentation and stimulation (SG-Self condition, SG-Background condition, MT-Self condition, and MT-Background condition) to test for differences in variance. Multiple comparison tests (Bonferroni method) were then performed to test for differences between the conditions. The significance level was set at 5%. Statistical analyses were performed using SPSS Statistics ver.25 (IBM).

3. Results

EMG

One-way ANOVA showed that the effect of the combinations of presentation and stimulation conditions was significant ($F(3, 39) = 9.022$, $p = 0.001$, *partial* $\eta^2 = 0.410$). Multiple comparison tests revealed significant differences between

SG-Self and SG-Background ($t(13) = 3.522$, $p = 0.022$, $d = 0.633$), between SG-Self and MT-Background ($t(13) = 4.707$, $p = 0.002$, $d = 0.801$), and between MT-Self and MT-Background ($t(13) = 3.173$, $p = 0.044$, $d = 0.645$) (**Figure 3**).

EEG before the start of swallowing

The results of one-way ANOVA for the combinations of the presentation and stimulation conditions are as follows: The effect on alpha wave activity before start of swallowing was significant ($F(3, 39) = 3.396$, $p = 0.029$, *partial* $\eta^2 = 0.207$). Multiple comparison tests revealed a significant difference between SG-Self and MT-Background ($t(13) = 3.214$, $p = 0.041$, $d = 0.788$). There were no significant differences between SG-Self and SG-Background ($t(13) = -2.014$, $p = 0.39$, $d = -0.419$), between SG-Self and MT-Self ($t(13) = -1.216$, $p = 1.000$, $d = -0.349$), between SG-Background and MT-Self ($t(13) = 0.411$, $p = 1.000$, $d = 0.122$), between SG-Background and MT-Background ($t(13) = -1.619$, $p = 0.774$, $d = -0.307$), or between MT-Self and MT-Background ($t(13) = -1.947$, $p = 0.438$, $d = -0.472$) (**Figure 4**).

The effect on beta wave activity before start of swallowing was not significant ($F(3, 39) = 2.591$, $p = 0.084$, *partial* $\eta^2 = 0.166$). Multiple comparison tests revealed a significant difference between SG-Self and MT-Background ($t(13) = 3.296$, $p = 0.035$, $d = 0.776$). There were no significant differences between SG-Self and SG-Background ($t(13) = 2.389$, $p = 0.198$, $d = 0.722$), between SG-Self and MT-Self ($t(13) = 1.901$, $p = 0.480$, $d = 0.502$), between SG-Background and MT-Self ($t(13) = -0.803$, $p = 1.000$, $d = -0.238$), between SG-Background and MT-Background ($t(13) = -0.818$, $p = 1.000$, $d = -0.205$), or between MT-Self and MT-Background ($t(13) = 0.284$, $p = 1.000$, $d = 0.074$) (**Figure 5**).

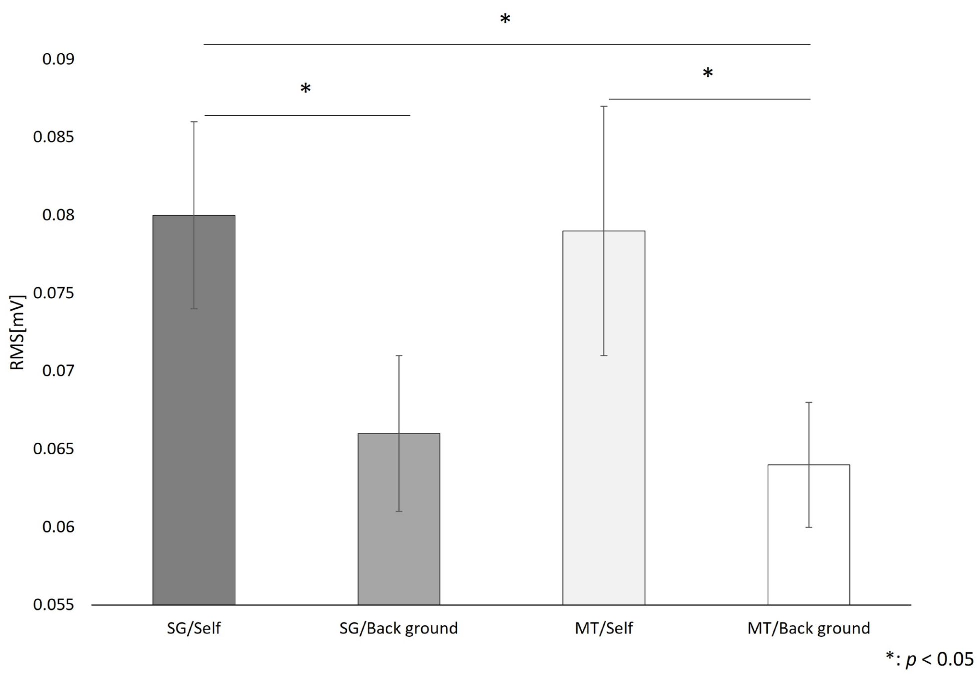

Figure 3. EMG of the suprahyoid muscle group during swallowing (comparisons between the combined conditions of presentation and stimulation). *Error bars indicate standard deviations.

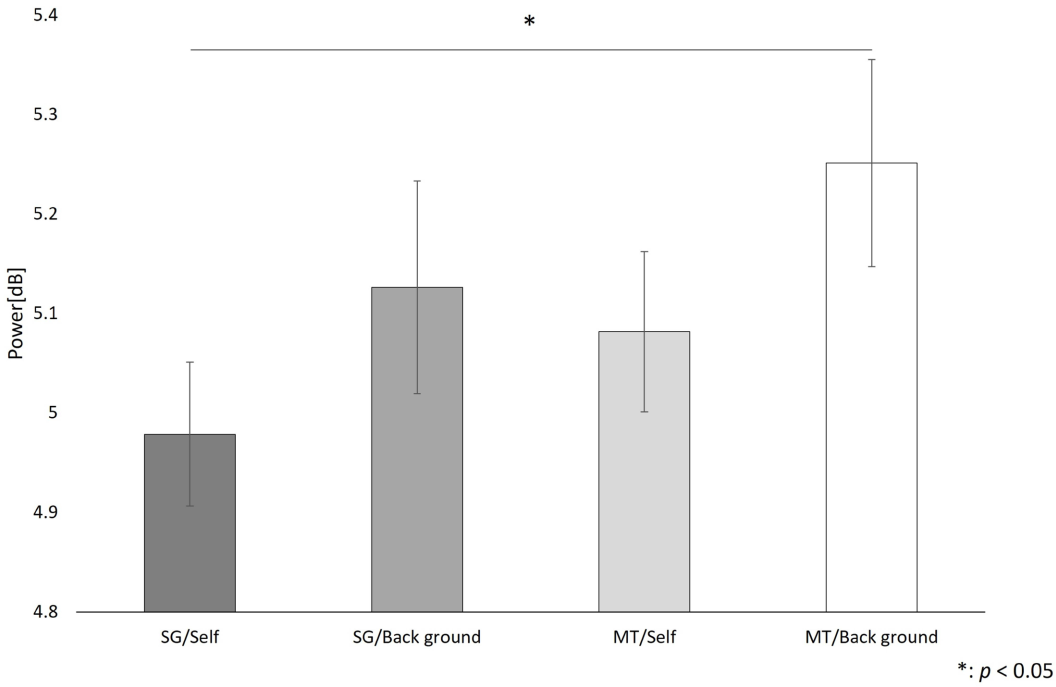

Figure 4. Activity of alpha waves on EEG for each condition before start of swallowing (comparisons between combined conditions of presentation and stimulation). *Error bars indicate standard deviations.

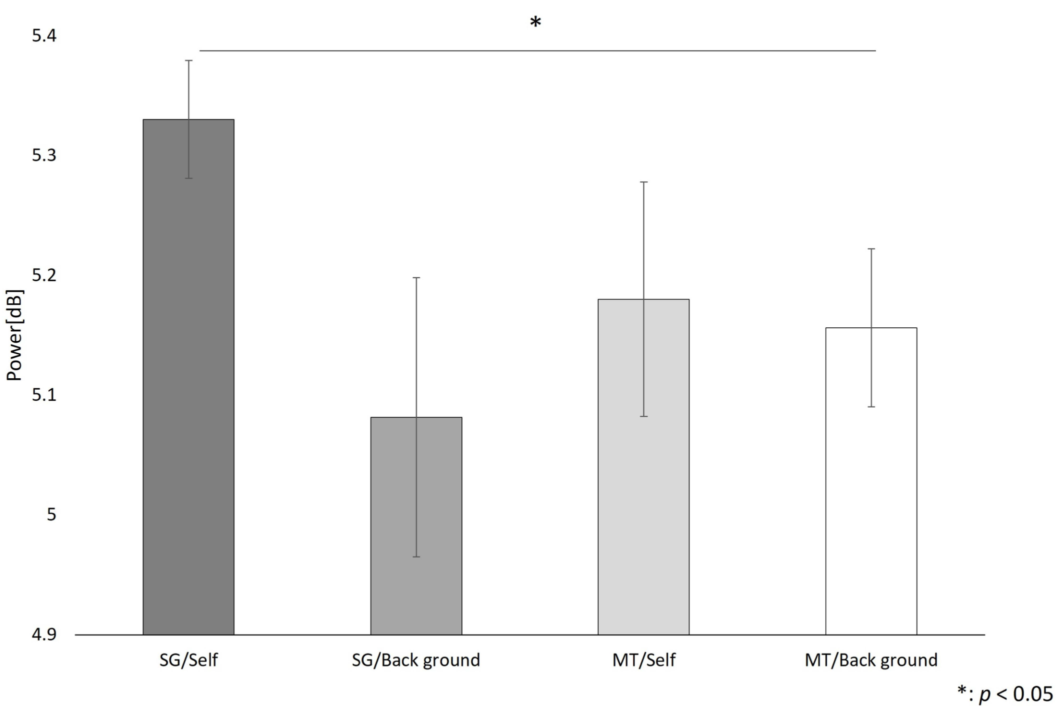

Figure 5. Activity of beta waves on EEG for each condition before start of swallowing (comparisons between combined conditions of presentation and stimulation). *Error bars indicate standard deviations.

The effect on beta-alpha ratio before start of swallowing was significant ($F(3, 39) = 9.401$, $p < 0.001$, *partial* $\eta^2 = 0.420$). Multiple comparison tests revealed significant differences between SG-Self and SG-Background ($t(13) = 3.242$, $p =$

0.039, $d = 1.321$), and between SG-Self and MT-Background ($t(13) = 5.181$, $p = 0.001$, $d = 1.652$). There were no significant differences between SG-Self and MT-Self ($t(13) = 2.716$, $p = 0.108$, $d = 1.140$), between SG-Background and MT-Self ($t(13) = −1.571$, $p = 0.840$, $d = −0.469$), between SG-Background and MT-Background ($t(13) = 0.544$, $p = 1.000$, $d = 0.127$), or between MT-Self and MT-Background ($t(13) = 2.270$, $p = 0.246$, $d = 0.706$) (**Figure 6**).

EEG after the start of swallowing

The results of the one-way ANOVA for the combinations of the presentation and stimulation conditions are as follows: The effect on alpha wave activity after start of swallowing was significant ($F(3, 39) = 5.843$, $p = 0.006$, partial $\eta^2 = 0.310$). ANOVA showed that there were significant differences between SG-Self and SG-Background ($t(13) = −3.971$, $p = 0.010$, $d = −0.816$), between SG-Self and MT-Background ($t(13) = −3.352$, $p = 0.031$, $d = −0.971$), and between MT-Self and MT-Background ($t(13) = −3.207$, $p = 0.041$, $d = −0.774$), while there were no significant differences between SG-Self and MT-Self ($t(13) = −0.425$, $p = 1.000$, $d = −0.144$), between SG-Background and MT-Self ($t(13) = 1.925$, $p = 1.000$, $d = 0.629$), or between SG-Background and MT-Background ($t(13) = −0.760$, $p = 1.000$, $d = −0.145$) (**Figure 7**).

The effect on beta wave activity after start of swallowing was significant ($F(3, 39) = 6.267$, $p = 0.007$, *partial* $\eta^2 = 0.325$). Multiple comparison tests revealed significant differences between SG-Self and SG-Background ($t(13) = 3.176$, $p = 0.044$, $d = 0.477$), between SG-Self and MT-Background ($t(13) = 4.056$, $p = 0.008$, $d = 1.094$), and between MT-Self and MT-Background ($t(13) = 3.587$, $p = 0.020$, $d = 0.697$), while there were no significant differences between SG-Self

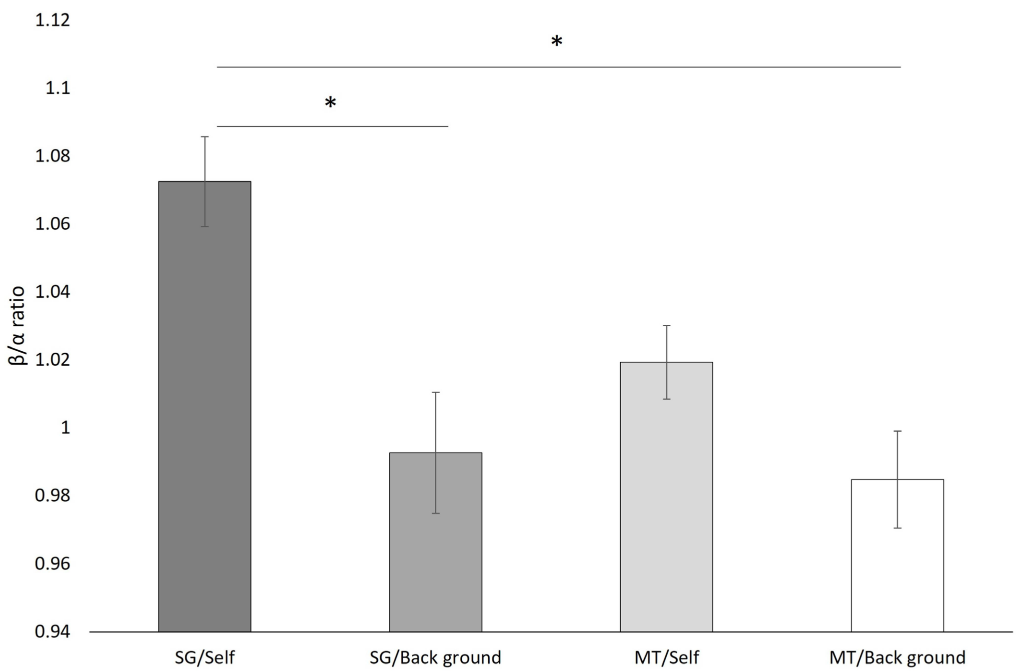

Figure 6. EEG beta-alpha ratio for each condition before start of swallowing (comparisons between combined conditions of presentation and stimulation). *Error bars indicate standard deviations.

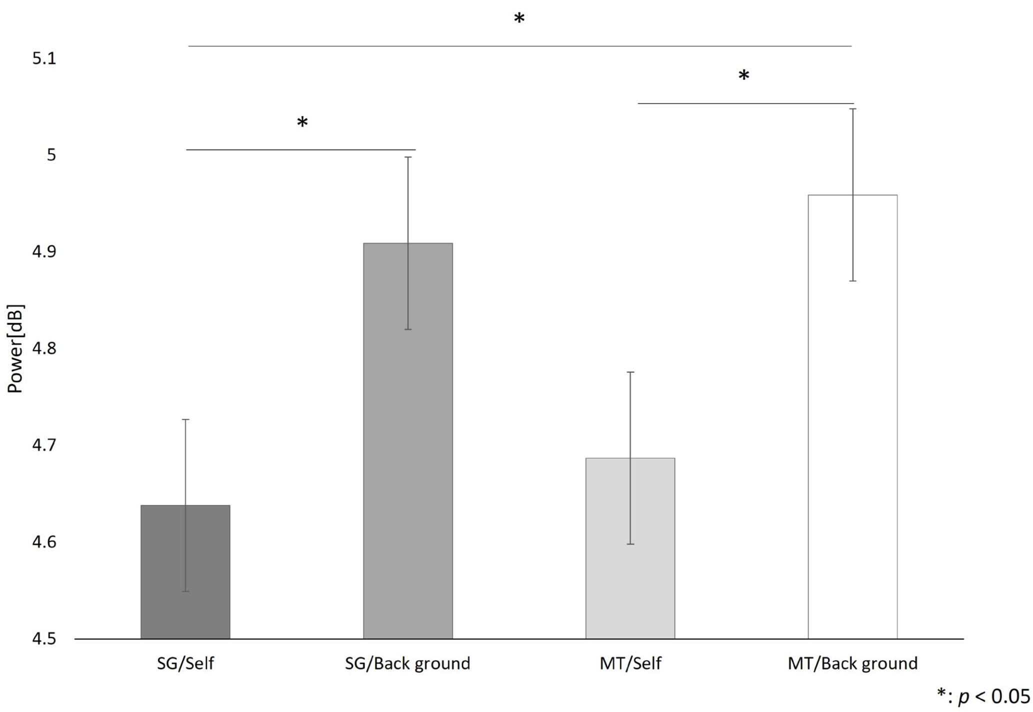

Figure 7. Activity of alpha waves on EEG for each condition after start of swallowing. *Error bars indicate standard deviations.

and MT-Self ($t(13) = 1.100$, $p = 1.000$, $d = 0.345$), between SG-Background and MT-Self ($t(13) = -0.368$, $p = 1.000$, $d = -0.099$), or between SG-Background and MT-Background ($t(13) = 2.417$, $p = 0.186$, $d = 0.655$) (**Figure 8**).

The effect on beta-alpha ratio after start of swallowing was significant ($F(3, 39) = 11.306$, $p < 0.001$, partial $\eta^2 = 0.465$). Multiple comparison tests revealed significant differences between SG-Self and SG-Background ($t(13) = 4.791$, $p = 0.002$, $d = 1.402$), between SG-Self and MT-Background ($t(13) = 4.239$, $p = 0.006$, $d = 1.864$), and between MT-Self and MT-Background ($t(13) = 5.141$, $p = 0.001$, $d = 1.491$), while there were no significant differences between SG-Self and MT-Self ($t(13) = 1.134$, $p = 1.000$, $d = 0.530$), between SG-Background and MT-Self ($t(13) = -2.219$, $p = 0.270$, $d = -0.926$), and between SG-Background and MT-Background ($t(13) = 2.377$, $p = 0.204$, $d = 0.818$) (**Figure 9**).

4. Discussion

The EMG results revealed significant differences between SG-Self and SG-Back-ground, between SG-Self and MT-Background, and between MT-Self and MT-Background. These results suggest that the stimuli may have a greater influence on the muscle activity of the suprahyoid muscle group during swallowing than the devices used to present the stimuli, such as smart glasses and a monitor. Since there was no significant difference between the SG-Self and MT-Self conditions, the effect of the presentation condition may be small. Reynaud *et al.* reported an experiment in which rhesus monkeys performed a simple task and found that the presence of another individual beside them improved their

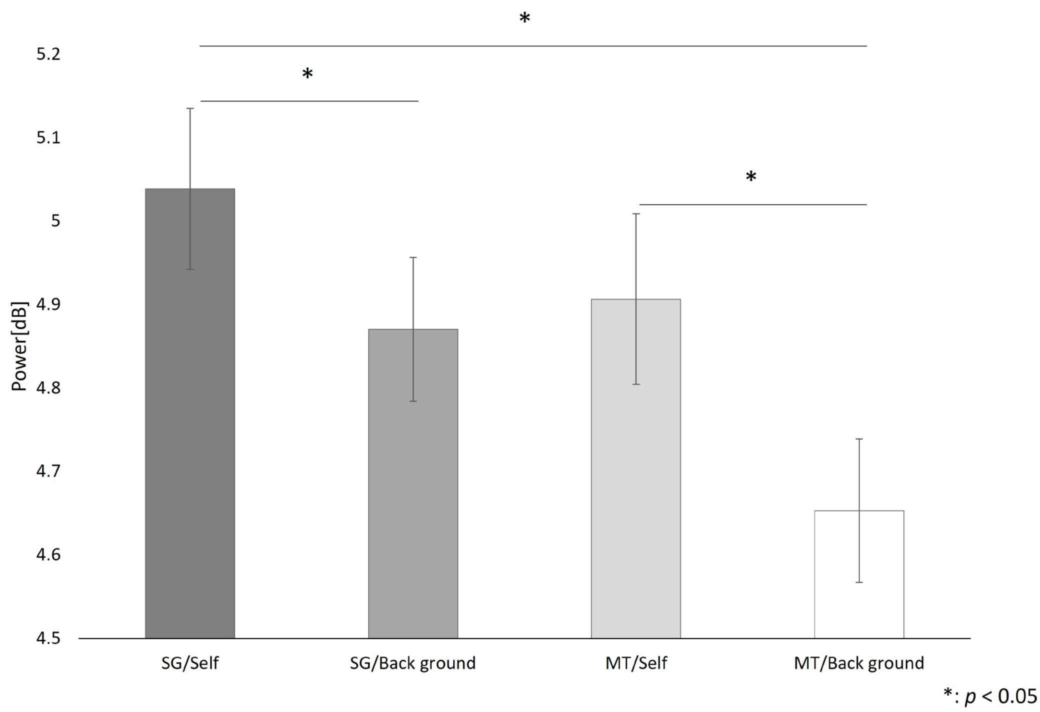

Figure 8. Activity of beta waves on EEG for each condition after start of swallowing. *Error bars indicate standard deviations.

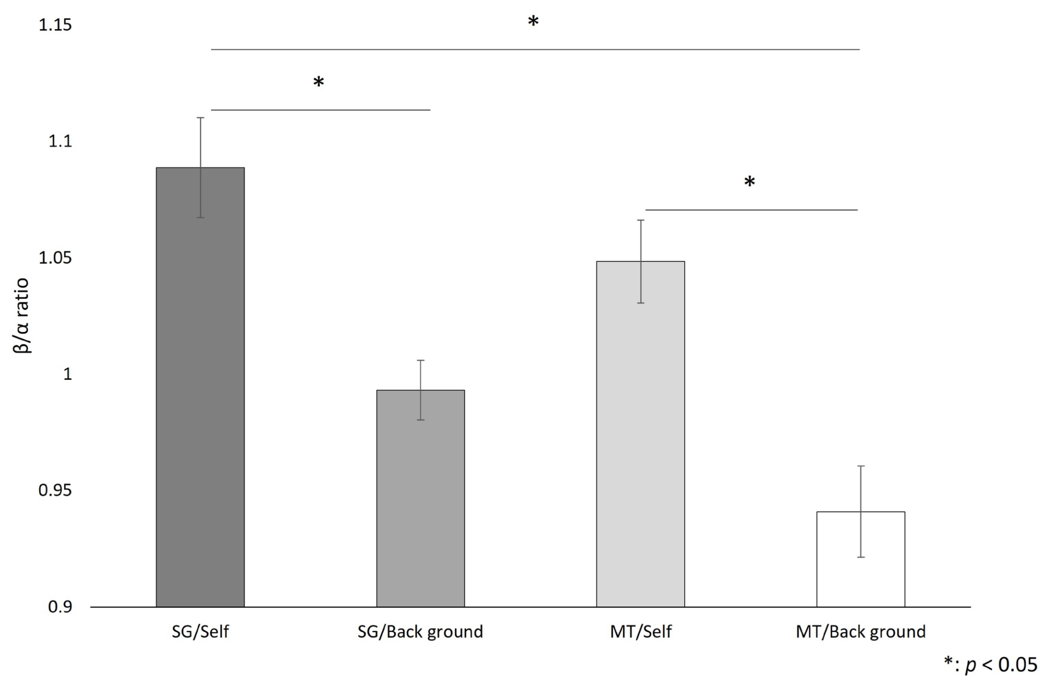

Figure 9. EEG beta-alpha ratio after start of swallowing. *Error bars indicate standard deviations.

performance [17]. Gates reported that the presence of an observer improved task performance [18]. These findings suggest that the presence of other individuals, including humans, may influence muscle activity.

Before the start of swallowing, there was a significant difference between

SG-Self and MT-Background for both alpha and beta waves on EEG. These results suggest that the effect of the presentational device is minimal. In contrast, in the comparison between the condition in which smart glasses were used to project the self-image and the condition in which a monitor was used to project it, small to moderate effect sizes were observed in both the alpha and beta bands, suggesting that the presentation condition may affect EEG before the start of swallowing. In addition, SG-Self had significantly lower alpha wave activity and higher beta wave activity than MT-Background. The alpha wave is attenuated during gaze [19], which suggests that the smart glasses allowed the participants to gaze at the images more closely than the monitor. Further, the self-image was more likely to attract attention than the background image, which may explain the significant attenuation of the alpha wave.

The beta-alpha ratio was higher in the SG-Self condition than in the SG-Background and MT-Background conditions. The beta-alpha ratio is considered a useful measure of the state of human mental activity [20] [21]. The alpha wave is known to be active when resting with the eyes closed or when trying to not think, when possible, while the beta wave is active during mental activity such as thinking [22]. These considerations suggest that when the self-image was projected on smart glasses, mental activity increased and the relative beta wave activity increased. However, when the self-image was projected on the monitor, there was no significant difference in the beta-alpha ratio compared to the other conditions. This result suggests that the effect of the self-image may change depending on the device used for projection. In addition, the act of paying attention and gazing is known to attenuate the alpha wave [19], which may explain the reduced attention to the image on the monitor compared to the smart glasses.

After the start of swallowing, the alpha wave was significantly lower in SG-Self than in SG-Background and MT-Background, and lower in MT-Self than in MT-Background, while the beta wave was significantly higher in SG-Self than in SG-background and MT-background, and higher in MT-Self than in MT-Back-ground. These results suggest that, regardless of the presentation condition, the presentation of a self-image may have affected EEG after the start of swallowing. Alpha wave attenuation has been observed under social facilitation in which two people worked together [23] and when swallowing while distracted [24], and a beta wave increase was observed when two people worked together [23]. Furthermore, Stancák *et al.* reported that the beta wave increased after the start of exercise [25]. In the present study, the increase of the beta wave when presented with a self-image may reflect the effect of social facilitation and brain activity after the start of exercise. In the present experiment, the EEG electrodes were placed on the frontal plane (near Fpz in the 10 - 20 system), which reflects the activity of the frontal lobe. Liu *et al.* reported that alpha wave attenuation and beta wave amplification were observed in the frontal lobe in two-person tasks compared to single-person tasks [23]. Alpha wave attenuation and beta wave amplification observed in the present experiment may indicate the effect of social facilitation. In the case of self-image projection using smart glasses and a monitor, a small effect size was observed in the beta wave, which points to the possibility that the difference in the presentation condition affected brain activity.

The beta-alpha ratio was significantly higher in the SG-Self condition than in the SG-Background and MT-Background conditions, and higher in the MT-Self condition than in the MT-Background condition. These results suggest that, regardless of the presentation condition, the beta wave was relatively higher when a self-image was presented. The beta-alpha ratio is considered an index of mental activity [20] [21], and the presentation of a self-image, as was the case in before the start of swallowing, contributed to the relative increase in the beta wave. In the SG-Self condition, as with the EEG before the start of swallowing, the beta wave displayed a relative increase compared to the SG-Background and MT-Background conditions, suggesting that the increase in mental activity before the start of swallowing continued, even after swallowing. In the EEG after the start of swallowing, the beta wave demonstrated a relative increase in the MT-Self condition compared to the MT-Background condition, which suggests that the additional increase in beta wave activity after the start of exercise [24] led to the increase in the beta-alpha ratio.

The smart glasses used in this study had transparent displays that projected images onto the surrounding environment, and the lack of clarity of the images compared to a monitor may have prevented the effects of social facilitation from being fully realized, which may partially explain the lack of significant difference in the EMG or EEG in this study. However, comparisons between the two different presentation conditions revealed a medium effect size in the EEG before and after the start of swallowing, suggesting that smart glasses may have influenced brain activity. In the case of projecting the self-image on the smart glasses, the image could be viewed regardless of posture or movement, which may have allowed our participants to perceive human presence more easily. However, since there was no significant difference in the EMG or EEG, we cannot conclude that the smart glasses facilitated the presentational effect of self-images. In the future, it is necessary to consider the effects of the projection environment and the presented image.

The present findings suggest that the presentation of self-images influences muscle and brain activity during swallowing. In addition, the presentation of images using smart glasses may influence the presentational effect of self-images, but further research is needed to verify this observation by re-examining the related factors.

5. Conclusion

We investigated the effects of HMD as a means of presenting self-images during ingestion of Diet modification for dysphagia. The results of the experiment suggest that self-images influence muscle and brain activity during swallowing, regardless of the presentation conditions of the HMD or monitor.

Acknowledgements

We thank the students of the Fukui Health Science University for their cooperation as examinees in this experiment. We would like to thank Editage (https://www.editage.com/) for English language editing.

Conflicts of Interest

The authors declare no conflicts of interest associated with this manuscript.

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