

Categorization of unilaterally presented emotional words: an ERP analysis

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Abstract. This study is intended to clarify the functional role of different ERP components as indicators of the processing of emotions. The effect of emotional connotation of words on hemispheric lateralization is also explored. Visual ERPs were recorded to unilaterally presented positive, negative, and neutral words that should be categorized according to their emotional connotation. The P2 amplitude was larger to positive than to negative words whereas P3 amplitude was larger to positive words compared with neutral ones. The slow positive wave (SPW) was influenced by words emotionality at anterior and posterior sites differently. The amplitude of the N1 component was larger in the left hemisphere to contralaterally presented words. The P2 and P3 components were larger over the left hemisphere whereas the N3 and N4 components were larger over the right hemisphere to ipsilateral stimulation. The results support our hypotheses on the functional role of positive ERP components in the processing of an affective words connotation: the P2 wave reflects a general evaluation of emotional significance, the P3 a task-related decision, and the SPW an additional decision control in the context of the emotional experience of an individual. Neither the "right hemisphere hypothesis" nor "valence hypothesis" on lateralization of the processing of emotions were confirmed. Each hemisphere seems to exert its effect on emotion through specific hemispheric resources that are unequally allocated along the different stages of task processing and may cause alternation of hemispheric dominance.

Key words: information processing, emotion, hemispheric lateralization, event-related potentials

INTRODUCTION

The differentiation of emotional connotations of verbal stimuli on the basis of ERP means that the stimuli that have emotional significance are processed in specific ways. Substantial differences between emotional and neutral words were demonstrated in early-latency (Begleiter et al. 1979) and mostly in middle-latency ERP components (Kostandov and Arzumanov 1977, Johnston et al. 1986, Vanderploeg et al. 1987, Naumann et al. 1992, 1997). These findings suggest that the emotional connotations of words are processed at different stages. Psychological mechanisms underlying these stages, however, are not yet clear.

The P3 (P300) wave deserved the main attention of investigators. It increased to emotional stimuli (both positive and negative) in comparison with neutral ones. Some authors tend to interpret the P3 wave as "primary evaluation stage" (Johnston et al. 1986) and as an index of a completely automatic detector system for emotional stimuli (Naumann et al. 1992). However, some findings do not correspond to these points of view. Firstly, the effect of emotionality was obtained at the earlier ERP components, e.g. N1-P2 (Begleiter et al. 1979) and therefore the processing of emotion begins earlier than the P3 wave appears. Secondly, this effect seems to be altered by focusing attention to the emotional content of stimuli (Naumann et al. 1997), that casts doubt on completely automatic processing at this stage.

According to our hypothesis, the process underlying the P3 component should be connected with evaluation of subtle features of stimulus extracted at the preceding stages in context of further behavior. If an affective rating of a word is required in the task, we might expect that the P3 should reflect an involvement of a word into a broad semantic network facilitating subsequent categorization of that word. Thus, P3 should be more sensitive to the task-relevant features of the stimuli than to the preceding ERP components.

Foregoing studies did not pay enough attention to early ERP components. Apparently, the experimental design of the studies was not appropriate for stimulating of early processing. Only Begleiter et al. (1979) showed the effect of emotional valence on N1-P2 peak-to-peak measures. Moreover, positive words were not differentiated from the negative ones on the basis of the N1-P2 components. In another experimental paradigm, where the negative or positive emotions were elicited by receiving or losing money for the task performance, the P2 (P180) peak appeared to be sensitive to both positive and

negative emotions (Sobotka et al. 1992). As the N1 and P2 components are commonly examined in the context of orienting behavior (Squires et al. 1975, Ruchkin et al. 1987), it might be assumed that they are associated with primary evaluation of the affective content of a stimulus. The primary response of the brain to an emotional event is critical for the programming of further avoidance or withdrawal behavior (Gray 1987, Lang 1995). Keeping this assumption in mind we hypothesized that the N1 and P2 components should reflect a global (and presumably, automatic) emotional evaluation according to the negative or positive significance of the stimuli.

The function of the slow positive wave (SPW) in the processing of emotion is not investigated enough. In comparison with N1, P2 and P3 the SPW represents a quite different kind of processing of stimuli with emotional connotation, as the amplitude, latency and scalp distribution of the SPW are highly sensitive to stimulus feature (e.g. word or picture) and experimental task (Vanderploeg et al. 1987). For example, in Nauman et al. (1992) study participants had to evaluate adjectives according to their emotional valence ("affective" processing) or their length ("structural" processing). Only in the "affective" processing group a long lasting fronto-central SPW was obtained. This fact was interpreted as an index of "affective" processing functions. However, the recent study using emotional nouns failed to replicate this effect (Naumann et al. 1997) - in all experimental conditions a parietal SPW was found to be maximal. As proposed by Johnston et al. (1986) the SPW is related more to a final evaluation of the outcomes of the previous processing stages, rather than to special "affective" processing.

It is not clear whether the SPW may be influenced by the emotionality of the stimuli themselves, as none of the cited authors reported the "valence effect" on SPW. Probably, the tasks they imposed were simple and did not require an additional processing cycle (i.e., final evaluation) from the participants. According to our hypothesis, the SPW should be sensitive to emotional content of words in the affective rating task as the SPW would reflect an additional processing stage directing to the final evaluation of the decision taken about a word.

At present the role of the brain hemispheres in the processing of emotions remains unclear and disputable in many aspects (see for review Gainotti 1989). One of the widely accepted hypotheses, the "valence hypothesis", implies that negative emotions are processed mainly in the right hemisphere and positive emotions in the left one. However, another well-known hypothesis, the

"right hemisphere hypothesis", receives some support from the ERP data based on the superiority of the right hemisphere in the processing of both negative and positive stimuli. The right hemisphere advantage in P300 amplitude was obtained if both emotional and neutral words (Williamson et al. 1991) or pictures (Laurian et al. 1991) were presented. If only neutral words were used the hemispheric differences failed to occur (Kok and Rooyakkers 1986). Begleiter et al. (1979) reported a lack of hemispheric asymmetry in N1-P2 components in an affective rating task. These studies failed to show any interactive effect between hemisphere and the word's emotionality on any ERP component. It is supposed that neither of the hemispheres is favored at all the processing stages. It seems likely that its effect on emotion is mediated through specific hemispheric capacity of performing the task and this capacity is unequally allocated inside the different stages of processing.

The functional role of different ERP components in the processing of emotions might be better understood if they are analyzed as a complex of links within one task on processing of the emotionally significant stimuli. However, there are few ERP studies demonstrating all the components within a framework of one complex task. Therefore the effect of hemispheric laterality in these studies deserves more attention.

In the present study we were mainly interested in how the ERP correlates to intuitive (i. e., predominantly, unconscious) processing of emotional information. For this purpose, we used conditions in which the decision about a word was to be made within each presentation. Memorizing experimental words before the experiment should lead to pure cognitive categorization based mostly on the matching of the incoming stimulus with the trace in memory that should eliminate the effect of emotionality (Leiphart 1993). Therefore our experimental conditions differed from traditional ones (e. g. Williamson et al. 1991, Naumann et al. 1992, 1997) in some substantial aspects: (1) participants were not familiarized with the words before the experiment; (2) they were asked to respond spontaneously, relying on their intuition; (3) the full perception of words was more complicated (as both brief and peripheral presentations were used); (4) we used a special procedure to control the quality of eye fixation. We combined the emotional rating task together with a brief presentation of words in order to create conditions in which participants should categorize the word (sometimes) without its full perceptual recognition. This task seems to be appropriate for testing hypotheses on the

functional role of the P2, P3 components and the SPW in the processing of an affective word's connotation.

Faced with controversial findings on the role of the brain hemispheres in the processing of emotions, we used a divided visual field presentation of words in order to clarify the involvement of the hemispheres in different stages of the processing in case the affective connotation of a word should be evaluated.

METHODS

Subjects

Fifteen participants (7 men and 8 women) aged from 24 to 34 years old took part in the experiment. All the participants were right-handed according to the Edinburgh Inventory (Oldfield 1971). They were all native speakers of German and had normal or corrected-to-normal vision.

Stimuli, apparatus and task

Stimuli were 18 German one-syllable nouns presented on a VGA display of an IBM-compatible PC. Stimuli consisted of four, five or six white capital letters that were presented horizontally on a dark background. The visual angle of the stimuli varied between 2 (4 letter words) and 4 degrees (6 letter words). Words were presented in the left or right visual field (LVF, RVF). Simultaneously with each word, a gray rectangle of the same size appeared in the opposite side of the screen to delay lateral eye movements toward a word. In the cases of LVF or RVF presentation the last or the first letter of the word (respectively) was situated at a constant and equal distance of 2 degrees laterally from the fixation point, which was an asterisk (0.5 by 0.5 degrees) in the centre of the screen.

The 18 nouns were pre-selected according to the following criteria. Six nouns were chosen for each of three evaluative categories (negative, positive, or neutral affective connotation), according to a rating of 90 words on a 5-point bipolar scale (from "very unpleasant" to "very pleasant") by participants from the same population (students of the University of Osnabrück who did not participate in the experiment). The emotionality scores of words selected for experiment were: negative - $m = 1.27$, $SD = 0.36$, neutral - $m = 3.15$, $SD = 0.41$, positive - $m = 4.72$, $SD = 0.18$.

Words were matched across the three categories for word frequency, according to norms for German words

(Hager and Hasselhorn 1994): each category contained three words of average frequency (100-800) and three high frequency words (1,300-2,300). In addition, each word from every given category had a "counterpart" with an identical first letter at least in one of the remaining two categories, e.g. "Feind" (enemy) vs. "Freund" (friend). This was done to reduce the possibility that participants could perform the task without accessing the semantic content of each word, that is, merely on the basis of its first letter. Finally, words were matched across three categories for word concreteness and imagery according to Hager and Hasselhorn (1994).

Participants sat with their heads in a chin rest and had to focus on the fixation point. The distance to the screen was 57 cm. In order to facilitate fixation, each trial started with the facilitating presentation of a special stimulus pattern consisting of three successive squares decreasing in size that were followed by the fixation point and the word. This procedure simulated an illusory motion toward the fixation point. It was used successfully to support external, automatic control of fixation without the extra effort that is needed when participants have to control fixation by active, conscious effort (Stelmach and Herdman 1991). The fixed rhythm of 3 successive squares was chosen to maximize the possibility of early (i.e., partly unconscious) anticipatory selectivity in word processing. The temporal characteristics of each trial were (see Fig. 1): (1) the pre-stimulus interval of 90 ms; (2) three successive squares

decreasing in size were shown for 180, 120 and 90 ms respectively; (3) the fixation point appearing after the last square in the centre of the screen for 90 ms, followed by (4) the presentation of a word in one visual half field and a gray horizontal bar of equal size in the other visual half field for 150 ms. This was followed by an intertrial interval of 3,350 ms. The fixation point remained in the centre of the screen during the exposition of the word as well as for the first 2,000 ms of each intertrial interval.

Procedure

The participant's task was a binary classification of each word presented as to whether it was an emotional (positive or negative) or a neutral one. Two vertically aligned buttons in the sagittal midline were used for response registration. This should exclude spatial stimulus-response compatibility effects (Heister 1987). Participants were instructed to press the upper button with their middle finger if the word had an emotional connotation, and the lower button with their index finger if the word had a neutral connotation. In order to avoid the one-hemisphere prevalence caused by responding with the one hand (e.g., Measso and Zaidel 1990) half of the participants began responding with their right hand and changed their hand after the second block of trials. The other half of participants started with their left hand. Participants were asked to respond spontaneously, relying on their intuition. It was emphasized that errors

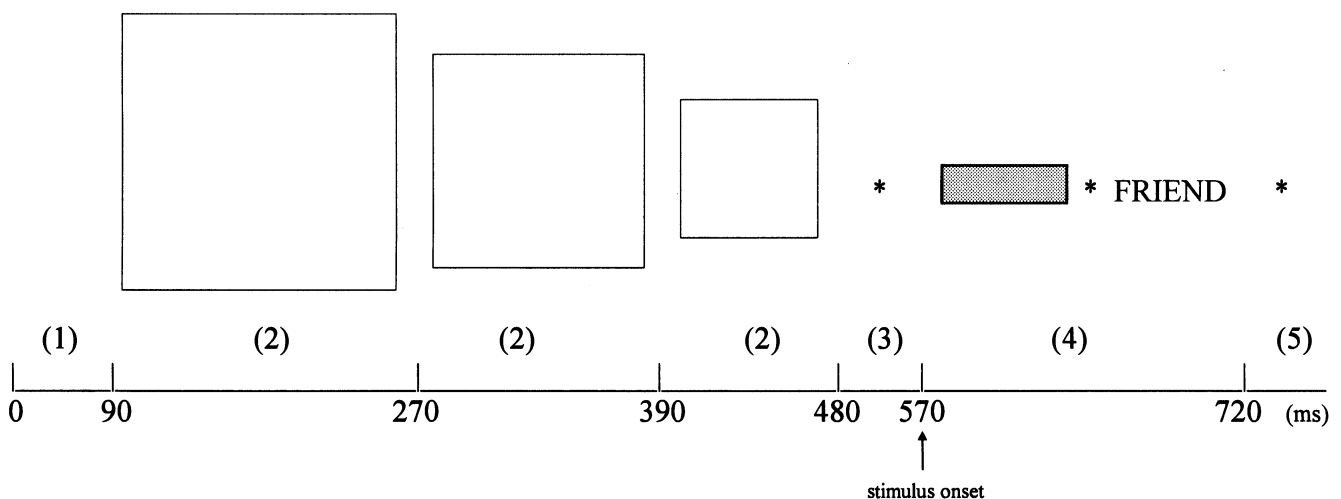


Fig. 1. The temporal events underlying the trials. (1) the prestimulus interval; (2) three successive squares stimulated an illusory motion; (3) the fixation point appearing in the center of the screen; (4) the presentation of a word in one visual half field and a gray horizontal bar in the other visual half field; (5) the fixation point.

would be expected because of the brief and peripheral stimulus presentation. Such an instruction was chosen on the assumption that affective evaluation may be done without full perceptual recognition of a word. Also we tried to encourage the participants to involve unconscious processes for making spontaneous evaluation rather than to evaluate a word based on its full perceptual recognition.

Each experiment started with a training session consisting of about 100 trials. The words in the trials were not included into the main experiment. One half of them were presented before electrode placement and the other half after electrode placement. After each training session was run, participants were asked to report the words that they recognized. Training continued until the participant correctly reported 50% of the words. No feedback was provided before the end of the experiment. Each of the four blocks of the main experiment included 144 trials presented in pseudo-random order (4 presentations of each of the 18 words in both LVF and RVF). There were 5-min. breaks between the blocks.

At the end of the experiment participants completed a 5-point rating scale (from "very unpleasant" to "very pleasant") for each word seen during the experiment. This was done to control "paradoxical" evaluations (e.g., the negative word was evaluated as positive or neutral) that might be caused by participants life history. No "paradoxical" evaluations were obtained by post-hoc analysis.

Psychophysiological recording

The EEG was recorded with Ag/AgCl electrodes (MES company, Germany) from 14 homologous scalp sites (Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, T3, T4, O1, O2) according to the "10-20" system. Both vertical and horizontal EOGs were recorded. The linked mastoid was used as a reference electrode. Electrical impedances were kept below 5 k Ω throughout the experiment. The Neuroscan system (Neuroscan Inc., USA) was used for EEG registration and ERP processing. Signals were filtered (0.2 to 30 Hz bandpass with 24 dB/oct slope of the filters). The sampling rate was set at 200 Hz. The length of each epoch was 2,560 ms including 90 ms of the pre-stimulus background for baseline assessment.

Data analysis

Each response was scored as correct if the appropriate key had been pressed in a time window lasting from 200 to 3,000 ms after stimulus onset. The 200 ms limit was

chosen to avoid counting any premature responses. Both the percentage and the reaction times (RTs) for correct categorizations were analyzed.

For ERP analysis all sweeps were digitally pre-filtered at 30 Hz and baseline was corrected according to the pre-stimulus background. For elimination of EOG artifacts the procedures of both EOG correction and rejection were used. The sweeps were rejected if the amplitude of the vertical or horizontal EOG exceeded 100 μ V. Subsequently, remaining EOG artifacts were corrected on the basis of a regression analysis algorithm (Semlitsch et al. 1986) for each sweep in the frequency domain. However, after this procedure artifacts caused by lateral saccadic eye movements remained undercorrected because of its small amplitude and short duration. In order to refine our data, the effect of saccades on the ERP amplitudes until 400 ms was statistically examined. A 2 x 2 ANOVA for homologous lateral electrodes was performed. The factors were: visual field (left, right) and hemisphere (left, right). It is well-known that the saccades influence the ERP amplitudes as follows: the amplitudes are larger (1) at the site ipsilateral to stimulus presentation compared with contralateral ones and (2) at the anterior than at the posterior locations. In the case we obtained the significant interaction of visual field x hemisphere caused by the larger ERP peak amplitude at the site ipsilateral to stimulus presentation compared with contralateral ones and this effect attenuated markedly in the posterior direction, we decided that the amplitude of ERP peak was hardly affected by saccades. Such pairs of electrodes were excluded from further analysis. According to this criterion the pairs Fp1 - Fp2, F7 - F8, T3 - T4 were not accepted for analysis of any ERP peaks; moreover F3 - F4 pair was eliminated from P2 peak analysis.

The ERPs were averaged only for correct categorizations in the time window lasting from 200 to 3,000 ms after stimulus onset. Six ERP types (2 levels of visual fields by 3 levels of emotionality) were obtained for each electrode. The most prominent ERP components were identified by visual inspection of individual sweeps as well as grand mean ERPs in the following time windows: N1 (100-200 ms), P2 (200-300 ms), P3 (300-450 ms), N3 (450-650 ms), N4 (650-1,000 ms), and SPW (1,000-1,800 ms). Base-to-peak computations of each peak were done individually for each participant.

The amplitude for each ERP component was subjected to an ANOVA with repeated measures. Emotionality (negative, positive or neutral), visual field (left or

right), hemisphere (left or right), and anteriority (frontal, central, parietal or occipital) served as within-subject factors. For P2 peak analysis the factor "anteriority" had only three levels: central, parietal and occipital. The interactions between experimental variables were further explored by post-hoc paired comparisons. Greenhouse-Geisser epsilon values were applied to correct the lack of sphericities in the covariance matrices involving repeated measures factors with more than two levels.

RESULTS

Behavioral measures

The effect of emotionality on RTs was marginally significant ($F_{2,28} = 2.55$, $P < 0.09$, $MSe = 6,106$). Post-hoc comparisons revealed faster responses to neutral words (1,084 ms) compared with both negative (1,129 ms) and positive (1,104 ms) words. The effect of emotionality on percentage of correct categorizations was also marginally significant ($F_{2,28} = 2.64$, $P < 0.09$, $MSe = 209.53$), reflecting a somewhat better categorization of neutral (62%) compared with positive (54%) words; the performance of negative words (60%) differed not significantly from remaining word types. Words exposed in RVF were categorized more accurately than when presented in LVF (63% vs. 54% respectively), $F_{1,14} = 7.77$, $P < 0.02$, $MSe = 126, 12$.

As the categorization accuracy was not affected by the words emotionality, on the basis of behavioral measures we cannot provide any suggestions about mechanisms underlying the processing of affective content of words. Moreover, the categorization accuracy was at the intermediate level, so one might speculate that on some trials participants have been choosing a response randomly without identification of the emotional connotation. Obviously, a difficult task might force the subject to do this. Therefore we took into consideration only those trials in which the categorization was correct and analyzed only ERPs as indicators of the processing of emotional connotation. When the predicted effects of emotionality on ERP components were obtained, it suggested that the emotional content of words was really processed.

Event-related potentials

THE N1 (N140) COMPONENT ANALYSIS

The N1 component was increased at posterior sites compared with anterior ones ($F_{3,42} = 8.61$, $P < 0.000$,

$MSe = 17.75$). The main effect of emotionality was not significant. The main effect of visual field showed larger N1 amplitude with RVF presentation than with LVF (Fig. 2). In addition, an interaction of visual field x anteriority x hemisphere was obtained ($F_{3,42} = 11.33$, $P < 0.000$, $MSe = 0.33$). The post-hoc analysis for paired electrodes revealed two effects attributable for this interaction: (1) the N1 amplitude was larger at the left frontal sites with RVF presentation than with LVF and (2) it was smaller at the right parietal sites with LVF presentation if compared to amplitudes in the remaining conditions. These results suggest the dominance of the left hemisphere in early word processing.

THE P2 (P230) COMPONENT ANALYSIS

The P2 component reached its maximum at central sites. However, this tendency was only marginally significant ($F_{2,28} = 2.91$, $P < 0.07$, $MSe = 46.78$). The main effect of emotionality was not significant. An anteriority x emotionality interaction was significant ($F_{6,84} = 3.69$, $P < 0.01$, $MSe = 0.47$). Planned comparisons indicated that the P2 amplitude was larger to positive than to negative words at the central sites but not at the other sites (Fig. 3B). Separate comparisons for C3 and C4 electrodes revealed an identical effect of emotionality. The main effect of visual field ($F_{1,14} = 4.79$, $P < 0.05$, $MSe = 5.87$) and a two-way interaction of visual field x hemisphere ($F_{1,14} = 15.53$, $P < 0.001$, $MSe = 3.35$) resulted from the fact that P2 was larger with LVF than with RVF presentation and that the left hemisphere was more sensitive to the LVF stimulation than the right one (Fig. 2). This interaction was observed on parietal and occipital locations only ($F_{1,14} = 3.67$, $P < 0.04$, $MSe = 1.0$). To summarize, the P2 component seems to reflect an early processing of emotional connotations. The amplitude of P2 was larger at the site ipsilateral to stimulus presentation than at the contralateral one. The dominance of the left hemisphere in P2 can be emphasized.

THE P3 (P330) COMPONENT ANALYSIS

The P3 component was larger at parieto-occipital areas than at fronto-central ones (main effect of anteriority, $F_{3,42} = 13.48$, $P < 0.000$, $MSe = 28.59$). Post-hoc comparisons showed no significant differences between parietal and occipital sites as well as between frontal and central sites. There was a main effect of emotionality ($F_{2,28} = 4.60$, $P < 0.02$, $MSe = 5.01$) based on larger P3 amplitude to positive words compared with neutral ones

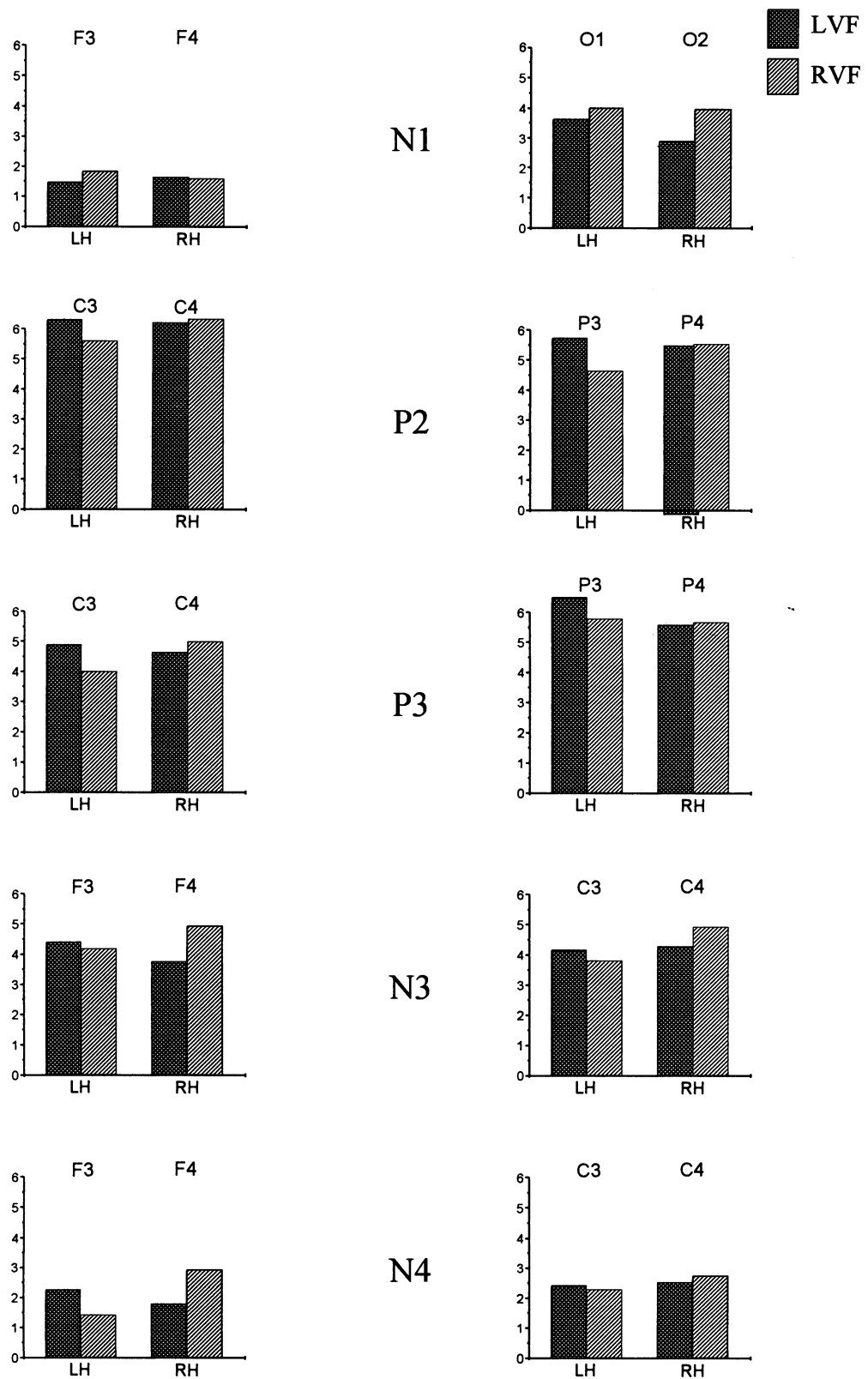


Fig. 2. Mean ERP amplitudes of the N1, P2, P3, N3, N4 components (in microvolts) as a function of visual field and hemisphere. RH, right hemisphere; LH, left hemisphere; L VF, left visual field; R VF, right visual field.

(Fig. 3C). An interaction of hemisphere \times visual field was observed due to the left hemisphere superiority if the words were presented in the LVF ($F_{1,14} = 12.03$, $P < 0.004$, $MSe = 5.85$). The P3 component seems to be associated with "affective" processing, but in a different way if compared with the P2 component. The amplitude of P3 was larger at the ipsilateral site than at the contralateral to stimulus presentation and larger all over the left hemisphere.

THE N3 (N550) COMPONENT ANALYSIS

The N3 amplitude was influenced by an anteriority \times visual field interaction based on the increased amplitude to RVF presentation compared with LVF at frontal sites only ($F_{3,42} = 3.57$, $P < 0.02$, $MSe = 1.58$). A main effect

of emotionality was not obtained. There were interactions of hemisphere \times visual field ($F_{1,14} = 10.33$, $P < 0.006$, $MSe = 2.79$) as well as anteriority \times hemisphere \times visual field ($F_{3,42} = 3.29$, $P < 0.03$, $MSe = 0.81$). Post-hoc tests revealed larger N3 amplitude all over the right hemisphere to RVF presentation (Fig. 2); this effect reached significance at frontal and central, but not at parietal and occipital sites. The results showed that the N3 component was not an indicator of the processing of emotions. The amplitude of N3 increased all over the right hemisphere to ipsilateral stimulation.

THE N4 (N750) COMPONENT ANALYSIS

The N4 component showed a clear-cut amplitude shift towards anterior sites. The main effect of anteriority was

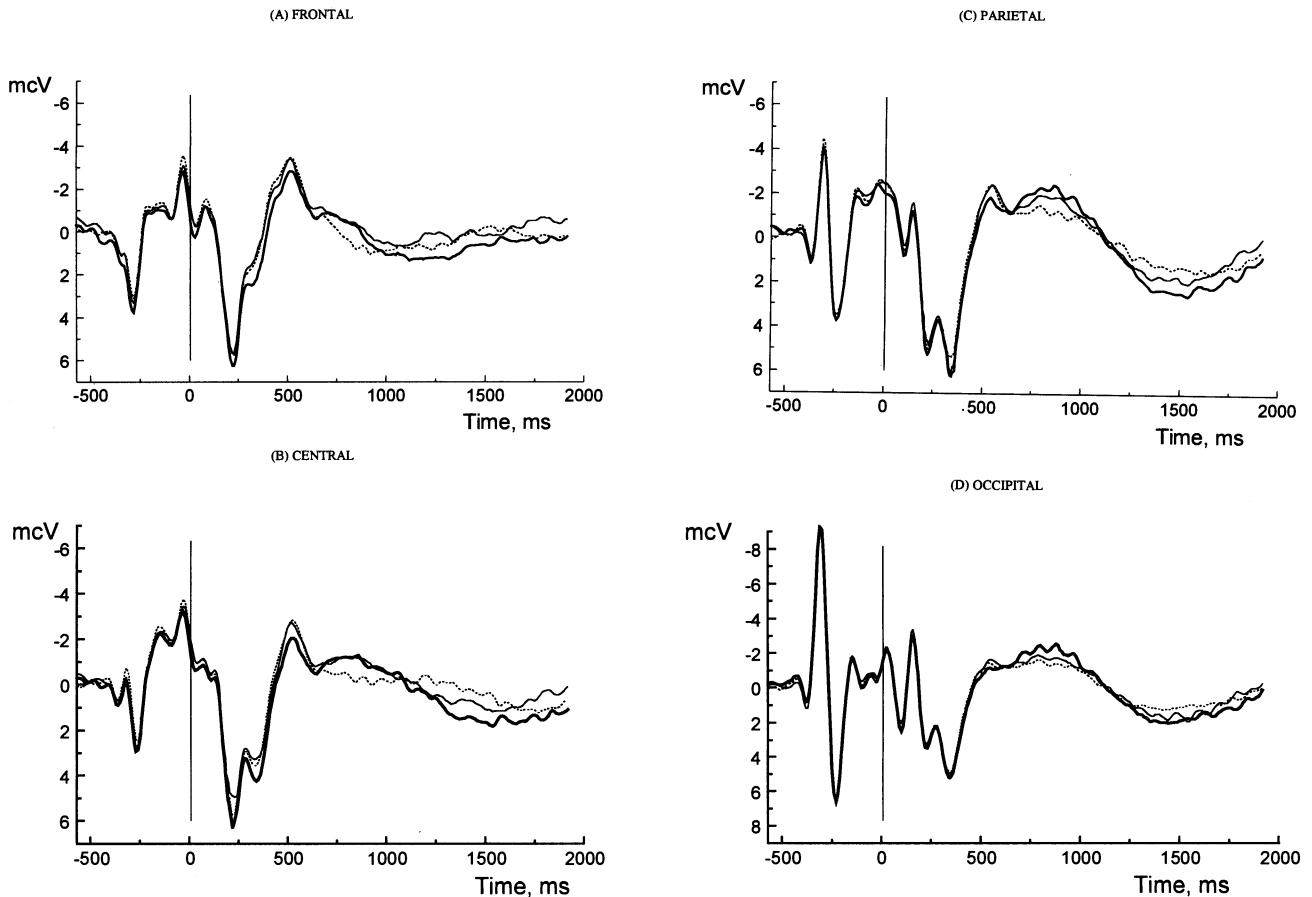


Fig. 3. Grand-average ERP waveforms to negative (thin solid), neutral (dotted), and positive (thick solid) words at frontal (A), central (B), parietal (C), and occipital (D) sites. The vertical line is the onset of word presentation. The ERP components before the vertical line are elicited by three successive squares stimulated an illusory motion toward the fixation point (see Fig. 1). Negativity up.

based on larger N4 amplitude at fronto-central locations if compared with parieto-occipital ones ($F_{3,42} = 4.31$, $P < 0.01$, $MSe = 14.66$). Post-hoc comparisons indicated no significant differences between parietal and occipital sites as well as between frontal and central sites. A main effect of emotionality was not obtained. The analysis of the interaction of hemisphere \times visual field showed the largest N4 amplitude in the right hemisphere with RVF presentation ($F_{1,14} = 4.58$, $P < 0.05$, $MSe = 3.34$). The other interaction of hemisphere \times visual field ($F_{3,42} = 5.17$, $P < 0.004$, $MSe = 1.96$) was found due to the fact that N4 amplitude decreased in the anterior-to-posterior direction with LVF stimuli whereas it did not decrease with RVF stimuli (Fig. 2). The amplitude of N4 was affected by the same factors that influenced the N3 component. This suggests that the N4 peak seems to be closely linked with the processes reflected in N3. These processes seem to have no direct influence on the processing of affective connotations.

THE SLOW POSITIVE WAVE (SPW) COMPONENT ANALYSIS

A main effect of emotionality was not obtained. There was an interaction of anteriority \times emotionality based on larger SPW amplitude to positive if compared with negative words in frontal areas (Fig. 3A) whereas at parietal sites (Fig. 3C) the amplitude was larger to positive if compared with neutral words ($F_{6,84} = 2.57$, $P < 0.03$, $MSe = 0.95$).

To summarize, the word emotionality influenced the P2, P3 and SPW, but in different ways. It suggests the critical role of these components in understanding the processing of affective content. Both hemisphere and visual field influenced the ERP amplitudes, not depending on the factor of word emotionality. The results suggest an indirect contribution of the brain hemispheres into the processing of emotion. The influence of hemispheres seems to be different across the ERP components.

DISCUSSION

Processing of emotions and positive ERP components

According to Zajonc (1980) the early evaluation of affective connotation ("affective reaction stage") is processed automatically and independently from conscious inferences. If we assume that both negative and positive words cause brief activation of both reward and punish-

ment systems (Gray 1987, Lang 1995) the early global evaluation of affective connotations appears to be critical for further approach or withdrawal behavior. The differences in P2 amplitudes to positive *versus* negative words (Fig. 3B) could be interpreted in accordance with these assumptions. It suggests that the underlying processes should be understood as a global affective evaluation depending on whether a stimulus is dangerous or attractive for an individual. We should notice that latency and scalp distribution of P2 registered in our experiment is very similar to Ruchkin et al.'s P3e (1987). The sensitivity of P3e to stimulus significance and its interpretation as an indicator of processes relating to, "...the identification of which of a number of possible meanings is to be assigned to the event" (Ruchkin et al. 1987, p. 100) is quite consistent with our assumption of the functional role of the P2 component. In contradiction to our expectations, another early component, N1, appeared to be insensitive to emotionality of words. Two possible explanations deserve special attention. First, the effortful experimental task increased the cognitive effort and that might overlap the effect of emotionality. Second, the lack of an N1 effect might be caused by the individual differences in early processing of emotional stimuli based on various coping strategies of an individual. The study of Haschke and Kuhl (1994) makes the last explanation more preferable.

The larger P3 amplitude to positive words compared to neutral ones (Fig. 3C) is a common result (Begleiter et al. 1979, Naumann et al. 1992, 1997). Some investigators pointed out that the increase of the P3 amplitude is directly associated with (1) the incentive value of stimuli, (2) the amount of information transmitted as well as (3) the cognitive difficulty of a task, i.e., the amount of cognitive operations required (Begleiter 1983, Johnson 1988). All these factors might partly contribute into the increase of P3 to positive words as they were significant for the subject and therefore they transmitted more information than the neutral ones. Besides, the decision about positive words might require an excessive processing of emotional connotation while the neutral words did not require it. The latest explanation gets some support from the fact that positive words were somewhat more difficult to categorize than neutral ones (see behavioral data).

However, in the above-mentioned experiments the P3 amplitude to both negative and positive words was larger than to neutral ones. This tendency is shown in our data (Fig. 3C). It might be speculated that the relaxed ex-

perimental conditions attenuate the punishment system of participants, and thus, negative words (as aversive stimuli) elicit small P2 and P3 amplitudes. Moreover, negative words selected by expert rating might be not aversive enough for participants. Based on previous findings (Begleiter et al. 1983, Johnson 1988) we can interpret P3 in our experiment as a mechanism reflecting the memory storage that is well established in the "motivational" system (Lang 1995). Through this mechanism the affective connotation of a stimulus becomes involved into a broad semantic network closely connected with structures of "affective" memory (Ruchkin et al. 1987). This mechanism seems to be necessary to categorize a word as emotional or neutral. One of the possible explanations of increasing of both P2 and P3 amplitudes to positive words is that those effects result from an overlap between both positive components. However, correlations between amplitudes of P2 and P3 to positive words computed separately for central and parietal sites were non-significant. It suggests that the observed effects cannot be attributed to overlap of P2 with P3.

The SPW was equally distributed across the anterior-posterior dimension. As we had expected, the SPW amplitude was sensitive to the emotional content of words. It is interesting, that the SPW, on the one hand, was larger to positive than to negative words at frontal sites (as P2, Fig. 3B), and on the other hand, larger to positive than to neutral words at parietal and occipital sites (as P3, Fig. 3C). It seems very likely that the SPW "contained" the effects of two preceding stages. The processes taking place at the SPW time window may be linked with testing new hypotheses concerning emotional content of word. It might be speculated that testing of new hypothesis involves tuning or readjusting former representations according to the individuals current emotional experience. As the SPW appears when the motor response has been already carried out it may suggest that this wave reflects the evaluation of the response, i.e., the result of emotional categorization. Our SPW data are consistent with the data from studies in which SPW was recorded to emotional stimuli and was interpreted as an index of an additional processing stage related to the re-activation of "emotional" trace in memory (Johnston et al. 1986). Moreover, our results are supported by the studies that show the sensitivity of the SPW to feedback signals indicating the correctness of the outcomes and are interpreted as the correction of the ongoing behavior (Johnson and Donchin 1985, Stuss et al. 1980). Thus, our SPW might be considered as the process of correction of

the decision taken about a word in context of the emotional experience of an individual.

The results of the present study suggest that different stages of affective words categorization might be interpreted as follows: (1) general evaluation of whether the stimulus is dangerous for an individual or not; the outcome of this evaluation determines further approach or withdrawal behavior; (2) task-related processing involving activation of semantic memory; (3) additional decision control that takes into account past and current emotional experience of an individual.

Emotionality of words did not have an effect on the N3 and N4 components, which is in accordance with the results of other studies (Williamson et al. 1991) and suggests that the late negative components reflect the difficulty of involving a word into larger linguistic structures (Rugg et al. 1988, Kutas and Van Petten 1988) and do not depend on its emotional connotation.

Laterality findings

The present study does not support some generally accepted points of view on lateralization of the processing of emotions in a simple way. Words (not depending on emotionality) exposed in RVF were categorized more accurately than those in LVF, which contradicts both the "valence" and "right hemisphere" hypotheses on lateralization of emotion. The two possible explanations of the superiority of the left hemisphere may deserve attention: (1) it might be caused by its specialization in verbal processing (Gainotti 1989) and (2) the left hemisphere disposes mechanisms maintaining tonic activation (Derryberry and Tucker 1991), which is critical for sustained attention and readiness for response under effortful task. Such type of task was created in our experiment and might enforce the left hemisphere advantage in verbal processing and/or attenuate the influence of emotionality. However, our specific experimental conditions caused the intermediate level of categorization accuracy that does not give us an opportunity for wider interpretation of the results received. Therefore we will interpret the laterality effects mainly on the basis of ERP analysis as it was made in our discussion on stages of "affective" processing.

The increased P3 amplitude over the right hemisphere was commonly reported (Vanderploeg et al. 1987, Williamson et al. 1987, Laurian et al. 1991) and interpreted as a predominant involvement of the right hemisphere into the processing of emotions ("right hemisphere" hy-

pothesis). However, this result was not replicated in the present study. Moreover, neither emotionality x hemisphere interactive effect nor emotionality x visual field were obtained on any ERP components. This result does not support the "valence" hypothesis implying that negative emotions are processed mostly by the right hemisphere and positive emotions by the left hemisphere. We tend to interpret the results from the point of view that each hemisphere exerts its effect on emotion through its specific cognitive "ability" to perform the task (Hellige 1990). The affective connotation of a word is not necessarily processed fully by one hemisphere. The hemisphere that is dominant over one aspect of information processing may not be dominant over all the others involved into the task. Thus, the hemispheric dominance may alter across the processing stages.

The advantage of N1 with the RVF presentation is consistent with the results from other studies using the divided visual field paradigm (e.g. Kok and Rooyakkers 1986). Probably, the RVF advantage reflects increased left hemisphere activity if the verbal stimuli should be processed (Gainotti 1989, Hellige 1990). Usually, N1 amplitude is larger at sites contralateral to stimulus presentation. We found a contralateral effect on N1 at left frontal sites with RVF presentation only. As participants were not familiarized with the words before the experiment it might strengthen a participant's orienting reaction that resulted in enhancing of N1 amplitude. Taking into account the critical role of frontal lobes in control of arousal and emotional responsivity (Stuss and Benson 1984), the frontal shift of the N1 effect might be caused by a greater participation of frontal lobes (in comparison with the other sites) in early stages of processing, in case the stimulus has emotional significance. Moreover, this interpretation is supported by the fact that the latency of N1 at frontal sites was the shortest one (see Fig. 3A compared with 3C).

The P2 and P3 components were larger in the left hemisphere with LVF presentation whereas the N3 and N4 were more emphasized in the right hemisphere with RVF presentation (Fig. 2). The preponderance of the ipsilaterally over contralaterally stimulated effects on the late ERP components can not be considered as an artifact. It is hypothesized that the late ERP components elicited on the ipsilateral stimulated hemisphere, "in fact represent a response of the opposite hemisphere" (Kok and Rooyakkers 1986, p. 681). If this holds true, the larger P2 and P3 amplitudes over the left hemisphere with the LVF presentation may reflect the involvement of the

right hemisphere in case both global evaluation of stimulus valence and subtle processing of the task-relevant features are required. It corresponds to the findings on advantage of the right hemisphere in emotional processing (Gainotti 1989, Roschmann and Wittling 1992). So, the increase of N3 and N4 amplitudes over the right hemisphere with RVF presentation may result from an activation of the left hemisphere, which is dominant to maintain tonic activation and readiness for action (Derryberry and Tucker 1991). As both negative components return to the baseline directly before the response execution, the activation of the left hemisphere may reflect response preparation. However, these hypotheses need further exploration.

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