Effects of Acupuncture on Autonomic Nervous Function and Prefrontal Cortex Activity

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Abstract Acupuncture is helpful in treating various diseases, including autonomic nervous system (ANS) dysfunction caused by mental stress. On the other hand, the frontal lobe is suggested to play an important role in stress responses by modulating the ANS. The aim of the study was to evaluate the effects of acupuncture on ANS and frontal lobe activities. We investigated 18 normal adults. We measured the activity of prefrontal cortex (PFC) caused by real acupuncture (WHO-LI4) and sham acupuncture, employing optical topography. To evaluate ANS function, we analyzed heart rate variability (HRV). Analysis of HRV revealed a decrease of the LF/HF ratio, and an increase of the HF power by real acupuncture, indicating a shift to parasympathetic dominancy. Acupuncture also caused cerebral blood oxygenation changes in both directions, that is, an increase and/or a decrease of oxyhemoglobin (Oxy-Hb) in the bilateral PFC. However, the Oxy-Hb change was not correlated with HRV parameters in the majority of cases. One of the possible explanations of the poor correlations might be that the PFC activity induced by acupuncture is not closely linked with ANS function.

1 Introduction

There is increasing clinical evidence that acupuncture is helpful in treating various diseases, including autonomic nervous system (ANS) dysfunction caused by mental stress. For example, acupuncture at certain points could reduce sympathetic nervous system activity associated with pain [1]. In addition, it was demonstrated that acupuncture could inhibit sympathetic activation during mental stress in patients with heart failure [2]. However, the neurobiological basis of these effects is not yet clear.

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The prefrontal cortex (PFC) plays an important role in mediating behavioral and somatic responses to stress via projections to the autonomic centers [3]. Electroencephalographic studies have shown that a greater right frontal activation is associated with increased heart rate during unpleasant emotional stimuli [4]. A functional MRI study revealed that right dominance of PFC activity during mental stress tasks correlated with changes in heart rate [5]. In addition, our near infrared spectroscopy (NIRS) studies have demonstrated that the right PFC activity predominantly modulates sympathetic effects during a mental stress task [6–8]. However, it is not yet clear whether the PFC is involved in modulation of ANS function by acupuncture, and whether the laterality of the PFC activity plays a role in regulation of the ANS by acupuncture. In order to clarify these issues, we evaluated the effect of acupuncture on ANS function and frontal lobe activity using NIRS.

2 Methods

We investigated 18 healthy male adults (20–54 years; mean 42.7 years). Seventeen of them were right-handed, and one subject was left-handed as judged by the Edinburgh Handedness Inventory. To avoid the influence of environmental stress, the subjects were seated in a comfortable chair in a regular room with good air conditioning throughout the experiments.

We measured the frontal lobe activity caused by acupuncture. Real acupuncture was performed at acupuncture point Large Intestine 4 (WHO-LI4) of the right hand (r-LI4; 18 subjects) or left hand (l-LI4; 13 subjects), and sham acupuncture was performed at skin 2–3 cm distal to the r-LI4 (18 subjects). After disinfecting the skin surface with an alcoholic cotton swab, a disposable needle was inserted quickly by an experienced acupuncturist aiming at each point, and the point was stimulated for a minute with bidirectional needle rotation, then the needle was left at the point for 1.5 min without rotation.

We employed optical topography (OMM 2001, Shimadzu, Japan) to undertake two-dimensional (2D) imaging of the changes in concentration of oxyhemoglobin (Oxy-Hb), deoxyhemoglobin (Deoxy-Hb) and total-hemoglobin (= Oxy-Hb + Deoxy-Hb; Total-Hb) in the activated cortices of the bilateral frontal lobes. The hemoglobin concentrations were expressed in arbitrary units. The optodes for the NIRS topography were placed on the skull to cover the bilateral frontal lobes, employing a holder cap to avoid motion-related artifacts; the distance between each optode was 30 mm [9]. Heart rate was simultaneously monitored with PFC activity by placing a photo-electrical sensor (Tsuyama MGF KK, Tokyo, Japan) on the subject's first finger to measure pulse waves. ANS function was evaluated by heart rate variability (HRV) analysis; the low frequency (LF) amplitude (0.04–0.15 Hz) and the high frequency (HF) amplitude (0.15–0.4 Hz) were calculated by power spectral analysis. The values of the HRV parameters were expressed as a function of the

natural logarithm (Ln). To evaluate the effects of acupuncture, the mean values of the HRV parameters for 2.5 min were compared among the prestimulus control, test stimulus and poststimulus control.

3 Results

Analysis of HRV (Table 1) revealed that real acupuncture at r-LI4 caused significant decreases of HR (A; $p = 0.0409$) and Ln LF/HF (D; $p = 0.0044$), and a significant increase of Ln HF (C; $p = 0.0087$). The significant decrease of HR could be partly attributed to the subjects with higher value of the HR at prestimulus condition (E). Acupuncture at contra lateral l-LI4 showed the same tendency as r-LI4 acupuncture, but there was no statistically significant change of HRV parameters during acupuncture ($p > 0.05$). Sham acupuncture caused no significant change in HR or Ln HF ($p > 0.05$).

Table 1 Effects of acupuncture on heart rate (HR) and heart rate variability

		l-L14	r-L14	Skin
HR	pre	68.0 ± 2.6	71.4 ± 2.0	67. 9 ± 2.2
	test	67.5 ± 2.8	68.5 ± 1.9 *	69.1 ± 2.7
	post	67.3 ± 2.9	70.4 ± 1.6	70.0 ± 2.6
ln LF	pre	5.80 ± 0.24	5.68 ± 0.23	5.35± 0.25
	test	5.48 ± 0.24	5.49 ± 0.21	5.56 ± 0.21
	post	5.62 ± 0.16	5.42 ± 0.19	5.19 ± 0.25
ln HF	pre	5.19 ± 0.16	5.16 ± 0.18	5.14 ± 0.19
	test	5.36 ± 0.19	5.57 ± 0.19**	5.37 ± 0.20
	post	5.31 ± 0.23	5.20 ± 0.20	5.10 ± 0.21
N LF/HF	pre	1.12 ± 0.05	1.12 ± 0.05	1.10 ± 0.05
	test	1.04 ± 0.06	1.00 ± 0.04**	1.05 ± 0.03
	post	1.08 ± 0.04	1.07 ± 0.04	1.03 ± 0.04

Each value represents mean ± S.D. pre: pre-stimulus control; stim: during stimulus; post: post-stimulus control. Asterisks indicate that the values during stimuli are statistically significantly different from the pre-stimulus control (*: $p < 0.05$, **: $p < 0.01$; two-tailed paired t-test)

Optical topography demonstrated several different patterns of NIRS parameter changes. For example, Oxy-Hb increased in the bilateral frontal lobes during real acupuncture at r-LI4 in seven subjects. A typical pattern of these subjects is the increase of Oxy-Hb in the anterior portion, as well as the lateral portion of the bilateral PFC (Fig. 1a). In contrast, one subject showed Oxy-Hb decreases in these portions during real acupuncture at r-LI4 (Figs. 1b). In the remaining 9 subjects, the directions of the Oxy-Hb changes were intermingled: an increase, a decrease or almost no change (Fig.1c) occurred with different stimuli at different portions of the PFC. Table 2 shows the mean changes of Oxy-Hb in four different regions of the PFC in 18 subjects for r-LI4 and skin, and 13 subjects for l-LI4.

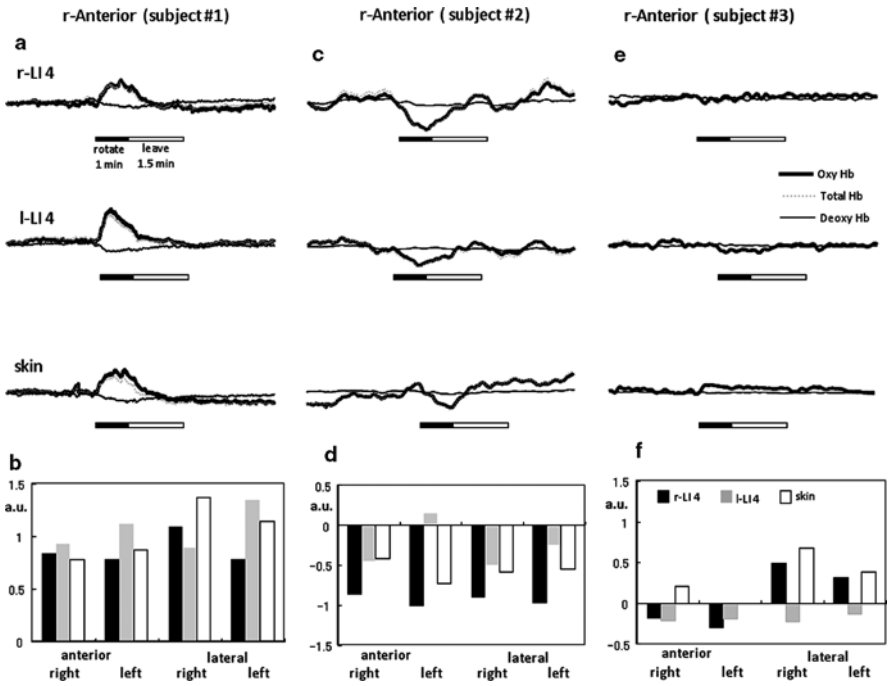

Fig. 1 Effects of acupuncture on NIRS parameters. Three typical patterns (a, b, c) of the concentration changes of NIRS parameters during acupuncture at r-LI4, l-LI4 and skin; traces of Oxy-Hb (*thick trace*), Deoxy-Hb (*thin trace*) and Total-Hb changes (*dotted line*) recorded on the *right anterior* PFC in three subjects (subject #1, #2, #3). Acupuncture was performed during the period indicated below each trace (*horizontal bar*); the *black* and *white bars* indicate the periods of rotation and leaving of the needle, respectively

Table 2 Effects of acupuncture on Oxy-Hb changes in the PFC

	r-APFC	l-APFC	r-LPFC	l-LPFC
r-L14	0.14 ± 0.41	-0.062 ± 0.38	0.56 ± 0.72	0.30 ± 0.64
l-L14	0.10 ± 0.37	0.25 ± 0.42	0.37 ± 0.56	0.32 ± 0.52
skin	0.19 ± 0.25	0.11 ± 0.32	0.43 ± 0.45	0.38 ± 0.45

APFC: anterior part of the prefrontal cortex, LPFC: lateral part of the prefrontal cortex. r-: right side, l-: left side. We analyzed the maximal value of Oxy-Hb changes in each region of the PFC. Each value represents mean $\pm$ S.D. Data are expressed in arbitrary units

Next we examined the relations between the changes in the HRV parameters and the Oxy-Hb change in the r-APFC, l-APFC and bilateral LPFC. In the r-APFC, a correlation was observed only between the change of Ln LF and the Oxy-Hb change during acupuncture at l-LI4 ($p = 0.009$; $r = 0.668$). In the other portions of PFC, a few positive correlations were observed. In the r-LPFC, the change of Ln HF was positively correlated with Oxy-Hb change with

acupuncture at the l-LI4 ($p = 0.0166$; $r = 0.648$). In the l-LPFC, the Ln HF was positively correlated with Oxy-Hb change with acupuncture at skin ($p = 0.0466$; $r = 0.493$). Although there was no correlation between HRV parameters and Oxy-Hb with acupuncture at the r-LI4, when combining both data of r-LI4 and l-LI4, the change of Ln HF was positively correlated with the Oxy-Hb change in the r-APFC ($p = 0.0138$; $r = 0.431$) and the l-LPFC ($p = 0.0448$; $r = 0.352$).

4 Discussion

We demonstrated that real acupuncture at r-LI4 caused a significant decrease of the HR, increase of the HF power and decrease of the LF/HF power during acupuncture, indicating that the HR was decreased by parasympathetic activation as well as sympathetic depression. A decrease in HR and an increase of HF power by acupuncture at LI4 have been reported recently [10], and these findings are consistent with the present study. They, however, reported a significant increase of the LF/HF ratio (i.e., sympathetic activation) during the first minute of stimulation. The difference between the present and the previous studies could be attributed to the difference in the methods such as manipulation of the needle.

Acupuncture caused an increase and/or a decrease of Oxy-Hb in the bilateral PFC. The increases and decreases of Oxy-Hb reflected activation and deactivation of the PFC, respectively [11]. Recently, we have demonstrated that the PFC plays an important role in regulation of ANS function [6, 7]. That is, the right PFC activity predominantly modulates sympathetic effects during mental stress tasks. In the present study, however, the degree of Oxy-Hb change was not closely associated with the ANS function. The Oxy-Hb change was correlated with HRV parameters only in a few cases. The reason why we could not find a statistical significant correlation between the PFC activity and ANS function during acupuncture might be the small number of subjects. Another possibility is that the PFC activity induced by acupuncture might not be closely linked with ANS function. Finally, it should be noted that task-related changes in systemic blood pressure may contribute to the CBO changes measured by NIRS [12]. Further studies are necessary to clarify these issues.

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