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Volitional control of the heart rate

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ABSTRACT

The heart rate is largely under control of the autonomic nervous system. The aim of the present study is to investigate the interactions between the brain and heart underlying volitional control of the heart and to explore the effectiveness of volition as a strategy to control the heart rate without biofeedback. Twenty seven healthy male subjects voluntarily participated in the study and were instructed to decrease and increase their heart beats according to rhythmic, computer generated sound either 10% faster or slower than the subjects' measured heart rate. Sympathetic and parasympathetic activities were estimated with the heart rate variability (HRV) obtained by power spectral analysis of RR intervals. Functional coupling patterns of cerebral cortex with the heart were determined by Partial directed coherence (PDC). In HR_{slow} task; HR and sympathetic activity significantly decreased. However parasympathetic activity and power spectral density of EEG in low Alpha (8–10.5 Hz) band significantly increased. Moreover information flow from parietal area (P3 and P4) to RR interval significantly increased. During HR_{quick} task; HR, sympathetic activity and power spectral density of EEG in low Beta (14–24 Hz) band significantly increased. Parasympathetic activity significantly decreased. Information flow from FT8, CZ and T8 electrodes to RR interval significantly increased. Our findings suggested that the heart beat can be controlled by volition and is related to some special areas in the cortex.

1. Introduction

The central nervous system (CNS) controls the heart rate by varying impulse traffic in sympathetic and parasympathetic nerve fibers terminating in the sinoatrial node (Robinson et al., 1966). Heart rate and rhythm are the result of the intrinsic automaticity of the sinoatrial node and the modulating influence of the autonomic nervous system (Lo et al., 2008). Previous studies established that human can generally increase, decrease, or stabilize their heart rates (HR) in response to instructions obtained through biofeedback (Schwartz, 1972). It has clearly demonstrated that patients can use biofeedback techniques to regulate the input of the autonomic nervous system to the heart (Kranitz and Lehrer, 2004; Weiss and Engel, 1971). Biofeedback is an effective way to affect HR, but some supporting devices are needed to apply the method.

Volition (or will) is one of the primary human psychological functions. Volitional control of skeletal muscle, such as moving our body, is driven by the cortex without any supporting device. We wonder if HR can also be controlled by volition, and by what mechanism. In the present study an experiment was designed to trigger voluntary increases and decreases in the heart rate, with the possible goal to introduce a new nonpharmaceutical method for treating arrhythmias.

Cardiovascular regulation center was believed to locate at the brain stem, but many publications showed that the heart is also modulated by the cerebral cortex (Marci et al., 2007). Anatomical investigations indicate that cortical areas are connected to hypothalamic, midbrain, pontine and medullary brain regions involved in cardiovascular control, and that the medial prefrontal cortex and insular cortex participate in the specific aspects of central circulatory control (Verberne and Owens, 1998). Critchley et al. found that cardiovascular arousal was correlated positively with right insula, midcingulate, brainstem and cerebellum blood flow (Critchley et al., 2000). Cortical regions, in which activity increased during higher heart rate and greater lower body negative pressure, included the right superior posterior insula, frontoparietal cortex and the left cerebellum (Kimmerly et al., 2005). Many cortex areas are involved in cardiovascular regulation, but we do not know which particular area is related to the heart beat control and how information is directly transported to the heart from these related areas when we try to control the heart beat through volition. This could possibly be obtained by investigating the heart and brain interactions as a causal relation. A few studies have been conducted to fulfill this approach (Abdullah et al., 2010; Yu et al., 2009).

A considerable number of approaches have been proposed to estimate the functional connectivity on EEG signals, such as the cross-correlation, spectral coherence and synchronization (Murata et al., 2004; Stam and B.W, 2002; Urbano et al., 1998). These techniques cannot reflect the direction of information flow within the functional coupling of EEG rhythms and were difficultly extended to

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analyze the brain–heart connectivity. Partial directed coherence (PDC) can overcome this limitation by multivariate autoregressive (MVAR) process and can detect the direct causality (Astolfi et al., 2007; Pereda et al., 2005). The information flow from the brain to the heart goes through the central nervous system at the hypothalamus and brainstem. Based on the facts that heart rate variability (HRV) or RR intervals were the effective indices of autonomic activity affecting the heart performance (Camm et al., 1996), and that EEG alpha activity was synchronized to the cardiac cycle and the fluctuation of HRV (McCraty, 2002), it is possible that the spectral power of EEG and the index of HRV (RR intervals) can be used to describe the functional interaction between the brain and heart. In this study, we applied the PDC to investigate the directional features between the cortex and heart to obtain information underlying the heart rate volitional control.

2. Methods

2.1. Subjects

27 healthy male subjects (22–27 years old) voluntarily participated in the study. The subjects were instructed to avoid alcohol, tea, coffee and strenuous exercise for 12 h before the experiment and screened carefully with history and physical examinations. The investigation was carried out with the approval of Xi'an Jiaotong University Ethics Committee, and informed written consent was obtained from every subject after the experimental procedures had been explained.

2.2. Experimental protocol

Experiments were performed in a quiet laboratory, where the temperature was 22 °C to 24 °C, between 7 p.m. and 10 p.m. and consisted of two tasks, slow HR control task (HR_{slow}) and quick HR control task(HR_{quick}). In HR_{slow} task, the subject was asked to drive his heart by volition to beat with a slower rhythm than his normal HR. In HR_{quick} task, the subject was asked to drive his heart by volition to beat with a quicker rhythm than his normal HR. Subject did not know the status of his heart during the experiment. Also the subjects did not know it is a slow or quick HR control task.

Before the experiment, the normal electrocardiogram (ECG) of the subject was recorded, and RR intervals were sent to a computer from which two kinds of auditory notes were produced. The notes were respectively corresponded to a 10% decrease and increase of the RR intervals, and used to initiate the volitional command "beat" during the HR_{slow} and HR_{quick} tasks (Fig. 1).

In order to confirm that the changes of HR were mainly affected by volition and eliminate the effects of the auditory note on subjects, baseline session was designed. During the baseline, subjects remained listening to the same note and then subvocalized "1" with it but did not concentrate their mind on the heart and did not output any volitional command to the heart.

In the HR_{slow} task, subjects first performed the baseline session for 5 min and then had 10 minutes rest. After that, subjects were asked to concentrate their mind on the heart and drive their heart to beat with volitional commands "beat" from the brain. The command was initiated by following the slower auditory notes and revealed that the volitional rhythm was slower than the normal HR. During baseline and volitional experiments, EEG, ECG and respiration were measured simultaneously.

In the HR_{quick} task, the protocol was the same as in HR_{slow} task except that the command followed the quicker auditory notes.

Subjects were specifically instructed to keep a comfortable breathing pace to avoid any unnecessary postural or striate muscle changes during the experiments.

2.3. Data acquisition

EEG activity was recorded from 18 electrodes using the Neuroscan 32 channel system (Neuroscan, El Paso, TX, USA). The cap electrodes were positioned according to the international 10–20 lead systems and the electrode impedance was below 5 kΩ per site. The 18 scalp positions were as follows: left and right frontal (FP1, FP2), mid-frontal (FC3, FC4 and FCz), central (C3, C4 and Cz), parietal (P3, P4 and Pz), occipital (O1, O2 and Oz) and temporal (FT7, FT8, T7 and T8) regions. All electrodes were referenced to linked ear lobe electrodes.

Surface Ag/AgCl electrodes were attached to the chest for recording ECG (two electrodes were attached to the right collarbone and left rib respectively. The grounding electrode was placed on the lower right rib). ECG was recorded as extra EEG channel data and respiration was monitored by recording chest wall movement using a piezoelectric sensor attached over the thorax. All physiological signals were filtered by a band pass filter from 0.01 to 100 Hz. The signal was sampled at 500 Hz and digitized at 16 bit.

2.4. Data analysis

HR was obtained from the RR intervals. Cardiac autonomic activity was estimated with power spectral analysis of RR interval named as heart rate variability (HRV). The components of HRV provide information related to sympathetic and parasympathetic modulations (Brunner et al., 2002; Critchley et al., 2003; Egizio et al., 2008; Murata et al., 2004). The algorithm based on wavelet transforms was used to get RR interval from ECG. The raw 5 min RR interval sequence was

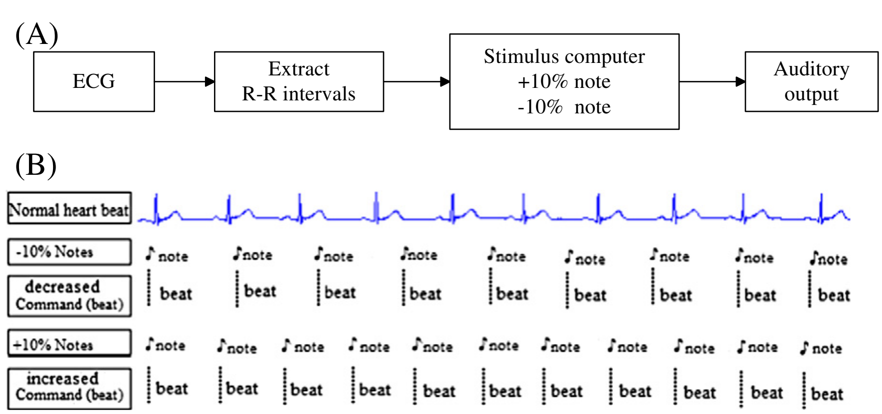

Fig. 1. Experimental protocol. (A) RR intervals were picked up from ECG and sent to a computer to produce auditory notes with which the subject will output a volitional command and try to drive the heart to beat. (B) Two kinds of auditory notes, respectively corresponding to decreased 10% and increased 10% rhythm of HR, were produced. The decreased 10% and increased 10% auditory rhythm will be generated with the computer and used to instruct the subject to drive the heart beat as an initiating signal for volitional command "beat" in HR_{slow} task and HR_{quick} task, respectively.