International Journal of Psychophysiology 79 (2011) 259–265

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Association between interoception and empathy: Evidence from heartbeat-evoked brain potential

Hirokata Fukushima [a,b,*], Yuri Terasawa [a,c], Satoshi Umeda [a]

[a] Department of Psychology, Keio University, 2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan
[b] Japan Society for Promotion of Sciences, Tokyo, Japan
[c] Centre for Advanced Research on Logic and Sensibility, Keio University, Tokyo, Japan

ARTICLE INFO

Article history:
Received 9 April 2010
Received in revised form 14 October 2010
Accepted 27 October 2010
Available online 3 November 2010

Keywords:
Interoception
Empathy
Heartbeat-evoked potential (HEP)
Electrocardiography (ECG)
Social neuroscience

ABSTRACT

Physiological bodily states play an important role in affective experiences. This study investigated whether the neural processing of internal body state (interoception) is associated with empathy, the understanding of the affective states of others. We used the 'heartbeat-evoked potential' (HEP), a surface electroencephalography (EEG) pattern, as a neural index of interoceptive processing. The HEP is contingent on the most prominent peak (R-wave) of the electrocardiogram (ECG) and is thought to reflect cortical processing of cardiac afferent input. Twenty-one healthy adults performed empathy and control tasks while EEG and ECG were recorded, where they made judgments based on either the affective or physical aspects of images of human eyes. HEP, ECG and heart rate in each task block were calculated and compared. Results showed that cardiac activity was not significantly different between tasks. In contrast, HEP showed a significant task difference, exhibited as an increased negativity during the empathy task over frontocentral sites at a latency of approximately 250–430 ms. Furthermore, a self-reported measure of empathy was associated with mean HEP amplitude during the period of task-related differentiation. These results suggest that afferent feedback from visceral activity may contribute to inferences about the affective state of others.

1. Introduction

Several theories of the neural basis of affective experience have proposed that physiological changes in the body are closely associated with emotion. For example, increasing heartbeat or tension in the bowels often corresponds to increasing stress and negative emotion. Theorizing about the interplay of body and mind, pioneers of modern psychology James (1884) and Lange (1885) both posited counter-intuitive causality, such that bodily changes actually caused emotion rather than the other way around. Although there has been a historical debate on this directional causality, it is currently widely believed that an interaction between body and brain exists bi-directionally, highlighting the fundamental importance of the body in emotional phenomena (Lane, 2008; Craig, 2002; Cameron, 2001; Damasio, 1994; James, 1884).

Consequently, the role of visceral sensory system, termed interoception, has been emphasized as the biological basis of the interaction between body and mind (Craig, 2009; Wiens, 2005; Cacioppo et al., 2000; Damasio, 1999). In psychophysiology, interoception has frequently been investigated in terms of cardiac perception (Wiens, 2005; Craig, 2002; Cameron, 2001). Several functional neuroimaging studies have shown that overt attention toward individuals' heartbeat primarily activates the insula and anterior cingulate cortex (ACC), as well as somatosensory areas (Pollatos et al., 2007a; Critchley et al., 2004; Cameron and Minoshima, 2002). Importantly, these areas have been implicated in the subjective experience of emotion (Blood and Zatorre, 2001; Critchley et al., 2001; Damasio et al., 2000; Mayberg et al., 1999; Lane et al., 1997; Reiman et al., 1997). Recent research has suggested that an association exists between a person's sensitivity to their own heartbeat and the intensity of emotion they experience (Herbert et al., 2007; Pollatos et al., 2007b; Wiens et al., 2000). Furthermore, a number of studies have reported that measures of the accuracy of heartbeat perception positively correlate with measures of affective traits, such as tendencies for general anxiety (Pollatos et al., 2007a, 2009; Stewart et al., 2001). These empirical studies support the notion that the central monitoring and representation of bodily signals play a fundamental role in emotion. Against this background, the central question that motivates this paper is what about the relationship between the body of one's own and the emotion of *another* person.

The neural substrates of empathy, that is, the sharing or understanding of another person's affective experiences, have been consistently found to overlap the cortical regions involved in self experience (Iacoboni, 2005; Decety and Jackson, 2004; Keysers et al., 2004; Wicker et al., 2003). For instance, observing another person expressing negative or positive affect while experiencing various taste

---

* Corresponding author. Department of Psychology, Keio University, 2-15-45 Mita, Minato-ku, Tokyo 108-8345, Japan. Tel.: +81 3 5427 1833.
E-mail addresses: fukush@flet.keio.ac.jp (H. Fukushima), yu-ri@psy.flet.keio.ac.jp (Y. Terasawa), umeda@psy.flet.keio.ac.jp (S. Umeda).

0167-8760/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpsycho.2010.10.015

stimuli was found to activate the insula and frontal operculum in the observer's brain. These same areas were also activated when the observer experienced the same taste stimuli themselves (Jabbi et al., 2007). Observing others' pain has also been robustly found to activate the brain regions such as the insula and ACC (Lieberman and Eisenberger, 2009; Jackson et al., 2005; Singer et al., 2004). One popular interpretation of such ‘shared representation’ between self and other's experience (Decety and Sommerville, 2003) proposes that the brain represents other's experiences in terms of the experiences of the self. In other words, the brain may refer to one's own internal state to understand the experiences of others (Iacoboni, 2009; Singer and Lamm, 2009; Rizzolatti et al., 2006). Although this view has been broadly (and often implicitly) accepted, the details of this putative self-referential process for understanding others remain largely unclear.

As described previously, it is widely accepted that the bodily monitoring (interoception) is an important factor in experiencing emotion. Thus, this study hypothesized that the neural activities for interoception are also involved in processing the affective state of other people. We predicted that cortical activity underlying visceral monitoring would be modulated by whether an individual was engaged in empathy or not. To test this hypothesis, we conducted simultaneous recording of electroencephalography (EEG) and electrocardiography (ECG) while participants were performing tasks that either involved empathy, or involved only non-empathetic cognition. The neural activity underlying cardiac self-monitoring was examined in terms of its variation between periods of the empathy and the control tasks.

A type of event-related brain potential measured by EEG, termed the ‘heartbeat-evoked potential’ (HEP), has been examined previously to study the cortical processing of signals arising from cardiovascular activities (Schandry et al., 1986; Jones et al., 1986). This potential is derived by averaging EEG segments that are time-locked to the R-peaks of the ECG waveform, such that each EEG segment for analysis is placed in accord with a corresponding R-peak in the ECG waveform. Several studies have reported that the highest level of HEP activity is found at the frontocentral electrodes (Pollatos and Schandry, 2004; Leopold and Schandry, 2001; Schandry and Montoya, 1996; Montoya et al., 1993; Riordan et al., 1990). The cardiovascular signals involved in generating the HEP are presumably conveyed via the visceral pathway from baroreceptors within vascular tissues or myocardial regions such as the carotid sinus and aortic arch (Pollatos and Schandry, 2004; Dirlich et al., 1998; Schandry and Montoya, 1996). The anterior or central distribution of HEP mentioned previously is considered to reflect its origin, arising from cortical areas involved in visceroafferent processing, such as the insula, ACC, and somatosensory cortex (Pollatos et al., 2005).

Previous studies reported that the HEP reflects psychological states, which are related to heartbeat perception. For example, Schandry and Weitkunat (1990) trained participants to detect their heartbeat accurately by presenting them with feedback that had a temporal discrepancy between their repetitive button presses and their heartbeats. Participants that successfully increased their heartbeat sensitivity were found to show a significant change in HEP; there was a negative shift of the waveform compared with pre-training between 250 and 400 ms at Fz, F7, F8, and Cz sites. Several studies have also demonstrated that focusing attention on heartbeats resulted in a negative shift of the HEP, in the latency range of 250–500 ms for frontal and/or central locations (Yuan et al., 2007; Montoya et al., 1993; Schandry and Weitkunat, 1990; Riordan et al., 1990). These reports have suggested that the HEP can be a useful indicator of the cortical activity underlying interoceptive processing.

The primary aim of this study was to test for an association between interoception and empathy in terms of neural activity. We examined the HEP as an index of interoceptive cortical processing. Thus, our specific aim was to test whether the HEP was significantly different when participants were engaged with an empathy task, relative to a control task not involving explicit empathy. To this end, we measured EEG and ECG while participants performed tasks that either did or did not involve explicit empathic processing. Participants were presented with pictures showing portions of human faces that included the eyes, and required to judge either affective or physical characteristics of the eyes. In the affective-judgment block (which served as an empathy task), participants evaluated the affective state (positive or negative) of the eyes. In the physical-judgment block (used as a control task), participants evaluated the degree of symmetry of the eyes. The two tasks were performed in a block design, so that the HEPs in the two task periods could be compared with each other. Furthermore, to further examine the interaction between interoception and empathy, a standard self-reported empathy questionnaire was administered (Davis, 1983) to test for a possible correlation between the empathetic trait and HEP amplitude.

2. Methods

2.1. Participants

Twenty-one healthy Japanese undergraduate students (15 females, aged 18–22 years, mean 19.2 years) participated in the experiment. Participants were paid 3000 yen (≈30 USD at the time of experiment) in addition to receiving extra course credit. Written informed consent was obtained from each participant before the experiment. The ethics committee of the Faculty of Letters at Keio University approved this study.

2.2. Apparatus and procedures

Participants were seated ≈1 m in front of a 22-inch CRT display in an electrically shielded room. Participants held a four-button response box with their left hand. Stimuli were produced from a database of face images (provided by Softopia Japan Foundation, Gifu, Japan), containing faces of Japanese persons ranging from 15 to 64 years of age. A set of 240 images (120 females and 120 males) displaying neutral expressions were selected and the eye regions (8 cm width and 3.5 cm height on the display) were cropped for use as stimuli. This study used eye stimuli with neutral expressions to diminish changes in participants' arousal. We were mainly interested in how the central monitoring of the cardiovascular system differed between conditions, and aimed to minimize changes in participants' cardiac activity as much as possible.

Participants performed two types of tasks (Fig. 1). For the affective-judgment task, participants were instructed to judge the valence of each image (how positive or negative they imagined the person to be feeling). For the physical-judgment task, participants were instructed to judge how symmetrical each eye appeared. Participants executed both tasks in a block design with a pseudo-random order. Each block contained eight consecutive trials of either the affective- or physical-judgments. In each trial, an eye image presented for 3 s followed by an inter-stimulus interval (ISI) of 1 s. The ISI displayed one of two cues (‘Expression’ or ‘Structure’), indicating the type of on-going task, and displaying a 4-point scale (for the affective blocks, 1, very unpleasant, 2, unpleasant, 3, pleasant, and 4, very pleasant, and for the physical blocks, 1, very symmetric, 2, symmetric, 3, asymmetric, and 4, very asymmetric). Participants evaluated each stimulus with the four-button device, pressing the button that corresponded to the appropriate item on the 4-point scale. Participants were required to respond before the next stimulus appeared; they were allowed to respond either during the eye stimuli, or in the inter-stimulus interval. No time pressure was given during this period. Rest periods were inserted between each block, the length of which was controlled by the participant. During rest periods, the display informed the participant of the task that the next block involved (Fig. 1).