Chapter 38
Influence of Pleasant and Unpleasant Auditory Stimuli on Cerebral Blood Flow and Physiological Changes in Normal Subjects

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Abstract The prefrontal cortex (PFC) plays an important role in emotion and emotional regulation. The valence asymmetry hypothesis, proposes that the left/right asymmetry of the PFC activity is correlated with specific emotional responses to stressors. However, this hypothesis still seems to leave room for clarifying neurophysiological mechanisms. The purpose of the present study was to investigate the effects of stimuli with positive and negative valence sounds (hereafter PS, NS) selected from the International Affective Digitized Sounds-2 on physiological and physiological responses, including PFC activity in normal participants. We studied the effect of both stimuli using 12 normal subjects (mean age 26.8 years) on cerebral blood oxygenation in the bilateral PFC by a multi-channel NIRS, alpha wave appearance rate in theta, alpha, beta by EEG, autonomic nervous function by heart rate, and emotional conditions by the State-Trait Anxiety Inventory (STAI) and the visual analogue scale (VAS). PS was selected over 7.00 and NS were fewer than 3.00 in the Pleasure values. Sounds were recorded during 3 s and reproduced at random using software. Every task session was designed in a block manner: seven rests with Brown Noise (30 s) and six tasks (30 s) blocks. All participants performed each session in random order with eyes closed. A paired Student's t-test was used for

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comparisons ($P < 0.05$). PFC activity showed increases bilaterally during both stimuli with a greater activation of the left side in PS and a tendency of more activation by NS in the right PFC. Significantly greater alpha wave intensity was obtained in PS. Heart rate tended to show smaller values in PS. The STAI level tended to show smaller values in PS, and a significantly greater VAS score was obtained in PS which indicated 'pleasant'. Despite the limitations of this study such as the low numbers of the subjects, the present study indicated that PS provided pleasant psychological and physiological responses and NS unpleasant responses. The PFC was activated bilaterally, implying a valence effect with the possibility of a dominant side.

Keywords Prefrontal cortex • Near-infrared spectroscopy • International Affective Digitized Sounds-2 • Electroencephalogram • Stress

1 Introduction

Many people suffer from many kinds of stress in their life. Normally, a balance in mental conditions is maintained between the activities of the sympathetic and parasympathetic nervous systems. Chronic stress can disturb the balance and cause stress-related health problems. When people are exposed to a stressor, the brain initiates a stress response. This stress response is thought to be a healthy defense mechanism. Many studies have investigated the effects of stress on: the reaction of the circulation and central nervous system [1], and activity in the prefrontal cortex (PFC) and the autonomic nervous system (ANS) [2, 3]. Even relatively mild acute uncontrolled stress can cause a rapid stress response and dramatic loss of prefrontal abilities [4].

The stress response involves activation of the PFC, which stimulates the hypothalamic-pituitary-adrenal (HPA) axis and influences ANS, since neuronal networks exist between the PFC and the neuroendocrine centers in the medial hypothalamus, and the PFC has direct access to sympathetic and/or parasympathetic motor nuclei in brainstem and spinal cord [5]. The PFC will set the endocrine/autonomic balance, depending on the emotional status [5]. The PFC is the region that is most sensitive to the effects of stress exposure [4].

According to the valence asymmetry hypothesis, the left/right asymmetry of the PFC activity is correlated with specific emotional responses to stressors and personality traits [6, 7]. The evidence supports a valence asymmetry hypothesis, suggesting that the left hemisphere is specialized for the processing of positive emotions, while the right hemisphere is specialized for the processing of negative emotions [8, 9], including the HPA axis system [2]. However, this asymmetry hypothesis has not received unequivocal support [10]. This hypothesis still seems to leave room for clarifying neurophysiological mechanisms involved.

The International Affective Digitized Sounds-2 (IADS) is a standardized database of 167 naturally occurring sounds, and that is widely used in the study of emotions. The IADS is part of a system for emotional assessment developed by the Center for Emotion and Attention [11–13]. Studies that have used IADS stimuli have revealed that auditory emotional stimuli activate the appetitive and defensive motivational systems similarly to the way that pictures do.

The purpose of the present study was to investigate the effects of stimuli with positive and negative valences selected from the IADS on psychological and physiological responses including the PFC activity measured by NIRS in normal participants.

2 Materials and Methods

A total of 12 healthy volunteers participated in the study (mean age 26.8 years). Participants were told to refrain from substances (e.g., coffee, etc. including caffeine) that could affect their nervous systems before and during the period of testing, and not to eat for 2 h before the test. They were also instructed to avoid excessive drinking and a lack of sleep the night before the test. In order to avoid the influence of environmental stress, the participants were seated in a comfortable chair in an air-conditioned room with temperature and humidity maintained at approximately 25 °C and 50 %, respectively. The study was conducted in accordance with the Principles of the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Tokyo Dental College (Ethical Clearance NO.436). Written informed consent was obtained from all participants.

After a 10-min rest, they then performed two auditory stimulation listening tasks by an earphone with eyes closed. Auditory tasks were positive and negative valence sounds selected from the IADS (hereafter PS, NS). PS tasks were selected over 7.0 and NS were fewer than 3.0 in the Pleasure value of IADS. Namely, PS was comfortable, and NA was uncomfortable. Sounds were recorded during 3 s and reproduced at random using software (Access Vision Co., Ltd., Japan). Each task session (in random order) was designed in a block manner; seven rests with a Smoothed Brown Noise (Technomind, Brazil) (30 s) and six tasks blocks with PS or NS (Fig. 38.1). The Noise was a low roar resembling a waterfall or heavy rainfall. It had more energy at lower frequencies. And it was used not too large in volume. Activity in the PFC was measured by a multi-channel NIRS; (OEG-16, Spectratech, Japan). The targets were placed at Fp1 and Fp2 in the international 10–20 system. Electroencephalogram (EEG) (Muse Brain System, Syscom, Japan) and heart rate (HR) (WristOx, NONIN, USA) were monitored simultaneously with the PFC activity. We used the 10-cm visual analogue scale (VAS) and the State-Trait

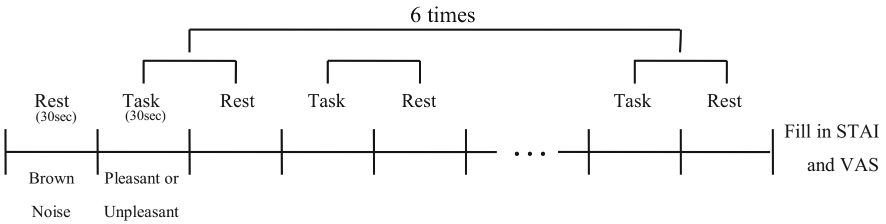

Fig. 38.1 Experimental protocol trial consisted of seven rests (Smoothed Brown Noise, 30 s) and six tasks blocks: Positive or Negative sounds from IADS. Two tasks were adopted at random

Anxiety Inventory (STAI) for psychological assessments. Statistical evaluations between PS and NS were performed using a paired Student's t-test (Excel Statistics, Microsoft Japan). A p-value of <0.05 was considered significant.

3 Results

Results are summarized in Table 38.1. PFC activity showed increases bilaterally during both stimuli with a greater activation of the left side in PS and a tendency of more activation by NS in the right PFC. Significantly greater alpha wave intensity

Table 38.1 Psychological and physiological assessment

			Stimulus or site	Mean (S.D.)	Statistics
Psychological assessment	STAI level (Bigger figure indicates "more unpleasant")		Positive sound	2.08 (0.79)	–
			Negative sound	2.41 (1.08)	
	VAS level (Smaller figure indicates "more unpleasant")		Positive sound	5.93 (0.96)	*
			Negative sound	4.02 (1.53)	
Physiological assessment	Heart rate (bpm)		Positive sound	62.46 (7.96)	–
			Negative sound	63.50 (8.59)	
	Alpha wave (%) (Appearance rate in theta, alpha, and beta)		Positive sound	47.88 (0.08)	*
			Negative sound	45.10 (0.07)	
	NIRS ⊿Oxy-Hb (a.u.)	Right PFC	Positive sound	0.06 (0.03)	–
			Negative sound	0.11 (0.08)	
		Left PFC	Positive sound	0.12 (0.09)	–
			Negative sound	0.11 (0.08)	
		Positive sound	Right PFC	Refer to the much column above	*
			Left PFC	Refer to the much column above	
		Negative sound	Right PFC	Refer to the much column above	–
			Left PFC	Refer to the much column above	

*$p < 0.05$

(appearance rate in theta, alpha, beta) was obtained in PS. HR tended to show smaller values in PS. The STAI level tended to show smaller values in PS, and a significantly greater VAS score was obtained in PS, indicating ‘pleasant.’

4 Discussion

Psychological assessment of both VAS and STAI results showed ‘more pleasant’ in PS and ‘more unpleasant’ in NS. These results showed the effectiveness of IADS in the Japanese population with a different culture and environment than an American/English population. Also, selected positive and negative sound stimulus could induce stressed and relaxed conditions, respectively.

Physiological assessment of HR showed smaller values and greater alpha wave in PS. Stress can induce sympathetic excitation [14] and cause a rapid increase in HR [15]. EEG reflects neuronal activities of the human brain which can be directly affected by emotional states. Especially the alpha wave (8-13Hz) appearance in the awake EEG with an eye closed condition seemed to indicate a relaxed state [6]. The mean amplitude of the alpha wave was significantly reduced while performing mental arithmetic and/or listening to an unpleasant tone [16]. The amplitude of the alpha wave while listening to a siren was reduced [17]. These two physiological assessments are also consistent with the effectiveness of IADS in the psychological assessments.

The results of the four above-mentioned assessments indicate that PS induced ‘pleasant’ and NS ‘unpleasant’, which might cause responses in the brain. Indeed, PS and NS induced Oxy-Hb increases in the bilateral PFC. The emotional task-induced PFC activation could cause activation of the HPA axis and influence ANS, on the basis of networks between the PFC and the medial hypothalamus and ANS [5] Further, the greater activation of the left side in PS and a tendency of more activation by NS in the right PFC were obtained in the present study. These results are similar to a neuropsychological study that used auditory stimuli and revealed greater left-hemisphere frontotemporal activation in response to positively valenced auditory stimuli, while bilateral frontotemporal activation was observed in response to negatively valenced auditory stimuli [18] and might support the valence asymmetry hypothesis [6, 7] in which the left hemisphere is specialized for the processing of positive emotions and the right hemisphere is specialized for the processing of negative emotions [8, 9].

In summary, despite the limitations of this study such as the low numbers of the subjects, the present study indicated that positive sounds provided pleasant psychological and physiological responses and negative sounds unpleasant responses. The PFC was activated bilaterally, implying a valence effect with the possibility of a dominant side.

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