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Title	Heartbeat-evoked brain potential suggests association between interoception and empathy
Sub Title	
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Publisher	Centre for Advanced Research on Logic and Sensibility The Global Centers of Excellence Program, Keio University
Publication year	2011
Jtitle	CARLS series of advanced study of logic and sensibility Vol.4, (2010.) ,p.21- 30
JaLC DOI	
Abstract	
Notes	Part 1: Brain and Evolution
Genre	Research Paper
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO12002001-20110331-0021

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3 Heartbeat-evoked Brain Potential Suggests Association between Interoception and Empathy

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I. Introduction

Several theories of the neural basis of affective experience have proposed that physiological changes in the body are closely associated with emotion (James, 1884; Damasio, 1994).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). 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., 2007; Wiens et al., 2000).

In line with this context, 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. HEP has been considered to reflect the cortical activity underlying interoceptive processing (Schandry & Montoya, 1996; Pollatos & Schandry 2004).

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 eyes (Figure 1). The two tasks were performed in a block design, so that the HEPs in the two task periods could be compared with each other. In addition, 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.

II. Methods

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 in addition to receiving extra course credit. Written in-

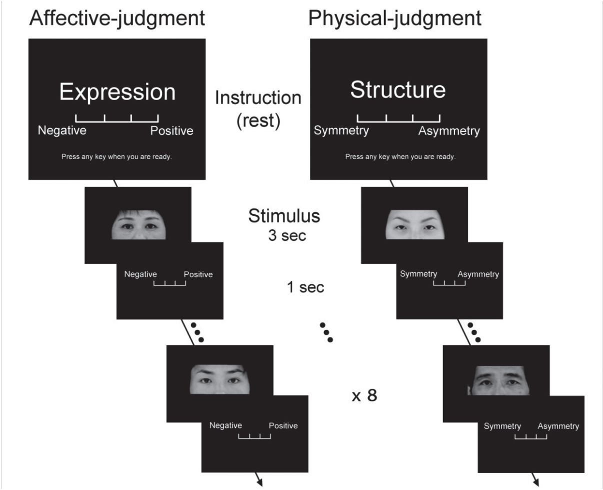

Figure 1. Task sequences.

formed consent was obtained from each participant before the experiment. The ethics committee of the Faculty of Letters at Keio University approved this study.

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. 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.

Participants performed two types of tasks (Figure 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 sec followed by an inter-stimulus interval (ISI) of 1 sec. The ISI displayed the type of task for the next block, as well as 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 during the tasks.

3. Electrophysiological measurements and analysis

Each participant's EEG, and ECG were recorded with Ag/Cl electrodes with a NeuroFax (Nihon-Kohden, Tokyo, Japan) system, sampled at 200 Hz with a 100-Hz low-pass filter. In the off-line analysis, a 30-Hz low-pass filter was reapplied. EEG electrodes were attached at 10 sites (Fz, F3, F4, FCz, Cz, C3, C4, Pz, P7, and P8, according to the International 10-20 system) using an electrode cap (Quik Cap; Neuroscan, Charlotte, NC), being referenced to the averaged mastoids. ECG electrodes were placed on the left and right wrist.

The peaks of the ECG R-waves were detected offline and used as triggers for EEG segmentation to calculate the HEPs. All EEG data were segmented into 900-ms epochs, including a 100-ms pre-stimulus baseline period, based on the R-peak markers. Segments in the affective- and physical-judgment blocks were averaged separately to calculate the HEPs for each condition. Only segments less than ±100 μV in each channel were analyzed and baseline-corrected. After obtaining raw HEPs, ECG artifacts on them were removed with the method described by Schandry and Weitknut (1990). The artifact-corrected HEPs in each channel were subjected to a successive two-tailed within-subject t-test at each data point. This test was combined with nonparametric cluster-based statistics to control for multiple comparisons (Maris & Oostenveld, 2007).

ECG waveforms were segmented into 1200-ms epochs based on the R-peaks including a 300-ms pre-R period to cover the PQ-segments. ECG segments of periods in which EEG data survived the artifact rejection were averaged for each task. The P- and T-wave amplitudes of the ECG signal were calculated and compared between tasks with within-subject two-tailed t-tests. Two-tailed t-tests were also applied at each ECG data point to further test possible task-related modulation.

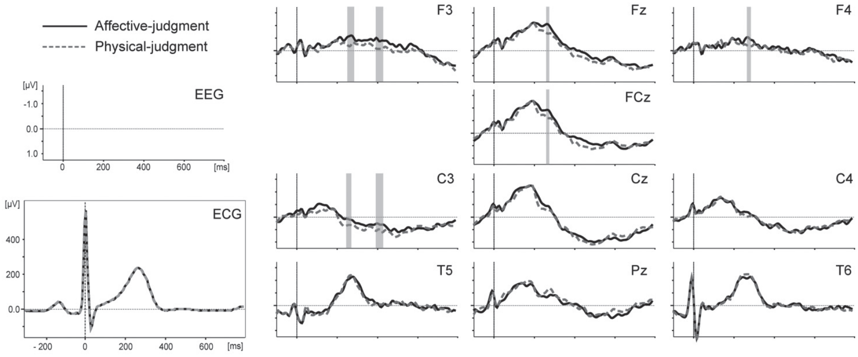

Figure 2. The grand-averaged HEP waveforms corrected for ECG contamination in two task conditions.
Shaded squares overlaid on the waveforms show the periods of statistically significant between-task differences. ECG waveforms are also illustrated; note that the ECGs for the two tasks overlap each other.

4. Questionnaire

During preparation for the physiological measurements, participants filled out a paper questionnaire measuring the tendency to empathy: the Interpersonal Reactivity Index (IRI; Davis, 1983).

III. Results

1. Cardiac measurements

The average (and SDs of) heart rate of participants during each task type were 63.25 (8.87) bpm for the affective-judgment blocks and 63.45 (8.95) bpm for the physical-judgment blocks. There was no significant difference between tasks (t_{20} = .62, p = .54).

The average P-wave amplitudes on the ECG were 45.79 (18.51) μV for the affective blocks and 46.04 (18.90) μV for the physical blocks, indicating that there was no task-related difference (t_{20} = .58, p = .57). The T-wave amplitudes were 286.16 (104.458) μV for the affective blocks and 286.00 (104.459) μV for the physical blocks, again showing no task difference (t_{20} = .14, p = .88). ECG waves were also subjected to a successive two-tailed within-subject t-test at each data point, comparing data for the two tasks, and

Table 1: Periods of significant differences between tasks in corrected HEP. Latencies for each period (shown in ms) and correlation coefficients (Pearson's r) for relationship between task-difference in HEP amplitude and scores on the empathy questionnaire (empathic concern in the IRI) are displayed. HEP amplitudes were calculated as differences in the mean amplitudes of each period between tasks (affective-judgment vs. physical-judgment).

	F3		C3		F_Z	FC_Z	F4
Latency for the task difference	250-285	395-430	245-270	395-430	260-275	260-275	265-285
Mean t-values	2.510	2.348	2.366	2.505	2.402	2.126	2.227
Correlation with the empathy score							
Affective-judgment task	0.53*	0.25	0.31	0.24	0.39†	0.19	0.45*
Physical-judgment task	0.36	0.18	0.29	0.13	0.41†	0.30	0.50*
Task difference	0.44*	0.16	0.08	0.13	0.07	-0.03	-0.19

†$p < 0,1$, *$p < 0.05$

no significant task difference was detected. ECG waveforms are illustrated in Figure 2, showing the total overlap between the two task conditions.

2. Brain potential (HEP)

Figure 2 shows HEPs following ECG-artifact correction. In the articat-corrected HEPs, a couple of periods of significant group differences were detected around fronto-central sites (F3, Fz, F4, FCz, and C3) in the latency range of 245 - 285 ms after the R peak. Left-hemispheric sites (F3 and C3) also exhibited a task difference in the latency range of 395 – 430 ms (see Table 1).

3. Correlation between empathy score and HEP

Average empathy questionnaire ('empathic concern'; EC) score (and SD) was 20.81 (4.35). To test for a correlation between questionnaire score and the HEP, mean amplitudes of HEPs for both task blocks were calculated at the electrodes within the periods in which significant task-related difference was detected (Table 1). The differences in mean amplitudes between the two tasks were also calculated in each period and electrode. The correlation between these amplitudes (from the two tasks and their differences) and EC scores was then calculated. Correlation coefficients (Pearson's r) for each test are illustrated in Table 1. HEP amplitudes for the affective-judgment task showed significant positive correlations at fronto-lateral sites (F3: $r_{21} = 0.53$, $p = 0.013$ and F4: $r_{21} = 0.45$, $p = 0.042$) in the 250 – 285 latency range.

Unexpectedly, the amplitude at F4 within the same period elicited in the physical-judgment task also correlated with EC score (r_{21} = 0.50, p = 0.022). Fronto-medial sites in the same latency range also showed weak correlations with trait scores, but these did not reach significance (Fz; in the affective task: r_{21} = 39, p = 0.080 and the physical task: r_{21} = 0.41, p = 0.062). As for the task-difference in HEP amplitude, the potentials recorded from F3 exhibited a significant correlation with EC score (r_{21} = 0.44, p = .048).

IV. Discussion

The present study examined whether interoceptive processing, considered to contribute to the basis of emotion, is associated with empathy, the ability to understand emotion in others. To this end, HEPs and cardiac responses of participants while performing empathy and control tasks (affective and physical judgment) were compared. Results did not reveal any task-related differences in cardiac measures (heart rate and ECG waveforms), whereas a significant task-related difference was observed in the HEP, which is considered to reflect cortical processing of cardiac activity. In addition, we detected a correlation between self-rated empathy scores and HEP amplitude. These results suggest that cardiac monitoring in the brain may be involved in processing the affective mental states of others.

It is well known that changes in cardiac activity, such as heart rate and amplitude of ECG components, are often accompanied by changes in emotional states (e.g. Furedy et al. 1996; Ekman et al., 1983). Although the present study monitored ECG only with lead-II derivation, which provides limited information of cardiac depolarization, there were no measures showing task-related difference in cardiac activities. This is likely to have occurred because task stimuli were eyes displaying neutral expressions, so that variations in participants' arousal were too slight to alter their cardiac state. Importantly, despite the absence of cardiac effects, HEP waveforms showed short-lasting but significant differences between the tasks. This result suggests that what changed the HEP waveform was not the afferent cardiac signal itself, but the cortical monitoring of it.

The difference in the HEP waveform was observed as a negative shift for the affective-judgment task relative to the physical-judgment task at frontal electrodes in a latency range of approximately 250 –430 ms. This result is in line with the results of previous studies showing that bodily attention influences the HEP waveform. In these previous studies, when participants were required to attend to their heartbeats, the HEP was modulated as a negative shift in frontal or central sites roughly around a 250–500 ms latency range, compared with HEP in the baseline state (Montoya et al., 1993; Schandry & Weitkunat, 1990; Riordan et al., 1990). Although the current task did not explicitly require participants to attend their heartbeat, we propose that the brain may implicitly increase its sensitivity in self-monitoring bodily states during empathic processing.

In addition to the differentiation of the HEP waveform, we also observed an association between the amplitude of HEP and scores on an empathy scale. The HEP amplitude recorded at frontal electrodes in the earlier period (approximately 250–280 ms latency range) was found to be correlated with empathy score. Specifically, left frontal (F3) potentials showed an association in the affective-judgment task, as well as in the amplitude difference with the physical-judgment task. This correlation lends support to the hypothesis that a link exists between empathy and physiological monitoring.

Unexpectedly, EC scores significantly correlated with HEP amplitude not only in the affective-judgment task, but also in the physical-judgment task, which was designed to act as a non-affective control task. We consider that this result could reflect implicit emotional processing (emotional empathy) also be involved in the physical task, even though explicit processing (cognitive empathy) was not required in this task.

Concerning possible neural substrates under the current findings, one previous study estimated that the sources of the HEP were located in the intra-operculum and the medial frontal lobes (particularly the insula and ACC; Pollatos et al., 2005). These cortical regions receive afferent feedback from the peripheral nervous system via the nucleus of the brain stem, hypothalamus and thalamus (Craig, 2002; Cameron, 2001). Several neuroimaging studies reported that these regions are actually activated during tasks for heartbeat perception (Critchley et al. 2004; Pollatos et al. 2005). Taken together, we propose that the influence of task on the HEP in the present study might reflect modulation in the intra-operculum and/or medial areas of the frontal lobe. However, techniques with higher spatial resolution than ERP measures are more suitable for elucidating the locus of neural interaction between interoception and social cognition in detail.

Overall, the present results suggest the existence of an interaction between the neural substrates of cardiac monitoring and affective cognition. In other words, the results indicate that interoception may be involved in empathy. The use of HEP measurements to examine neural activity directly reflecting interoceptive processing in the background of another simultaneous cognitive task has methodological advantages for further investigation of the interactions between body and mind.

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