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Heartbeat perception and P300 amplitude in a visual oddball paradigm

Olga Pollatos *, Ellen Matthias, Rainer Schandry

Department of Psychology, University of Munich, Leopoldstr. 13, 80802 Munich, Germany

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Abstract

Objective: The perception of bodily signals (''interoceptive awareness'') was found to modulate evoked potential components, especially the P300, in response to emotional pictures and to internal signals. It remains an open question whether this variable is related to more elaborated information processing in general.
Methods: The present study investigated the relationship between heartbeat perception and the amplitude of the P300 to target stimuli in a visual oddball paradigm.
Results: Interoceptive awareness was positively correlated with the P300 amplitude at Cz which remained significant after controlling for anxiety differences.
Conclusions: Our results demonstrate a positive relationship between interoceptive awareness and the attentive processing of visual stimuli.
Significance: Interoception is related to more elaborated information processing in general. This effect could be mediated by arousal differences and might rely on common neuroanatomical structures.

Keywords: Event-related potentials (ERPs); Visual attention; Interindividual differences; Interoceptive awareness; Trait anxiety; P300

1. Introduction

Mental processes related to visceral activity have regained growing interest during the last few years. Bodily changes and the ability to perceive these bodily changes (''interoception'', ''interoceptive awareness'') have found their way to modern neuropsychological theories such as the somatic marker theory of Damasio (Bechara and Naqvi, 2004; Damasio, 1999; Damasio et al., 2000). It incorporates feedback from the periphery to the cortex and postulates that many mental processes are influenced by ''marker'' signals arising through bioregulatory processes. Perceiving internal signals and their changes should facilitate decision making and performance in many everyday situations.

In order to assess the perception of bodily changes, the most extensively studied interoceptive process is heartbeat perception (Cameron, 2001; Wiens, 2005). The ability to detect one's heartbeats accurately can be measured by different heartbeat detection tasks and is often equated with interoceptive ability or interoceptive awareness in general (Critchley et al., 2004; Katkin et al., 2001; Pollatos et al., 2005a; Wiens, 2005). One common observation is the existence of substantial, interindividual differences in heartbeat perception, probably depending on such factors as gender, age, percentage of body fat and physical fitness (Cameron, 2001). But also other variables like anxiety or neuroticism were found to be correlated to heartbeat perception in healthy subjects (Critchley et al., 2004; Pollatos et al., in press-a, in press-b).

Concerning the processing of internal signals several studies could demonstrate that interoceptive awareness is related to the amplitude of central components of signal processing (Leopold and Schandry, 2001; Pollatos et al., 2005a; Pollatos and Schandry, 2004) and to activation

* Corresponding author. Tel.: +49 89 2180 6356; fax: +49 89 2180 5233.
E-mail address: pollatos@psy.uni-muenchen.de (O. Pollatos).

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strength of underlying brain structures (Critchley et al., 2004; Pollatos et al., in press-a). Recent studies on interoception and emotion (Pollatos et al., 2007a; Pollatos et al., 2005b) suggest that heartbeat perception is also correlated to evoked potential components, especially the P300 and the slow wave in response to emotional pictures chosen from the International Affective Picture System (Lang et al., 1999). Taking both results together it remains an open question whether interoceptive awareness is related to more elaborated information processing in general in response to stimuli of any kind.

The central processing of visual stimuli can be studied by means of event-related potentials (ERPs). The oddball paradigm is one of the most often used experimental designs in attention research and offers the possibility to investigate possible interactions between interoceptive awareness and the P300 amplitude as one index of attention and processing capacity (Polich and Kok, 1995). Using an oddball paradigm also provides the chance to compare these results with the VEPs to emotional pictures where most pronounced differences between subjects with high and poor interoception were found in the P300 time range (Pollatos et al., 2007a; Pollatos et al., 2005b). The P300 time range is interesting out of a second reason, too: a substantial part of interindividual P300 variation is attributable to the arousal level of the individuals (Polich and Kok, 1995). Former research has shown that interoceptive awareness co-varies both with reported arousal (Barrett et al., 2004; Pollatos et al., in press-b; Wiens et al., 2000) as well as peripheral indices of arousal such as cardiovascular reactivity (Pollatos et al., 2007) to emotional stimuli.

One could suggest that arousal differences could also be present during information processing and could mediate the P300 response in an oddball paradigm. If differences in the level of interoceptive awareness have physiological correlates that affect how information is processed and if this effect is not limited to emotional information alone, then interoceptive awareness should be associated with differences in basic information processes as measured by the P300 amplitudes to task-relevant stimuli.

The present study aimed at investigating the relation between heartbeat perception and the cortical processing of visual stimuli. Using an oddball paradigm we hypothesized a positive relation between interoceptive awareness and P300 amplitudes to task-relevant stimuli. As anxiety was found to be related to interoceptive awareness both in healthy participants (Critchley et al., 2004; Pollatos et al., in press-a, in press-b) as well as in clinical populations (Ehlers, 1995; Eley et al., 2004; Pineles and Mineka, 2005; Roth et al., 1992; Wald and Taylor, 2005; Zoellner and Craske, 1999) – though results are not univocal (Van der Does et al., 2000) – the mediating role of anxiety should also be further clarified.

2. Method

2.1. Participants

The sample consisted of 36 students (10 male) of the University of Munich. Subjects received € 20 (about $ 20) for their participation. The mean age was 27.6 (SD 7.2) years. The body mass index was 21.0, reported physical fitness on a five-point self-report scale (varying between 1 for very low and 5 for very high degree of physical fitness) was 3.7, reported average consumption of nicotine was 1.7 (mean amount of cigarettes on the present day and the day before) and alcohol was 0.2 (mean amount of alcohol on the day before). All experiments were conducted in accordance with the Declaration of Helsinki. All subjects gave their written informed consent.

2.2. Stimulus material

In the visual oddball paradigm, 80 white and 20 red crosses were used. The red crosses, which served as target stimuli, were presented randomly with a probability of occurrence of 20%. All pictures were presented approximately at a distance of 1.9 m from the subjects' eyes. The visible size of the pictures was 75×50 cm, resulting in a picture presentation with a visual angle of 22° horizontally, and 15° vertically.

2.3. Procedure

All experiments took place between 9 and 12 o'clock a.m. to control for diurnal influences. All subjects should have had their normal breakfast including coffee or tea. Upon arrival, subjects were given written information about the experiment and informed consent was obtained. First they filled in a questionnaire concerning personal data (height, weight, age, smoking attitudes, drinking attitudes, physical fitness on a five-point scale, task motivation based on three items asking about general motivation, interest and will to effort on a five-point scale) and the anxiety inventory by Spielberger et al. (1983) assessing state and trait anxiety. Additionally, a short semi-structured interview was conducted in order to rule out that there were physical or mental health problems and that medication was currently in use in all participants chosen for this experiment. Next, they were seated in a comfortable chair in a sound-attenuated chamber connected to the adjacent equipment room via intercom. Here, the electrode cap, the encephalic, EOG and ECG electrodes were attached. During this preparation time, all subjects were offered a cup of coffee or black tea. Following this, the heartbeat perception task was performed. During three intervals of 25, 35 and 45 s, participants were asked to count their own heartbeats silently in accordance with the mental tracking method suggested by Schandry (1981). The beginning and end of the counting phases were signalled by a start and stop tone. During heartbeat counting, subjects were instructed not to take their pulse or attempt to use other manipulations facilitating the counting of heartbeats. After the stop signal, subjects were required to verbally report the number of counted heartbeats. Subjects were not informed about the length of the counting phases or about their performance. A heartbeat perception score was calculated as the mean score of three heartbeat perception intervals according to the following transformation:

$$1/3\Sigma(1 - (|\text{recorded heartbeats} - \text{counted heartbeats}|)/\text{recorded heartbeats})$$

Finally, a visual oddball task was performed. Within 100 slides, 20 target slides were presented in randomized order. Each slide was visible for 1 s with an interstimulus interval of 3 s. Subjects had to watch attentively and silently count the number of target slides. At the end of the run subjects had to report the counted number of targets. The run lasted about 20 min.

2.4. EEG recording

EEG activity was recorded from 14 electrodes (FP1, FP2, FPZ, F3, F4, FZ, C3, C4, CZ, P3, P4, PZ, TP9, TP10) determined with an electrode cap (easy cap, Falk Minow Services). A DC amplifier (bandpass: 0.01–100 Hz; SYNAMPS, Neuroscan) was used, data were digitised at a sampling rate of 1000 Hz. The reference electrode was positioned at the tip of the nose, the ground electrode was placed on the left cheek. Offline, EEG was re-referenced to linked mastoids. Horizontal and vertical electro-oculograms (EOG) were recorded with two plus two electrodes placed lateral to the outer canthus of each eye (EOG_H) and above and below the left eye (EOG_V). Nonpolarizable Ag–AgCl electrodes were used. Electrode resistance was maintained at lower than 5 kΩ.

2.5. ECG recording

During the heartbeat perception task an ECG was measured using nonpolarizable Ag–AgCl electrodes attached to the right mid-clavicle and lower left rib cage. ECG activity was recorded analogous to the EEG with a DC amplifier (bandpass: 0.01–100 Hz; SYNAMPS, Neuroscan) and digitised at a sampling rate of 250 Hz.

2.6. Data reduction and analysis

The EEG record was examined for EOG, muscle activity, and other sources of electrophysiological artefacts. The analysis software (Brain Vision) performed EOG correction for blinks. EEG epochs were rejected from the analysis if the scalp EEG exceeded ±80 μV in any channel. Trials contaminated by artefacts were eliminated prior to averaging. This accounted for approximately 8% of the trials. The EEG was filtered with a bandpass of 0.01–30 Hz, and averaged offline. EEG sweeps were triggered by the onset of the slide presentation. Sampling epochs extended from 100 ms prior to the trigger onset to 900 ms after trigger onset.

The amplitude of the P300 component was defined as the maximum positive amplitude between 250 and 450 ms after stimulus onset. Focussing on the targets only correlation analyses between the interoceptive awareness score and anxiety measures as well as partial correlations between mean P300 amplitudes and interoceptive awareness or anxiety measures, respectively, were carried out taking significant relations between interoceptive awareness and anxiety measures into account.

3. Results

3.1. Interoceptive awareness and anxiety

The mean heartbeat perception score was .77 (SD .09). There were no significant differences in interoceptive awareness between male (mean score .82) and female participants (mean score .80; $F(1,34) = 0.559$, $p = .460$). Mean state anxiety was 41.7 (SD 8.7), mean trait anxiety was 45.5 (SD 9.0). As anxiety was found to be correlated positively to interoceptive awareness in former studies (Critchley et al., 2004; Pollatos et al., in press-b, in press-a) one-tailed correlation analyses between interoceptive awareness and anxiety were carried out showing that trait anxiety and heartbeat perception were positively and significantly correlated ($r = .30$, $p = .038$, one-tailed testing).

3.2. Task performance

The mean percentage of correct answers was 95.2% (SD 1.3). Neither interoceptive awareness, nor trait or state anxiety nor task motivation (assessed on correlate significantly with task performance).

3.3. Visual oddball

ERP traces for targets and non-targets are shown in Fig. 1.

As depicted in Fig. 1, we observed the general oddball effect with more positive P300 amplitudes in response to targets as compared to non-targets. For further analyses, P300 peaks in the time range of 250–450 ms were automatically detected and, after visual inspection, corrected if necessary. Further analyses focussed on peak amplitudes of targets at electrode locations Fz, Cz and Pz and their possible relationship with interoceptive awareness and trait anxiety only.

Because of the positive relationship between interoceptive awareness and trait anxiety, correlations and partial correlations were computed between these variables and the P300 amplitudes. When not controlling for trait anxiety, all correlations between the heartbeat perception score and the P300 amplitude both at Fz ($r = .44$, $p = .008$), Cz ($r = .46$, $p = .004$) and Pz ($r = .37$, $p = .026$) were significantly positive. In regard to the partial correlations,

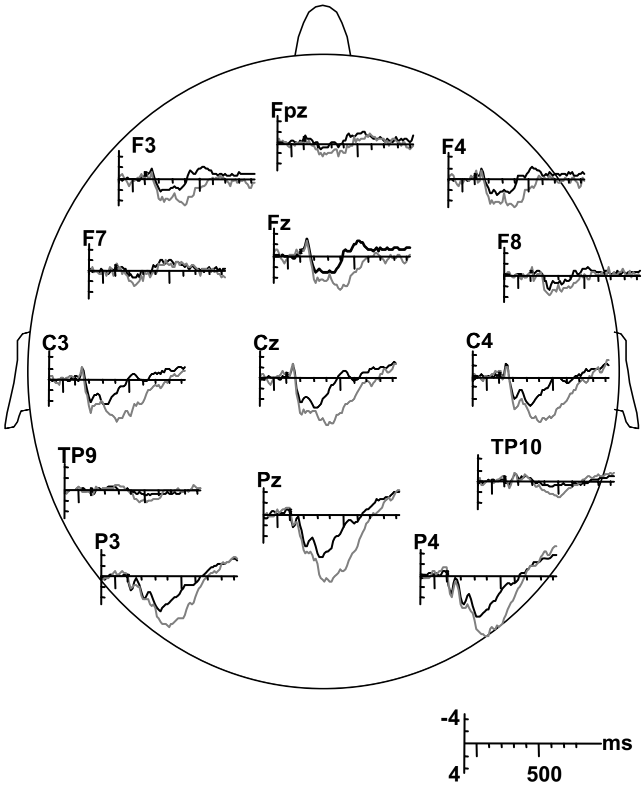

Fig. 1. VEPs to target (black line) and non-target (grey line) stimuli in the visual oddball.

interoceptive awareness still correlated positively with the amplitude at Cz ($r = .35$, $p = .046$). The partial correlation at Fz ($r = .31$, $p = .068$) and Pz ($r = .27$, $p = .116$) failed significance.

Fig. 2 displays the scatter plot with the uncorrected correlations between the heartbeat perception score and the P300 mean amplitudes at Cz.

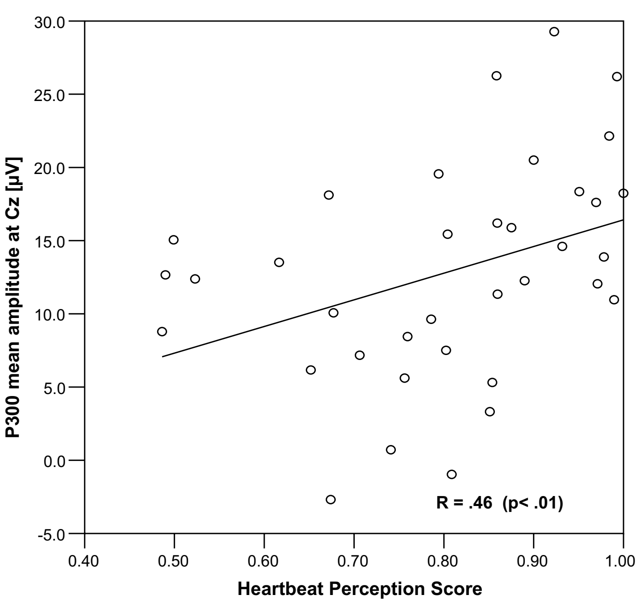

Fig. 2. Scatter plot between P300 mean amplitude at electrode locations Cz and the heartbeat perception score ($N = 38$).

Trait anxiety was positively related to the P300 amplitude at Fz ($r = .25$, $p = .146$), Cz ($r = .24$, $p = .166$) and Pz ($r = .31$, $p = .070$). When taking interoceptive awareness into account smaller correlations between trait anxiety and the amplitude at Fz ($r = .19$, $p = .274$), Cz ($r = .17$, $p = .314$) or Pz ($r = .25$, $p = .148$) were observed.

4. Discussion

In this experiment, the VEPs to visual stimuli were recorded and analyzed focussing on the role of interoceptive awareness on attention-related brain activity. In accordance with our hypotheses, interoceptive awareness did interact with the processing of external stimuli as assessed by the P300 amplitude in a visual oddball paradigm. The effect of interoceptive awareness on P300 amplitudes remained significant when controlling for trait anxiety as a covariate. This result substantially extends former studies showing an enhanced P300 response to emotional stimuli in subjects with high interoceptive awareness (Herbert et al., in press; Pollatos et al., 2005b; Pollatos et al., 2007a) by highlighting the general importance of this factor for the information processing of visual stimuli. In accordance with the somatic marker theory of Damasio (1999) the accurate detection of internal signals occurring in many everyday situations could facilitate information processes as reflected in the P300 amplitude. The perception of internal signals arising in bioregulatory processes associated with cognitive tasks like the oddball paradigm may support the establishment of "somatic markers" (e.g. changes in the cardiovascular system) which are required for signalling stimulus significance to the body (Damasio et al., 2000; Damasio, 1999; Kayser et al., 2000).

While in the present study the performance in the oddball task was not related to interoceptive awareness, other studies have shown that the P300 amplitude reflects cognitive resources for the evaluation of relevant information (Kida et al., 2004; Sachs et al., 2004), performance of cognitive processing (Ascioglu et al., 2004) and target detection (Cote, 2002). In the present study, the performance in the oddball task was quite high in all subjects because of the chosen experimental procedure (neither reaction time nor target detection was systematically manipulated) which is a shortcoming of this work. A possible design improvement might be to introduce task difficulty as an experimental variable in order to examine the relationship to interoceptive awareness in a more adequate way. Concerning emotional processing Katkin and coworkers (2001) observed a link between interoceptive awareness and task performance by showing that the ability to detect one's heartbeats correctly was related to better performance in a fear-conditioning experiment. They suggested that subjects with high interoceptive awareness used the perception of visceral cues from the conditional fear response to facilitate the prediction of shocks. In a similar way subjects with high interoceptive awareness could use the perception of internal signals to facilitate the detection of targets in an oddball paradigm. This interesting assumption needs further experimental clarification.

As there were no significant differences in other variables known to influence the P300 response such as biorhythms, alcohol, nicotine and caffeine (Polich and Kok, 1995; Polich, 2003; Smith et al., 2001) we interpret the observed differences in the P300 amplitude as being related to interoceptive awareness. It is an important to note that other variables such as motivation or interest can also substantially affect the P300 (Carrillo-de-la-Pena and Cadaveira, 2000). Task performance was not related to reported motivation, interoceptive awareness and anxiety though these results have to be interpreted with caution as the performance in the oddball task was quite high in all subjects. As stated above a possible design improvement would include a systematic variation of task difficulty in order to rule out motivational effects which could interfere with interoceptive awareness. Recent research could provide evidence against the assumption of a higher motivation in subjects with high interoceptive awareness by showing that the degree and effort in a physical exercise task was not positively related to interoception (Herbert et al., 2007).

The P300 amplitude is known to be substantially related to the arousal level of the individuals (Cuthbert et al., 2000; Keil et al., 2002; Polich et al., 1995). We therefore suggest that arousal differences could account for the observed differences in information processing in regard to interoceptive awareness. Support for this suggestion stems from research on emotion processes and interoception. The P300 was found to be enhanced for pictures that are rated as more emotionally intense (Bradley et al., 2001). Concerning interoceptive awareness former studies have shown this variable is accompanied with higher levels of arousal during the presentation of emotional pictures or emotional film clips (Barrett et al., 2004; Pollatos et al., 2005b; Pollatos et al., 2007a, in press-b; Wiens, 2005; Wiens et al., 2000). It can be concluded that also during attentional tasks a higher degree of arousal could occur during the presentation and processing of task-relevant stimuli and that a positive relationship to interoceptive awareness could exist. In order to confirm this interpretation further research assessment e.g. autonomic measures of arousal in relation to interoceptive awareness and information processing is necessary.

In regard to trait anxiety, the present study could demonstrate a positive relationship between anxiety and interoceptive awareness which is in accordance with former data (Pollatos et al., in press-b, in press-a; Ehlers, 1995; Eley et al., 2004; Van der Does et al., 2000). Opposite to results on trait anxiety interoceptive awareness remained significantly correlated to the P300 amplitude when controlling for interrelations between both variables. One must bear in mind that in the present study healthy subjects were used who were neither suffering from anxiety disorders nor selected in order to contrast highly and lowly anxious individuals. This is an important limitation of the presented data and their interpretation. Bearing in mind that many anxiety questionnaires like the used STAI assess introspectively accessible self-descriptions (Egloff and Schmukle, 2002) it is not surprising that subjects with high interoceptive awareness also score higher in anxiety. Taking all the results together, we would suggest that apart from a high degree of common variation between interoceptive awareness and trait anxiety, both variables might modulate the P300 amplitude in an independent way. Further research with bigger sample sizes as well as with clinical subpopulations are necessary to make more precise predictions about the relationship between information processing, interoceptive awareness and trait anxiety.

We conclude that differences in the level of interoceptive awareness have physiological correlates that affect basic information processes as measured by the P300 amplitudes to task-relevant stimuli. This observed interaction could be mediated by common neuroanatomical structures underlying both interoception as well as complex visual stimuli processing. Gregory and coworkers (Gregory et al., 2003) assumed that cognitive influences, such as heightened attention to the perception of visceral sensations, are potential contributors to interoceptive awareness. They could show that attention influences the cerebral processing of visceral sensations which is reflected in the activation of visceral sensory and cognitive networks comprising primary and secondary sensory cortices, prefrontal cortices and anterior cingulate. These structures play an important role not only for interoception (Critchley et al., 2004; Pollatos et al., in press-a; Pollatos et al., 2005a) but also for attentional processing of external stimuli of any kind (Corbetta et al., 1991; Coull, 2004; Phan et al., 2002). Imaging data on the topic of interoceptive awareness and the central processing of visual stimuli might shed light on possible brain structures connecting visual attention and interoception.

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