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Heartbeat evoked potentials (HEP): topography and influence of cardiac awareness and focus of attention *

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Summary Heartbeat evoked potentials (HEP) were recorded from good and poor heartbeat perceivers under two conditions differing in focus of attention. Under the first condition (ATT), subjects were instructed to count their heartbeats. Under the second condition (DIS), subjects were distracted from their heartbeats by having them count external tones. Electrical brain activity was recorded from 19 electrodes. EEG epochs were triggered by the R wave of the EKG. Analyses of variance yielded a significant difference for focus of attention in HEP amplitudes at central electrodes (Cz, C3, and C4) in the latency range 350–550 msec post R wave. No significant differences occurred between good and poor perceivers. The interaction between the Group and Condition factors was significant at F4, C4 and T6. The potential map of good perceivers showed a fronto-temporal positivity, which was reduced in poor perceivers. Our data suggest that paying attention to an internal event such as the heartbeat can modify the cortical evoked response associated with that event.

Key words: Heartbeat evoked potential; Heartbeat perception; Attention; Topography

Individuals differ from one another in the degree to which they are able to perceive sensations arising from the body. Interindividual differences in the experience of pain or the awareness of the heartbeat constitute good examples of this ability. To date, cortical processing of signals arising from the internal organs has only rarely been the subject of study by physiologists or psychophysiologists. Ádám (1967) reported a series of studies on humans in which the cortical alpha-blocking response to mechanical stimulation (balloon distention) of the duodenum could be demonstrated. Habituation and disruption of habituation were also observed for this response. Interestingly, the stimuli were not initially perceived consciously by his subjects. However, by using verbal feedback training techniques, it was possible to teach the experimental subjects "to detect and to bring into consciousness intestinal impulses, which prior to conditioning had been unconscious."

There have also been several reports on event-related potentials in response to electrical or mechanical stimulation of the urogenital system in humans (Badr et al. 1982, 1984; Haldeman et al. 1982; Sarica et al. 1986; Vodušek 1990; Loening-Baucke et al. 1991). The aim of these studies was to investigate nerve conduction processes along afferent fibers in patients. The most prominent peak was a negative shift with a latency of onset of about 100 msec and an amplitude ranging from 0.5 to 2 μV. In almost all cases, the maximum of electrical brain activity was observed under centrally located electrodes.

Perception of the heartbeat as a source of visceroceptive EPs has been investigated in more recent studies using non-invasive methods (Jones et al. 1986, 1988; Schandry et al. 1986; Riordan et al. 1990; Schandry and Weitkunat 1990; Weitkunat and Schandry 1990). In the first report of heartbeat evoked potentials (HEP) by Schandry and et al. (1986), subjects were classified into two groups according to their scores on an initial heartbeat perception test. A negative EP shift within a time interval of 200–300 msec after the R wave was observed. It was speculated that a cardiac event occurring around 100–200 msec after the R wave might be the stimulus which evokes this potential. The subject's accuracy in perceiving the heartbeat was found to correlate positively with the stability of the HEPs under varying experimental conditions. They also observed group differences by submitting the evoked potentials to principal component analysis. Good perceivers showed more positive factor scores for those components which yielded significant differences between conditions. Jones et al. (1986) observed that

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subjects who showed a higher cardiac awareness produced HEP amplitudes more positive in the time range 250–450 msec than low cardiac awareness subjects. Recently, Riordan et al. (1990) examined the HEPs of a group of good perceivers. They found that a positive shift (0.25–1.5 μV) occurred around 120–160 msec. The peak was largest over the right anterior portion of the scalp.

Jones et al. (1988) investigated the possibility that artificially increasing pulsatile cardiac sensations by inflating a cuff around the finger would lead to effects on the HEP amplitude. Two electrodes were placed rostral to C3 and C4. Although no effects due to increased cardiac sensation were found, the authors noted that individual differences in the ability to perceive heartbeat sensation affected the HEP amplitude in the time range 250–500 msec. Schandry and Weitkunat (1990) found that an improvement of cardiac awareness through training procedures was related to increases in HEP amplitudes. In this experiment two groups of subjects were trained with different methods. Only the group which was superior in behavioral measures of heartbeat perception revealed an enhancement of the negative peak of the HEP at F8 in the interval between 250 and 400 msec.

Cognitive manipulation of heartbeat perception has also been shown to affect the amplitude of the HEP. Weitkunat and Schandry (1990) tested the hypothesis that motivating circumstances in the form of monetary incentives, as well as the subject's a priori ability to detect heartbeats, may influence the HEP amplitude. Subjects were previously grouped into good and poor perceivers. HEPs were recorded twice while subjects counted their heartbeats. Half of the subjects were told before the beginning of the second recording period that the correct report of counted heartbeats would be rewarded with a bonus at the end of the session. HEP amplitudes in the interval around 400 msec increased positively during the second period only for the good perceivers in the group which was rewarded. The HEPs observed by Weitkunat and Schandry (1990) showed also a more positive broad peak in the interval around 500 msec at Fz for good perceivers than for poor perceivers. From the above mentioned studies it may be inferred that the trait "cardiac awareness" exerts an influence on the HEP.

It is well established that evoked potentials triggered by external stimuli are sensitive to manipulation of attention (Shevrin and Rennick 1967; Groves and Eason 1969; Callaway and Halliday 1982; Salamy et al. 1984; Stelmack and Michaud-Achorn 1985). In general, these studies recorded brain activity in response to external stimulation (auditory or visual) under two different conditions. Under the first, subjects were required to focus their attention on the stimuli by counting them. Under the second, subjects were distracted by asking them to ignore the first stimulus or to count other kinds of stimuli. Focusing attention on a stimulus has been demonstrated to enhance the N1 component of the EP.

To date, most investigations on visceral EPs have been conducted using relatively few electrode locations (Fz, Cz, and Pz). As such, detailed topography of the EPs, and consequently, knowledge regarding the neuroanatomy of visceroafferent projections to the cortex in humans, is still deficient.

The present study was designed: (a) to determine whether the amplitude of the HEP can be affected by individual (good vs. poor heartbeat perception) and situational (attention focused towards heartbeats or distraction) differences regarding the perception of the heartbeat signal, and (b) to gain detailed topographic information regarding the HEP.

Methods

Subjects

Twenty-eight healthy subjects, 11 females and 17 males, aged 20–43 years (mean = 26.8, S.D. = 5.4), participated in this experiment. All subjects were recruited by announcements at the University of Munich and paid DM 60.- for their participation.

Procedure

After electrodes were attached, the subjects participated in a heartbeat perception test. They were instructed to count their heartbeats within 3 given time intervals (25, 35 and 45 sec); they were not told how long the intervals actually were. The absolute difference between the number of actual and counted heartbeats divided by actual heartbeats was computed for each time interval. The subject's error score was the average of these 3 values (Schandry 1981). Perfect perception yielded an error score of 0; undercounting or overcounting yielded a score generally not exceeding 1. On the basis of their error scores on this heartbeat perception test, subjects were assigned either to the good perceiver group (error score < 0.15) or the poor perceiver group (error score ≥ 0.15) [1].

During the following main part of the session, the EEG time-locked to the R wave of the EKG was recorded either with the subject's attention focused on his or her heartbeats (ATT condition) or while distracted from internal sensations by being requested to attend to a series of tones (DIS condition).

Under the ATT condition, subjects were asked to count their heartbeats silently. No external stimulation

[1] The same criterion was used by Weitkunat and Schandry (1990) to assign the subjects into the good or the poor perceiver group.

was given during this condition. Under the DIS condition, subjects were presented with runs of 100 tones (25 targets of 2000 Hz and 75 non-targets of 1000 Hz; all with a duration of 200 msec) and were asked to attend to the target tones and to report the number of them at the end of the run. The tones were presented at a rate of one every 1 or 2 sec (randomly determined). Ten ATT runs alternated with 10 DIS runs with 30 sec pauses between individual runs. The beginning and the end of each run was signaled by a tone.

To prevent a drop in motivation during the very long and at times tedious experimental phases, subjects were rewarded for a correct report of the total counted stimuli (heartbeats or tones) with up to DM 5.- per condition at the end of the session. No further statistical analysis was carried out on the counting data.

Physiological recording

Electrical brain activity was recorded using Ag/AgCl electrodes placed at the 19 scalp locations of the 10–20 system. An electro-oculogram (EOG) was obtained from two electrodes placed below and above the right eye. An additional electrode was placed on the tip of the nose and was used as a reference signal for an EKG artifact elimination method (see below). All active electrodes were referenced to linked mastoids. Electrode impedances were kept below 10 kΩ. Two EKG electrodes were attached in the area of the seventh left ventral rib and the right clavicle. A ground electrode was placed on the forehead. All signals were registered by an ED24 Picker polygraph. The gain was set at 20 μV/cm for EEG, EOG and nose signals, and 500 μV/cm for EKG. High and low frequency filters for all signals were set at 15 and 0.016 Hz respectively. The sampling rate was 200 Hz. A PC (HP Vectra RS 25) collected and stored all physiological data.

The peak of the R wave served as the trigger for the recording of all derivations in both ATT and DIS conditions. One sweep lasting 800 msec was defined as the interval between 100 msec before and 700 msec after the R wave. One thousand sweeps were recorded corresponding to 1000 heartbeats for each condition.

Data reduction and analysis

A number of steps were conducted to prepare the raw data for analysis. Individual averages were computed off-line for each condition and each electrode site, resulting in 44 waves (2 Conditions × 19 EEG, 1 EKG, 1 EOG and 1 nose-reference signal). To reduce the influence of eye movements on the EEG, all sweeps with an EOG activity above 50 μV were excluded from further analysis. A baseline correction was performed subtracting the mean of the first 75 msec before the trigger onset (EKG R wave) from the entire average for each individual averages. A second correction procedure utilizing the electrical activity picked up at the nose was applied to eliminate the EKG artifact [2].

In the present study we investigated the HEP amplitude in the interval 350–550 msec after the EKG R wave. The main electrical brain activity in response to the heartbeat had been observed in this latency range in earlier studies (e.g., Jones et al. 1986; Schandry et al. 1986). Mean amplitudes for each of the 44 averaged curves (EEG, EOG, nose, and EKG) were computed in two time windows (350–450 msec and 450–550 msec after the R wave). These values were separately analyzed for the EEG and the EKG data using analyses of variance for repeated measures. An analysis of the corresponding mean voltages of the EKG data was carried out to check for the possibility that differences in HEP could be due to differences in EKG. If the EKG wave differed at the same latency range as is the case for the HEP, it might have been difficult to exclude the possibility that EKG effects were responsible for differences in HEP amplitude.

The EEG data were statistically analyzed using a multivariate 3-way analysis of variance with 1 between-subject factor Cardiac Awareness (good vs. poor perceivers), and 2 within-subject factors Focus of Attention (attend to heartbeats vs. external tones) and Electrode Site (19 electrodes) for each time window. The multivariate approach was used to avoid violations of variance-covariance homogeneity assumptions. In order to further investigate differences in the scalp distribution of the HEP, we also averaged the HEP voltage over the following electrode sets: frontal (Fz, F3, F4, F7, F8, Fp1, and Fp2), central (Cz, C3, C4, T3, and T4), and posterior (Pz, P3, P4, T5, T6, O1, and O2). For each time window, statistical contrasts comparing frontal versus central, central versus posterior, and frontal versus posterior sets were performed. In the presence of any interaction of the factor Electrode Site, further 2-way ANOVAs were performed for each of the 3 sets.

Furthermore, to elucidate where differences between both groups and/or between both conditions

[2] The signal at the nose was considered to be caused solely by cardiac potentials and free of EEG influence (Weitkunat and Schandry 1990). A least square fitting of the amplitude around the R peak latency (10 msec before to 50 msec after R wave) was computed for the nose signal and subtracted from all EEG averages. A factor α was computed so that the sum of the difference amplitudes between the tip of the nose (Z) and the HEP (Y) would be minimized around the R wave:

$$\sum_{i=R-10\text{ msec}}^{i=R+50\text{ msec}} (Y_i - \alpha Z_i)^2 = \min$$

The corrected HEP signal (Y′) is then the difference between the raw HEP and the weighted nose signal (αZ):

$Y' = Y - \alpha Z$ (for all sampling points).

might occur, univariate 2-way mixed ANOVAs [3] were carried out for each electrode site separately. In the presence of Cardiac Awareness × Focus of Attention interactions, differences between the groups at each condition (ATT, DIS) were tested for significance by using the Tukey HSD post-hoc procedure.

Finally, topographic displays of HEP amplitude for the two time windows were plotted for each group and condition. All 19 EEG electrodes were used in creating the maps. The software program (Neuro Scan) used a linear interpolation algorithm, which computed the values for the 4 nearest neighboring electrodes. The amplitudes were expressed in a color scale with 15 grades, from $+3$ μV (rose) to -1 μV (intense blue).

In a previous screening of the data, the mean voltage of one subject yielded values which were classified by an SPSS PC + procedure as an extreme outlier. The subject's data were discarded from further analysis. The sample size was thus reduced to 27 subjects.

Results

Eleven subjects (1 female and 10 males) were classified as good perceivers and 16 (10 females and 6 males) as poor perceivers. A 1-way ANOVA on the heartbeat perception scores confirmed statistically the difference between poor (mean: 0.37; S.D.: 0.15) and good perceivers (mean: 0.08; S.D.: 0.05; F (1, 26) = 38.49, $P < 0.001$).

The raw data and the reduction of EKG artifact are shown for one subject in Fig. 1. The 19 HEP raw averages were corrected by subtracting the "EEG-free" signal of the nose from each HEP. Obviously, in the corrected HEP averages the influence of the R wave is reduced, although the presence of a small peak can still be observed around the R wave latency in the corrected potentials. The correction method for this subject appears to be more effective (in the sense of reduction of the "scalp R wave") at frontally and centrally than posteriorly located electrodes. The corrected grand averages for the ATT and the DIS conditions in the two groups at all EEG electrode sites are presented separately in Fig. 2.

EKG

Separate 2-way mixed ANOVAs were performed on the mean amplitude of the EKG signal for both time windows. Neither the Cardiac Awareness nor the Focus of Attention effects or the Cardiac Awareness ×

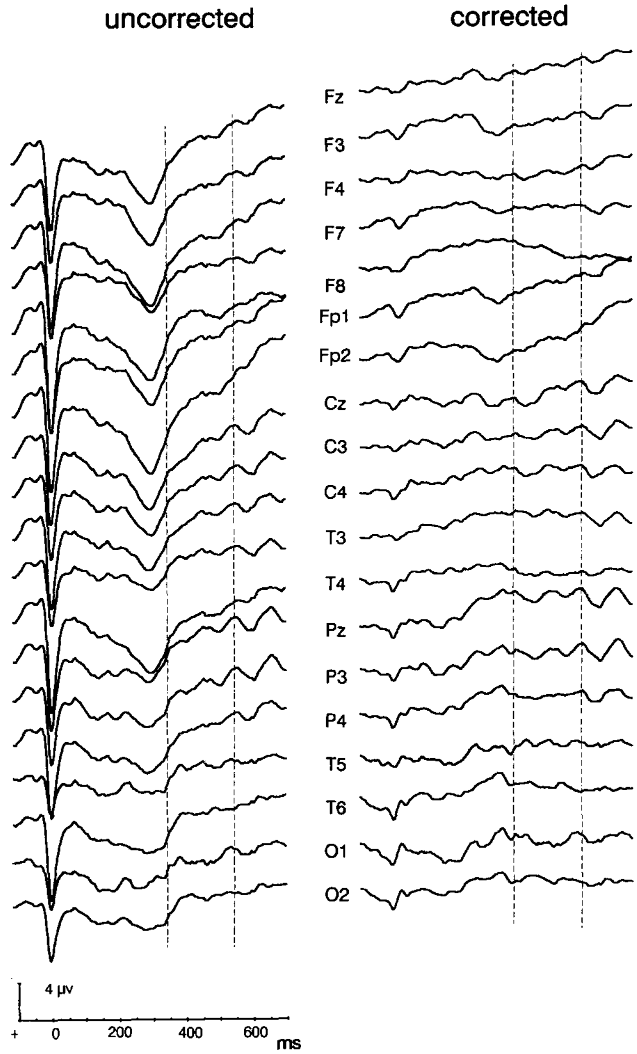

Fig. 1. Effect of the nose-correction method over the raw wave forms of a subject during the ATT condition. Time base point 0 is coincident with the EKG R wave.

Focus of Attention interaction were statistically significant at any of the two time windows.

HEP

Electrode site effects. The results of the multivariate analyses of variance are shown in Table I. A significant main effect for the factor Electrode Site was found in both time windows. The specific contrasts among the 3 electrode sets revealed that the averaged HEP amplitude was greater frontally (350–450: mean = 1.64 μV, S.D. = 20.08; 450–550: mean = 1.51 μV, S.D. = 2.36) and centrally (350–450: mean = 0.64 μV, S.D. = 1.66; 450–550: mean = 0.42 μV, S.D. = 1.42) than posteriorly (350–450: mean = 0.25 μV, S.D. = 1.55; 450–550: mean = -0.01 μV, S.D. = 1.19), as well as greater frontally than centrally.

Effects of cardiac awareness. In the overall analyses, the HEP amplitude was not significantly different between the two heartbeat perceiver groups in any of

[3] Since the levels of the within-subject factor were less than 3, the degrees of freedom were not corrected with the Greenhouse-Geisser epsilon.

TABLE I

Multivariate repeated measures analyses of variance for HEP amplitudes and difference contrasts between 3 electrode sets: frontal (Fz, F3, F4, F7, F8, Fp1, and Fp2), central (Cz, C3, C4, T3, and T4), and posterior (Pz, P3, P4, T5, T6, O1, and O2).

Effect	*df*	350–450 msec		450–550 msec	
		F	*P*	*F*	*P*
Electrode Site	18, 450	3.85	0.029	3.76	0.031
frontal vs. central	1, 25	14.88	0.001	11.63	0.002
frontal vs. posterior	1, 25	11.31	0.002	10.27	0.004
central vs. posterior	1, 25	13.53	0.001	10.46	0.003
Cardiac Awareness	1, 25	0.74	0.398	0.28	0.602
Focus of Attention	1, 25	2.95	0.098	1.99	0.171
Card. Awareness × Electrode	18, 450	0.80	0.669	0.97	0.551
Focus of Attention × Electrode	18, 450	2.02	0.157	3.17	0.050
Cardiac Awareness × Focus of Attention	1, 25	3.82	0.062	0.99	0.329
Card. Awar. × Focus of Att. × Electrode	18, 450	1.45	0.304	1.19	0.420

the time windows (cf., Table I). No Cardiac Awareness × Electrode Site interaction was found. However, in the univariate analyses, carried out for each electrode separately, a marginallly significant trend ($P < 0.1$) toward greater mean HEP amplitudes in the good perceiver group was found for F7 and T3 during the time window 450–550 (Table II).

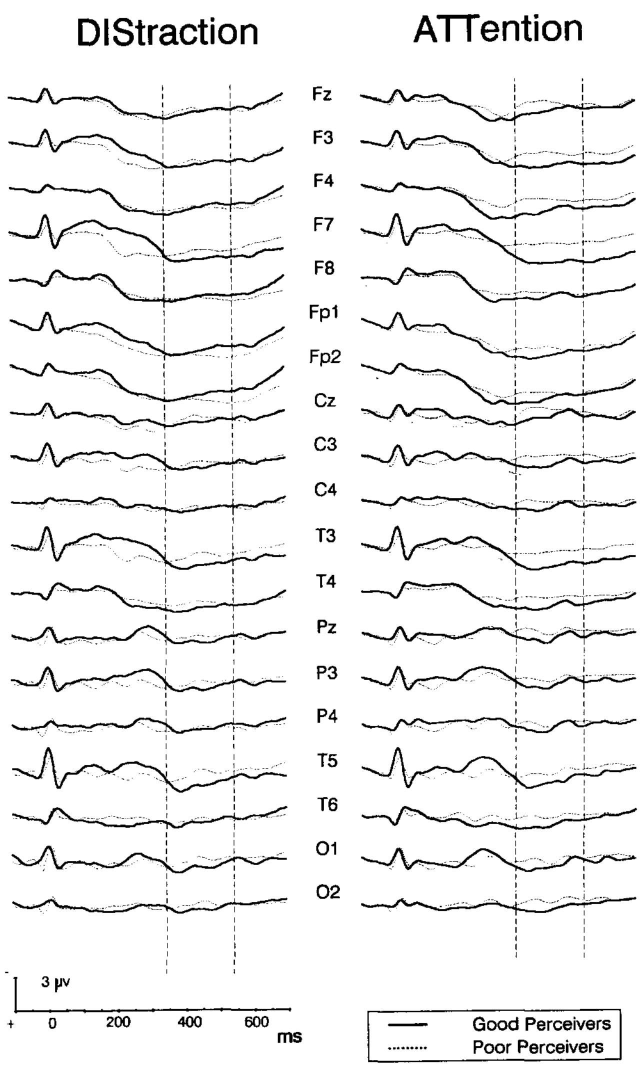

Fig. 2. Corrected grand averages during the ATT (right) and the DIS (left) conditions for the good perceiver and the poor perceiver groups. Time base point 0 is coincident with the EKG R wave.

Effect of Focus of Attention on HEP amplitude. The main effect Focus of Attention failed to reach the significance level. The Focus of Attention × Electrode Site interaction was significant in the time window 450–550 msec, but not in the preceding time window 450–550 msec (cf., Table I). Further analyses of variance in each electrode set revealed that the condition manipulation was significant for the central electrode set (350–450: $F\ (1, 25) = 5.87$, $P < 0.023$; 450–550: $F\ (1, 25) = 5.82$, $P < 0.024$).

TABLE II

Effects of Cardiac Awareness on HEP amplitude. Mean HEP amplitude (μV) and standard deviations (in parentheses) at all EEG electrodes for the good perceiver group (n = 11) and for the poor perceiver group (n = 16) in the time interval from 350 to 550 msec after the R wave of the EKG.

Elec-trodes	350–450				450–550			
	Good		Poor		Good		Poor	
Fz	1.28	(2.64)	0.69	(1.89)	0.84	(3.08)	0.70	(1.63)
F3	1.82	(2.12)	1.20	(1.88)	1.54	(2.66)	1.12	(1.58)
F4	1.90	(2.14)	1.21	(1.52)	1.40	(2.83)	1.24	(1.25)
F7	2.12	(1.51)	1.18	(2.08)	2.03	(1.60)	1.04	(1.56)
F8	1.60	(2.16)	1.32	(1.49)	1.30	(2.84)	1.42	(1.19)
Fp1	2.48	(4.17)	2.19	(2.77)	2.05	(5.20)	2.28	(3.15)
Fp2	2.50	(4.29)	2.17	(2.24)	2.00	(5.57)	2.32	(2.57)
Cz	0.68	(1.70)	0.16	(2.02)	0.27	(1.78)	0.06	(1.55)
C3	0.75	(1.56)	0.24	(2.33)	0.45	(1.64)	0.05	(1.75)
C4	0.65	(1.27)	0.23	(1.78)	0.31	(1.56)	0.15	(1.41)
T3	1.55	(1.22)	0.68	(2.38)	1.31	(1.15)	0.42	(1.74)
T4	1.38	(1.67)	0.69	(1.34)	1.02	(1.95)	0.59	(1.01)
Pz	0.29	(0.93)	−0.21	(2.03)	0.08	(1.19)	−0.29	(1.56)
P3	0.43	(0.96)	0.04	(2.14)	0.20	(1.07)	−0.18	(1.66)
P4	0.23	(1.31)	0.01	(1.75)	−0.08	(1.50)	−0.19	(1.32)
T5	1.09	(1.33)	0.33	(2.79)	0.67	(1.00)	−0.09	(1.99)
T6	0.75	(1.17)	0.21	(1.58)	0.34	(1.06)	0.05	(1.18)
O1	0.63	(0.90)	0.04	(2.31)	0.21	(0.93)	−0.18	(1.72)
O2	0.40	(0.68)	−0.11	(1.39)	0.12	(0.61)	−0.30	(1.15)

TABLE III

Effects of Focus of Attention on HEP amplitude. Mean HEP amplitude (μV) and standard deviations (in parentheses) at all EEG electrodes during focusing of attention on heartbeats (ATT) and on external tones (DIS) in the time interval from 350 to 550 msec after the R wave of the EKG (n = 27).

Electrodes	350–450 msec		450–550 msec	
	ATT	DIS	ATT	DIS
Fz	0.71 (2.64)	1.15 (2.30)	0.56 (2.62)	0.96 (2.09)
F3	1.24 (2.01)	1.66 (2.18)	1.14 (2.33)	1.45 (1.99)
F4	1.37 (1.78)	1.61 (1.97)	1.21 (2.06)	1.40 (2.10)
F7	1.43 (1.72)	1.70 (2.34)	1.39 (1.79)	1.51 (1.73)
F8	1.34 (1.75)	1.53 (1.90)	1.28 (1.99)	1.46 (2.08)
Fp1	2.20 (3.71)	2.42 (3.20)	2.08 (4.49)	2.30 (3.74)
Fp2	2.20 (3.48)	2.41 (3.04)	2.05 (4.40)	2.32 (3.73)
Cz	0.05 (1.87)	0.70 (2.02) **	−0.16 (1.82)	0.46 (1.55) **
C3	0.20 (1.88)	0.70 (2.31) *	−0.04 (1.92)	0.47 (1.61) *
C4	0.21 (1.56)	0.60 (1.65) **	0.03 (1.60)	0.40 (1.36) *
T3	0.93 (1.77)	1.14 (2.37)	0.70 (1.64)	0.86 (1.69)
T4	0.83 (1.61)	1.11 (1.45)	0.62 (1.57)	0.91 (1.39) *
Pz	−0.15 (1.80)	0.14 (1.60)	−0.30 (1.76)	0.01 (1.22)
P3	0.08 (1.83)	0.32 (1.73)	−0.15 (1.78)	0.09 (1.25)
P4	−0.02 (1.74)	0.21 (1.47)	−0.28 (1.66)	−0.01 (1.20)
T5	0.55 (2.28)	0.72 (2.39)	−0.16 (1.78)	0.29 (1.73)
T6	0.39 (1.60)	0.47 (1.33)	0.11 (1.30)	0.22 (1.03)
O1	0.22 (1.96)	0.34 (1.85)	−0.06 (1.61)	0.02 (1.47)
O2	−0.02 (1.25)	0.21 (1.15)	−0.26 (1.09)	0.00 (0.98)

$^*P < 0.05$.
$^{**}P < 0.01$.

These results were confirmed by the univariate analyses for each electrode site. HEP mean amplitudes for each condition are summarized in Table III. The Focus of Attention effect was statistically significant for Cz (350–450: F (1, 25) = 9.44; 450–550: F (1, 25) = 10.45), C3 (350–450: F (1, 25) = 4.51; 450–550: F (1, 25) = 4.87), and for C4 (350–450: F (1, 25) = 9.72; 450–550: F (1, 25) = 7.27) during the 2 time windows, and only during the time window 350–450 for T4 (F (1, 25) = 4.62). It is also noteworthy that the mean amplitude diminished for both ATT and DIS conditions over the time from the first time interval (350–450 msec) to the second (450–550 msec).

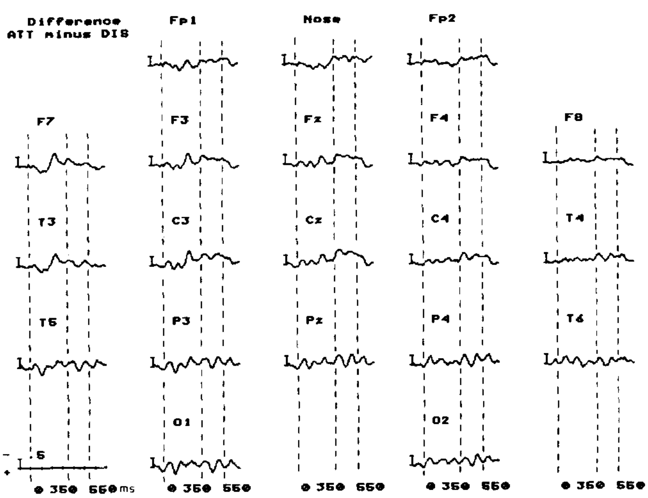

Fig. 3. Difference potential (HEP potentials during the ATT condition subtracted from those during the DIS condition). Time base point 0 is coincident with the EKG R wave.

TABLE IV

Difference potential ATT minus DIS. Peak amplitudes (μV) and latencies (msec) at all EEG electrodes for the time windows 200–300 msec and 350–550 msec.

Electrodes	Peak between 200 and 300 msec		Peak between 350 and 550 msec	
	μV	msec	μV	msec
Fz	−0.42	240	−0.52	375
F3	−0.65	235	−0.55	370
F4	−0.15	245	−0.38	375
F7	−0.70	240	−0.41	370
F8	−0.17	205	−0.31	375
Fp1	−0.28	240	−0.32	545
Fp2	−0.03	245	−0.34	545
Cz	−0.52	240	−0.81	395
C3	−0.78	240	−0.61	390
C4	−0.25	240	−0.57	375
T3	−0.66	240	−0.34	355
T4	−0.18	200	−0.46	380
Pz	−0.38	250	−0.58	495
P3	−0.48	250	−0.45	495
P4	−0.16	295	−0.56	495
T5	−0.33	255	−0.35	395
T6	−0.16	200	−0.29	500
O1	−0.30	255	−0.33	510
O2	−0.35	295	−0.55	500

Difference potential. The influence of focus of attention on HEP amplitude was further examined by calculating the difference potentials, subtracting each data point of the potentials during the DIS from those during the ATT condition. The rationale for this is that HEPs obtained under the DIS condition serve as a baseline (control) potential elicited by the heartbeat signal, regardless of whether it is perceived or not. Thus, the difference potentials (ATT minus DIS) indicate how much activity is elicited as a consequence of focusing attention on the heartbeats.

The difference potentials are shown in Fig. 3. The waves at F7, F3, Fz, T3, C3, and Cz show a negative peak with a maximum at about 250 msec. This peak is followed by a negative shift extending roughly from 350 to 550 msec. In order to examine further these two negativities, we determined for each location the voltage of the most prominent peak occurring within the time interval from 200 to 300 msec and from 350 to 550 msec. The maximal values and onset latencies for the peaks in both time intervals are illustrated in Table IV.

Interaction between cardiac awareness and focus of attention. In the analyses carried out with the electrode site as a within-subject factor there were neither Cardiac Awareness × Focus of Attention nor Cardiac Awareness × Focus of Attention × Electrode Site interactions. However, the univariate tests for each electrode revealed that the Cardiac Awareness × Focus of Attention interaction was significant for F4 (F (1, 25) = 4.91, $P = 0.036$), C4 (F (1, 25) = 4.61, $P = 0.042$), and T6 (F (1, 25) = 70.06, $P = 0.014$), in the time window 350–450. A non-significant tendency ($P < 0.10$) was also observed for F4, T6, and O2 in the second time window (450–550).

In Fig. 4 the HEP mean amplitudes are illustrated for good and poor perceivers at the positions F4, C4, and T6 and their symmetrical counterparts (F3, C3, and T5) during both the ATT (Fig. 4a) and the DIS

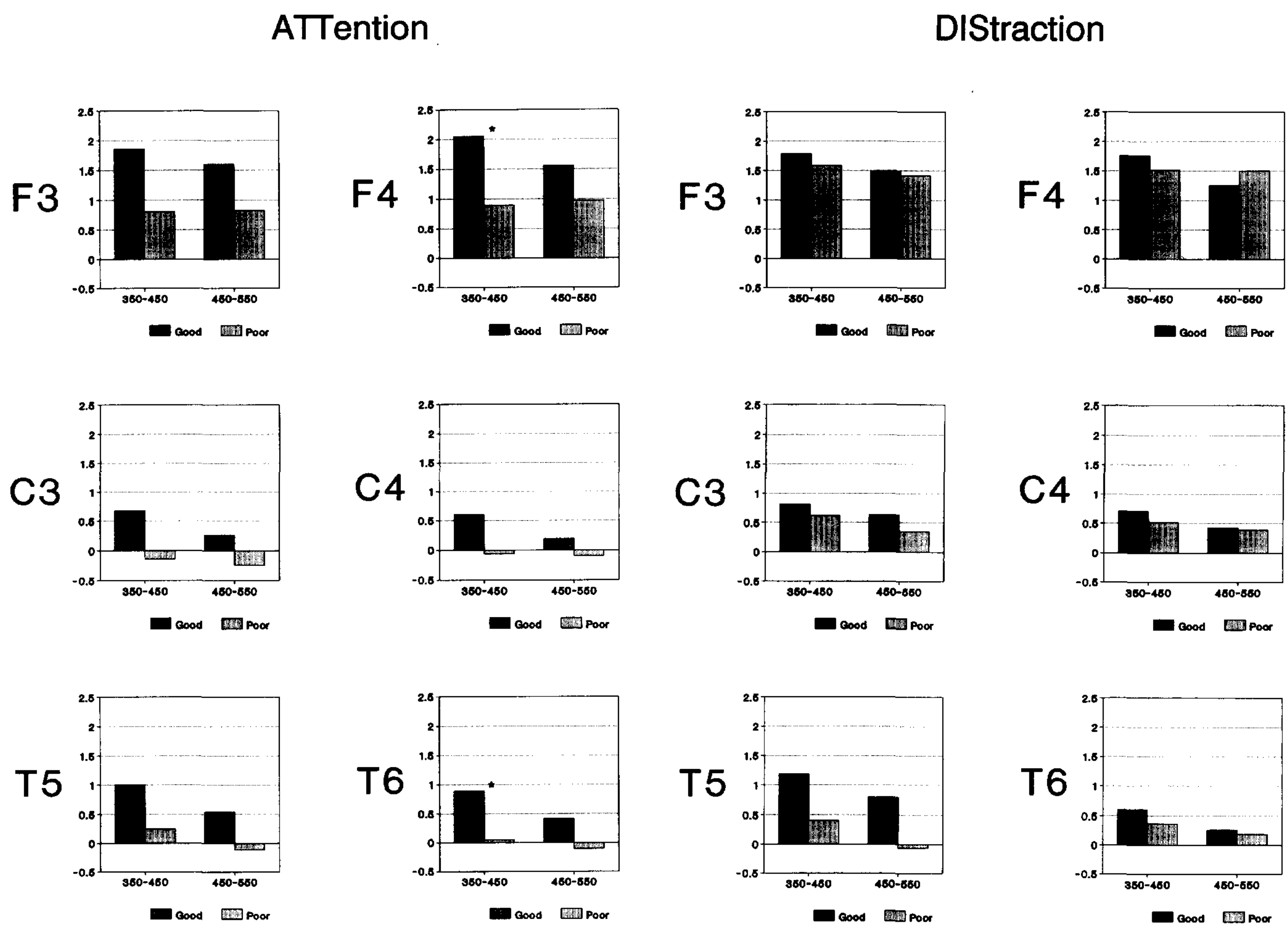

Fig. 4. Mean amplitudes (μV) at the selected electrodes during both the ATT and the DIS condition for the good perceiver and the poor perceiver groups (numbers give time after the EKG R wave in milliseconds). Asterisks indicate a significant difference between the two groups (Tukey post-hoc comparison, $P < 0.05$).

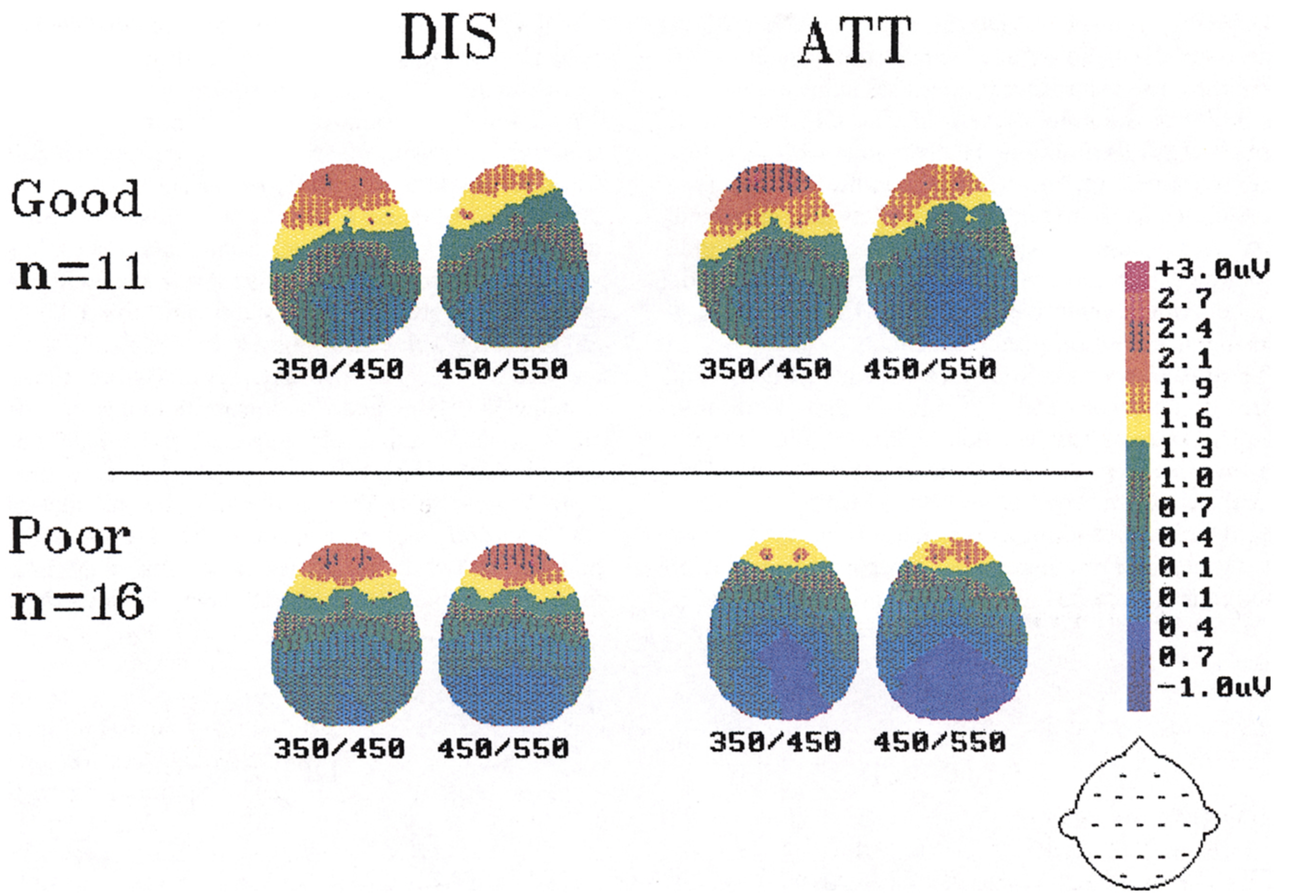

Fig. 5. Brain potential maps for the good and the poor perceiver groups during both the ATT and the DIS conditions between 350 and 550 msec (numbers give time after the EKG R wave in milliseconds).

conditions (Fig. 4b). In general, subjects with low cardiac awareness showed a decrease in the HEP amplitude from DIS to ATT condition. This effect was not observed in the good perceiver group. Furthermore, post-hoc comparisons indicated that for F4 and T6 ($P < 0.05$) the differences between the groups were just significant during the ATT condition, but not during the DIS condition.

In both conditions, HEP amplitudes were greater and more positive at fronto-temporal electrodes (F3, F4, T5, T6) than at central (C3, C4) leads. Moreover, mean amplitudes were greater in the first time window than in the second.

Topography of the HEP. The topography of the HEP was also examined using potential maps of the mean amplitude during both the ATT and the DIS conditions. Fig. 5 shows the potential maps for good and poor perceivers.

The most pronounced feature of the topographical mapping is the frontally distributed positivity in both conditions and groups. Additionally, reduced amplitude occurs at central and posterior recording sites during the attention condition. These effects were most prominent in the poor perceiver group when subjects were focusing their attention on heartbeats.

Discussion

The results of the present study confirm previous findings demonstrating the existence of changes in cardiac-related brain activity associated with the perception of cardiac sensations. In accord with our hypothesis, it was found that changes in the amplitude of cortical response evoked by the heartbeat occur depending on the ability to perceive heartbeats and on focus of attention. In addition, topographical analysis of the HEP showed that these effects were more pronounced at frontal and central regions. The implications of these findings for the study of the processing of signals arising from the viscera will be discussed below.

The major HEP effects occurred in the time intervals from 350 to 550 msec after the R wave. However, it must be kept in mind that the R wave served only as a trigger for the HEP averaging procedure. The EKG is a readily obtainable product of the electromechanical processes occurring in the heart; the R wave is the most prominent wave in the EKG. We certainly do not assume that the R wave serves as the signal in perceptual processes involved in heartbeat detection. Pertaining to possible signal sources, behavioral data indicating a temporal location of heartbeat perception merit consideration. Some authors (Clemens 1984; Yates et al. 1985; Brener and Kluvitse 1988) have reported that for most subjects heartbeat sensations are perceived as occurring between 200 and 300 msec following the R wave. Assuming that the stimulus eliciting the HEP occurs at this time, one may conclude that the observed effects appearing 50 msec (350 minus 300) to 350 msec (550 minus 200) after the cardiac sensation reflect brain electrical processes involved in the evaluation of this information. This is the latency range where changes in sensory evoked potentials are normally observed.

Focus of attention and cardiac awareness effects

Attending to cardiac sensations, as compared to being distracted from them, resulted in changes of the HEP amplitude, most prominent over central electrodes. As can be seen from the difference potentials computed by subtracting the wave forms elicited during the ATT from those elicited during the DIS condition, the effect of focusing attention on the heartbeats was reflected as a negative shift peaking around 390 msec. A similar shift has been observed in studies on cortical processing of exteroceptive signals (Shevrin and Rennick 1967; Groves and Easson 1969; Callaway and Halliday 1982; Salamy et al. 1984; Stelmack and Michaud-Achorn 1985). In these studies, stimulus counting conditions elicited increased EP amplitudes as compared with distracting conditions. Furthermore, they also reported that the major differences appeared over central locations. These morphological analogies lead us to consider that viscerally evoked potentials are influenced by cognitive manipulations (like attentional processes) in a way similar to that of exteroceptive signals. This hypothesis receives further support from the data of Weitkunat and Schandry (1990), who found that the HEP amplitude was affected by motivational processes.

Moreover, the data from the present experiment indicate that a priori differences in the trait "cardiac awareness" are also reflected in the cortical processing of the cardiac information. In fact, the HEP amplitude changed as a function of cardiac awareness and focus of attention. Thus, subjects with low cardiac awareness showed a reduction of the HEP amplitude during the attending condition as compared with the distracting condition. In contrast, no changes were found in subjects with high cardiac awareness. The stronger effect for the poor perceivers may be a consequence of the greater novelty of the heartbeat sensation during the attention condition as compared to the good perceivers: in good perceivers there is probably a permanent tendency to monitor their heartbeats, such that the focus of attention is habitually directed (also under "distraction" instructions) towards cardiac sensations (cf., Pennebaker 1982). Thus, it may be speculated that the explicit instruction to attend to heartbeats yields only a relatively small change in cortical activity as compared to resting or distracting situations. On the other hand, for poor perceivers the instructional demands exert their full impact on brain electrical activity.

Differences between the two groups were only observed when attending to heartbeats, with good perceivers showing greater amplitudes than poor perceivers. This is in agreement with previous findings confirming the relationship of cardiac awareness and HEP amplitude (Jones et al. 1986, 1988; Schandry et al. 1986). In addition, the present data suggest that individual differences in the processing of visceral information are influenced by instructional demands. Thus, our findings add further support to the notion that the perception of cardiac sensations has cortical correlates.

Topographical effects

Although it has not been proved that the heartbeat signal is transmitted by visceral or somatosensory pathways, it is clear that a heartbeat signal must reach cortical centers in order to be processed. Our data indicated that HEP amplitudes were greater and more positive over frontally located electrodes than over central or parietal sites. Furthermore, the HEP amplitude diminished progressively from frontal to posterior regions. These findings are in agreement with previous data from our laboratory (Schandry et al. 1986; Schandry and Weitkunat 1990; Weitkunat and Schandry 1990). In these studies, the most prominent peaks were obtained at Fz, F7, and F8. As a whole, these data seem to indicate that frontal regions are more involved in the processing of the heartbeat than central or posterior ones. This supports the idea that this information might be transmitted primarily via visceral (sympathetic or parasympathetic) afferents rather than by somatosensory pathways, which project to the gyrus postcentralis. Additional evidence pertaining to the cortical projection of visceral afferents in humans has recently been provided by some authors (Hammond et al. 1990; Rutecki 1990). It was shown that electrical stimulation of the vagus nerve elicits changes in EEG synchronicity. Furthermore, it has been suggested from a neuroanatomical point of view that the premotor and the orbital areas of the frontal lobe receive projections of visceral afferent pathways from the hypothalamus and the thalamus (Fuster 1980; Nauta and Feirtag 1986; Netter 1987; Nieuwenhuys et al. 1988).

Conclusions

In summary, the present findings indicate that the registration of cardiac-related brain activity is a useful tool in investigating psychophysiological and neuroanatomical questions of visceroceptive information processing.

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