Flickering exercise video produces mirror neuron system (MNS) activation and steady state visually evoked potentials (SSVEPs)

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Abstract The action of observing can be used as an effective rehabilitation paradigm, because it activates the mirror neuron system. However, it is difficult to fully use this paradigm because it is difficult to get patients to engage in watching video clips of exercise. In this study, we proposed a steady state visually evoked potential (SSVEP) based paradigm that could be used in a Brain Computer Interface, and examined its feasibility by investigating whether flickering video could activate the mirror neuron system and evoke SSVEPs at the same time. Twenty subjects were recruited and asked to watch the flickering videos at a rate of 20 Hz of upper limb motion and visual white noise, while an EEG signal was recorded. The mu rhythm (8–13 Hz) suppression and the SSVEP (19–21 Hz) evocation were analyzed from recorded EEG. The results showed that SSVEPs, evoked by the flickering stimulus, was observed in both conditions on O1 and O2, but the mu rhythm suppression on C3 and C4 was observed only in the exercise video condition. These results could signify that the flickering video is applicable for the BCI rehabilitation game, activating the mirror neuron system at the same time.

Keywords Mirror neuron system (MNS) · Action observation training · Steady state visually evoked potential (SSVEP) · Brain computer interface (BCI) · Rehabilitation · Stroke

1 Introduction

The principle of brain plasticity, which serves as a therapeutic basis for the rehabilitation of stroke patients, is the phenomenon whereby brain neurons are structurally changed and reorganized by external stimuli and experiential learning. The reorganization of motor function after a stroke depends on the substantial functional division of the cerebral cortex, which is not impaired. For the effective functioning of the brain, fast and intensive exercise training should be provided [1–3].

Although it is very important to perform rapid rehabilitation training at the early stage of onset, most patients suffer from severe nerve damage shortly after the onset of a stroke, leading to considerable difficulty in participating in training, due to the loss of motor ability. To overcome these limitations, a theory based on the activation of the mirror neuron system (MNS) has been used recently to introduce new rehabilitation methods.

The MNS is activated in response to observing one's own specific movements, or another's movements. The observation of an action can be expected to increase in function by the activation of the MNS [4]. It has been shown that brain reorganization can be achieved by means of motor imagery or observation of movements, and such experiences can have a positive impact on patient rehabilitation after a stroke [5, 6], and are particularly useful for the rehabilitation of stroke patients who have difficulty exercising, by facilitating the brain reorganization [7, 8].

The most important requirements for the activation of the MNS are: (1) stimuli to activate the MNS (video clips or virtual reality), and (2) to make the user observe the stimuli actively. There are a few studies on how to make the user actively engage in observing the stimuli, although

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many of the studies were conducted regarding the activation of the MNS [9, 10].

The Brain computer interface (BCI) technology could provide a good paradigm for a user to be attentively engaged in the contents that the computer provides. In BCI, one of the key components is to hook the user's current intention or perception by analyzing their EEG, so that a computer could perform what the user wants [11–13]. Steady state visually evoked potentials (SSVEPs) are brain responses that occur when a person observes flickering stimuli, and are one of the features that computers could recognize when a user observes a specific stimulus [14]. Using an SSVEP based BCI model, a computer could encourage users to focus on a specific task by making them respond properly, according to what they are watching.

Here we suggest that an integrated BCI paradigm, using SSVEP with flickering videos that activate the MNS, could provide a new tool for effective mirror therapy by attentively engaging the user into a BCI game while watching action video clips. Therefore, in this paper, we aim to investigate whether flickering video clips could activate the MNS and evoke SSVEPs at the same time.

2 Method

2.1 Subjects

Twenty healthy adults participated as volunteers in this study (IRB number: 40525-201612-HR-140), resulting in a final sample size of 17 subjects (seven males and ten females). The mean age was 22.45 years (± 2.31). One subject was left-handed and one subject was ambidextrous, based on a self-report measure. There was no reward for participating in the experiment.

2.2 Stimuli

Three flickering 3-s videos were used as stimuli (see Fig. 1): Stimulus 1: Right upper limb exercise video. This was a black and white video showing right elbow flexion–extension, occurring at a rate of approximately 0.67 Hz (two movements per trial). (2) Stimulus 2: Left upper limb exercise video. This was a flipped video of stimulus 1. (3) Stimulus 3: Visual intensity matched white noise video. This was produced by randomly rearranging pixels of the stimulus 1 video, and was presented as a baseline condition. All stimuli were flickered at a rate of 20 Hz and presented 40 times, to obtain enough clean EEG data for analysis (40 trials per stimulation). The stimuli were provided in a pseudorandomized order, and randomization was constrained so that a straight sequence of three trials from the same stimulation did not occur. In between

each trial, a rest image was randomly presented for 1.5, 2, or 2.5 s.

2.3 Procedure

All subjects were seated in a comfortable chair, and the experimental session started after the EEG cap had been placed, and all the procedures to take the EEG signal, including calibration and signal quality check, had been performed. Subjects were instructed to view a stimulus displayed at the center of an LCD screen, which was positioned approximately 50 cm away, with a resolution of 1920×1080 pixels, and a vertical refresh rate of 60 Hz. The experiment took about 10 min to complete, ensuring the subject experienced all 40 trials and resting states per stimulation.

2.4 EEG recordings and data analysis

EEG was collected from 19 electrodes, using a DSI-24 (wearable sensing, San Diego, USA). Data were sampled at a rate of 128 Hz. Artifact rejection was performed offline, and bandpass filtering was set to between 0.1 and 30 Hz. Signal processing was performed for each of the 120 trials. The first one-second of each trial was removed for rejection of visual evoked potential. The trials exceeding the threshold (100 μ V) were considered as noise-included trial, and were not included in the analysis. The short-time Fourier transform (STFT) analysis was conducted with a one second window size and 90% overlap so that the time interval for each STFT was 0.1 s. To analyze the activity of the mirror neuron system, mu power was extracted from C3 and C4 channels by calculating the average power between 8 and 13 Hz in each epoch and averaging them in time in each condition. The mu suppression was also calculated with the log ratio between mu power in the flickering video stimulus and mu power in the noise stimulus. The intensity of SSVEPs was extracted from the averaged power spectrum of O1 and O2 channels, between 19 and 21 Hz. The mu rhythm suppressions were statistically analyzed using one sample *t* test, and SSVEP evocations were analyzed using the independent two-sample *t*-test.

3 Results

3.1 Spectrum analysis

The spectrum analysis shows that the mu band suppression, after onset of the flickering video stimulus, was present, but there was no suppression in the noise condition. However, both conditions revealed SSVEP evocation after onset of the stimulus (Fig. 2).

Fig. 1 **a** Stimulation 1: *Right* elbow flexion/extension exercise video. **b** Stimulation 2: *Left* elbow flexion/extension exercise video. **c** Stimulation 3: Visual intensity matched white noise video. **d** Rest image

Fig. 2 Averaged power spectrum of all subjects in C3, C4, O1 and O2. The x-axis is the elapsed time after onset of the stimulus. A time value of 0 s means onset of the stimulus so the plots range from −1 to

3 s. The y-axis is the frequency value. The color means the power at that frequency and time

In detail, in flickering exercise video condition, the mu power (8–13 Hz) before stimulation was about $14.05 \mu\text{V}^2$, and it fell to about $11.3 \mu\text{V}^2$ after onset of stimulation in

C3 channel. The mu power in C4 channel was also decreased from 14.87 to $12.39 \mu\text{V}^2$. In contrast, the mu powers changes in noise video condition were not observed

between before and after stimulation. In C3 channel, the mu power was slightly decreased from 14.48 to 14.12 μV^2 , and C4 channel showed little mu power decrease from 14.82 to 13.76 μV^2 .

Regarding the SSVEP power (19–21 Hz) before and after stimulation, the power in O1 was about 4.59 μV^2 before the simulation, then it was risen to about 13.66 μV^2 after stimulation in flickering exercise video condition and the power in O2 was also increased from 4.41 to 11.33 μV^2 . Similarly, the noise video condition made the similar SSVEP powers change to those of flickering exercise video condition, which were increased from 4.46 to 15.73 μV^2 in O1 channel, and from 3.89 to 10.79 μV^2 in O2 channel.

3.2 Mu suppression

The results show that the mu rhythm suppression was superior in the flickering exercise video condition in the C3 and C4 channels ($t(16) = -2.538$, $p < 0.011$ and $t(16) = -2.947$, $p < 0.005$, respectively) (Fig. 3). The mu suppression, video to noise log ratio, in C3 channel was -0.0824 and the ratio in C4 channel was -0.0818 . The minus value represents the amount of mu rhythm suppression, because the values were calculated with log ratio between the flickering exercise video stimuli and the noise stimuli.

3.3 SSVEP power

In the comparison between the video condition and noise condition, the SSVEP mean powers of flickering exercise

Fig. 3 Mu suppression ratio. Bars represent the mean log ratio of power in the mu frequency (8–13 Hz) in C3 and C4 channels during observation flickering exercise video stimulation conditions and noise video stimulation conditions. Error bars represent the standard error of the mean. A mean log ratio greater than zero indicates mu enhancement, and a mean log ratio less than zero indicates mu suppression. * and ** represent a significant value of $p < 0.05$ and $p < 0.01$ respectively

video condition were 14.437 (± 3.43) and 11.947 (± 1.98) μV^2 in O1 and O2 channels while the powers of noise condition were 17.708 (± 5.53) and 11.477 (± 1.84) μV^2 in O1 and O2 channels. The results show that the average band powers between 19 and 21 Hz, in each condition, were not significantly different in either the O1 or O2 channel (O1 $t(16) = -1.343$, $p < 0.198$; O2 $t(16) = 0.243$, $p < 0.811$) (Fig. 4).

4 Discussion

Although there have been many studies on exercise observation training, there have been few studies on how to actively view the stimulation, which is an important factor in exercise observation training. This study proposed a new stimulus to observe the stimulation while activating the MNS by combining the SSVEP paradigm, which is usually utilized in BCI technology, allowing the user to watch the stimulation actively. As the first step, we examined whether a flickering video could activate the MNS and evoke SSVEPs at the same time.

The mu rhythm suppression on C3 and C4 electrodes was investigated in order to examine whether the MNS was activated [15–17]. Analysis of the MNS activity showed that the flickering video stimulus suppressed the mu rhythm, while the base stimulation did not suppress it on either of the C3 or C4 electrodes. This means that the MNS can be activated even if the flickering video is provided as a stimulus. At the same time, we analyzed whether SSVEPs appeared in response to the stimulation. When the proposed stimulus was observed, it was confirmed that the SSVEP signal was expressed in both O1 and O2 electrodes, and there was no statistically significant difference between the two groups. This means that the proposed flickering

Fig. 4 SSVEP powers. Bars represent the average of STFT powers in the SSVEP frequency (19–21 Hz) in O1 and O2 channels in flickering exercise stimulations and noise conditions. Error bars represent the standard error of the mean. There was no significant difference in SSVEP mean power between exercise stimulations condition and noise condition

video stimulus can evoke SSVEPs without any reduction, compared to that of the baseline stimulus. These results confirm that flickering video can be fully utilized as a BCI technique.

However, there are several points to be considered in further studies. In this study, we only examined whether the flickering video with 20 Hz flickering could activate the MNS and evoke SSVEPs, but we did not investigate how other flickering frequencies could influence the results. Video clips are flickered at over 60 Hz, which we are not able to recognize. Therefore, we could theoretically obtain 60 Hz SSVEPs, and the activation of the MNS, meaning that playing a video would produce the mirror neuron activation and SSVEPs. However, in order to provide at least 60 Hz stimulus, the monitor's refresh rate should be greater than 120 Hz, making it difficult to implement practically. In addition, the power-line noise, with a frequency of 60 Hz makes it difficult. However, it is worthwhile investigating the optimum flickering frequency required to produce the MNS and SSVEPs, and to minimize any discomfort.

In addition, there would be expected to have a significant difference in mu suppression between C3 and C4 depending on either the left or right upper limb movements in the video [18], but we did not have any difference in the comparison between them. These results may be due to ambiguity in perceiving whether the limb in the exercise video is right or left. It is expected that the difference in mu power between C3 and C4 channels will be more prominently by presenting the exercise video having obviously recognizable whether the upper limb is left or right.

Moreover, users, for example patients with stroke, could activate the SSVEPs by looking at the background which turns white and black rather than the flickered upper limb movements in order to play the BCI game. It would lessen the efficiency in rehabilitation training for the patients with stroke because patients could play the BCI game without looking at motion at all. In order to overcome this possible problem, making the background of the flickering video transparent would be helpful to make users look at the flickered arm only.

In this study, we validated a flickering video paradigm that could activate the MNS and evoke SSVEPs at the same time, which indicates that it could be effectively used in motor observation training when combined with an SSVEP based BCI game technique. This rehabilitation paradigm, combined with a BCI game with flickering video, would encourage patients who have difficulty in voluntary movements and need motor observation training to participant more actively in the training, thereby helping with their recovery. In the BCI system perspective, combining SSVEPs and the Mu rhythm suppression would be help to increase classification accuracy. The flickering video

paradigm for motor observation training would be synergistic when applied with other rehabilitation strategies, such as Virtual Reality and Functional Electrical Stimulation.

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