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Classifying Real and Imaginary Finger Press Tasks on a P300-Based Brain-Computer Interface

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Abstract—**Brain computer interfaces based on P300 and sensory-motor rhythms are widely studied and recent advances show some interest in the combination of the two. In this paper, typical P300 paradigm is modified by adding animation guide of the finger press as a stimulus and by using different response strategies (silent counting and actual/imaginary left or right index finger press following the animation). Both P300 potentials and sensory-motor rhythms are directly exploited and discussed. Classification results showed that even under very demanding conditions, which was, 200ms inter-stimulus interval of the P300 stimuli and actual/imaginary finger press once per 1.6s, the paradigm can evoke both P300 potentials and sensory-motor rhythms simultaneously. Actual finger press increased single trial P300 selection accuracy of different subjects by 5-29.5% compared with silent counting; imaginary finger press did not increase the P300 selection accuracy apparently for most subjects except the two who were very poor at counting task. This showed by using different interface design and adopting certain mental response strategies, the 'BCI illiteracy' may be cured. Also imaginary task had good performance of left versus right classification (with the best subject reached 81.1% of accuracy), which is an additional information that can be used to improve system performance.**

I. Introduction

Brain-computer interface(BCI) can help the disabled to communicate and interact with the outside world without normal pathways[1]. BCIs based on P300[2] and motor related rhythms modulation (for example, slow cortical potential[3,4], event-related (de-)synchronization[5,6]) are widely studied. P300 ERPs is a positive deflection of the electroencephalography(EEG) about 300ms after target stimulus. Usually subjects are asked to respond to the target stimulus overtly(e.g., press a button) or covertly (e.g., silent counting of target stimulus). The effects of button press on the P300 potential are well studied but results are rarely in agreement[7]. Whether it increase the P300 amplitude or not, results show that P300 topography in button-pressing tasks is confounded by motor potentials[8]. This is not good for the study of P300 topography and need a correction[8], but the melding of P300 and the motor-related rhythms offers a chance for BCIs to: 1.simultaneously extract two independent control signals, for example, in [9], The horizontal and vertical movements of the cursor were controlled by mu/beta rhythm and P300 potential respectively. 2.improve system performance by combining both features together[7]. It's known that different kinds of BCIs have both benefits and drawbacks. For P300 BCIs, due to the low signal-to-noise ratio, it's hard to classify single trial EEGs, and multiple trials are needed to make a selection, whether by averaging the time points to enhance the features[10] or adding the decision values of different trials[2]. Compared with time-locked P300 potentials, motor-related BCIs do not need repetitions, in [4], single trial classification (left versus right) of upcoming finger movements in a natural keyboard typing task can be done with very short response time(at an average speed of one key per 2.1 seconds) and high accuracy(>96%). 2.1 seconds is close to the duration of a single trial in a typical 8 target P300 paradigm with inter-stimulus interval(ISI) 200ms (200ms*8=1.6s). if the classification of left versus right hand in a button-pressing P300 paradigm can reach a similar accuracy, there must be ways to improve the single trial performance of the system, which is very encouraging. In [7], a different way was investigated, standard counting of target stimuli as well as the conduction of real and imaginary movements were tested using a modified four-directional P300-BCI. The results showed that the P300 versus No-P300 classification accuracy of real movement exceeded imaginary movement, while the latter exceeded standard counting. But it required large ISI(800ms) compared with standard P300 paradigm. Also it used four different movements to represent the four directions which would increased the complexity and when the task difficulty/complexity exceeded the attention resources of the subject the P300 became smaller[11]. Also In [7] the sensory-motor rhythms(SMRs) were not exploited directly.

In this paper, three different response strategies to the target stimuli was tested based on a 8 target P300 paradigm, silent counting of target stimuli, left or right finger press sync to target stimuli and imaginary left or right finger press sync to target stimuli. Compared with [7], there ISI decreased from 800ms to 200ms, the number of stimulus increased from 4 to

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8, the task(finger press) was much simple. The speed of finger press or imaginary finger press was once per 1.6s (200ms*8), which was very fast. To decrease the difficulty of the task, the animation of correspond finger press was presented to the subject, and the subject was told to simply follow the guide of the animation to fulfill the actual or imaginary finger press. Both the P300 and the SMRs were directly exploited, and the methods for combining of the two were discussed.

II. EXPERIMENT DESIGN

A. Subjects and Data Collection

A total of eight subjects(seven undergraduate students and one teacher) take participants in the experiment, including seven male and one female. Their ages are between 20 to 32. All of the subjects are right hand dominant, with no disease known to affect the EEG recording. They are all totally new to the experiments design, but some of them have the experience of the typical P300 paradigm[12] or left/right motion[13] imaginary experiments. They are well explained of the experiment and the mental strategies (for example, silent counting or kinesthetic motor imaginary[14]) they should take during the experiments. The EEG data were collected with a NeuroScan NumAmps system at a sampling rate of 250Hz. A total of fourteen electrodes(FZ, FCZ, CZ, CPZ, PZ, OZ, FC3, FC4, C3, C4, CP3, CP4, T3, T4) according to the 10/20 standard setup were used to record the EEG signals. All electrodes were referenced to the nose and grounded at the forehead (see our previous work[12]).

B. Experiment Design

Three experiments with different stimulus (Figure 1) and different response strategies are tested with eight subjects. The first is a typical P300 paradigm with eight stimulus as shown in the upper corner of Figure 1, with the background color changing from black to red, and last 100ms, which is called the stimulus on state, and the color changing back to black and last 100ms, which is called the stimulus off state. the subject sit quietly before the screen, and adjust his/her head position in a way that he/she can easily gazing at each of the eight hands without much eye movement. The experiment begins with the progress bar reaching the end (lasting 3s), followed by 20 trials (Figure 2, top). Every trial contains the following parts (Figure 2, middle): first a second of delay time, then a blue arrow appears and stays, point to the target the subject should focus on. The target is randomly chosen, but different from the last one. 3 seconds later, stimulus (as mentioned above) is presented with 10 rounds. In every round (Figure 2, bottom), each of the eight hands is randomly set to stimulus on and off states (100ms+100ms) by exactly one time. The subjects were told to follow the blue arrow. Whenever the arrow point to a new target, the subjects had 3 seconds (as mentioned above) to prepare for the incoming trial, this including adjust gaze direction, eye blinks, chews and etc... across the trial, the subject are told to silently count the number of flashes of the target hand.

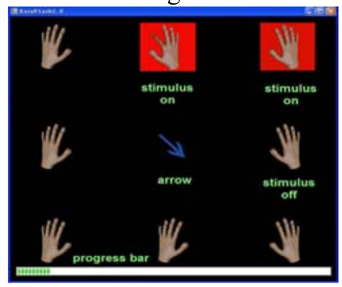

Figure 1. In expereiment one, the stimulus was color change while in experiment two and three, the stimulus was both color change and an animation of the index fingre pressing down.

The second experiment is almost the same with the first one, except that the stimulus is not only the color change, but also with the index of the virtual hand pressed down (Figure 1, top middle) for exactly 100ms and then return to stimulus off state. The subjects are told to put his/her hands on the keyboard, with left index finger on “F” key and right index finger on “J” key, as if he/she is typing on the keyboard. During the experiment, the subject has to follow the stimulus and make a actual press of the related key. On average, the subjects make a key press in one round, which is exactly 1.6s (Figure 2, bottom). The keyboard press information is recorded along with the EEG signals for next step analysis.

The third experiment has the same stimulus paradigm of experiment two, except that the subjects were told to just imagine the correspond index finger pressed down following the stimulus. Again, the subjects fulfilled such an imaginary in every 1.6s on average, which was very fast.

Progress bar	Trial 1	Trial 2	Trial 3	......	Trial 20	delay	Sesstion end
3000ms						1000ms	

delay	Arrow on	prepare	Stimulus presented
1000ms	Point to target	3000ms	10 rounds

Stimulus 1		Stimulus 2	Stimulus 3	......	Stimulus 8
100ms on	100ms off	Exp1:hand flash	Exp2:hand click	......	

Figure 2. Each session contains 20 trials and each trial contains 10 rounds. Stimulus are present with an ISI of 200ms. Before every trial an arrow will point to the hand the subject should focus on.

C. Data Processing

Both P300 and SMR were exploited with the same data. All data was used with no rejection of poor signals of any kind. For each session there was 200 (20trials per session and 10 repetitions per trial) single trials, including 1600(eight epochs for every single trial) epochs, 200 of which was target and the others non-target.

the P300 classification is as following. Single trial data (or the data of one round as described in previous section) is low pass filtered at 15Hz, followed by a minus of a two degree of polynomial fit of the signal. Then 800ms of data is epoched for every stimulus and all fourteen channel data is merged together, that is a 250*0.8*14 length of features. Then baseline correction is done by minus the sample mean, followed by a down sampling of 10Hz, by picking one sample out of ten. Thus the features passed to the final classifier is of length 280(250*0.8*14*/10). The remain task is to find out one target epoch out of eight epochs. Fisher’s linear discriminant (FLD) was known to have good performance and simple implementation for practical classification of P300 data [15]. Here we adopted the way of [15] for the detection P300 epochs. By assigning class labels of +1 and -1 to the target and non-target stimuli, respectively, a decision hyper-plane is defined by:

$$wf(x)+b=0 \tag{1}$$

The one with maximum output of decision value out of eight epochs tends to be the mostly likely of a target defined by the training data. To make decision across multiple trials (rounds), the decision values of single trial are normalized between (0, 1), and then summed over across trials according to the stimulus code. Four-fold cross validation was done to the data of each session, the selection accuracy for single trial, adjacent two trials, adjacent three trials…, all ten trials were all calculated.

The SMRs of each session is also analyzed. According to the experiment design, the subjects pressed (or imagine pressed) the right or left index finger sync to the target stimulus. To see if there was really motor-related features in the data, a frequency-temporal-spatial adaption method (see our previous work [13]) was adopt to analysis the data. This method searched the frequency and temporal grid to find the most discriminant frequency band and temporal region, then applied the common spatial pattern filterer, and finally used a FLD to classify the extracted features. It had been proved to be work well for both fast finger press task and continues motor imagery task [13]. For each experiment session, 200 finger press (or imagined finger press) epochs for left or right hand were extracted, which was 800ms long since the target stimulus on. Another 1400 epochs for non-target stimulus were also extracted. The classification accuracy of left versus right of the 200 epochs was calculated, as well as target versus non-target of the total 1600 epochs using the same method.

III. RESULTS AND DISCUSSIONS

The ground average of the P300 versus non-P300 epochs was plotted for all three experiments, as shown in Figure 3. Mostly finger press task had the highest P300 amplitude, and mental counting had the lowest P300 amplitude. This was not agree with the found of [7]. The reason may be: 1.the 200ms ISI in this study was much short than 800ms in [7], the subject had to concentrate much more to react in such a short time; 2. In this study, the animation of the finger press was shown to the subjects, which helped the concentration of the subjects and elicit higher P300 amplitude. Another point worth mentioning is that actual/imagined finger press had a short delay of the P300 peak then mental counting as in Figure 3. This may be also caused by the animation of the finger pressing down and then released shown to the subjects, because the subject not only noticed the color change of the stimulus, but also the finger pressing down and released. And according to the subjects' comments after the experiment, they tend to focus on the finger rather than the color change, although they were presented at the same time.

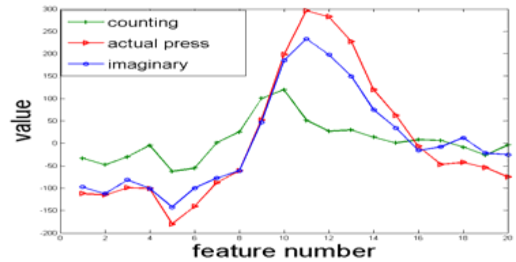

Figure 3. The ground average of P300 features of the three experiments at channel CZ. 20 features of each epoch (0.8s post stimuli) were extracted.

The accuracy of the P300 selection was shown in Figure 4. All subjects had the best performance in actual finger press task, by an amount of 5-29.5% (single trial) compared with mental counting, and all reached 100% after 5 repetitions. Remember that we didn't use the state of the art algorithms for classification nor did we utilize the electrodes by channel selection. The improvement is due to the response strategy(finger press) taken by the subject and the modification of the interface(adding animation guide of finger press). The subjects preferred the finger press task and the modified interface because they were much more concentrated on the task by what they were seeing and what they were doing, this can be seen from the amplitudes of the P300 features in Figure 3. One question remained: did the muscle artifacts caused by actual finger press improve the performance. The movement of calf extension of legs and hand-wrist extension last 0.8s did not effect P300 classification according to [7], so we believe muscle artifacts caused by finger press is not the reason of the high performance.

Imaginary task didn't increase the accuracy apparently except for two subjects who were relatively poor at counting task, with single trial accuracy of 37.5% and 59.27%, but much better at imaginary task, with accuracy of 51.87% and 76% respectively(Figure 4, middle and bottom). One subject can't reach 100% accuracy even after 10 repetitions at counting task, but this changed at imaginary task(finger 5, middle). The subjects can't use a BCI system for effective control were also called 'BCI illiteracy'. and here we see by changing the interface and adopting certain mental response strategies, the 'illiteracy' may be cured.

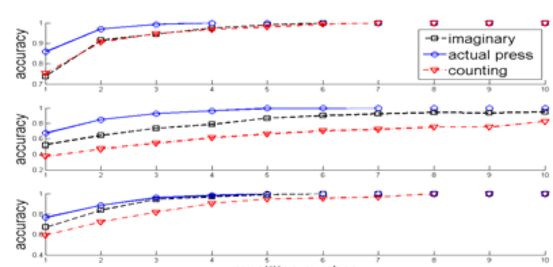

Figure 4. The P300 select accuracy of three subjects acroos different repetitions number. The performance of actual press exceeds the the performance of counting about 5 to 29.5%. And after 5 repetions the accuracy of actual presss selection reaches 100% for all subjects. Subjects poor at

counting task shows good performance at imaginary finger press task.

The accuracy for left versus right hand classification was shown in Figure 5. Actual press task had the accuracy of 61 to 70.5, just a litter above chance level, which was much lower than our previous work [13]. The reason may be two: 1, in [13], finger press was in a self-chosen order and timing, and the task was simple, while in this study, the finger press was guided by the target stimulus of a classical P300 task. 2. The experiment was set on typical P300 paradigm, and the presentation of stimulus was very fast, that was, the subject had to fulfill a finger press in every 1.6s on average. Although under a strictly P300 paradigm, the imaginary task reached 81.1% of accuracy with the one subject familiar with motor-imaginary task while other subjects above chance level. What was very strange was that in the mental counting experiment, the accuracy of left versus right hand classification was above chance level for every subject, about 55% to 73%. This may be caused by the eye gaze direction or other unknown reasons which worth investigate much more for it contains dicriminant information that may be used to improve the system performance. The accuracy of target versus non-target classification was about chance level, 50%. This can explained by the subjects' comments after the experiments: during the 10 repetitions of one target, they had to focus on the corresponding hand indicated by the arrow all the time. When imaginary a simple finger press sync to the target stimulus, the subjects can not immediately stop this kind of mental activity before the non-target stimulus followed by, so the data was polluted.

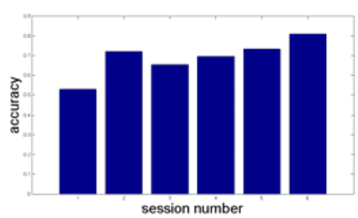

Figure 5. Left versus right hand epochs are classified, with the best subject reaching the accuracy of 81.1% for imaginary finger press in session 6. Session 1 and 2 are counting task, session 3 and 4 are imaginary task.

IV. Conclusions

In this paper, we modified the typical P300 paradigm by adding animation guide of the finger press as a stimulus and by using different response strategies (silent counting and imaginary left or right index finger press). We extracted both P300 and motor-related features of the same signal for classification, and found that although the presentation speed of stimulus was very fast (200ms ISI), the paradigm can evoke both P300 potentials and SMRs simultaneously. Actual finger press increased P300 selection accuracy by 5-29.5%; imaginary finger press didn't increase the P300 classification accuracy apparently except for the two who are very poor at counting task, which showed by using different interface design and adopting certain mental response strategies, it's possible to cure the so called 'BCI illiteracy'. Also imaginary task had good performance of left versus right classification (the best subject reached 81.1% of accuracy), which is an additional information that can used to improve system performance. Since a strict BCI does not need the normal pathways of peripheral nerves and muscles, such as finger press, later work is to focus on the hybrid features of the imaginary task sync to the P300 stimuli, and find ways to combine the features or the decision values to improve the performance of the system, especially the single trial classification accuracy.

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