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Visual evoked potentials, heart rate responses and memory to emotional pictorial stimuli

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Abstract

Although the effects of emotional stimuli on event-related cortical potentials, heart rate, and memory have been extensively studied, the association of these variables in a single study has been neglected. The influence of pleasant, unpleasant, and neutral photographic slides on visual evoked potentials (VEPs), heart rate responses, and free recall, was investigated in 20 normal subjects. VEPs were recorded from Cz and Pz locations, and analyses were performed on both amplitudes and latencies of identifiable endogenous peaks (P2, N2 and P3), and mean amplitude in the 100–200-ms, 400–600-ms, and 600–900-ms latency ranges. An emotional effect was present on VEPs starting from about 282 ms on, as revealed by the N2, P3, and late components. Both pleasant and unpleasant slides yielded larger cortical positivity as compared to neutral ones. Peak latencies did not show any emotional effect. Heart rate data showed a deceleratory response that was larger to unpleasant slides. Free recall of the projected slides showed a better performance for emotional slides compared to neutral ones. VEPs and memory data showed the same pattern: both pleasant and unpleasant slides induced larger positivity in the event-related potentials and were better remembered than neutral slides. Positive correlations were found between the late negative VEPs component (600–900 ms), recorded from Cz, and heart rate deceleration ($r = 0.62$), and between P3 (at Pz location) and the number of remembered slides ($r = 0.53$). © 1997 Elsevier Science B.V.

Keywords: Emotion; Visual evoked potentials; Heart rate; Memory

1. Introduction

1.1. Event-related potentials to emotional pictorial stimuli

The investigation of event-related potentials to emotional visual stimuli has generally shown higher cortical positivity in response to emotional material as compared to neutral material. Such pattern has been viewed as indicative of deeper processing of the emotional information. However a number of problems characterized previous studies on this topic, as the fact that the visual stimuli covered a restricted semantic category and/or were not standardized.

Lifshitz (1966) and Begleiter et al. (1967) first reported the influence of emotional visual stimuli

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on event-related cortical responses. Later on, Radilovà and coworkers (Radilovà, 1982; Radilovà et al., 1983, 1984) studied visual evoked potentials (VEPs) while subjects watched emotional pictures. In the first study (Radilovà, 1982), unpleasant visual stimuli, tachistoscopically presented, produced more positive P3 waves as compared to neutral stimuli. Two other experiments (Radilovà et al., 1983, 1984) showed that P3 was more positive for erotic (sexual slides) than non-erotic (landscapes, flowers, etc.) slides. These studies yielded the conclusion that the emotional impact of visual stimuli increased the amplitude of the P3 independent of the pleasant or aversive characteristics of the induced emotion (Radilovà, 1989). Nevertheless, the comparison between negative and positive emotions was not included in a single study by these authors.

Data from Johnston and coworkers (Johnston et al., 1986; Johnston and Wang, 1991) were consistent with the above-cited results. In their first study (Johnston et al., 1986), subjects watched sexual (opposite and same sex models), pleasant (babies), neutral (ordinary people) and unpleasant (dermatological pictures) slides. Female model pictures induced larger P3 and P4 (max. at 540 ms) than both pleasant and unpleasant slides, which, in turn, yielded larger cortical positivity compared to neutral slides. Johnston and Wang (1991), using the same visual stimuli, additionally supported the finding that P3 was larger for emotional than for neutral material.

Those studies that investigated lateralized visual evoked potentials to emotional pictures also yielded similar results (Vanderploeg et al., 1987; Laurian et al., 1991): larger P3 to emotional material compared to neutral one; data on laterality were not so clearcut.

In order to obtain a replicable data set, in our laboratory (Mini et al., 1996), visual evoked potentials were investigated to standardized emotional slides. Slides were selected from the International Affective Picture System (IAPS: Center for the Study of Emotion and Attention, 1995), a cross-cultural validated set that includes a wide range of semantic categories varying along the valence dimension (pleasant, unpleasant, and neutral). Results showed more cortical positivity to emotional than neutral slides, in both the analyzed latency ranges: 300–400 ms and 400–500 ms.

The brief review of studies presented here highlights a quite general agreement about a larger positivity to emotional pictorial stimuli as compared to neutral ones. This effect was mainly showed in the P3 and later components.

1.2. Heart rate and emotions

In general, cardiovascular changes reflect metabolic adjustment to environmental demands. Therefore, heart rate modifications should be expected during almost every emotional state. Although heart rate responses have been largely investigated during emotional induction, the data available up to now are controversial (reviews on this argument are in Wagner, 1989; Levenson, 1992; Zajonc and McIntosh, 1992; Cacioppo et al., 1993).

Either physiological or psychophysiological factors account for some divergent findings. First, the heart is doubly innervated by sympathetic and parasympathetic nervous systems, which can vary reciprocally, independently or coactively in front of different stimuli (Berntson et al., 1991, Berntson et al., 1993). Second, the different experimental methods used to induce emotions, particularly imagery vs perception, may be responsible for different effects (Lang et al., 1993; Palomba, 1993; Philippot, 1993).

Cardiac changes during emotional perception have been explained in the light of Laceys' model of information processing (Lacey and Lacey, 1970). The model indicates that stimulus intake (outward directed attention) produces heart rate deceleration associated with cortical activation. On the other hand, stimulus rejection (inwards directed processing) is associated with heart rate acceleration and cortical inhibition. According to this model, heart rate increases occurring during intense emotional states should be associated to cortical deactivation and inhibited information processing, as predicted by the defense reaction (DR). Milder emotional stimulations are likely to produce an orienting reaction (OR); under these conditions a heart rate reduction should be

observed (Sokolov, 1963; Graham and Clifton, 1966; Turpin, 1986).

Indeed, when subjects watch visual stimuli varying along the valence dimension, cardiac deceleration prevails over acceleratory changes. Moreover, larger heart rate decelerations occur following unpleasant stimuli as compared to pleasant ones (Winton et al., 1984; Vrana et al., 1988; Patrick et al., 1993; Palomba et al., 1994). When highly-fearful subjects are presented with unpleasant, phobic material, cardiac acceleration (DR) replaces the usual orienting cardiac deceleration (Klorman et al., 1977; Lumley and Melamed, 1992). A completely different pattern is observed during imagery or social induction tasks: cardiac acceleration is often present, and the amount of heart rate increase seems to be influenced by the intensity of emotion, and to a lesser extent, by its valence (Vrana et al., 1988; Gollnisch and Averill, 1993; vanOyen Witvliet and Vrana, 1995).

In summary, cardiac responses to emotional stimuli reflect both cognitive (mostly attentional) processes and the modality of affective processing. Given the complex interaction between central and cardiovascular processes during emotional states, it might be of particular interest to study their association within a single study.

1.3. Memory and emotions

Cortical processing of emotional material can be studied through cortical indexes (as the above considered VEPs), but also indirectly by investigating emotional influences on cognitive functions such as memory.

During the first part of this century it was a common belief that pleasant events were remembered more than unpleasant ones (Matlin and Stang, 1978). However, this effect has mostly relied on speculative concepts and questionable evidence (see Singer and Salovey, 1988). In particular, the mechanisms underlying the effect were almost unclear.

Later on, several models have been proposed to explain relations between emotions and memory. Widely accepted in cognitive psychology is the assumption that retrieval is largely dependent upon mood states and context cues available at encoding and recall (Bower, 1981; see also: Blaney, 1986; Singer and Salovey, 1988, for reviews on this topic). Those studies that assessed the impact of emotional material on memory performance independent of mood and context influences, indicate that emotional events are remembered better than neutral, ordinary ones. Bradley and Baddeley (1990), and Paul and Whissell (1992), investigating memory for emotional words, showed that they were remembered more than neutral ones while pleasant and unpleasant words were not differentially recalled. These general findings, however, are still questionable due to methodological differences which make it difficult to compare results obtained in different studies (see Christianson, 1992 for a review). Few studies, indeed, used standardized emotional material to assess affective memory. Bradley et al. (1992) investigated the free-recall of a large number of emotional slides, varying along the dimensions of valence and arousal, selected from the International Affective Picture System (Center for the Study of Emotion and Attention, 1995). In immediate free recall test, both pleasant and unpleasant slides resulted in better memory performance as compared to neutral ones. Long-term recall, as assessed one year later, yielded the same effect. A slight advantage for pleasant slides, found in immediate recall, disappeared in long-term recall.

1.4. Goals of the present study

The purpose of the present experiment was to investigate changes in visual evoked potentials and heart rate during the viewing of standardized emotional photographic pictures, and to assess the immediate free recall for the same slides.

According to the literature, both pleasant and unpleasant emotional stimuli were hypothesized to yield larger cortical positivity compared to neutral ones. This effect was expected to occur in VEP endogenous components in a latency range between 200 and 900 ms. Moreover, on the basis of our previous study (Mini et al., 1996), in which Fz and Cz locations yielded similar scalp amplitudes, in the present study visual evoked poten-

tials were obtained only from two recording sites (Cz and Pz).

Heart rate was expected to show larger decelerations following unpleasant stimuli as compared to pleasant ones, as already reported in previous studies (Winton et al., 1984; Vrana et al., 1988; Patrick et al., 1993; Palomba et al., 1994). Moreover, according to Laceys' model (Lacey and Lacey, 1970) and further demonstrations of positive relationships between heart rate deceleratory changes and cortical negativity (Hatfield et al., 1987; Putnam, 1990; Rockstroh and Elbert, 1990; Walker and Sandman, 1982), it was expected a positive relationship between visual evoked potentials negativity and heart rate decelerations in response to emotional material.

Recall for emotional stimuli was assessed as a subjective measure of emotional processing. In line with Bradley et al. (1992), both pleasant and unpleasant slides were expected to yield a better memory performance as compared to neutral ones. Furthermore, the influence of emotional stimuli on encoding can be fruitfully tested by recording event-related potentials during stimulus presentation and by comparing the direction of changes in both event-related potentials and memory performance to pleasant, unpleasant, and neutral material. Indeed, in the literature, the P3 component has been related to the updating of representations in working memory, by the context-updating model (Donchin and Coles, 1988). Updating of memory representation is assumed to facilitate subsequent recall. Some studies have shown that event-related potentials to subsequently recalled or recognized stimuli were more positive than those to forgotten ones. Moreover, the P3 (and/or later positive components) varied as a function of subsequent memory performance (e.g. Neville et al., 1986; Paller et al., 1987; Paller and Kutas, 1992; Sanquist et al., 1980). Therefore, in the present study it was predicted that those slides that evoked more positive endogenous waves would also be better remembered.

2. Method

2.1. Subjects

Subjects were twenty psychology students (17 female and 3 male; mean age: 25.3 years) participating as a course requirement. All subjects had normal vision and were not suffering from any neurological disorder. All subjects gave informed consent to the participation in the study.

2.2. Stimuli

Sixty emotional slides[1] were selected from the International Affective Picture System (IAPS: Center for the Study of Emotion and Attention, 1995). The slides were selected according to the valence dimension (20 pleasant, 20 unpleasant and 20 neutral). Pleasant slides represented happy babies, puppies, etc., neutral slides represented common objects such as an umbrella, a fork, a hairdryer, etc., unpleasant slides were mostly mutilated bodies or faces and wounded people. Slides, projected at a distance of 1.7 m from subjects' eyes, with a dimension of 86×58 cm, subtended a visual angle of 34° (diagonal). The luminance of the stimuli had been previously assessed by means of a professional exposimeter (Gossen Lunasix 3, Germany); ANOVA statistic showed no luminance differences between pleasant, neutral and unpleasant slides (respectively 9.5, 9.7 and 9.6 EVs; $F_2 = 0.218$, ns). Subjects were randomly assigned to one of the two randomized sequences of slides.

2.3. Physiological recordings

Electroencephalogram (EEG) was measured through Ag/AgCl electrodes placed at Cz and Pz locations, according to the International 10/20 System (Jasper, 1958) and using linked mastoids as reference. Electrode sites were cleaned with alcohol and abraded to reduce electrode impedance. The EEG was amplified with a gain of 20 000 and filtered by a 0.03 Hz high-pass filter

[1] The IAPS identification numbers are the following: pleasant slides: 161, 171, 175, 192, 204, 205, 207, 208, 215, 216, 226, 234, 254, 466, 520, 560, 576, 583, 733, 758; neutral slides: 220, 221, 704, 551, 615, 770, 771, 700, 701, 705, 708, 709, 710, 713, 715, 717, 750, 755, 756, 219; unpleasant slides: 273, 280, 300, 301, 310, 312, 313, 314, 315, 317, 318, 322, 601, 620, 623, 900, 905, 925, 940, 941.

(time constant: 5 s) and a 30 Hz low-pass filter.

To control for eye movement artifacts, vertical electrooculogram (EOG) was recorded from electrodes placed above and below the left eye. The EOG was amplified with a gain of 5000, and the same bandpass used for the EEG.

The electrocardiogram (ECG) was measured through Ag/AgCl electrodes attached to the right mid clavicle and lower left rib cage, in correspondence with the II Einthoven's derivation. Electrode sites were cleaned with alcohol to improve contact. The signal was filtered by a time constant of 30 ms and a low-pass filter set to 100 Hz. A Schmitt trigger detected the R-waves of the electrocardiogram and fed them into a Macintosh Mac II computer that measured the intervals between successive R-waves with a precision of 2 ms.

For physiological recordings, a 150/160 LTD Digitimer amplifier system was employed. The amplified signals were fed into an analog-to-digital converter (CED 1401, Cambridge) and were converted at a sampling rate of 256 Hz. Data acquisition and the control of experimental stimuli were implemented by a PC IGS (286) computer.

2.4. Procedure and data reduction

Subjects sat in a reclining chair in a sound attenuated dimly lit room. After electrode attachment and laboratory adaptation, subjects were told that a number of emotional slides would be presented and that their task consisted in watching them attentively, trying not to move their eyes. At this time, they were instructed that a subsequent memory task would be performed.

Each slide was presented for 6 s with an intertrial interval randomly varying between 18.5 and 28.5 s. Soon after the presentation of all slides, subjects performed a free recall task, in which they were asked to write down a word or a small sentence describing each slide. No time limit was imposed to perform this task.

The electroencephalogram was recorded for 1 s (100 ms before and 900 ms during slide presentation). Trials containing electrooculographic shifts exceeding 100 μV were automatically rejected from further analysis. The percentage of accepted trials was: 57% positive, 64% neutral, and 59% negative slides. Visual inspection of the averaged evoked potential (see Fig. 1) revealed four primary components in the selected time interval (200–900 ms): a positive component reaching the maximum value at 218 ms (P2), a negative component with a peak at 282 ms (N2), a positive component peaking at 351 ms (P3), and a negative slow wave developing at about 400 ms. after stimulus onset (referred to as slow negative wave = SNW).

Three peaks (P2, N2 and P3) and two epochs (400–600 ms and 600–900 ms) were investigated. Furthermore, the 100–200 ms epoch was analyzed to rule out effects determined by physical properties of the stimuli. Mean epoch amplitudes were computed as the mean of all data points within the selected window[2]. Peak amplitudes were computed as differences with 100 ms baseline. Analyses were performed on mean amplitudes of the selected epochs, peak amplitudes, and peak latencies.

ANOVAs were performed with electrode location (Cz, Pz) and valence (pleasant, unpleasant, and neutral) as within-subject factors (2 electrode $\times$ 3 valence repeated measures design). In order to ensure VEP data independency from electrooculographic artifacts, ANOVAs with valence as a factor were performed on the EOG in the same time intervals used for visual evoked potential analyses (including also the 200–300 ms and 300–400 ms windows, as a control for the N2 and P3 components).

The electrocardiogram was measured 2 s before slide onset (baseline) and during 6 s of slide presentation. The cardiac phasic response to emotional visual stimuli has been systematically studied within this time interval (Lang et al., 1993). Interbeat intervals were computed and then converted into heart rate (HR) in beats per min (bpm). Data were reduced off-line in half-second bins according to the harmonic mean criterion (Graham, 1980). HR changes to emotional slides

[2] The mean value computation was preferred to the area equivalent method. It has also the advantage to improve consistency between figures and tables.

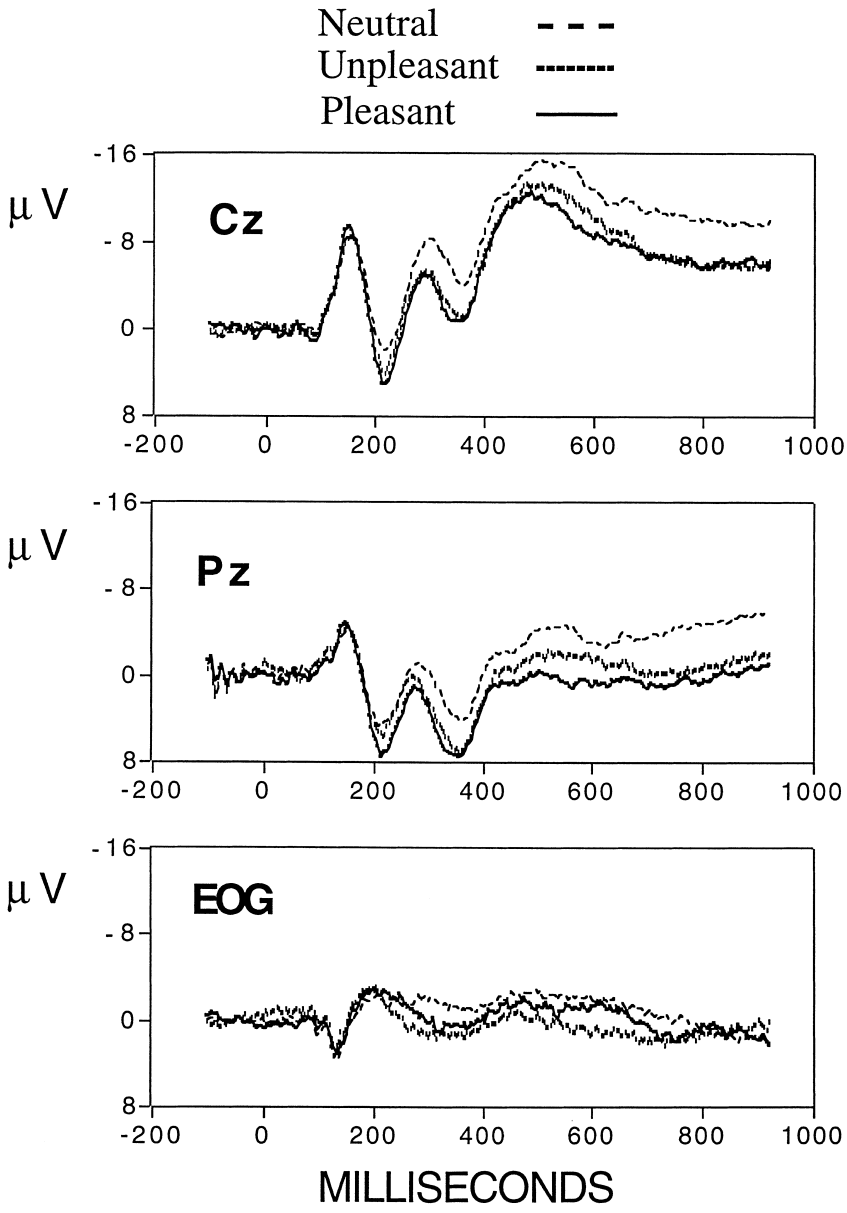

Fig. 1. Averaged visual evoked potentials recorded from Cz (top) and Pz (bottom). Each graph represents the mean waveforms to the three valence categories: pleasant, unpleasant, and neutral. Stimuli were delivered at 0 ms, and negativity is reported as upward deflection. EOG responses are also shown.

were computed as differential values between 6 s of slide presentation and 2 s baseline. In addition, heart rate changes between the first 2 s of slide presentation and baseline were computed. HR data were entered into an ANOVA with valence category (pleasant, unpleasant, and neutral) as factor. Data from one subject were lost because of electrode malfunctioning.

Recall was assessed by a single researcher on the basis of the subjects' descriptions. The numbers of remembered slides for each category (pleasant unpleasant and neutral) were entered

Table 1
Mean peak amplitudes (μV) and latencies (ms), and mean epoch amplitudes of the VEPs are reported together with the respective standard deviations

Peaks		Cz			Pz		
		Ple	Neu	Unp	Ple	Neu	Unp
P2	amp	7.4 (9.2)	4.9 (8.2)	6.4 (8.5)	9.8 (9.3)	7.4 (7.7)	8.1 (8.2)
	lat	221 (25)	220 (21)	221 (28)	217 (24)	215 (17)	217 (28)
N2	amp	−7.8 (9.0)	−11.1 (9.8)	−8.0 (9.5)	−1.3 (7.7)	−4.2 (6.1)	−2.2 (6.9)
	lat	288 (33)	292 (28)	287 (34)	274 (28)	280 (28)	269 (26)
P3	amp	2.1 (7.7)	−1.6 (7.6)	1.5 (8.8)	10.3 (7.1)	6.7 (5.7)	9.2 (8.1)
	lat	351 (23)	353 (29)	348 (34)	348 (26)	356 (22)	351 (30)
Epochs							
100–200	amp	−4.2 (3.8)	−4.6 (3.5)	−4.1 (3.8)	−1.0 (4.7)	−1.4 (4.5)	−1.5 (3.6)
400–600	amp	−10.5 (6.4)	−13.8 (6.1)	−11.7 (6.6)	0.5 (5.3)	−3.4 (5.1)	−1.4 (4.7)
600–900	amp	−6.6 (7.5)	−10.5 (5.4)	−6.7 (6.5)	0.3 (4.7)	−4.5 (4.8)	−0.9 (5.3)

into an ANOVA with valence as factor. One subject refused to perform this part, hence his data were lacking.

Finally, Pearson's correlations between VEP, HR and memory scores were performed. In correlational analyses outliers (one for each correlation) were discarded in order to avoid the influence of extreme values (Stevens, 1990). However, correlations are presented both including and discarding the outliers. The unadjusted P values for effect within variables having more than two levels (valence) are reported together with the Greenhouse–Geisser Epsilon (ϵ) to correct for lack of sphericity (Greenhouse and Geisser, 1958). Tukey's Honestly Significant Difference (HSD) post-hoc test further specified significant effects.

3. Results

3.1. Visual evoked potentials

The grand-averaged VEP waveforms for the three emotional conditions are shown in Fig. 1.

Mean amplitude of each selected latency range, along with peak amplitudes andlatencies are reported in Table 1.

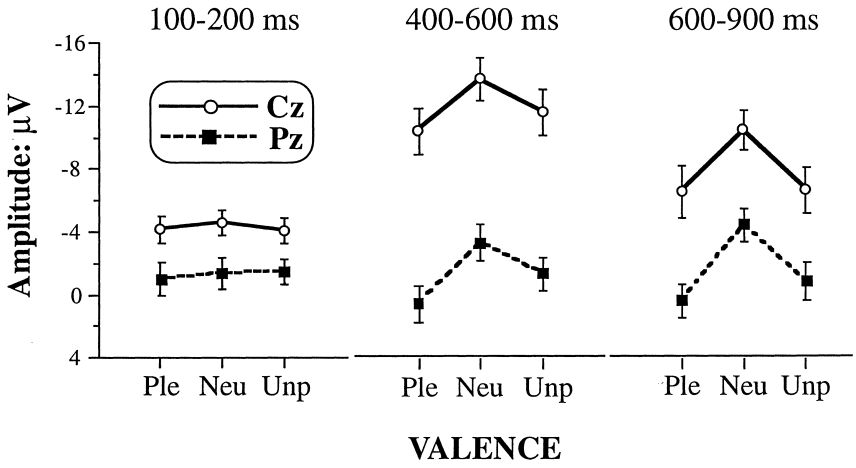

Fig. 2. Emotional effect on visual evoked potentials. Consecutive mean epoch amplitudes (and S.E.) are shown at each of the two cortical leads (Cz and Pz).

All statistical analyses, including 100–200 ms, 400–600 ms, and 600–900ms time windows, and P2, N2 and P3 peak amplitudes, showed a highly significant location effect, with Pz always more positive than Cz (all $P < 0.0007$). There were no latency differences between the two locations. The interaction of location by emotional valence did not show any significant effect, while the emotional valence effect yielded the following results (Fig. 2):

3.1.1. Mean amplitudes

The 100–200 ms epoch did not yield a valence effect ($F[2,38] = 0.19$, $P < 0.83$, $\epsilon = 0.87$). In the 400–600 ms latency range the valence effect ($F[2,38] = 6.4$, $P < 0.004$, $\epsilon = 0.92$) showed more relative positivity during pleasant slides as compared to neutral ones (Tukey's HSD $P < 0.01$), with unpleasant slides in between. In the 600–900 ms epoch the valence effect ($F[2,38] = 9.1$, $P = 0.0006$, $\epsilon = 0.98$) showed that unpleasant and pleasant slides yielded relative greater cortical positivity than neutral ones (Tukey's HSD $P < 0.01$).

3.1.2. Peak amplitudes

P2 did not differentiate emotional stimuli ($F[2,38] = 3.1$, ns). N2 showed a significant valence effect ($F[2,38] = 6.4$, $p < 0.004$, $\epsilon = 0.99$), revealing higher positivity to both pleasant and unpleasant material, as compared to neutral stimuli (Tukey's HSD: $p < 0.01$, and $p < 0.05$, respectively).

P3 also yielded a significant valence effect ($F[2,38] = 7.1$, $P < 0.002$, $\epsilon = 0.92$) showing higher positivity for pleasant and unpleasant slides, as compared to neutral ones (Tukey's HSD: $P < 0.01$, and $P < 0.05$, respectively).

3.1.3. Peak latencies

No significant valence effects were found for peak latencies (P2: $F[2,38] = 0.17$; N2: $F[2,38] = 1.6$; P3: $F[2,38] = 0.85$).

3.1.4. EOG

Analyses of electrooculographic data performed in the same time-windows (including 200–300 ms and 300–400 ms windows) of the visual evoked potentials confirmed statistical independence of VEP data from ocular artifacts. None of the EOG epochs showed a valence effect ($F_s[2,38] < 0.7$).

3.2. Heart rate

As shown in Fig. 3, an overall decelerative response was induced by slide viewing.

The valence effect on heart rate responses during the 6 s of slides viewing ($F[2,36] = 7$, $P < 0.003$, $\epsilon = 0.99$) showed a significantly larger heart

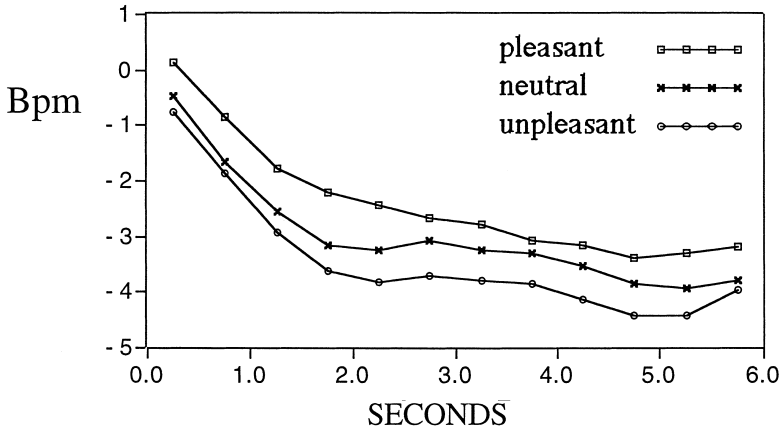

Fig. 3. Averaged heart rate responses during slide viewing for each valence category. After reduction to half-second bins, all data points were subtracted 2-s baseline.

rate deceleration during unpleasant slides as compared to pleasant ones (Tukey's HSD $P < 0.01$) with neutral slides falling in between. Furthermore, a significant valence effect was found during the first 2 s of slide presentation ($F[2,36] = 8.4$, $P < 0.001$, $\epsilon = 0.97$), showing smaller deceleration to pleasant compared to neutral (Tukey's HSD $P < 0.05$) and unpleasant (Tukey's HSD $P < 0.05$) slides.

3.3. Memory

Subjects' slide recall (Fig. 4) showed that emotional content influenced memory ($F[2,36] = 11.6$, $P < 0.0001$, $\epsilon = 0.95$). Memory for neutral slides was lower as compared to both pleasant (Tukey's HSD $P < 0.01$) and unpleasant stimuli (Tukey's HSD $P < 0.05$). No specific advantage for pleasant or unpleasant slides was found.

3.4. Correlations between variables

A positive correlation was found between the last part of the SNW (600–900 ms) at Cz and 6 s heart rate deceleratory changes ($n = 18$, $r = 0.623$, $P < 0.006$; including the outlier, $n = 19$, $r = 0.478$, $P < 0.038$). Larger cortical negativity in the SNW at Cz was associated with larger heart rate decrease (Fig. 5a).

Furthermore, a significant correlation was found between P3 peak amplitude at Pz and the total number of remembered slides ($n = 18$, $r = 0.531$, $P < 0.02$; including the outlier, $n = 19$, $r = 0.377$, $P < 0.11$) (Fig. 5b).

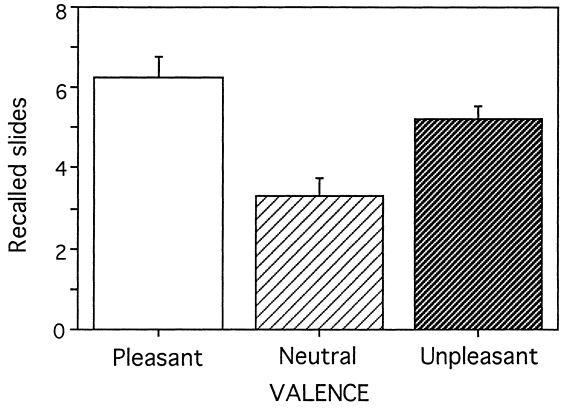

Fig. 4. Emotional effect on slide recall. Number of recalled slides (and S.E.) for each valence category is shown.

4. Discussion

4.1. Event-related potentials to emotional pictorial stimuli and memory performance

Processing visual emotional material produced significant changes in both the central nervous system (CNS) and cardiac activity.

In agreement with our expectation no signifi-

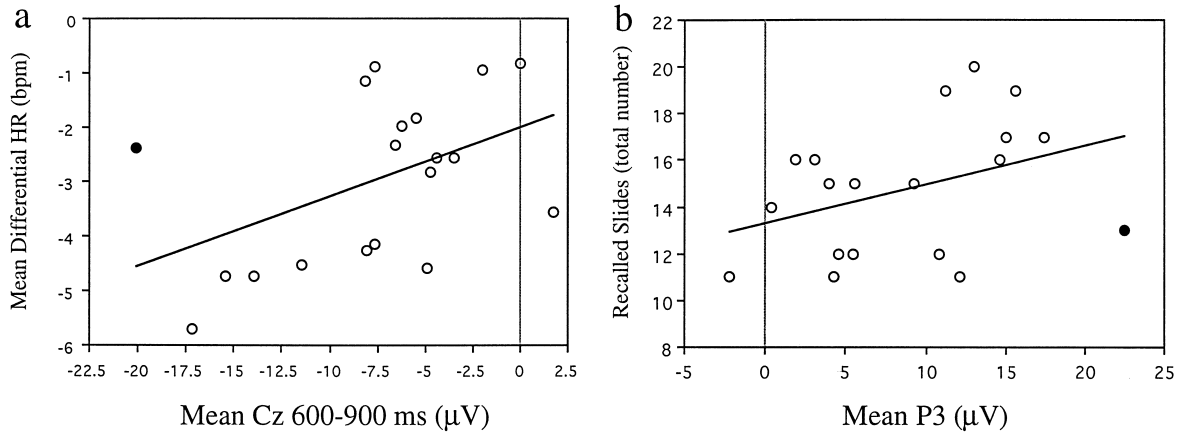

Fig. 5. (a) Correlation between the mean 600–900-ms epoch amplitude recorded at Cz and the mean heart rate response during the 6 s of slide presentation. (b) Correlation between mean P3 peak amplitude recorded at Pz and the total number of remembered slides. Black circles represent outliers.

cant effects due to physical differences between stimuli were detected in the first analyzed latency range, the 100–200 ms window. The earliest emotional effect was found about 282 ms after stimulus onset. N2, P3, and later components (400–600 ms and 600–900 ms latency ranges) showed that emotional slides, both pleasant and unpleasant, yielded a significantly larger positivity as compared to neutral ones. Such an effect indicates that emotional stimuli were preferentially processed in comparison with neutral ones. A similar response pattern has been observed in other psychophysiological responses in experiments using the same slide set. Both pleasant and unpleasant slides have been found to be more interesting and to elicit longer free viewing times and larger skin conductance responses as compared to neutral ones (Greenwald et al., 1989; Lang et al., 1993). As suggested by Polich and Kok (1995) psychophysiological arousal may contribute to event-related cortical responses and especially to P3 amplitude.

The present results on event-related potentials confirm previous findings from our laboratory (Mini et al., 1996). Using the same slide set, it was found that emotional slides yielded more positive VEPs in the 300–400 and 400–500 ms epochs in comparison with neutral ones.

Furthermore, these results are consistent with data obtained with other emotional stimuli (e.g. Johnston et al., 1986; Johnston and Wang, 1991), and further support the hypothesis of a deeper processing of emotional as compared to neutral material. Many studies (e.g. Birbaumer and Elbert, 1988; Rockstroh et al., 1989, 1992; Birbaumer et al., 1990, 1994; Schupp et al., 1994) have indicated that cortical negativity can be considered as an index of higher cortical excitability, while positivity is related to cortical inhibition to a new sensory input; the latter cortical state, as a consequence, should be related to the cognitive processing of the stimulus. In the present study, P3 was larger to emotional than to neutral stimuli, suggesting that processing of affectively relevant characteristics of stimuli occurs at this stage.

The Slow Negative Wave showed higher negativity during neutral slides, while emotional information processing yielded a relative cortical inhibition (relative positivity) which might prevent additional information intaking. Thus, processing of high informative material (neutral slides) along with inhibition of perceptual incoming should enhance the cognitive processing of emotional material.

Results on memory performance are also in line with the above findings. As reported in previous studies (Bradley et al., 1992) emotional slides, either pleasant or unpleasant, were remembered more as compared to neutral ones. Therefore, the recall data pattern mirrored the VEP pattern: larger VEP positivity for both pleasant and unpleasant slides was associated with an improved memory performance for these stimuli compared to neutral ones. This conclusion is further supported by the positive correlation found between the P3 amplitude at Pz and the total number of remembered slides: P3 did reflect stimulus encoding, as shown by its positive correlation with memory performance.

A slight (although not significant) advantage in memory task was found for pleasant slides as compared to unpleasant ones. This is in agreement with data reported by Bradley et al. (1992). Interestingly, this effect was paralleled by a non-significant, but still evident, higher cortical positivity to pleasant, than to unpleasant slides.

4.2. Heart rate changes to emotional slides

Heart rate data were in agreement with previously reported results (Winton et al., 1984; Vrana et al., 1988; Patrick et al., 1993; Palomba et al., 1994). A general decelerative response, which is commonly associated to the presentation of visual stimuli, was shown together with a larger deceleration to unpleasant slides compared to neutral and pleasant ones. Therefore, HR changes varied along the valence dimension differentiating pleasant and unpleasant stimuli, while VEP and memory responses did not. Data also showed a correlation between the Slow Negative Wave (600–900 ms epoch), at Cz, and heart rate changes: those subjects who showed higher cortical negativity (cortical excitability) also presented higher heart rate deceleration. Cortical negativity was present at both locations and with all emotio-

nal categories starting from 400 ms. This result, together with a dominant heart rate deceleration, suggests that the pictorial stimuli induced in subjects an overall attentional disposition. It is also reasonable that late VEP components were associated with HR changes to a greater extent than early components, due to different response latencies of the two systems. This also suggests that an extension of the analysis of VEPs in response to emotional stimuli over a longer period (i.e. 2 s) might be useful for further future studies.

In conclusion, the present data along with results available from the literature indicate that psychophysiological measures differentiate emotions to a different extent. In addition to memory and cortical event-related potentials, there are other measures (electrodermal activity, interest and viewing time; Bradley et al., 1992; Lang et al., 1993) able to distinguish emotional stimuli from non-emotional ones. These measures possibly reflect quantitative characteristics of emotional responses. Heart rate, facial muscle activity (Greenwald et al., 1989; Lang et al., 1993), and the eyeblink startle response (Lang et al., 1990) are able to differentiate pleasant and unpleasant stimuli. Facial EMG activity is strongly related to communicative features of emotions; therefore its capability to discriminate specific emotions is not surprising. Startle and HR differential changes to pleasant and unpleasant stimuli can be interpreted on a different basis. Recent research (Iwata et al., 1987; Hitchcock and Davis, 1991) has identified the amygdala, among the other subcortical structures, as an important structure involved in startle and HR control. The amygdala plays a major role in the modulation of motivational states such as avoidance, and both startle reflex and heart rate do vary along the approach/withdrawal dimension (Lang et al., 1990). Thus, the results of the present experiment are consistent with the view that cortical activity sustains identification, recognition and memory of emotional stimuli from low informative material. Heart rate, possibly through the amygdala, lateral hypotalamus, and the autonomic nervous system (see LeDoux, 1995), would distinguish the motivational aspects of emotions, that is, the pleasantness or aversiveness of the stimuli.

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