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Effects of Jaw Clench Actions on Steady-State Visual Evoked Potential Detection at Some Typical Frequencies

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Abstract— **More and more hybrid brain-computer interfaces (BCI) supplement traditional single-modality BCI in practical applications. Combinations based on steady-state visual evoked potential (SSVEP) and electromyography (EMG) are the widely used hybrid BCIs. The EMG of jaw clench is commonly used together with SSVEP. This article explored the interference with SSVEP from occipital electrodes by the jaw clench-related EMG so that SSVEP with specific frequency can be identified even during occlusal movements. The experiment was divided into three sets base on the jaw clench patterns (no clenches, chew, and long clench). In each set, the subjects used the same visual stimuli, which were realized by the three flashing targets at different frequencies (6.2Hz, 9.8Hz, and 14.6Hz). After collecting the SSVEP at 4 sites in the occipital region, the SSVEP response spectrum of each stimulus was observed under the three jaw clench patterns. Then, the SSVEP signal was identified by the canonical correlation analysis method for accuracy statistics. Spectrum responses showed that the interference of the jaw clench EMG on SSVEP could be avoided when the stimulation frequency is lower than 20Hz. SSVEP could be identified based on the frequency domain characteristics of these signals. During steady-state visual stimulation with jaw clenches, the recognition rate of SSVEP was still high (no clenches: 100.0%, chew: 94.7%, and long clench: 100.0%). Through reasonable frequency selecting and signal processing, the influence of the jaw clench movement on the SSVEP could be reduced and a high recognition accuracy could be achieved, even the jaw clench actions and the SSVEP stimulation occur simultaneously.**

I. INTRODUCTION

In recent years, some researchers have proposed hybrid brain-computer interfaces (h-BCI) to solve some shortcomings in the field of BCI to improve the final accuracy of the system and increase the number of controllable targets [1]. For the usage of EEG-based BCI, one of the methods is to combine one type of EEG with another one. For example, some researchers combined steady-state visual evoked potential (SSVEP) with P300, SSVEP with event-related desynchronization potential, and P300 with motor imagery (MI) [2-4]. The other way is to combine EEG signals with other physiological signals, including electrocardiogram (ECG), electrooculography (EOG), and electromyogram (EMG) [5-7].

Among all the above h-BCIs, SSVEP is a widely used method for its high information transmission rate potential and no-repeat training (only first guide needed) [8,9]. Compared with ECG and EOG, EMG is an easy-generated and stable source. Therefore, the h-BCI of SSVEP and EMG is a proper combination of whether to increase the command outputs or take EMG as a confirmation and urgent stop command. Good performances in system accuracy and safety have been achieved in recent studies [10, 11].

However, in the previous combination of SSVEP and EMG, the EMG basically does not directly affect the signal of SSVEP. EMG signals in some studies were obtained from the arm or hand [10]. Even there are some from the head, the detection of EEG and EMG was performed non-simultaneously. In other words, when there were prescribed EMG actions, SSVEP was not detected [11]. Therefore, when the stimulation of both EMG of the head and SSVEP occur at the same time, the influence of the EMG on the SSVEP has not been discussed.

In addition, among all the head above movements such as raising eyebrows, raising auricular, making expressions, and conducting mastication, jaw clenches can generate powerful action. Goncharova found that bites can generate a widespread electrical signal on the surface of head [12]. So the jaw clench action could be used as an EMG source to combine with SSVEP.

Therefore, this paper attempts to clarify the jaw clenches' interference with the SSVEP and the SSVEP classification under jaw clenches. If the proper SSVEP stimulate frequency could avoid the interference of jaw clench actions, jaw clenches along with SSVEP could increase the BCI outputs. The study could provide a reference for using SSVEP and jaw clenches' EMG meanwhile.

II. METHODS

A. Participants

Ten healthy volunteers (24.5±1.7 years) with corrected or normal vision, no facial nerves, and muscle diseases participated in the experiment. Beihang University Ethics Committee approved the experimental procedures and all subjects gave written informed consent.

B. Data Acquisition

The EEG signals were recorded at 1k Hz in a quiet room using NeuroScan acquisition system (SynAmps2, US). We took four electrodes (POz, O1, Oz, and O2 with international

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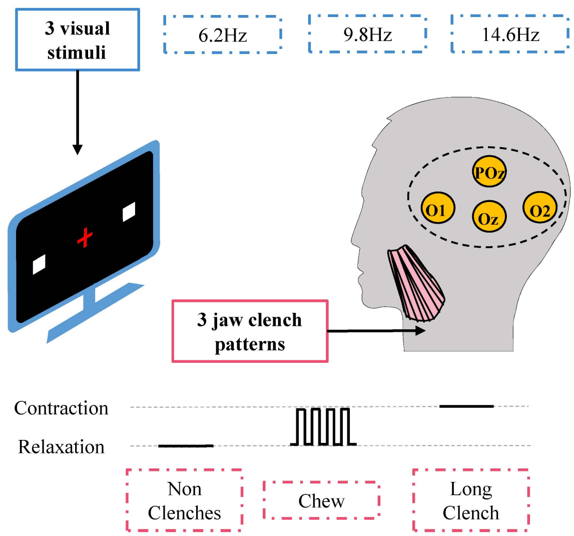

Figure 1. Experiment set-up.

10-20 system) as representative occipital electrodes. The electrode impedances were kept below 10kΩ during recording.

The visual stimuli for SSVEP were presented on an LCD monitor (24-inch, 16:9, resolution 1920×1080 pixels, refresh rate 60Hz, Acer). The stimuli were implemented by Psychophysics Toolbox Version 3 (PTB-3) in MATLAB (2013b). It is about 70cm between the screen and the subject's eyes. During the experiment, the subjects were seated in a comfortable chair and asked to be body motionless.

C. *Experimental Task*

Depending on the jaw clench pattern, three sets of tasks were carried out in the experiment. In the first set, there were only visual stimuli, but no jaw clenches. Jaw remained relaxed while the subject stared at the flashing target. In the second set, regular chewing activity (4 to 5 continuous short clenches, each last for 0.2-1 seconds) was performed while the subject stared at visual stimuli. In the third set, visual stimuli staring task and prescribed jaw clench (keep clenching while the stimuli targets flashing) were performed. The detailed experimental explanation is shown in Fig. 1.

In each set, 15 subsequences were included (3 frequency*5 times). Each subsequence consisted of 3 phases: 1) Phase Ⅰ (0.5s): A red "+" appeared at the position of the target block, prompting the upcoming flashing target to be stared; 2) Phase Ⅱ (6s): The red "+" disappeared, specified masseter action was done while gazing at the target block. 3) Phase Ⅲ (0.5s): The screen turned black, indicating the subject to have a short break. After completed one set, the subject had a 3-minute intermission till the next set.

We adopted a widely used steady-state visual stimulus here – the sinusoidally modulated method [13]. The suitable range of stimulation frequency was 6-15 Hz from early studies. Three typical frequencies were adopted at 6.2Hz, 9.8Hz, and 14.6Hz. A total of three square stimuli were presented on the LCD (black background). Each square stimuli corresponded to a modulation frequency.

D. *Signal Processing of SSVEP*

In order to get the efficacious EEG and jaw clench segments, the EEG data were cut from 6s length to 4s (0.2s-4.2s) before signal processing. All the collected signals were processed by a 50Hz notch filter to eliminate the power-line interference to obtain the notched fusion signal.

The SSVEP data were filtered using a band-pass filter ([3-40] Hz) first to remove noise. Then canonical correlation analysis (CCA) is applied to classify the EEG data [14]. The reference signals were composed of sinusoidal pairs at the same frequency of the stimulus and its second harmonics.

Before the recognition of SSVEP, the FFT spectrums of all jaw clench conditions were calculated to explore the jaw clenches on SSVEP responses. Then the accuracy of SSVEP was calculated by the definition: the number of correct recognition/the total number of recognitions×100%.

III. RESULTS

A. *Frequency Spectrum*

Fig. 2 shows the average spectral distributions from one representative subject (in 12 subgraphs). Each subgraph shows three clench patterns (non-clenches, chew, and long clench) at one electrode and one stimulate frequency. The non-clench pattern is a solid black line, the chewing pattern is a dotted black line, and the long clench is a solid gray line .

When jaw clench occurs, the EMG component mainly distributes after 20Hz (in chew and long clench conditions). Compared with the non-clenches pattern, the amplitudes of chew and long clench are higher after 20Hz. Especially at 20-100Hz, there are significant peaks caused by jaw clench. The amplitude of the long clench is higher than the other two. The amplitude order before 10-20Hz is chew>long clench>non-clenches, while the order is long clench>chew>non-clenches after 10-20Hz.

In the non-clenches pattern, the SSVEP response show at the original stimulates frequency and its twice frequency. For example, there are peaks at 9.8Hz and 19.6Hz for the 9.8Hz stimulate.

The SSVEP responses show a slight difference when the jaw clench occurs. *1) First column subgraphs (stimulate frequency 6.2Hz):* When subjects perform chewing pattern and long clench, the clearest peaks appear at their twice frequency (12.4Hz). The peaks at 6.2Hz are lower than those at 12.4Hz. *2) The second column (stimulate frequency 9.8Hz)*: The most apparent spikes show at 9.8Hz in chew and long clench patterns. The peaks at 19.6Hz are all lower than those at 9.8Hz. *3) The third column (stimulate frequency 14.6Hz)*: The 14.6 Hz response is transparent while the twice one (29.2Hz) is merged into the EMG component in chew and long clench patterns.

After comparison, there is no significant difference in spectral distribution between four electrodes and ten subjects.

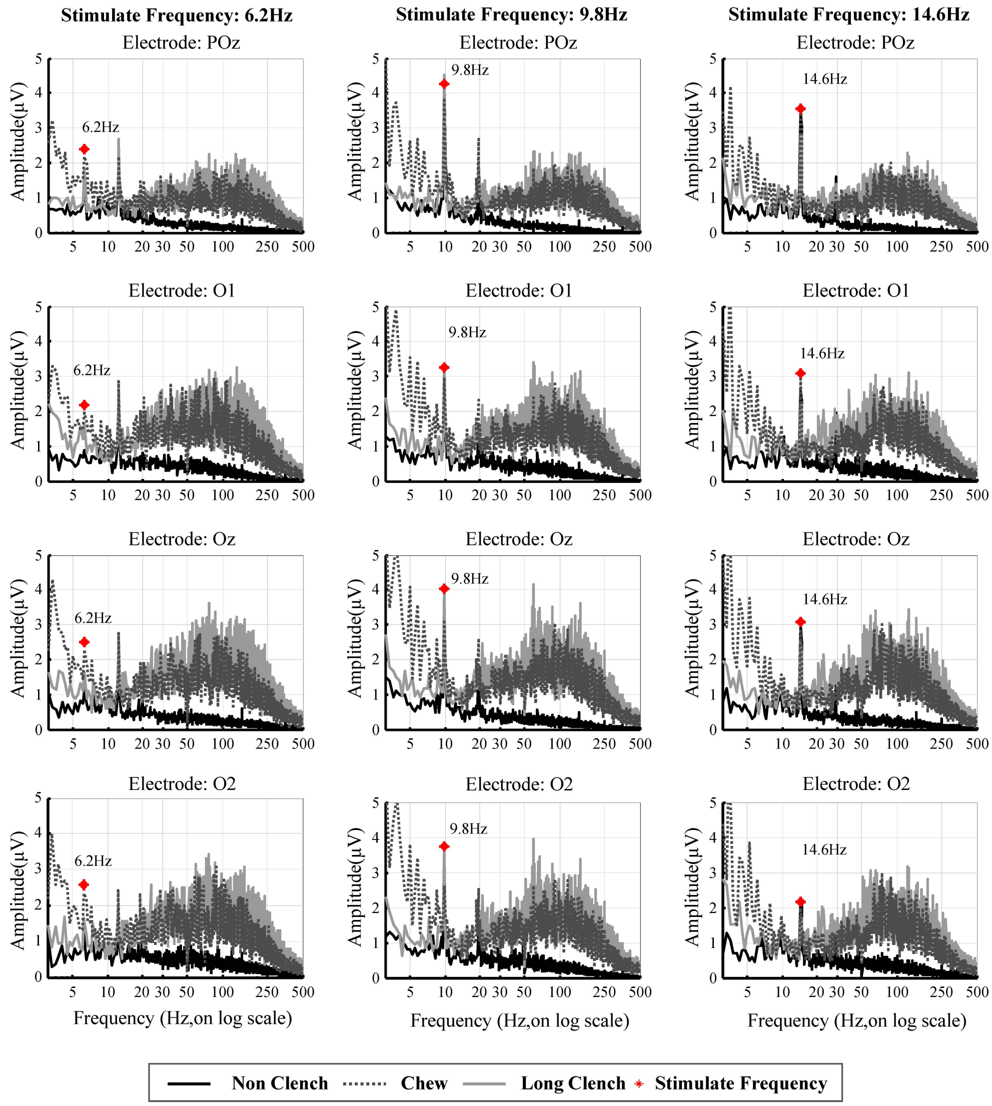

Figure 2. Average frequency spectrum on 4 electrodes at 3 frequencies from one representative subject.

B. SSVEP Recognition

TABLE I. ACCURACIES OF SSVEP RECOGNITION IN THREE CLENCH PATTERNS (%)

Subject	Clench Patterns		
	Non-clenches	*Chew*	*Long clench*
S1 (F 27 [a])	100.0% (15/15 [b])	93.3% (14/15)	100.0% (15/15)
S2 (F 23)	100.0% (15/15)	100.0% (15/15)	100.0% (15/15)
S3 (M 23)	100.0% (15/15)	100.0% (15/15)	100.0% (15/15)
S4 (F 22)	100.0% (15/15)	93.3% (14/15)	100.0% (15/15)
S5 (M 24)	100.0% (15/15)	86.7% (13/15)	100.0% (15/15)
S6 (M 23)	100.0% (15/15)	100.0% (15/15)	100.0% (15/15)
S7 (M 27)	100.0% (15/15)	93.3% (14/15)	100.0% (15/15)
S8 (M 24)	100.0% (15/15)	93.3% (14/15)	100.0% (15/15)
S9 (F 26)	100.0% (15/15)	100.0% (15/15)	100.0% (15/15)
S10 (F 26)	100.0% (15/15)	100.0% (15/15)	100.0% (15/15)
Average	**100.0% (150/150)**	**96.0% (144/150)**	**100.0% (150/150)**

a. gender and age in the parentheses.

b. the ratio in the parentheses means correct results/total subsequences.

The accuracies of SSVEP recognition under jaw clench-related muscle contractions and relaxation are shown in Table 1. The average classification of non-clenches and long clench is 100%, whereas the recognition of chewing is a bit lower at 96.0%.

IV. Discussion

In order to obtain clean evoked EEG, subjects were asked to be motionless in the early SSVEP experiments. The jaw clench occlusion action is strictly limited when collecting EEG. Because the jaw clench-related EMG can be detected throughout the scalp and face, interfering with the EEG acquisition, some researchers choose EMG of hand and arm [10, 12]. Therefore, as a supplement to the influence of head and face electromyography on the recognition of SSVEP, this study described the partial interference of jaw clench-related EMG on SSVEP.

Typically, the effect of EMG component on the EEG signal in the time domain is apparent. Nevertheless, after the fusion signal was processed via the Fourier transform, the

SSVEP features were preserved in the frequency domain. The previous study has shown that the leading energy of the EMG signal generated by jaw clench action concentrated at 0-200 Hz [12]. The results in the frequency domain above showed that the evoked EEG signal at 6.2, 9.8, and 14.6 Hz was almost free from the jaw clench-related EMG. Thus, it did not significantly affect the extraction of SSVEP features and the recognition of SSVEP.

From the statistics in Table 1, we found that the average recognition accuracy of SSVEP is 98.7%. The accuracy of non-clenches and long clench is 100%; chew, 96.0%. The jaw clench action has a slight effect on the recognition rate of SSVEP with the conventional CCA algorithm. Compared with the SSVEP classification in similar works of literature (88.3% [10], 93% [11], 96% [15]), it achieves a relatively higher level. After detailed observation of the six error recognition segments in the chew pattern, we found that the continuous clenches (chewing) activity may increase the abnormal EMG contamination patterns. Three are the common “noise-like” pattern, which consists of irregular peaks and varying frequency waveforms [12]. The other three are attributed to the alpha rhythm-like pattern. It is a similar concept to the beta rhythm-like pattern reported by Goncharova et al. [12].

According to Fig. 2, due to jaw clenches, the myoelectric component significantly increased after 20Hz. Similarly, Goncharova described the EEG contamination of myoelectric signals produced by the temporalis muscle contractions. At the temporal sides, they showed the largest amplitude between 40-80Hz with a smaller peak around 20Hz, whereas the EEG signals were little affected in the posterior occipital [12]. Therefore, choosing the stimulate frequency under 20Hz could avoid the effect of jaw clench-related EMG.

From Fig. 2, the SSVEP response at 9.8Hz stimulus is the clearest and biggest one. But it had a low amplitude representation in the spectrum at lower frequency stimulation (6.2 Hz). It is a typical feature of SSVEP at the lower frequency that the second harmonics is more obvious. The reason may be that the subject felt its twice frequency stimulate (12.4 Hz) much more intensely and the SSVEP SNR between 10-13Hz is higher than that before 10Hz [13]. Fortunately, this feature did not affect the recognition at 6.2Hz. If a further researcher would like to avoid such a situation, the FFT spectrum suggests that choosing stimuli frequency around 9.8Hz could be a better choice.

Due to the amplitude of the masseter clench action is much greater than that of the EEG, the frequency of the SSVEP only affects the signal at certain frequency points. The frequency band of the EMG signal is very wide, so SSVEP has a little direct effect on the EMG signal. The potential impact may reflect in the distribution of attention and the execution of synchronized actions. However, the recognition of various jaw clench movements still needs further exploration.

Future work may focus on introducing more stimulation frequencies into the experiment for research. For instance, the stimulus frequency near and above 20Hz should also be validated. Besides, although some researches obtained over 40 frequency discriminations for SSVEP, its application together with jaw clench’s EMG should be validated. In summary, this study could provide a reference for using SSVEP and jaw clenches’ EMG simultaneously to increase the BCI outputs.

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