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Effect of heartbeat perception on heartbeat evoked potential waves

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Abstract: Objective Early researches found that different heartbeat perceivers have different heartbeat evoked potential (HEP) waves. Two tasks were considered in our experiments to get more details about the differences between good and poor heartbeat perceivers at attention and resting state. **Methods** Thirty channels of electroencephalogram (EEG) were recorded in 22 subjects, who had been subdivided into good and poor heartbeat perceivers by mental tracking task. Principal component analysis (PCA) was applied to remove cardiac field artifact (CFA) from the HEP. **Results** (1) The good heart-beat perceivers showed difference between attention and resting state in the windows from 250 ms to 450 ms after R wave at C3 location and from 100 ms to 300 ms after R wave at C4 location; (2) The difference waveforms between good and poor heartbeat perceivers was a positive waveform at FZ from 220 ms to 340 ms after R wave, which was more significant in attention state. **Conclusion** Attention state had more effect on the HEPs of good heartbeat perceivers than that of poor heartbeat perceivers; and perception ability influenced HEPs more strongly in the attention state than in the resting state.

Keywords: heartbeat perception; heartbeat evoked potential; cardiac field artifact; principal component analysis

1 Introduction

The interaction between brain and afferent signals from inner organs plays an important role in lifecycle[1]. Brain controls visceral activities, and afferent signals also have influences on brain function. The mental processes related to interoception have gained growing interests during last years. Interoceptive responses are demonstrated in heart rate, respiration, blood pressure, urine production, alimentary motility and so on. Since heart is the most important visceral organ and cardiac perception is palpable, most studies concerning the interoception are focused on cardiac per-ception. Functional magnetic resonance imaging (fMRI), heartbeat evoked potential (HEP), and positron emission tomography (PET) have all been used in cardiac perceptional research.

Compared with brain imaging methods, HEP has higher time resolving power and fewer restrictions for environments. Two groups, Schandry *et al*. and Jones *et al*. firstly investigated HEP[2,3]. Schandry *et al.* researched factors related to HEP[4-6], sources of HEP[7], and relationship among interoceptive awareness, emotional experience, and brain processes[8]. They found that HEP waveforms were influenced by motivation, attention, heartbeat perception ability and so on.

However, the differences of HEP between good and poor heartbeat perceivers in latency and amplitude and the differences of HEP between attention state and resting state for good and poor perceiver were not described detailedly. Two tasks (attention and resting state) were considered in the present experiments to solve these suspicions. Thirty channels of electroencephalogram (EEG) were recorded in 22 subjects, who had been subdivided into good and poor heartbeat perceivers by mental tracking task.

Evaluating subjects' heartbeat perception ability is a key point for HEP and heartbeat perception research. The method of evaluating heartbeat perception ability is still disputable nowadays[9,10]. Usually, two methods, mental tracking task and heartbeat discrimination procedure, are used to evaluate heartbeat perception. In the first method, subjects are told to count their heartbeats silently during

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Article ID: 1673-7067(2007)06-0357-06
CLC number: R338.8
Document code: A
Received date: 2007-08-20

experiment[11]. Heartbeat perception ability is decided by a score which is calculated from the difference between real heartbeat times and the times they count. The latter method, subjects should discriminate the timing of their own heartbeats by choosing the tones appeared during 0-500 ms after electrocardiograph (ECG) R-wave[12]. For the first method, it is suspected that evaluation towards heartbeat perception will be influenced by the subjective factors such as expectation or experience about heartbeat. The second method had criticism as well, because the evaluation towards heartbeat perception will be influenced by tone's distinguish ability and the attention to tones will influence the attention to heartbeat. Considerring the second method will carry another factor tone's identification and make the experiments more complexly, we choose the first method. Nevertheless, how to evaluate heartbeat perception objectively is still a question for discussion.

How to remove cardiac field artifact (CFA) from the HEP is another key problem in HEP research. Two kinds of potentials are considered to contribute to the main components in the scalp potentials: HEP and CFA, and CFA is dominant in mixed potentials. Dirlich *et al*. pointed out that the electrical field of the heart propagated throughout entire body and caused changes in surface potentials on the scalp[13]. When HEP was averaged, CFA resulted in a high-amplitude in surface potentials. There are two main difficulties to remove CFA from HEP. Firstly, the cardiac field can not be measured in sufficient detail; and secondly, the rules of propagation towards the scalp are not known precisely enough.

Many researchers tried to remove CFA in their experiments by mathematic or experimental method. Schandry *et al*. first applied principal component analysis (PCA) for a set of HEP waveforms to estimate the artifact amplitude[3]. Dirlich *et al*. varied the spatial relations between the sources of two components (heart and brain) by turning head to remove the cardiac field effect[13], but the CFA cannot be eliminated completely. Recently, Perez *et al*. used a new method to remove the CFA from the HEP basing two hypotheses, but they only got the CFA-free HEP in mid-sagittal plane and coronal plane[14]. Considering PCA is more effective, we applied PCA mainly in this study to eliminate the CFA.

2 Materials and methods

2.1 Participants Thirty one students (all males) from the University of Electronic Science and Technology of China (UESTC) participated in the experiments. All the subjects were free of neurological diseases. Twenty two subjects' data were finally filtrated. These subjects, ranging from 20 to 26 years [(23.2±1.68) years], were subdivided into good (11 subjects) and poor (11 subjects) heartbeat perceivers according to the scores in heartbeat perception tasks.

2.2 Equipments and parameters EEG activity was recorded from 30 leads (SYNAMPS, NeuroScan, USA) at the following positions: FP1, FP2, F7, F8, F3, F4, FZ, FT7, FT8, FC3, FC4, FCZ, T7, T8, C3, C4, CZ, TP7, TP8, CP3, CP4, CPZ, P7, P8, P3, P4, PZ, O1, O2, and OZ. Linked mastoids served as reference. AFZ (the electrode located at calvaria) was chosen as ground. ECG electrodes were placed below left and right clavicles. Horizontal electro-oculogram (EOG) was picked up with two electrodes placed laterally to the outer canthus of each eye. Nonpolarizable silver-silver chloride electrodes were used. Electrode impedance was kept below 5 kΩ. The EEG wave was band-pass filtered at 0.1-40 Hz on-line and digitalized at a sampling rate of 1 000 Hz. The ECG R-waves were recorded as triggers for later off-line EEG averaging.

2.3 Experimental procedure After filling in some basic information, the subjects moved into a metal-shielded and sound-insulated room with light off to resist electromagnetic, auditory, and visual disturbances. The subjects kept eyes open during experiments. The whole experimental procedure included two tasks: ignoring heartbeat (resting state) and concentrating on heartbeat (attention state).

In the first task, subjects were asked to sit quietly avoiding paying attention to any regular things such as counting numbers rhythmically. EEG (930 s) consisting of 4 segments was recorded. The second task consisted of 10 heartbeat-counting phases lasting for 100, 120, 80, 90, 110, 70, 120, 90, 70, and 80 s, respectively (totally 930 s). During every phase, participants were asked to concentrate on their heartbeats and count their heartbeats silently. The beginning and end of counting were signaled by a start and stop tone, respectively. Another two continuous tones (about 30 s before the start tone) were given to the subjects for preparation. Subjects were requested not to count heartbeats by other physiological signals such as pulse. After the stop tone, participants reported the number of heartbeats they had counted and had a short break. These two tasks lasted for about 1 h in all.

2.4 Data analysis In the present study, we applied metal tracking task to determine subjects' heartbeat perception abilities.

A heartbeat perceptive score (from 0 to 1) was calculated according to the following equation (referring to Schandry's experiment[7]):

$$P = \frac{1}{k}\sum_{i=1}^{k}\left(1 - \frac{|m_i - n_i|}{m_i}\right) \quad (1)$$

In the equation above, P denotes the perceptive score, k is the number of heartbeat-counting phases in attention state (11 in this experiment), m represents the number of real heartbeats, and n represents the number of heartbeats reported by subject. The participants were divided into two groups according to their heartbeat perceptive scores. The subjects having scores higher than 0.9 were considered as good heartbeat perceivers and the others were attributed to poor heartbeat perceivers.

The EEG wave was firstly bandpass filtered from 1 Hz to 40 Hz off-line to remove the myoelectric and high frequency disturbances. The data were then divided into epochs according to the ECG R-waves (extending from 200 ms before and 600 ms after the ECG R-wave). The epochs stained by ocular movements were rejected in all 30 channels. Average reference was adopted. Finally, epochs were added and averaged in two tasks separately to get the event related potential (ERP). For each group, the HEP wave was the average wave of all 11 subjects.

3 Results

3.1 Remove CFA from HEP by PCA Singular value decomposition (SVD) was used here to get principal components (PCs), the theory is showed below:

$$X^{*} = USV^{T} \quad (2)$$

Here, U is the m step ortho-matrix, V is the n step ortho-matrix, S is the $m \times n$ step matrix. U stands for the time series of HEP and V stands for the space series of HEP. PCs for good heartbeat perceivers in attention state are shown in Fig. 1, and the space distribution for these PCs is shown in Fig. 2.

In order to determine the artifact components in these PCs, the correlation coefficients were calculated and the first 95% components in all components were shown in Tab. 1. For the first three PCs, they had high correlation coefficients with ECG in Fig. 1 and Fig. 2. These three PCs had the comparability with ECG in time series and the global distribution property in space distribution. Therefore, these three PCs were considered as CFA and removed from HEP.

For good heartbeat perceivers in resting state and for poor heartbeat perceivers in attention and resting state, the same method was used to identify CFAs.

3.2 Comparison of HEP between attention and resting state After removing CFA from HEP by PCA, thirty channels of grand average HEP in attention and resting states

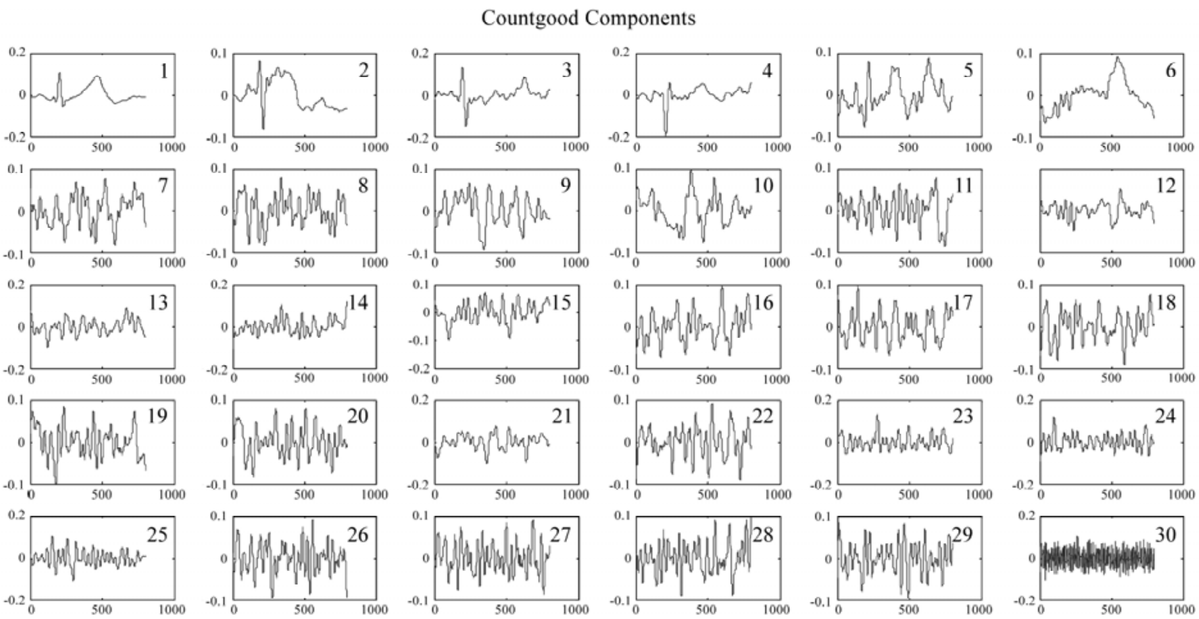

Fig. 1 Components of recorded HEP for good heartbeat perceivers in attention state. These PCs are separated from the grand average HEP which is the average of all 11 good heartbeat perceivers. The corresponding space distributions of components are shown in Fig. 2.

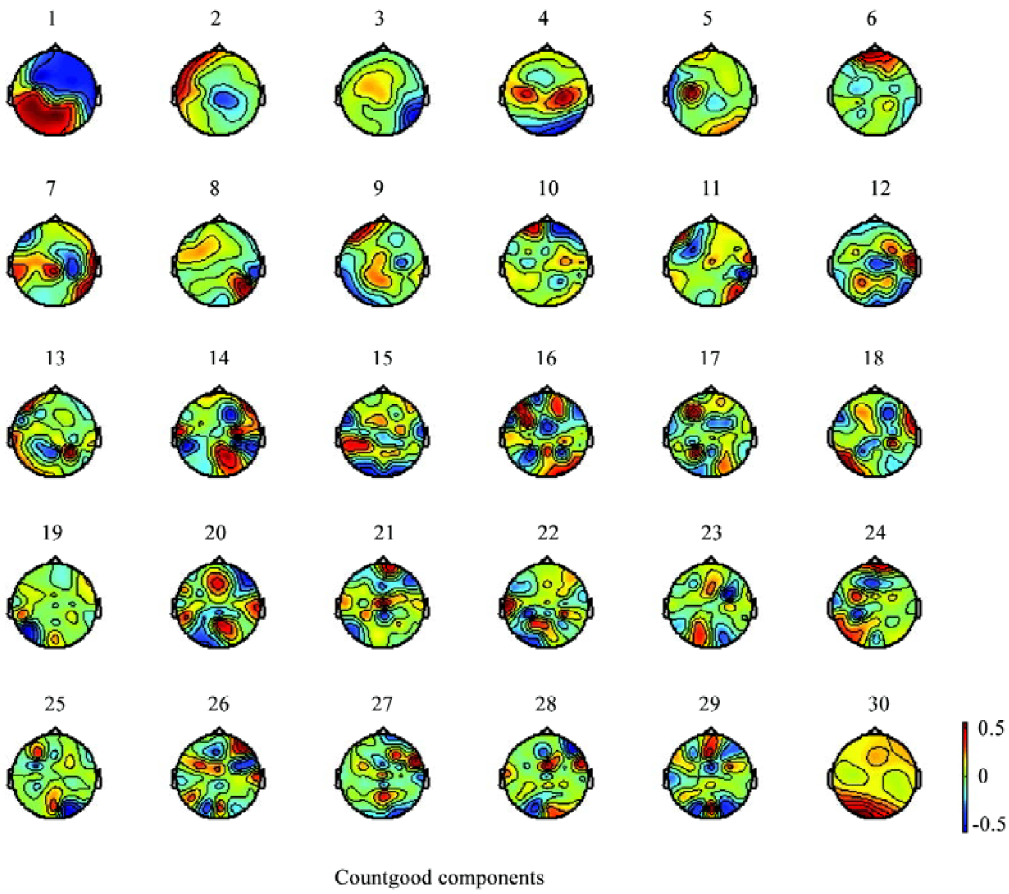

Fig. 2 Space distribution of components of recorded HEP for good heartbeat perceivers in attention state. Every PCs' space distributions are shown in the same locations as they are shown in Fig. 1.

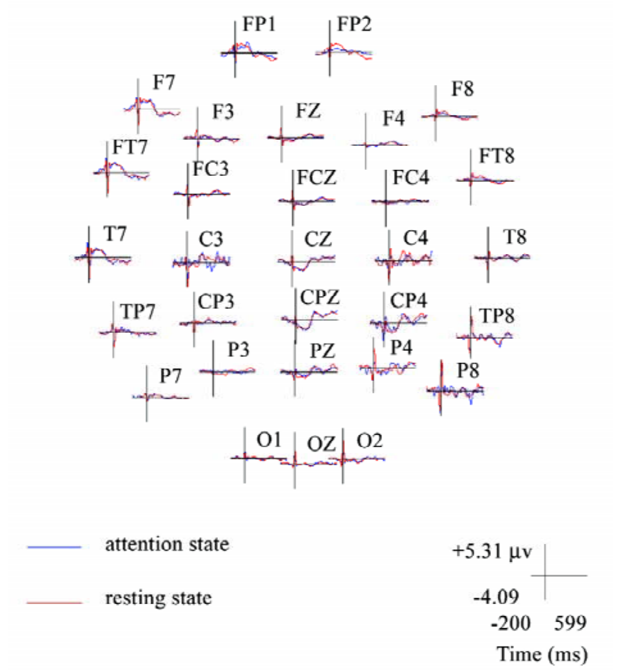

Fig. 3 CFA-free HEP for good heartbeat perceivers in attention and resting state. The real line stands for the attention state, the dashed line stands for the resting state.

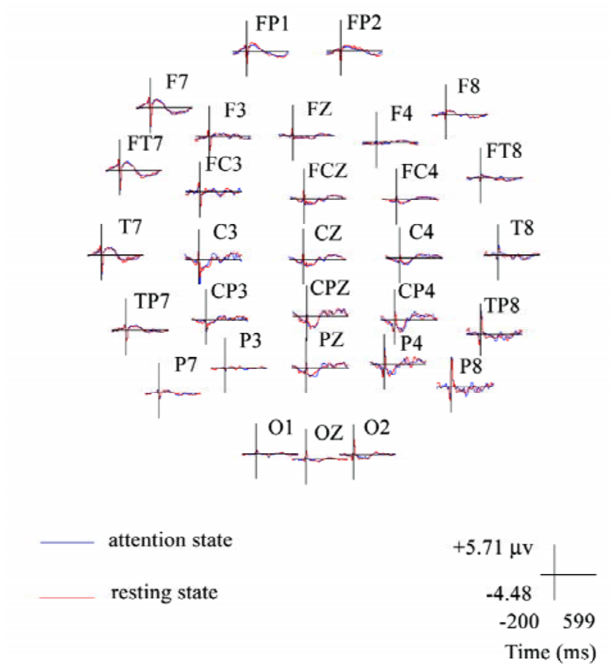

Fig. 4 CFA-free HEP for poor heartbeat perceivers in attention and resting state. The real line stands for attention state, the dashed stands for resting state.

Tab. 1 Correlation coefficients between PCs and ECG for good heartbeat perceivers in attention state

PCA Components	Correlation coefficient between PCs and ECG	Percentage of PC in all components (%)
1	0.85288	34.103
3	0.34783	11.841
2	0.2582	19.015
5	0.16459	4.0686
8	0.094245	1.7848
13	0.09018	1.0194
7	0.063634	1.9566
9	0.056605	1.7479
10	0.048354	1.5794
14	0.03291	0.91956
11	0.027241	1.2565
12	0.024837	1.1331
6	0.023314	3.8463
15	0.02122	0.82209
4	0.012809	10.194

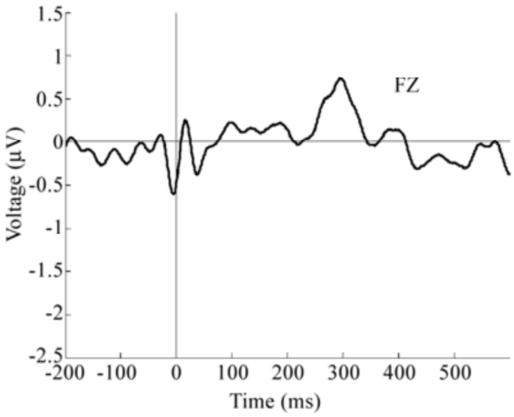

Fig. 5 Difference waveform between good and poor heartbeat perceivers in attention state at FZ.

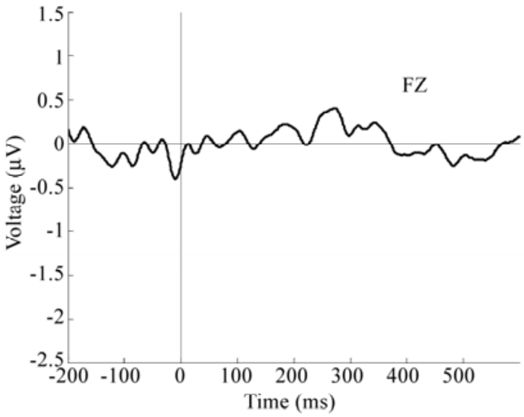

Fig. 6 Difference waveform between good and poor heartbeat perceivers in resting state at FZ.

for good heartbeat perceivers and poor heartbeat perceivers are shown in Fig. 3 and Fig. 4, respectively. Good heartbeat perceivers showed more obvious differences between attention and resting state at C3 and C4 (Fig. 3), suggesting that attention factor mainly influences good heartbeat perceivers.

3.3 Comparison of HEP between good and poor heartbeat perceivers After removing CFA from HEP, the difference waveforms between good and poor heartbeat perceivers were obviously found at FZ in attention state (Fig. 5). The difference waveform showed as a positive waveform from 220 ms to 340 ms at FZ. However, in resting state, no obvious difference was found (Fig. 6).

4 Discussion

The neurotransmission from heart to brain results in HEP. It is common to say that the stimulator is the mechanical receptors around the heart[15], but little is known about the mechanisms of the interaction between inner organs and higher mental function. The brain being as central nervous system is connected with the visceral organs through automatic nervous system. The vagus, as a mixed nerve, carries visceral afferents and efferents. Sense axons project to the brain stem and end at the nucleus of the solitary tract (NTS). Then the NTS projects to the para-brachial nuclei as a pontine relay station and the locus coeruleus. Projections then go to themultiple higher centers such as the hypothalamus and the thalamus before reaching the cortex. Schandry and Montoya[6] consider that the brain electrical activity is independent of the conscious perception of the heartbeat signal. It means that the regularly occurring heartbeats are constantly monitored by certain cortical areas. From Fig. 1 and Fig. 2, we can see that the brain electrical potentials appears both in attention and resting state for both good and poor heartbeat perceivers, which implicated that the potentials we recorded was independent with heartbeat perceptive ability and attention statels, but the HEP waves may be modulated by these two factors.

CFA was removed from HEP by PCA in the present study. By using the CFA-free waveforms, we found that: (1) attention factor may influence good heartbeat perceivers strongly; and (2) perceive ability factor will influence HEPs strongly at attention state. The difference waveforms showed as positive waveforms at FZ from 220 ms to 340 ms after R wave. It seems that attention factor may affect the HEP of good heartbeat perceivers more significantly.

Acknowledgements: This work was supported by the National Natural Science Foundation of China (No.30400105), the National Basic Research Development Program (973) (No. 2003CB716106), and the National Science Fund for Distinguished Young Scholars of China (No. 30525030).

References:

[1] Critchley HD, Wiens S, Rotshtein P, Ohman A, Dolan RJ. Neural systems supporting interoceptive awareness. Nat Neurosci 2004, 7:189-195.

[2] Jones GE, Leonberger TF, Rouse CH, Caldwell JA, Jones KR. Preliminary data exploring the presence of an evoked potential associated with cardiac visceral activity. Psychophysiology 1986, 23: 445.

[3] Schandry R, Sparrer B, Weitkunat R. From the heart to the brain: A study of heartbeat contingent scalp potentials. Int J Neurosci 1986, 30: 261-275.

[4] Montoya P, Schandry R, Muller A. Heartbeat-evoked potentials (HEP): topography and influence of cardiac awareness and focus of attention. Electroencephalogr Clin Neurophysiol 1993, 88: 163-172.

[5] Schandry R, Weitkunat R. Enhancement of heartbeat-related brain potentials through cardiac awareness training. Int J Neurosci 1990, 53: 234-253.

[6] Schandry R, Montoya P. Event-related brain potentials and the processing of cardiac activity. Biol Psychol 1996, 42: 75-85.

[7] Pollatos O, Kirsch W, Schandry R. Brain structures involved in interoceptive awareness and cardioafferent signal processing: a dipole source localization study. Hum Brain Mapp 2005, 26: 54-64.

[8] Pollatos O, Kirsch W, Schandry R. On the relationship between interoceptive awareness, emotional experience, and brain processes. Brain Res Cogn Brain Res 2005, 25: 948-962.

[9] Knoll JF, Hodapp V. A comparison between two methods for assessing heartbeat perception. Psychophysiology 1992, 29: 218-222.

[10] Phillips GC, Jones GE, Rieger EJ, Snell JB. Effects of the presentation of false heart rate feedback on the performance of two common heartbeat-detection tasks. Psychophysiology 1999, 36: 504-510.

[11] Ring C, Brener J. Influence of beliefs about heart rate and actual heart rate on heartbeat counting. Psychophysiology 1996, 33: 541-546.

[12] Acosta A, Pegalajar J. Facilitation of heartbeat self-detection in a choice task. Psychophysiology 2003, 47: 139-146.

[13] Dirlich G, Vogl L, Plaschke M, Strian F. Cardiac field effects on the EEG. Electroencephalogr Clin Neurophysiol 1997, 102: 307-315.

[14] Perez JJ, Guijarro E, Barcia JA. Suppression of the cardiac electric field artifact from the heart action evoked potential. Med Biol Eng Comput 2005, 43: 572-581.

[15] Pollatos O, Schandry R. Accuracy of heartbeat perception is reflected in the amplitude of the heartbeat-evoked brain potential. Psychophysiology 2004, 41: 476-482.

心跳感知对心跳诱发脑电位的影响

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摘要：目的 早期研究发现心跳感知能力不同的人其心跳诱发脑电位 (heartbeat evoked potential，HEP) 存在差异。本文设计两个实验以对比研究在关注状态和静息状态下，心跳感知能力强和心跳感知能力弱的人HEP的具体差异。**方法** 采集22名被试者的30通道的脑电波，通过精神跟踪方法将被试者分为心跳感知能力强和感知能力弱两组。使用主成分分析方法去除掺杂在HEP中的心电场伪迹。**结果** (1) 对于心跳感知能力强的被试者，关注状态和静息状态的HEP存在着差异。差异主要体现在C3处心电R波后250-450 ms和C4处心电R波后100-300 ms。(2) 感知能力强和感知能力弱的被试者的HEP差异波主要体现为FZ处心电R波后220-340 ms的一个正波；在关注状态下，这种差异更明显。**结论** 关注因素可能更容易影响心跳感知能力强的被试者；在关注状态，感知能力对 HEP 的影响更为明显。

关键词：心跳感知；心跳诱发脑电位；心电场伪迹；主成分分析