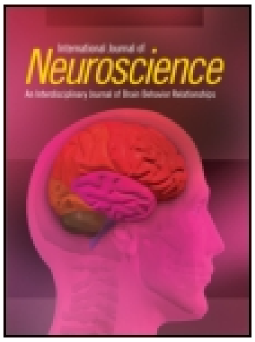

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Edward S. Katkin, Victor L. Cestaro & Rolf Weitkunat

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INDIVIDUAL DIFFERENCES IN CORTICAL EVOKED POTENTIALS AS A FUNCTION OF HEARTBEAT DETECTION ABILITY

EDWARD S. KATKIN AND VICTOR L. CESTARO

State University of New York at Stony Brook

ROLF WEITKUNAT

Staticon Corporation

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Much work has been done to assess individual differences in the ability to detect visceral activity, and most of this work has focused on heartbeat detection ability. This experiment attempted to determine if some underlying cortical event is associated with heartbeat detection ability, and further, to assess whether this cortical event is lateralized to the right hemisphere. Event-related cortical potentials, time-locked to the EKG R-wave and averaged over 400 samples, were studied at Fz, Cz, F7, and F8 in 12 subjects. The primary dependent measure of heartbeat detection accuracy was the standard deviation of the mean temporal latency, measured from peak EKG R-waves to the subjects' report of physical sensation of heartbeats. A significant relationship was found between the amplitudes of event related potentials (ERPs) in the right hemisphere and heartbeat detection accuracy.

Keywords: evoked potentials, heartbeat detection, laterality, heartbeat evoked potential, visceral perception.

Recently, much attention has been focused on visceral self-perception, particularly on individual differences in the ability to detect one's heartbeat. The first systematic attempts to assess autonomic perception used the Autonomic Perception Questionnaire (APQ), developed by Mandler, Mandler, and Uviller (1958). They found that APQ scores were significantly correlated with scores on trait anxiety scales, and that subjects with high APQ scores displayed significantly greater autonomic activity than low scorers. Other researchers reported little or no evidence to support the hypothesis that these scores indicate better than chance ability to perceive certain visceral activity and set out to develop more objective measures of this ability. Techniques that do not rely on subjective self-reporting have been developed by Brener and Jones (1974), Ashton, White, and Hodgson (1979), Schandry and Specht (1981), McFarland (1975), and Whitehead, Drescher, Heiman, and Blackwell (1977), and more recently by Katkin, Morell, Goldband, Bernstein and Wise (1982), and Brener and Kluvitse (1988).

Whitehead, et al. (1977) developed a procedure in which contingent and noncontingent exogenous signals were generated by a subject's heartbeats. These exogenous stimuli were presented to subjects either 128 ms (S+) after their R-waves or 384 ms (S−) following their R-waves, and the subjects were asked to discriminate between the two delay intervals. If subjects have no ability to perceive their heartbeats, there

Address correspondence to Edward S. Katkin, Department of Psychology, State University of New York at Stony Brook, Stony Brook, NY 11794-2500

will be no distinguishable differences between the two sets of stimuli, because the interstimulus interval in both cases is identical. Only those subjects who have the ability to perceive their own heartbeats will be able to discriminate the differential delay between the occurrence of the heartbeat and the presentation of the exogenous stimuli. Whitehead showed that few subjects, in fact, were able to make this discrimination.

Katkin, et al. (1982) devised a modification of Whitehead's task in an attempt to improve the sensitivity of the measure, and their procedure was used successfully in a series of studies examining the parameters of heartbeat detection (see Katkin, 1985). Yet, they found also that few subjects could perform well on the task without extensive training, and questions were raised about the adequacy of the task for uncovering individual differences in heartbeat detection ability.

Brener and Kluvitse (1988) developed an alternative procedure in which subjects were allowed instrumentally to control the delay between their heartbeats and the presentation of exogenous stimuli within a range from 0 ms to 500 ms in 100 ms increments. They were instructed to select the interval that they believed to be simultaneous with their R-waves. A subject who cannot perceive the occurrence of a heartbeat will select a heartbeat-to-signal delay randomly and over a series of trials will have a rectangular distribution of preferred intervals and a large standard deviation around the mean interval selected; on the other hand, an accurate perceiver is likely to select intervals that are the same from trial to trial, or in a narrow range, resulting in a smaller standard deviation. Therefore, standard deviations of the preferred intervals are used as a measure of the subject's accuracy of detection, smaller standard deviations being associated with a higher degree of accuracy.

More recently, a number of researchers have addressed the question of whether the "perceived" R-wave has a cortical representation. An experiment by Schandry, Sparrer, and Weitkunat (1986), for instance, studied the influence of cardiovascular events on cortical activity specifically related to attentional processes and individual performance in heartbeat discrimination. They reported that when a subject's attention was directed to heartbeats, an event-related potential (ERP) was obtained at the Fz and Cz sites at about 250 ms after the R-wave for "good" perceivers but not for "poor" perceivers on the Schandry (1981) procedure, a mental tracking task that required subjects to count their heartbeats silently. A heartbeat detection score on this procedure is derived by dividing the absolute difference between actual and counted heartbeats (over some time interval) by the number of actual heartbeats. Schandry, et al. (1986) were concerned about the possibility of EKG T-wave influence on this ERP, but they hypothesized that under conditions of selective attention to heart sensations this ERP may be of sufficient amplitude to override the T-wave. Further, other artifacts due to the pulsing of cerebral fluids could also become enhanced due to the time-locked averaging referenced to the R-wave. Thus Schandry et al. used signal processing and filtering procedures to separate the signals of interest from these artifacts. They concluded that cardiovascular events are accompanied by cortical potentials, and that they are influenced by psychological variables, such as motivation. Schandry, et al. did not evaluate the extent to which there might have been lateral specificity of the "heartbeat evoked potential" (HEP) although there has been considerable speculation in the literature that there may be lateral specificity of cardiac afference to the cortex.

Evidence for specific right hemisphere activation associated with cardiac afference has been reported by Walker and Sandman (1979) in an investigation of the relationship between heart rate and visual evoked potentials. They found that visual evoked potentials from the right hemisphere during slow heart rates were demonstrably different from evoked potentials recorded during fast heart rates, but no such differences were noted for evoked potentials from the left hemisphere. In a second experiment (Walker and Sandman, 1982), they found that the evoked P1 response from the right hemisphere was larger during diastole than during systole, but again, no such relationship was found in the left hemisphere.

Additional data linking cardiac function to the right hemisphere has been reported by Hugdahl, Franzon, Andersson, and Walldebo (1983), who found that heart rate responses differed when visual stimuli were presented to either the right or left visual field. They concluded that lateralized specificity may play a role in the relationship between behavior and cardiac events.

In a related vein Hantas, Katkin, and Reed (1984) found that subjects who manifest a cognitive style characterized as "right hemisphere preferent" as assessed by conjugate lateral eye movements demonstrated much better performance on a heartbeat detection task than those who are "left hemisphere preferent." In a follow-up to that study, Katkin and Reed (1988) replicated these findings, but concluded that although the "right hemisphere appears to be involved in facilitating performance on the heartbeat detection task . . ." their data could not address the question of specific cortical representation of cardiac events.

The purpose of this experiment was to replicate and extend the findings of Schandry et al. (1986), using the Brener-Kluvitse task (1988) while also examining the question of lateral specificity of the HEP. On the assumption that the occurrence of a reliable HEP is associated with the behavioral discrimination of heartbeats, subjects who were accurate heartbeat perceivers were expected to show a HEP contingent on their heartbeats whereas inaccurate perceivers were not. Further, on the assumption that the representation of cardiac events at the cortex is lateralized it was expected that this potential would be observed primarily in the right hemisphere.

METHOD

Subjects

Fourteen subjects, six males and eight females, participated in this experiment. Their mean age was 18.6 years, ranging from 17 to 21. Each subject received credit in an introductory psychology course for participation. One male subject's data set was lost and one female's data were too noisy to be scored. Thus, the final subject set comprised five male and seven female subjects.

Apparatus

Amplification and signal conditioning of EEG were done with Grass 7P1 pre-amplifiers; EKG signals were shaped with a Grass 7P6 pre-amplifier. High and low frequency roll-off were 35 Hz and 0.8 Hz for EEG and 35 Hz and 0.03 Hz for EKG. Calibration of signals was performed at the end of each session by sending a rectangular calibration signal (20 μV for EEG and 600 μV for EKG) through the recording system.

Data acquisition was done on a 16 Mhz AT style computer with a 12-bit Data Translation DT-2811 A/D board which sampled all channels at 200 Hz. Sweep-wise acquisition was triggered by the occurrence of an EKG-R-wave, detected by a hardware Schmitt trigger (Shimizu, 1976). Amplification was set to get maximum A/D resolution with no range overflows. Sweep length was 1.2 seconds with a 100 ms pretrigger. To avoid overlap of sweeps, a monostable multivibrator was wired behind the hardware peak detector, restricting transmission of incoming TTL signals to the first A/D board digital input channel to a frequency of less than 1 per 1.5 seconds. Four hundred sweeps were sampled.

A response box consisting of six push-button switches corresponding to each of the preferred interval delays, with a yellow LED mounted above each switch to show which delay was in effect, and one additional switch to allow the subject to signal that a choice had been made, was connected to the computer through the digital input-output section of the A/D board. Routines within the software monitored these switches for subject responses to the heartbeat detection task.

Procedure

During the entire experiment subjects were seated in a comfortable leather reclining chair, placed in the upright position, inside an acoustically damped chamber. Directly in front of the subject was a 25 inch video monitor which displayed messages for prompting responses. The subject was also given a response box with which to signal choices to the computer. Once the subject was connected to the electrodes and situated in the chamber, all further verbal instructions were provided by prerecorded audio tape.

In the first half of this procedure, before EEG data collection, all subjects were tested on a light-tone timing task (Brener and Kluvitse, 1988) to familiarize them with the heartbeat task and to assess their perception of simultaneity of two exogenous stimuli. On the light-tone task subjects were required to judge the simultaneity of light flashes (from a light box mounted above the video monitor) and tones delivered through a headset, each delivered at a rate of 60 per minute. Each 50 ms light flash was followed by a 50 ms tone, with the interstimulus interval (ISI) determined by the six response box delay switches that were selectable by the subject. The possible ISIs were 0, 50, 100, 150, 200, and 250 ms, with the assignment of ISIs to response box push-buttons changed on a quasirandom basis after each trial. The subject's task was to determine which ISI created simultaneity between the light and tone, and then to press the button signalling that a choice had been made. Each of the ten trials ended following this response. This procedure was immediately followed by 40 trials of the heartbeat detection task described by Brener and Kluvitse (1988). In the heartbeat detection task, the subjects were informed that their task was identical to the previous light-tone task, with the exception that the light flashes would be replaced by their heartbeats. In other words, they were to judge the simultaneity of heartbeats and tones. In all cases, tones were generated by the subject's EKG-R-waves and delayed by the selected ISI. The ISIs in the heartbeat detection task were 0, 100, 200, 300, 400, and 500 ms.

ERP data were collected at four sites, one in each hemisphere and two centrally. The sites chosen were Fz (front-central), Cz (midcentral), F7 (left-frontal), and F8 (right-frontal), according to the international 10-20 system (Jasper, 1958), referenced to linked mastoids. An additional electrode was placed at the tip of the nose in order to obtain a reference signal for the elimination of EKG artifacts in HEPs. For half the subjects EKG was derived from right midclavicula and the 7th left rib; for the remaining half, the left rib electrode was moved to the left ankle. Since this EKG signal was used only for triggering the data collection system, the changed placement had no effect on the data. The skin was cleaned with 90% isopropyl alcohol to keep EEG electrode impedances below 4000 ohms, and Ag-AgCl electrodes were fixed with collodion (scalp electrodes) or self-adhesive rings (EKG electrodes).

Immediately following the heartbeat detection procedure, the subjects were given instructions for performing the second half of the experiment, and the procedure was started. The subject's task during this portion of the experiment (EEG data collection) was to keep his or her eyes closed while silently counting heartbeats. No audio or visual feedback was provided. All nonessential electrical equipment in the subject chamber was turned off at this time to reduce noise pickup in the EEG electrodes. Event related potential data collection was time-locked to peak R-wave over 400 sample intervals and averaged for each subject at each site.

RESULTS

After calibration, the averages were baseline-corrected by subtracting the mean of the first 15 samples (75 ms) from the entire average. EKG artifact correction was done by subtracting the nose-average from all EEG averages after adjustment by least square fits around the R-wave peak latency (Schandry, Weitkunat, and Sparrer, 1987).

The displayed signals were scored with respect to the R-wave peak by positioning a moveable cursor along the wave form and reading amplitude and latency directly. The primary dependent measures of heartbeat detection were the subjects' standard deviations from their mean preferred intervals (Brener and Kluvitse, 1988). This may be thought of as a measure of the accuracy of perception of the heartbeat, with a small standard deviation indicating greater accuracy. Due to the small subject population, nonparametric statistical methods were used to analyze the resulting data. Each subject's standard deviation was compared to his or her N1 amplitude at each site using Spearman's coefficient of rank correlation, *rho*. A significant negative *rho* was obtained between N1 amplitude and standard deviation of preferred interval only at the F8 site, $rho(11) = -.75$, $p < .02$. Although negative potentials also were observed at the other sites, none of these achieved a statistically significant correlation with the index of heartbeat detection (Fz, Cz, and F7 sites, $rho(11) = .01$, .12, and −.25 respectively). These correlations are depicted graphically in Figure 1. Although the sample size was technically too small to justify parametric analysis, similar results were obtained using Pearson product-moment correlations. The Pearson r between the standard deviations of the mean preferred intervals and N1 amplitudes at F8 was −.88, $p < .02$. Simply stated, N1 amplitudes in the right frontal hemisphere were greatest for those subjects who had the most accurate performance on the heartbeat detection task. To rule out the possible influence of EKG T-wave contamination of the cortical potentials, correlations were calculated between the peak T-wave and N1 onset latencies for each subject. No significant phasic relationships were found.

DISCUSSION

Although previous research has indicated that there are individual differences in the ability to detect one's own heartbeat, little effort has been addressed to the mechanisms underlying this ability. The data of the present study suggest that accurate heartbeat perception is associated with a cortical event, and that this event appears to occur specifically in the right frontal hemisphere. Thus the present data support Katkin's earlier speculation that ". . . the right hemisphere may be specialized for the processing of specific afferent information from the cardiovascular system, and

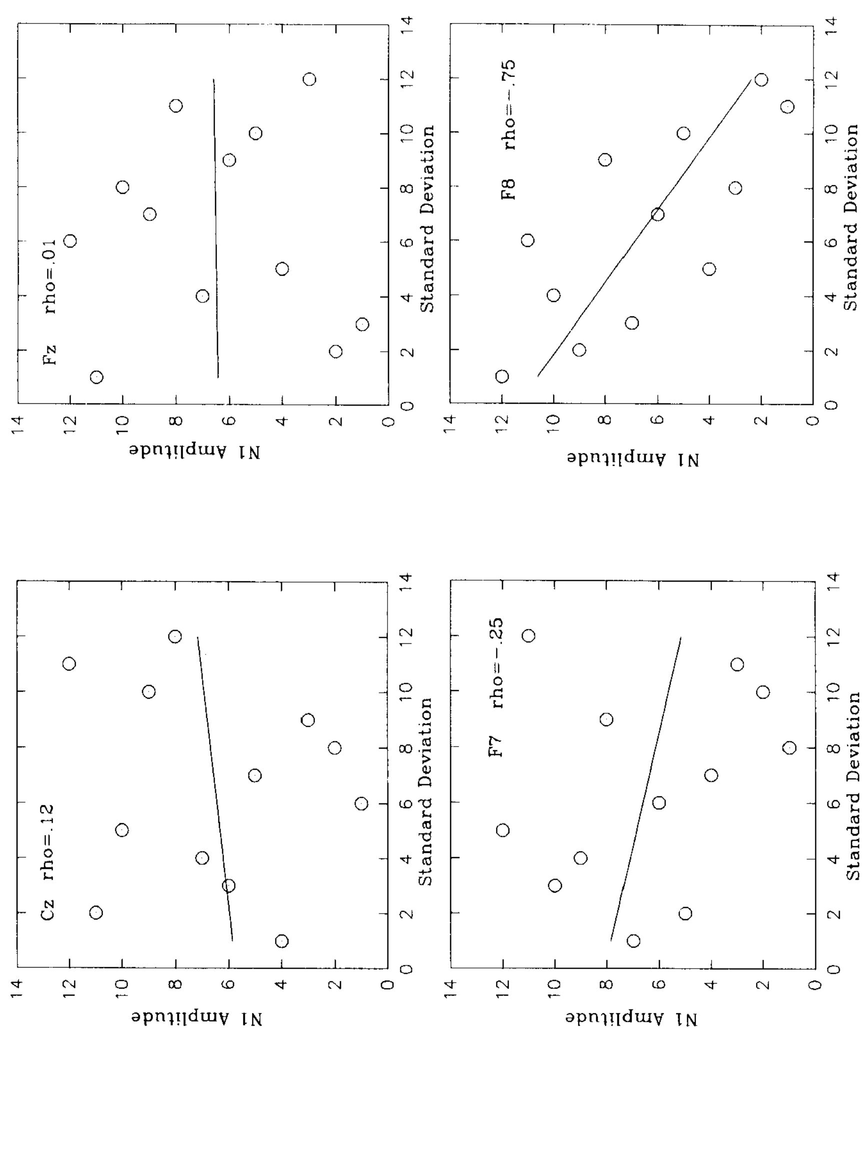

FIGURE 1 Spearman rhos between N1 amplitude at Cz, Fz, F7, and F8 and standard deviation of preferred interval on the heartbeat detection task.

that good performance on a heartbeat detection task might be associated with right hemisphere activation" (1985, p. 132).

Whether the observed N1 associated with heartbeats is directly associated with cardiac afference, or with sensory input from elsewhere in the body is still unclear. If cardiovascular receptors are involved in the sensation of heartbeats, then it would be expected that mean latencies from ventricular contraction would lie in the range of 100–150 ms. Three subjects chose mean preferred intervals of 100 ms, indicating that cardiovascular mechanoreceptors rather than peripheral sensory receptors may have been involved in their heartbeat sensations, since tones presented at this interval would have occurred prior to the completion of ventricular contraction.

Research on the precise mechanisms underlying visceral versus somatic sensation has a long history. More than 100 years ago Ross (1888) suggested that visceral pain can be divided into two categories: "splanchnic" pain derived from a viscus and felt in the same area, and "somatic" pain, derived from a viscus and felt in a part of the body different from the source. A half-century later Ruch (1946) proposed a "convergence-projection" theory of referred pain to account for this phenomenon. According to Ruch, visceral and cutaneous pain afferents converge upon the same neuron somewhere in the sensory pathway. Cervero and Tattersall (1986) have noted that as early as 1909, Mackenzie stated that all models of referred pain ". . . take into account the clinical observation that visceral pain is usually referred to a somatic area innervated by the same spinal cord segments that receive the input from the originating viscus" (Cervero and Tattersall, 1986, p. 191). No exclusive visceral sensory pathway has been found, and it is likely that the sensation of visceral pain results from the spread of activation to regions innervated by somatic nerves, causing sensations that are poorly localized and perceived as emanating from somatic structures (Cervero and Tattersall, 1986). This may help to explain the large variations in locus of sensation as well as temporal variations reported by subjects in a heartbeat detection task. It is well known that patients suffering from a myocardial infarct often report pain localized to the left arm, indicating that sensory pathways associated with the left side of the body may have convergent input from cardiovascular sensory receptors. This phenomenon supports the idea that right hemisphere activation may indeed be involved in the perception of cardiac sensations.

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