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著者	Fukushima Hirokata, Terasawa Yuri, Umeda Satoshi
journal or publication title	International Journal of Psychophysiology
volume	79
number	2
page range	259-265
year	2011-02
権利	(C)Elsevier, This article is Post Print-Version. Publisher-Version is available at http://www.sciencedirect.com/science/article/pii/S0167876010007403
URL	http://hdl.handle.net/10112/7557

doi: 10.1016/j.ijpsycho.2010.10.015

Manuscript accepted for publication in *Internationa Journal of Psychophysiology* 2011, 79(2), 259-265
http://dx.doi.org/10.1016/j.ijpsycho.2010.10.015

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

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Running head: Interoception and empathy

Key words: 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.

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, Berntson, Sheridan, & McClintock, 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, Schandry, Auer, & Kaufmann, 2007; Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004; Cameron & Minoshima, 2002). Importantly, these areas have been implicated in the subjective experience of emotion (Blood & Zatorre, 2001; Critchley, Mathias, & Dolan, 2001; Damasio et al., 2000; Mayberg et al., 1999; Lane, Reiman, Ahern, Schwartz, & Davidson, 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, Pollatos, & Schandry, 2007; Pollatos, Traut-Mattausch, Schroeder, & Schandry, 2007; Wiens, Mezzacappa, & Katkin, 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, Traut-Mattausch, & Schandry, 2009; Pollatos, Traut-Mattausch, et al., 2007; Stewart, Buffett-Jerrott, & Kokaram, 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 & Jackson, 2004; Keysers et al., 2004; Wicker et al., 2003). For instance, observing another person expressing negative or positive affect while experiencing various taste 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, Swart, & Keysers, 2007). Observing others' pain has also been robustly found to activate the brain regions such as the insula and ACC (Lieberman & Eisenberger, 2009; Jackson, Meltzoff, & Decety, 2005; Singer et al., 2004). One popular interpretation of such 'shared representation' between self and other's experience (Decety & 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 & Lamm, 2009; Rizzolatti, Fogassi, & Gallese, 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 above, 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, Sparrer, & Weitkunat, 1986; Jones, Leonberger, Rouse, Caldwell, & Jones, 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 frontocentral electrodes (Pollatos & Schandry, 2004; Leopold & Schandry, 2001; Schandry & Montoya, 1996; Montoya, Schandry, & Muller, 1993; Riordan, Squires, & Brener, 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 & Schandry, 2004; Dirlich, Dietl, Vogl, & Strian, 1998; Schandry

& Montoya, 1996). The anterior or central distribution of HEP mentioned above is considered to reflect its origin, arising from cortical areas involved in visceroafferent processing, such as the insula, ACC, and somatosensory cortex (Pollatos, Kirsch, & Schandry, 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, Yan, Xu, Han, & Yan, 2007; Montoya, et al., 1993; Schandry & 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 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.

Methods

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.

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 (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 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 (Figure 1).

Figure 1 about here.

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 (shown in Figure 2), the ECG waveforms were scaled to fit EEG channels and subtracted from raw HEP waveforms to remove ECG artifacts, following the method described by Schandry and Weitknut (1990). Coefficients for multiplying the ECG waveforms to fit EEG waves were calculated using a least-squares method with amplitudes in the latency range of the ECG-R wave (30 ms before to 30 ms after the R-peak). Amplitude fitting was computed for each head channel because ECG contamination was expected to differ across cranial sites.

Previous studies showed modulation of HEPs in somewhat scattered scalp regions (around central or frontal sites) and a range of latencies (broadly between 200 and 600 ms; Pollatos & Schandry, 2004; Montoya, et al., 1993; Schandry & Weitkunat, 1990; Riordan, et al., 1990). As such, we explored all data points and electrode sites to investigate task differences in the HEP wave, rather than postulating *a priori* regions and latencies of interest. 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). In this analysis, all data points where $p < 0.05$ (uncorrected) were identified and clustered on the basis of temporal and spatial adjacency. Cluster-level statistics were then calculated by taking the sum of the t-values within each cluster. The probabilities of these cluster-level statistics were calculated by performing a large number (1,000 times) of random assignments of conditions (i.e. tasks) across 21 subjects. The significance threshold (corrected) in the given data was determined based on a histogram of the clustered statistics derived from this Monte Carlo test.

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. It has been reported that the ECG waveforms, such as the amplitude of the P-wave and T-wave, are modulated mainly by sympathetic activity, and could reflect psychological states (Hijzen & Slangen, 1985; Kline, Ginsburg, & Johnston, 1998; Furedy, Szabo, & Peronnet, 1996). Thus 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.

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). Scores on the IRI subscale termed ‘empathetic concern’, which reflects the capacity of the respondent for warm, concerned, compassionate feelings for others, were calculated for each participant. This measure has been shown to positively correlate with the magnitude of neural activity related to empathy, for instance, that of insula activity during pain observation (Singer et al., 2006; Singer, et al., 2004).

Results

Behavioral measurement

In both the affective-judgment and physical-judgment tasks, evaluation of stimuli was performed with a four-point scale (1, 2, 3, and 4. Mean 2.5). The average judgment scores on the affective and physical tasks (and SDs) were 2.40 (0.25) and 2.49 (0.26), respectively.

Figure 2 about here.

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

Brain potential (HEP)

Raw waveforms of grand-averaged HEPs for the affective and the physical judgment tasks are shown in Figure 2. These uncorrected waveforms show the contamination of the ECG data. The raw HEPs contained sharp peaks at all electrode sites in the latency of the ECG R-wave. The HEPs evoked in both tasks exhibited comparable waveforms, but some differences were detected around frontal electrode sites. Continuous *t*-tests revealed increased negative amplitude in the affective trials compared with the physical trials at left frontal (F3) and medial frontal (Fz) electrodes within a latency range of 250 – 285 ms (F3: 250 – 285 ms; Fz: 260 – 275 ms).

Figure 3 about here.

Table 1 about here.

Figure 3 shows HEPs following ECG-artifact correction. In the corrected HEPs, broader periods of significant group differences were detected in comparison to the differences in the raw HEPs, 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).

Correlation between empathy score and HEP

Average empathy questionnaire ('empathic concern'; EC) score (and SD) was 20.81 (4.35). This distribution falls within the average range reported previously for a normal Japanese population (Sakurai, 1988). To test for a correlation between questionnaire score and the HEP, mean amplitudes of artifact-corrected 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).

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 (Furedy, et al., 1996; Ekman, Levenson, & Friesen, 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 accord with this suggestion, it has been indicated that emotion influences sensitivity of external perception (such as visual perception) at early stages of processing (Vuilleumier & Driver, 2007; Phelps, Ling, & Carrasco, 2006). Thus, it is possible that similar interactions exist between emotion and interoception, and that this was reflected as HEP modulation in the current results.

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.

However, several unexpected patterns were exhibited in the relationship between neural responses and EC. First, the correlation between HEP and the questionnaire score emerged as a positive, rather than an inverse, correlation. That is, a higher trait empathy score corresponded to a positive deflection in the recorded potential. Because the influence of the affective task on the HEP was observed as an amplitude shift in the negative direction, an inverse correlation between the HEP amplitude and empathy score would be expected. As such, the positive correlation shown in the results appears difficult to interpret. Previous studies have, however, also reported similar discrepancies in the properties of the HEP. Studies on individual differences have demonstrated that HEPs from good heartbeat perceivers tend to show more positive deflection than bad perceivers within ≈350 ms latency (Pollatos & Schandry, 2004; Katkin, Cestaro, & Weitkunat, 1991), although within-subject examinations have shown that directing attention toward heartbeats can cause negative deflection (shift to the cathode direction) as illustrated above. This discrepancy between intra- and inter-individual variations in the HEP has not yet been resolved. The result of the present study was at least in accord with some previous reports.

Second, 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. The nature of empathy processing, as well as the characteristics of the current tasks must be considered in interpreting this result. The evaluation of another person's emotion can be achieved in more than one way, i.e. via autonomic perception ("emotional empathy"), and/or intellectual reasoning of the other's mental state ("cognitive empathy"; Decety & Lamm, 2006; Preston & de Waal, 2002; Davis, 1983). The present affective task primarily involves cognitive aspects of empathy, for the reasons mentioned above. However, it should be noted that the participants were presented with eye image stimuli not only in the affective-judgment task, but also in the physical-judgment task. Thus, *implicit* emotional processing (emotional empathy) might also be involved in the physical task, even though explicit processing (cognitive empathy) was not required in this task. Considering that the EC score is a measure of an emotional (rather than cognitive) aspect of the empathic trait (Davis, 1983), implicit and automatic emotion perception might have influenced the physical-judgment task so that the HEPs in this task appeared to be associated with scores on the empathy questionnaire. Nevertheless, the HEP demonstrated intra-individual modulation as a function of task, and the difference in amplitude between the tasks also showed a correlation with questionnaire score. These results suggest an interaction between interoception and empathy in terms of neural processing. On the other hand, only limited conclusions can be drawn from the correlation analysis between ERP data and single trait questionnaire score. As such, individual differences in HEP and other socio-emotional traits should be further examined in future research.

Overall, we found that a task of interest modulated brain electrophysiological potentials, and the potential of interest showed a correlation with a trait measurement that was relevant to the task. Taken together, 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 measurement of ERPs generally provides little information about the exact spatial locations of the neural origin of measured signals. Moreover, the present experiment involved a limited number of electrodes and did not utilize source localization methods. Therefore only speculative conclusions can be drawn about the neural mechanisms underlying the present findings, based on previous reports. 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, 2003; Cameron, 2001). Previous functional neuroimaging studies have robustly reported the activation of these viscerosensory areas during tasks requiring interoceptive awareness (Pollatos, Schandry, et al., 2007; Critchley, et al., 2004; Van Oudenhove, Demyttenaere, Tack, & Aziz, 2004). In addition, some previous functional neuroimaging studies utilizing stimuli and tasks similar to the present experiment reported activation of the same frontal regions (Baron-Cohen et al., 1999; Mitchell, Banaji, & Macrae, 2005). Therefore, 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.

Finally, it should be noted again that social cognition (including empathy) consists of a range of multidimensional processes, which are typically described along the emotional/cognitive or reflexive/reflective dimensions (Lieberman, 2007; Preston & de Waal, 2002; Davis, 1983). While the present study was concerned with cognitive aspects of empathy, it would be helpful for future research to examine emotional empathy, characterized as an automatic sharing of emotion, using the current paradigm. For example, future studies could investigate the neural response to observing strong emotions in others that might elicit actual cardiac changes in the observer. Moreover, non-affective mentalizing (theory of mind) is another suitable target for future research into mind-body interaction. In addition, functional properties of the HEP, such as the possible effects of cognitive load and task difficulty, are still largely unknown. To clarify the general properties of the HEP, further exploration into the relationships among personal traits, social behavior, physiological response, and neural activity for interoception are required.

Conclusion

Interoception is widely considered to be a fundamental factor in the generation of emotion. The present study demonstrated that cortical activity underlying interoception is influenced by overt socio-emotional cognition. We found modulation of interoceptive processes associated with an empathy task (affective judgment of others) and individual differences regarding empathy traits. Taken together with previous findings, these data suggest that the central monitoring of the cardiovascular activity of one's own body is likely to be involved in processing the affective states of others. 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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Figure Legends

Figure 1. Task sequences. Participants performed two types of task in a block design. For a block of the affective-judgment (empathy) task, participants evaluated the affective valence and magnitude of the person depicted in each photo. In the physical-judgment (control) task, they evaluated the symmetry of the observed person's eyes. Each block contained eight consecutive trials from either of the two tasks.

Figure 2. The raw waveforms of grand-averaged heartbeat evoked potentials (HEPs) in two task conditions. All potentials are aligned to the R-wave of the ECG. Shaded squares overlaid on the waveforms at F3 and Fz show the period of statistically significant between-task differences (250 – 285 ms). ECG waveforms are illustrated with extending pre-R-wave period to cover whole ECG components. Note that the ECGs for the two tasks overlap each other.

Figure 3. The 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 (245 – 285 ms and 395 – 430 ms latency range).

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		Fz	FCz	F4
Latancy 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

† $p < 0.1$, * $p < 0.05$

Figure 1

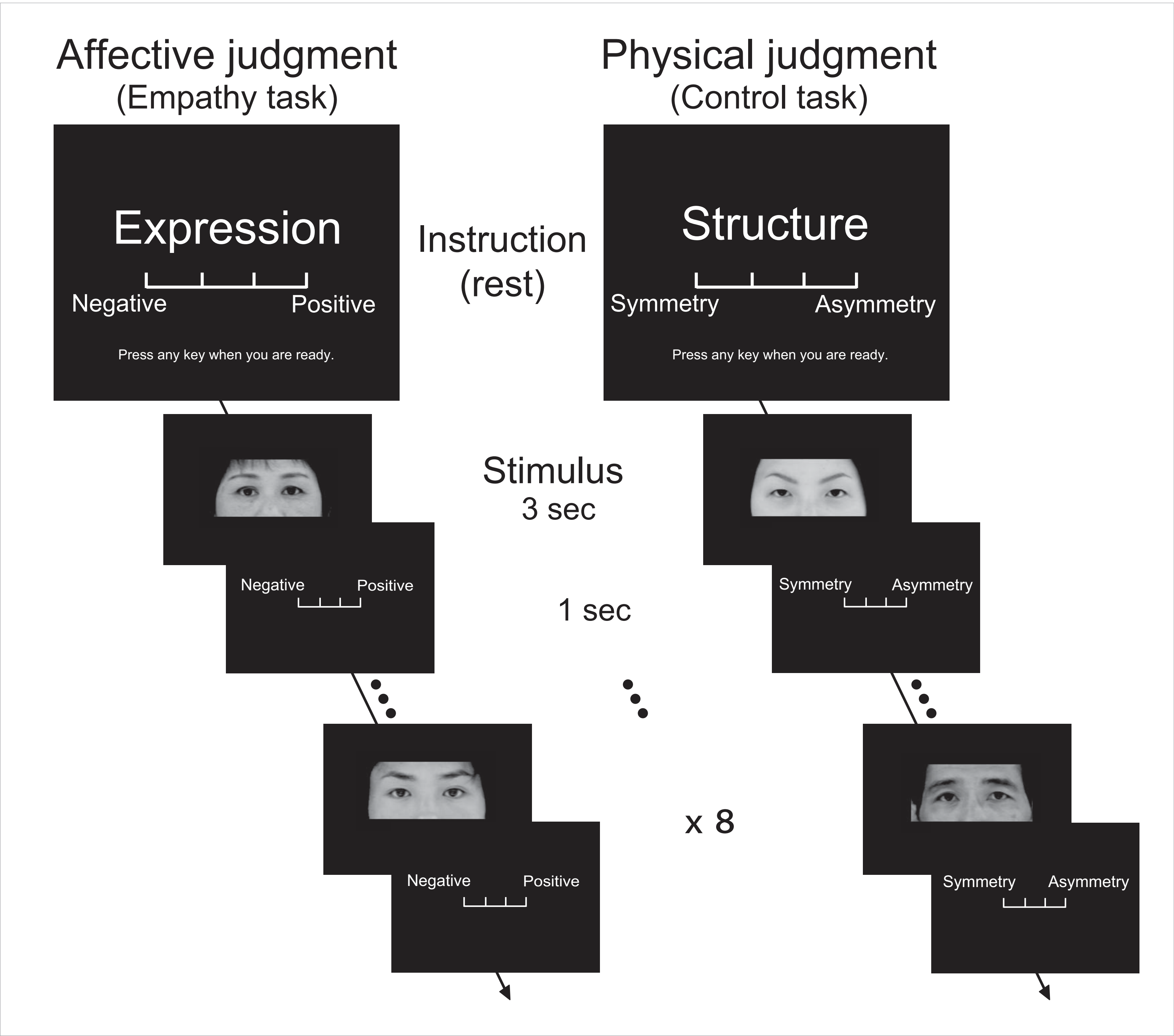
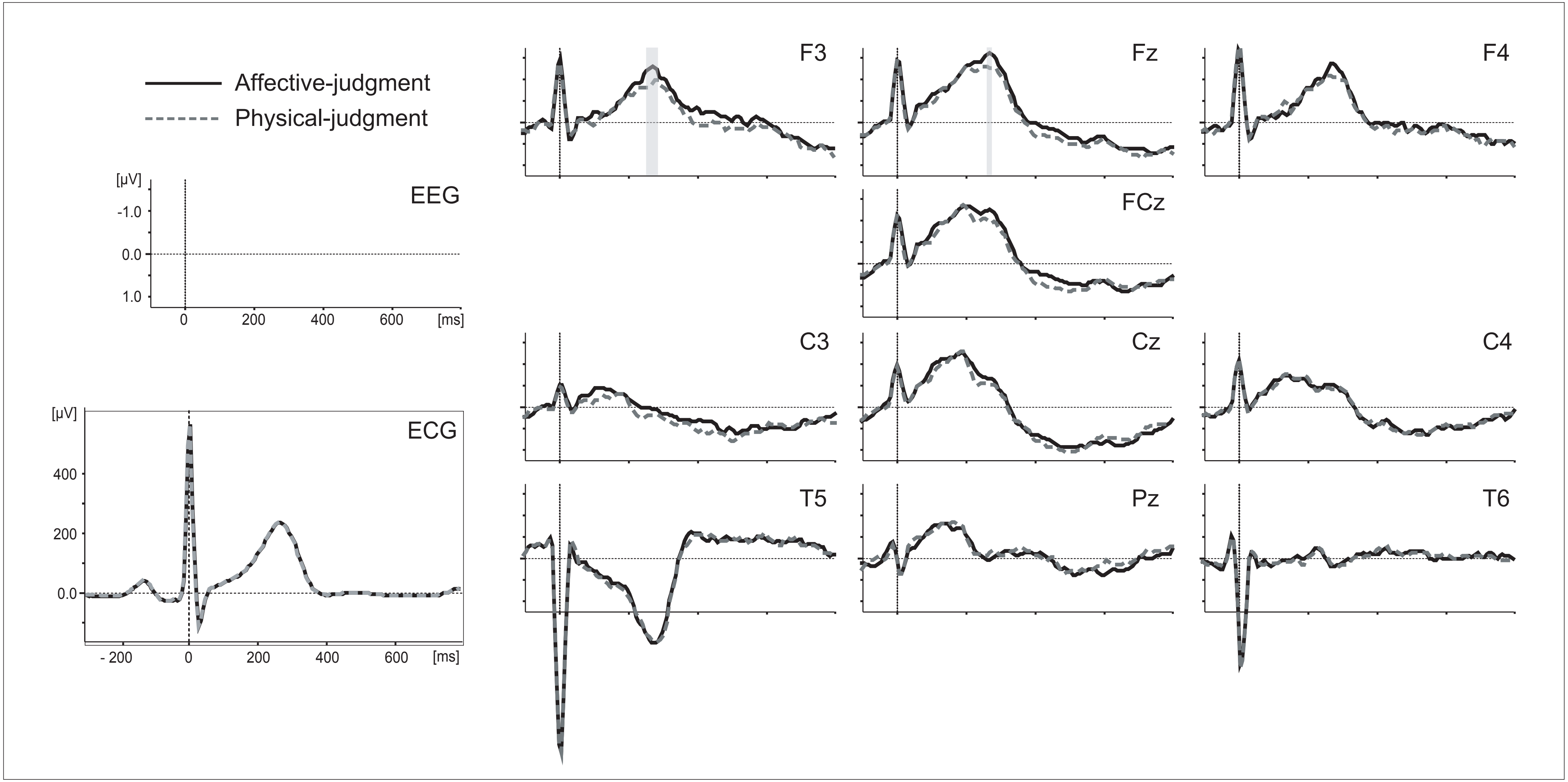

Affective judgment
(Empathy task)
Physical judgment
(Control task)
Expression
Negative
Positive
Press any key when you are ready.
Instruction
(rest)
Structure
Symmetry
Asymmetry
Press any key when you are ready.
Stimulus
3 sec
Negative
Positive
1 sec
Symmetry
Asymmetry
x 8
Negative
Positive
Symmetry
Asymmetry

Figure 2


Affective-judgment
Physical-judgment
[µV]
-1.0
0.0
1.0
EEG
0
200
400
600
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ECG
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400
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- 200
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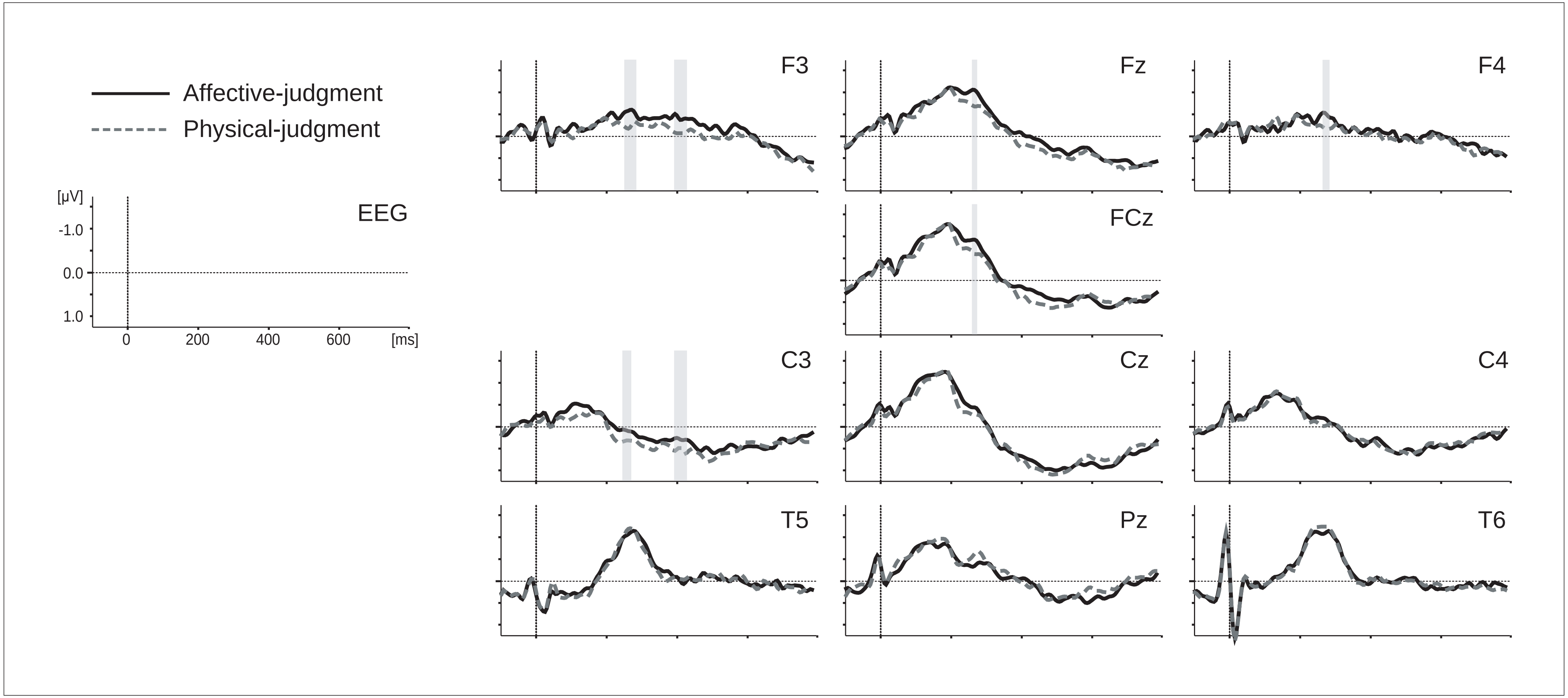
F3
Fz
F4
FCz
C3
Cz
C4
T5
Pz
T6

Figure 3


Affective-judgment
Physical-judgment
[µV]
-1.0
0.0
1.0
0
200
400
600
[ms]
EEG
F3
Fz
F4
FCz
C3
Cz
C4
T5
Pz
T6