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Improvement of mental tasks with relevant speech imagery for brain-computer interfaces

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ABSTRACT

Brain-computer interfaces (BCIs) based on electroencephalography (EEG) have been attracted enough attention by researchers. In order to determine whether silent reading can improve mental tasks for BCI systems, this paper proposed a two-step experiment: mental tasks with speech imagery and mental tasks without speech imagery. Reading Chinese characters in mind is set as speech imagery. Since Chinese characters are monosyllabic, it is very convenient to read them in mind with related mental tasks simultaneously. Ten Chinese subjects are trained by two steps in this experiment. Feature vectors of EEG signals are extracted and classified by common spatial patterns (CSP) and support vector machine (SVM), respectively. Compared with just mental tasks, the accuracies between two tasks have been significantly improved by appending speech imagery, and the average of accuracies of ten subjects is increased from 76.3% to 82.3%. During the imagery period, the temporal stability of EEG signals is evaluated by Cronbach's alpha coefficients. The steadiness of signals is different between mental tasks, and EEG signals are more stabilization with speech imagery. The stability of brain activity is conducive to the operation of BCIs.

1. Introduction

With the rapid development of computer science and biomedical technology, human bio-potential signals can be extracted to meet people's assisted living and entertainment. A new channel is provided by brain-computer interfaces (BCIs) to help patients with motor dysfunction [1], such as amyotrophic lateral sclerosis (ALS), stroke, spinal cord injury, and traumatic brain injury. Bypassing the peripheral nerve and muscle tissue, the channel of BCIs can directly control assistive technologies with various facilities. The quality and convenience of patients' life can be effectively promoted. There are some existing applications of BCIs for the disabled, e.g. movement within virtual reality environments [2], operation of computer cursors [3], virtual speller [4] and wheelchairs operation [5]. After experiencing the virtual reality system afforded by BCIs, not only the patients but also healthy people can enjoy the fun [6].

BCI systems can be divided into two categories: noninvasive and invasive. Though invasive BCIs can acquire signals with a higher signal to noise ratio, they still remain lots of technical difficulties and clinical risks. Noninvasive BCIs, especially based on electroencephalography (EEG), can provide multidimensional control with security and cheapness [7]. There are several brain activities to control EEG signals, e.g. event-related (de)synchronization (ERD/ERS) [8], mental arithmetic task [9], steady-state evoked potentials (SSEPs) [10], P300 evoked potentials [11], auditory imagery and spatial navigation imagery [12]. SSEPs and P300 are related to the BCIs based on visual and auditory. As higher communication speeds, they have become popular [13]. However, they must be operated with additional equipment to produce stimuli. It is not very convenient, especially for patients. Since higher information transfer rate (ITR) can be obtained by classifying single trial EEG, it has been attracted enough attention by researchers. ERD/ERS is calculated from single trial EEG signals, and both overt motor execution and motor imagery can induce ERD/ERS of sensory-motor rhythms. To the best of our knowledge, satisfactory classification accuracy and abundant application can be provided by the motor imagery-based BCIs [14], which have been advanced significantly in flight controls in recent years, like controlling virtual helicopter and physical quadcopter [15–17]. However, their maximum number of categories is limited to four-dimensional (right hand, left hand, tongue and foot) [18]. Besides these main methods, other mental tasks are also proposed [19], e.g. visualizing some words being written on a board, non-trivial multiplication and mentally rotating a 3D object. Novel BCI systems based on

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speech imagery are proposed too. Leuthardt had used electrocorticography (ECoG) speech network to control a BCI [20]. In their study, the letters of the alphabet, including OO, EE, AH and EH, were selected as the speech imagery. /a/ and /u/ were proposed by DaSalla as vowel speech imagery for an EEG-based BCI [21].

In addition to explore more of the experiment paradigms, it is a big challenge to produce reliable and consistent EEG signals when users operate BCI systems. The EEG signals are much related to users' mental states. Anxiety, fatigue and frustration may lead to emotional instability, and then unstable EEG signals may be accompanied. In daily life, in order to concentrate on reading, people often read every word with covertly speaking, and even read it out in a low voice. During mental arithmetic, they may silently read the whole calculation process if the arithmetic is complicated. According to these phenomena, it can be speculated that silent reading can help to enhance attention. Metacognitive regulation can be enhanced by mindfulness meditation. Therefore, meditation training can improve the accuracy of BCIs [22]. Hebert found that time-domain phase synchrony of alpha rhythm could be enhanced during Transcendental Meditation [23]. The attention can be promoted by meditation, and the EEG signals are also more stable. Meditation includes concentrative-based meditation and mindfulness-based meditation. Keeping silent reading a Chinese character is similar to concentration-based meditation, which focuses the attention on a single stimulus. In our previous study [24], the EEG signals from speech imagery based on two Chinese characters have been analyzed and classified. Unlike the letters of the alphabet and vowels, a single Chinese character expresses a specific meaning. Furthermore, it is very natural to perform mental tasks with reading relevant characters. For BCI systems, it is meaningful to study whether silent reading can improve classification accuracies of mental tasks. The accuracy of a hybrid BCI can be improved by performing motor imagery and SSVEP simultaneously [25]. There is no study about performing mental tasks and speech imagery simultaneously.

In this paper, we intend to analyze and classify EEG signals from the mental tasks with and without characters speech imagery. To continue the previous study, "左(left)" and "壹(one)" are also selected as the characters for the speech imagery. "左" is pronounced as "zuo" in the third tone, and it means left in English. "壹" is pronounced as "yi" in the first tone, and it means one in English. Each Chinese character has its specific strokes. The educated subjects are good at visualizing the Chinese strokes being written on a board, and it is similar with visualizing some English words being written [19]. The strokes of "壹(one)" is shown in Fig. 1.

It is very common to do some matters and read related characters at the same time, e.g. boxing (hitting the arm and shouting simultaneously) and writing a word with reading it. In the experiment, subjects must complete two steps to estimate the effect of speech imagery for the mental tasks. In the first step, they are required to image rotating the body to the left with reading "左(left)" in mind. They are also demanded to visualize writing a stroke of "壹(one)" one by one according to the order of the strokes and read "壹(one)" in mind simultaneously. In order to avoid the interference between the two steps, the second step is finished after several months. In the second step, subjects respectively image rotating the body to the left and visualize writing the strokes of "壹(one)" without reading relevant characters in mind. The mental tasks have a relationship with each character, so it is not hard to perform speech imagery and mental tasks simultaneously. Compared with just mental tasks, the burden of training is not evidently increased in this paper. The above-mentioned point is also proved by questionnaires after the experiment.

In order to judge the effect of speech imagery, the classification accuracy and temporal stability of EEG signals should be calculated in different mental tasks. Imaging the body rotate to the left and visualizing strokes of "壹(one)" being written are totally different mental tasks, so common spatial patterns (CSP) and support vector machine (SVM) are successively used to extract and separate the EEG signals of two tasks. CSP is a state-of-the-art algorithm to extract discriminant spatial features. As different mental tasks are handled by different cerebral cortex, CSP is very suitable in the paper. Spatial filters can be constructed to maximize the variance of an imagination and to minimize the variance of the other one simultaneously. The robustness of SVM is respected to the curse-of-dimensionality, so it can obtain satisfactory results even trained by a small set with high dimensional feature vectors [26].

The following section introduces the method of acquisition, analysis, feature extraction and classification for the EEG signals. Section 3 gives the results of analysis and classification. The further analysis about experimental results is discussed in Section 4. Section 5 concludes the paper.

2. Methods

2.1. Data acquisition

Ten Chinese (seven males and three females), right handed students of Southeast University participate in the no feedback experiment. Aged 22–28, with the average of 23.6 years and the standard deviation of 1.7 years, they are in good health and vision. Drinking alcohol within 24 h before the test, coffee or tea within 4 h is not allowed. Seven subjects have attended the experiment of speech imagery before, but all the subjects do not have the experiences of experiment about imaging the body rotate and visualizing the Chinese strokes. This experimental protocol has been permitted by the Academic Ethics Committee of Southeast University. After explaining the purpose and instructions of the experiment, they sign Informed Consent. The subjects are seated on a comfortable chair in a room, approximately 1 m in front of a 22 in. LCD monitor. When performing the tasks, they are required

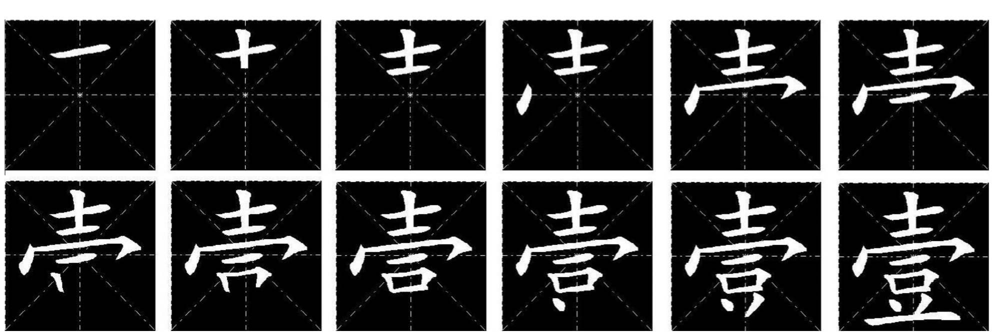

Fig. 1. The order of strokes of "壹(one)".