

Identification of Emotion in a Dichotic Listening Task: Event-Related Brain Potential and Behavioral Findings

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The lateralization of emotion perception has been examined using stimuli in both auditory and visual modalities. Studies using dichotic stimuli have generally supported the hypothesis of right-hemisphere dominance for emotion perception, whereas studies of facial and verbal emotion perception have provided evidence for the right-hemisphere and valence hypotheses. A dichotic target detection task was developed to enable acquisition of event-related potentials (ERP) from subjects engaged in emotion detection. Nonsense syllables (e.g., ba, pa) stated in seven different emotional intonations were dichotically presented to 24 young adults, in a target detection task during four separate blocks (target emotions: happiness, interest, anger, or sadness). Accuracy and reaction time and ERP measures were also collected. ERPs were recorded from 14 scalp electrodes with a nose reference and quantified for N100, sustained negativity, late positivity, and slow wave. Significantly greater left- than right-ear accuracy was obtained for the identification of target prosodic emotion. Hemispheric asymmetries of N100 and sustained negativity

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were found, with left-hemisphere amplitudes greater than right-hemisphere amplitudes. These ERP asymmetries were not significantly correlated with the left-ear dichotic advantage and may be related more to early phonetic processing than to emotion perception. Since the behavioral evidence supports the right-hemisphere hypothesis for emotion perception, behavioral and ERP asymmetries evident in this task reflect separable patterns of brain lateralization. © 1998 Academic Press

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INTRODUCTION

The study of emotional functioning in patients with unilateral brain damage, individuals with seizure disorders, and normal subjects has produced three hypotheses regarding lateralization for emotion. The right-hemisphere hypothesis posits that the right hemisphere is specialized for the perception, expression, and experience of emotion (Borod, Koff, & Caron, 1983; Heilman & Bowers, 1990; Ross, 1985; Tucker, 1981). The valence hypothesis attributes the experience and expression of positive emotions to the left hemisphere and negative emotions to the right hemisphere (Ehrlichman, 1987; Sackeim, Greenberg, Weiman, Gur, Hungerbuhler, & Geschwind, 1982; Silberman & Weingartner, 1986). A variant of the valence hypothesis proposes that the posterior regions of the right hemisphere are specialized for the perception of both positively and negatively valenced emotions, while frontal regions of each hemisphere are specialized for emotional expression and experience, based on the valence of the emotion (Borod, 1992; Davidson, 1984; Levy, 1990). Though a number of techniques have been implemented to test these hypotheses, the role of the left and right hemispheres in emotional functioning has not been fully delineated.

Dichotic listening is the most frequently utilized technique for studying lateralization for emotional prosody. Prosody, in this context, refers to the intonational pattern of the voice used to convey particular emotions. Investigators using this paradigm to examine the perception of prosodic emotion have generally found evidence in support of the right hemisphere hypothesis. These studies have used dichotic presentation of nonverbal sounds (Carmon & Nachshon, 1973; King & Kimura, 1972; Mahoney & Sainsbury, 1987), neutral sentences stated with emotional intonation (Bryden & Ley, 1982; Herrero & Hillix, 1990; Saxby & Bryden, 1984; Shipley-Brown, Dingwall, Berlin, Komshian, & Gordon-Salant, 1988; Strauss & Goldsmith, 1987), and emotionally intoned neutral and nonsense sentences in competition with white noise or babble (Haggard & Parkinson, 1971; Hatta & Aye-tani, 1985; Henry, 1983; Safer & Leventhal, 1977). Of note was a study by Bryden and MacRae (1989) which used a dichotic emotional words test. Overall, a right-ear advantage (REA) was obtained for detection of target words, while a left-ear advantage (LEA) was obtained for detection of target emotional intonation. The latter finding was interpreted as providing support

for the right-hemisphere hypothesis, although a trend ($p < .06$) for a greater left-ear advantage for negatively than positively valenced emotional tones could be construed as partial evidence for the valence hypothesis.

In the current study, a new dichotic listening task was developed to examine lateralization for prosodic emotion perception. The task was designed to enable acquisition of event-related brain potentials (ERPs) while subjects executed the task. Although ERPs have been acquired in cognitive tasks with verbal or nonverbal dichotic stimuli (Haaland, 1974; Mononen & Seitz, 1974; Neville, 1974; Tenke, Bruder, Towey, Leite, & Sidtis, 1993; Van de Vijver, Kok, Bakker, & Bouma, 1984), they have not been collected during a *dichotic emotional discrimination task*. Previous ERP studies using dichotic stimuli were designed to determine the physiological or cognitive basis of behavioral ear-advantages and reported results regarding latencies and amplitudes of components such as N100, P200, P300, and slow wave. Few studies (e.g., Haaland, 1974; Mononen & Seitz, 1974; Neville, 1974) have explored the correspondence between behavioral and ERP measures. Two studies that did examine this issue found a strong association between dichotic ear asymmetry and hemispheric asymmetries of ERP components (Tenke et al., 1993; Van de Vijver et al., 1984). Van de Vijver et al. (1984) reported on the association of ear asymmetry and hemispheric asymmetry of a sustained positivity in a verbal dichotic listening task. Tenke et al. (1993) reported a similar correspondence for the late positive P3 potential using complex tones.

Erwin et al. (1991) and Twist, Squires, Spielholz, and Silverglide (1991) examined electrophysiological correlates of emotion perception in the auditory modality, using neutral words stated with emotional intonation. Neither study found evidence for hemispheric asymmetries in ERPs as a function of emotion. Examination of ERP correlates of emotion perception via the visual modality has revealed an enhancement of the late potentials (P300 and P400) for emotionally charged as compared to neutral stimuli (Cuthbert, Bradley, McManis, Bruner, & Lang, 1993; Johnston, Miller, & Bursleson, 1986; Kayser, Tenke, Nordby, Hammerborg, Hugdahl, & Erdmann, 1997), as well as alterations in P300 amplitude as a function of the emotional content of the category being processed (Cuthbert et al., 1993; Lang, Nelson, & Collins, 1990), although only midline electrodes were used in these studies.

Investigations in which visual emotion perception has been examined while recording from electrodes placed over the right and left hemispheres have found hemispheric asymmetries as a function of emotion. Kayser et al. (1997) reported greater right hemisphere augmentation of N2–P3 amplitudes for negative as compared to neutral stimuli consistent with a differential right hemisphere contribution to the regulation of affect, particularly in the classification and evaluation of the affective significance of a stimulus. Laurian, Bafder, Lanares, and Oros (1991) also interpreted their data as supporting the right hemisphere hypothesis. Vanderploeg, Brown, and Marsh (1987) suggested that each hemisphere is involved in distinct stages of emotional

processing; the left hemisphere is important for discrimination of emotional from nonemotional faces, while the right hemisphere is important for continued processing of emotional information conveyed by an emotionally expressive face (regardless of the valence of the emotion). Kestenbaum and Nelson (1992) also reported evidence that the right hemisphere is more activated than the left hemisphere during emotional perception. The information provided by these ERP studies of emotional processing, however, must be interpreted cautiously. There have been considerable differences in the paradigms utilized, with limitations imposed by number and location of electrode sites, number of emotion categories, and varied definitions of ERP components in terms of peak latency or area.

The present study was designed to combine the complementary strengths of dichotic listening and event-related potential techniques so as to enable the convergence of behavioral and physiological evidence regarding lateralization for auditory emotional perception. It incorporates three methodological improvements over previous studies: (1) electrode montages that permit analysis of both inter- and intrahemispheric differences in ERPs; (2) a wider array of emotional stimuli, with seven emotional categories presented to participants (though only four served as target emotions); and (3) behavioral methods which would not confound response parameters with perception and discrimination parameters. Finally, the use of a target detection task provides behavioral laterality measures of response time and accuracy, which could be compared with concurrent measures of ERP hemispheric asymmetry.

Nonsense syllables stated with emotional tones were dichotically presented to participants, who were requested to respond as quickly as possible to a target emotion by pressing a response button. Behavioral measures of accuracy and response time *and* ERP measures of N100, sustained negativity, late positivity, and slow wave were obtained. Support for the right hemisphere hypothesis would take the form of greater accuracy scores and shorter reaction times to target items presented to the left than the right ear and greater P300 amplitudes over the right than left posterior region. However, the current study might also provide support for the valence hypothesis, as found for some emotion perception tasks and for tasks eliciting emotional experience or expression (e.g., Davidson, 1984). Although the task in the present study was created to study emotional perception, there may also have been an experiential component due to sustained exposure to emotionally laden stimuli. Support for the valence hypothesis would involve greater accuracy and shorter reaction time for left-ear presentations of negatively valenced emotions and for right-ear presentations of positively valenced emotions, as well as greater P300 amplitudes over the right than the left hemisphere to negatively valenced target items and greater P300 amplitudes over the left than the right hemisphere for positively valenced target emotions.

METHODS

Participants

Twenty-four (13 male, 11 female) right-handed, native English speakers (or individuals fluent in English by age 7), between the ages of 18 and 32 ($M = 24.62$, $SD = 3.66$), completed this study. Participants' education ranged from 13 to 20 years ($M = 16.08$, $SD = 1.98$). Participants included volunteers available through the New York State Psychiatric Institute Control Pool and Manhattan residents recruited through ads placed in local neighborhood newspapers. These individuals were screened for a history of psychiatric disorder, neurological disease, or substance abuse. Psychiatric screening was conducted via the Schedule for Affective Disorders and Schizophrenia—Lifetime Version (SADS-L) (Spitzer & Endicott, 1978). Handedness was verified using the Edinburgh Handedness Inventory (Oldfield, 1971). Hearing thresholds for each ear were determined through audiometric screening procedures. Individuals with hearing thresholds above 25 dB HL or interear threshold differences greater than 10 dB HL, at 500, 1000, and 2000 Hz, were excluded.

Task Development

Stimulus creation. A dichotic listening task was constructed in which six nonsense syllables (ba, ta, ga, pa, da, ka) were stated in different emotional tones. Three positively valenced emotions (happiness, interest, pleasant surprise) and five negatively valenced emotions (anger, sadness, disgust, fear, unpleasant surprise) (Borod, Welkowitz, Obler, Whalen, Erhan, & Grunwald, 1992) were included. One female voice produced the emotional utterances based on method acting and in accordance with what is known about the characteristics of different emotional intonations (Borod, Cicero, Obler, Welkowitz, Erhan, Santschi, Grunwald, Agosti, & Whalen, 1998; Borod, Erhan, Welkowitz, Obler, Whalen, & Grunwald, 1994; Scherer, 1979, 1981, 1982, 1989). The consonant–vowel nonsense syllables used in this study enabled accurate alignment of stimulus onset and ensured effective elicitation of competition between the two hemispheres.

A total of 196 trials of the six nonsense syllables stated four times with the different emotional tones was presented to 21 undergraduate students (13 females, 8 males) at Queens College for categorization into one of the eight emotional categories listed above. These raters were between the ages of 17 and 28 years ($M = 18.90$, $SD = 2.51$). Only items receiving an accuracy categorization of 60% or higher were retained and digitized to increase the validity of emotional categorization.

The Neuroscan SOUND software package (Neuroscan, INC., Neurosoft Inc. Co., 1991) was used to edit and digitize sound files to delimit the exact time of onset and offset of each utterance. Intensities of each utterance were

TABLE 1
Average Accuracy Ratings (*SD*) for Items
Selected in Each Category

Category	Mean % accuracy rating (<i>SD</i>)	Number of unique utterances/ category
Happiness	73.33 (13.66)	4
Pleasant surprise	70.00 (0.00)	3
Interest	85.00 (8.37)	4
Positive valence Emotions overall	76.11 (6.62)	11
Anger	70.00 (8.94)	3
Sadness	83.33 (5.16)	4
Fear	86.67 (12.11)	4
Disgust	78.33 (9.83)	4
Negative valence Emotions overall	79.58 (6.41)	15

standardized to a level of 74 dB SPL (Bryden & MacRae, 1989; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Saxby & Bryden, 1984; Shipley-Brown et al., 1988). Items which obtained accuracy ratings of 60% or greater were rerated after digitization to ensure the quality of the utterances by 10 new raters (6 females, 4 males) (mean age = 19.00, *SD* = 1.49; range = 17–23 years). Items receiving categorization ratings of 60% or more were selected for the formation of the pairs included in the dichotic test. As none of the accuracy ratings for items previously categorized as unpleasant surprise reached the 60% criterion level, this category was omitted from the experimental task.

Experimental task creation. Three or four utterances from each of the seven emotion categories were paired with items from every other category for a total of 21 unique combinations. Pairs were created such that the maximum item duration within a pair did not exceed 7% of the duration of the shorter item. Average differences were 3.41% for positively valenced pairs, 1.14% for negatively valenced pairs, and 1.83% for mixed pairs (Table 1). Overall mean accuracy ratings were 76% (*SD* = 6.62) for positively valenced emotions and 79% (*SD* = 6.41) for negatively valenced emotions (See Table 1). These accuracy levels prevent a ceiling effect and yet permit the possibility of categorization of items to one category.

A target detection paradigm comprising 30% target items and 70% nontarget items was used to present stimuli. Four blocks of 210 trials were presented for the detection of the four different target emotions. In each block, participants responded to the target emotion from an array of seven emotions

presented throughout the block. Two positively valenced emotions (happiness, interest) and two negatively valenced emotions (anger, sadness), very closely matched for category accuracy levels, were selected for target detection. Within a block, 30% of the trials ($n = 60$) were made up of 10 repetitions of the six pairs available for a target emotion. Each of the six pairs was repeated in a randomized fashion throughout the 210 trials. Five repetitions of the target emotion occurred in the right ear, and five occurred in the left ear. The remaining 150 trials were the nontarget items (15 pairs each, also presented 10 times).

Neuroscan stimulus presentation software (GENTASK) was used to generate and sequence stimuli. Matched TDH-49 headphones were used to present a binaural cue tone of 1000 Hz (100 ms duration) to the center of the head. This was followed 1 s later by the onset of a dichotic pair. Headphone placement was counterbalanced across subjects and was alternated across blocks of emotion for each subject. The intertrial interval (ITI) was 2.5 s. Reaction time was measured as the subject responded to a target item by pressing a hand-held response button. Hand order used to make responses was counterbalanced across subjects. A total of 840 trials was presented over four 20-min blocks, separated by breaks of 2 min. The probability of a target item occurring in each ear was 15% and throughout the entire block 30%.

Experimental Procedure

Behavioral task. Each subject listened to a binaural presentation of each of the utterances used to create the unique pairs to familiarize them with the stimulus materials. Each participant was subsequently presented with a 10-min practice session of a positively or a negatively valenced target emotion block, corresponding to the valence of the first block presented. Subjects were asked to keep their eyes on a fixation light throughout each trial. Subjects were instructed to respond to one target emotion (happiness, interest, anger, or sadness) in each of four separate blocks. Order of block presentation was randomized across subjects.

ERP recording. An Electro-cap (Neuroscience model) with tin electrodes was used to record from 14 electrode placements using traditional 10–20 nomenclature: (1) frontal: F3,F4,F7,F8; (2) central: Cz,C3,C4; (3) temporal: T3,T4; (4) centroparietal: CP5,CP6; and (5) parietal: Pz,P3,P4. This montage provided coverage of left- and right-hemisphere activity in both anterior and posterior regions. A tin electrode placed at the nose tip was used as reference, and an electrode placed at the left mastoid was used as ground (Tenke et al., 1993). Horizontal and vertical eye movements were recorded differentially using Ag/AgCl electrodes placed at each canthus and above and below the right eye orbit. The acquisition system consisted of an IBM-compatible computer with a Neuroscan continuous digitization system. Another computer was used for stimulus delivery and/or timing and coding of events.

EEG data were recorded with a 16-channel Grass Neurodata system at 10 K gain (.01–30 Hz bandpass) and sampled at 100 samples/s. Trials with excessive eye movement (+100 μ V cutoff) were excluded prior to data averaging.

ERP averaging. ERP waveforms were averaged both within and across subjects, separately for electrode site (low frontal, frontal, temporal, central, centroparietal, parietal); hemisphere (left, right); ear of stimulus presentation (left, right); and emotional valence (positive, negative). The ERP waveforms presented in this study are averages of correctly detected target items (hits) or correctly rejected nontarget items (correct rejections).

Statistical Analyses

Behavioral data analysis. Overall accuracy scores and accuracy scores for the two positive and two negative emotions were calculated as the percent of target items correctly detected. In addition, laterality quotients (LQs) were used to index the degree of ear advantage via the following formula:

$$\text{LQ} = 100 \times \frac{(\text{Right ear accuracy} - \text{Left ear accuracy})}{(\text{Right ear accuracy} + \text{Left ear accuracy})}$$

An overall mean LQ was calculated for each participant, averaging across the four emotions, as well as separate LQs for each emotion. Reaction time measures (in milliseconds [ms]) were normalized by log transformation (base 10) so that parametric statistical procedures could be used.

A repeated-measures analysis of variance (ANOVA, BMDP P4V, Dixon, 1985), with two within-factors, defined as Ear (left, right) and Valence (positive, negative), was conducted to verify the presence of a left-ear advantage on this task and to determine whether LQ varied as a function of emotional valence.

ERP analysis. The ERP recorded in response to the dichotic presentation of the emotionally intoned consonant–vowel syllables had four prominent components. The following windows were selected for computing the average amplitude of each component: N100, 50–170 ms; sustained negativity, 300–870 ms; late positivity, 880–1530 ms; and slow wave, 1540–2970 ms. These windows correspond well with data from individual subjects and stimuli, as well as with factors extracted using a covariance matrix principal component varimax procedure (BMDP P4M; Dixon, 1985). The average amplitudes for each of the four windows described above were subjected to a repeated-measures ANOVA with within-factors defined as condition (hits, correct rejections), valence (positive, negative), hemisphere (left, right), and electrode (Frontolateral [F7, F8], Frontomedial [F3, F4], Temporal [T3, T4], Central [C3, C4], Centroparietal [Cp5, Cp6], Parietal [P3, P4]). These initial analyses indicated that the alterations in component amplitudes of interest as a function of the within-factors, such as electrode, were restricted to the hit conditions. Therefore, a separate ANOVA with the grouping factor of

ear advantage (left-ear advantage, LEA; no left-ear advantage, NOLEA), in addition to the four within-factors described above, was conducted on each of the four ERP components for hits only to more clearly delineate the effect of these factors on ERPs in response to correct target detection: Greenhouse–Geisser epsilon corrections were used for within subject effects with two or more degrees of freedom (Keselman & Rogan, 1980).

Pearson product-moment correlations were computed to examine the relationship between the behavioral ear advantage (LQ) and ERP hemisphere asymmetries (left hemisphere–right hemisphere) for each pair of electrodes and for each ear of presentation. As there were no significant overall ear effects in the RT data, correlations were conducted only with the accuracy data.

RESULTS

Behavioral Data

Accuracy. Detection of target emotions presented to the left ear was better than detection of the same emotions presented to the right ear, regardless of valence (left ear $M = 74.55$, $SD = 17.75$; right ear $M = 68.44$, $SD = 18.10$; main effect for Ear, $F[1,23] = 10.46$; $p = .004$; main effect for Valence, $F[1,23] = 1.97$; $p = .173$; Ear \times Valence interaction, $F[1,23] = 1.43$; $p = .245$).

Reaction time. Reaction time measures submitted to the same analysis yielded no significant main effects nor interactions (left ear: $M = 1.17$ s, $SD = 1.20$; right ear: $M = 1.18$ s, $SD = 1.20$).

Subgroups based on degree of ear advantage. As is often the case in dichotic listening studies, not all participants demonstrated the expected ear advantage for the task at hand. It was of interest to determine whether there were any differences in emotional-tone identification based on presence or absence of the left-ear advantage. The accuracy data were used to make the ear-advantage breakdown as reaction time analyses did not demonstrate differences as a function of ear of target stimulus presentation. The median LQ value of -3.15 was used to divide subjects into two groups: those with LQs less than the median (relatively large left-ear advantage, LEA group; $n = 12$) and those with LQs greater than the median (relatively small or no left-ear advantage or a right-ear advantage, NOLEA group; $n = 12$). When the two ear-advantage subgroups were compared on gender, age, education, and handedness, there were no significant differences between NOLEA and LEA groups (Table 2). In addition, each group consisted of five individuals who responded with their right hand and five individuals who responded with their left hand. An ANOVA with the between-factor defined as LQ Grouping (LEA, NOLEA) and the two within-factors defined as Valence (positive, negative) and Ear (left, right) was used to examine the influence of ear advantage. While the NOLEA group demonstrated comparable perfor-

TABLE 2
Demographic Statistics for the LEA and NOLEA Groups

		LEA	NOLEA	<i>t</i> -value	<i>p</i>
Males	(<i>N</i>)	6	7		
Females	(<i>N</i>)	6	5		
Age	<i>M</i>	25.33	23.92	-.95	.354
	(<i>SD</i>)	(3.28)	(4.01)		
Education	<i>M</i>	16.67	15.50	-1.48	.152
	(<i>SD</i>)	(1.88)	(1.98)		
Handedness	<i>M</i>	80.68	72.71	-.86	.399
Quotient	(<i>SD</i>)	(16.34)	(27.47)		

mance in target emotion detection with both the left and right ears (left $M = 71.53$, $SD = 15.76$; right $M = 71.81$, $SD = 13.32$), accuracy scores for the left ear in the LEA group were significantly higher than those for the right-ear (left $M = 77.57$, $SD = 9.79$; right $M = 65.07$, $SD = 13.95$; $t[11] = 5.17$, $p < .001$; Ear \times LQ group interaction, $F[1,22] = 21.72$, $p < .001$). For the LEA group ($p = .057$), but not for the NOLEA group ($p = .351$), the left- versus right-ear difference for negatively valenced emotions ($M = 16.94$) was twice as large as the left- versus right-ear difference for the positively valenced emotions ($M = 8.05$; Valence \times Ear \times LQ group interaction, $F[1,22] = 5.40$, $p = .030$; see Fig. 1).

ERP Data

ERP differences related to condition. The grand average ERP waveforms in response to the dichotic consonant-vowel syllables stated in different emotional tones are shown in Fig. 2 for both hits and correct rejections (Condition Factor). Target ERPs were larger than nontarget ERPs for components of interest in this study. Significant Condition related differences were found for N100 (Condition \times Electrode, $F[4.05,93.20] = 4.08$, $p < .01$), Sustained Negativity potential (Condition \times Electrode, $F[3.46,79.51] = 36.85$, $p < .001$), and the late positive complex (Condition \times Electrode, $F[3.44,79.14] = 23.30$, $p < .001$), slow wave: Condition \times Electrode, $F[3.81,87.60] = 15.71$, $p < .001$). As indicated by the above interaction, target ERPs were larger than nontarget ERPs. Thus, the following summaries are of analyses conducted with ERPs to correctly detected stimuli.

N100. N100 amplitude had a central topography (Electrode effect, $F[1.97,43.38] = 39.60$, $p < .0001$) and was larger over the left (left hemisphere: $M = -2.82$, $SD = 2.29$) than over the right hemisphere (right hemisphere: $M = -2.37$, $SD = 2.42$; Hemisphere $F[1,22] = 20.11$, $p < .001$). The hemispheric asymmetry in N100 amplitudes was greater at temporal and centroparietal electrode sites than at frontal sites (Hemisphere \times Electrode: $F[2.84,62.55] = 5.25$, $p < .001$). This hemispheric asymmetry was greater

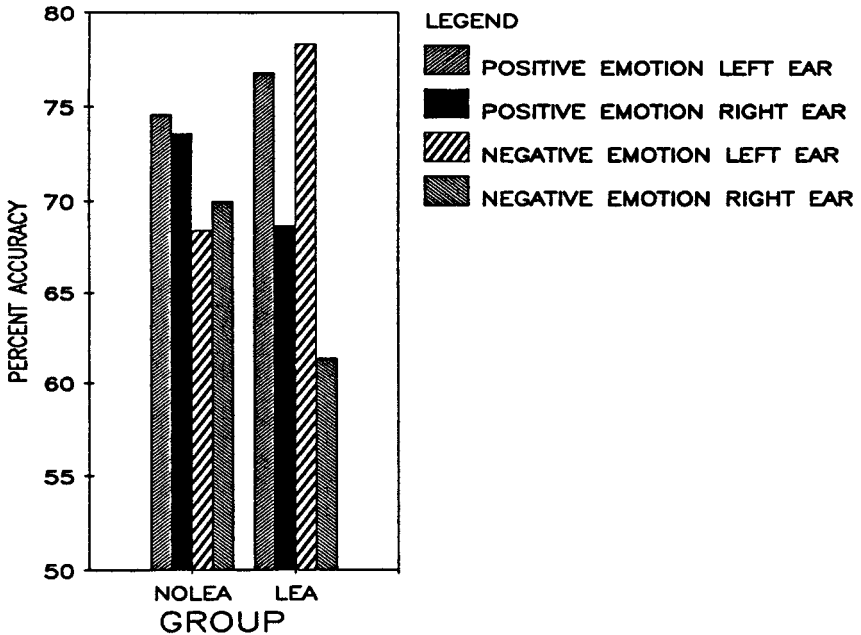


FIG. 1. The NOLEA subgroup demonstrated comparable left- and right-ear accuracy scores for both positively and negatively valenced emotions. The LEA group demonstrated ear asymmetry differences as a function of valence.

for negatively valenced emotions than for positively valenced emotions (Valence \times Hemisphere: $F[1,22] = 4.70, p < .05$). This valence-dependent asymmetry difference presumably reflects a lateralization of perception selective for physical differences related to the expression of positively valenced and negatively valenced stimuli that is unrelated to intensity differences since all stimulus pairs were matched for intensity.

Sustained negativity. The frontal topography of the sustained negativity was evident as a significant main effect of Electrode ($F[2.22,48.92] = 65.22, p < .0001$). At central electrodes, it was more negative over left (C3) than right (C4) hemisphere sites (Hemisphere \times Electrode: $F[5,18] = 3.43, p < .05$). The asymmetry was not evident at other sites and was in the same direction as the asymmetry of N100 (See Fig. 3). The sustained negativity to stimuli presented to the right ear was significantly more negative over the left than right hemisphere, while the same stimulus items presented to the left ear resulted in a smaller asymmetry in the same direction (Ear \times Hemisphere: $F[1,22] = 13.61, p = .001$), particularly at central electrodes (Ear \times Hemisphere \times Electrode: $F[2.68,58.8] = 7.83, p = .001$).

A closer examination of sustained negativity lateralization as a function of degree of ear advantage indicated that in participants belonging to the

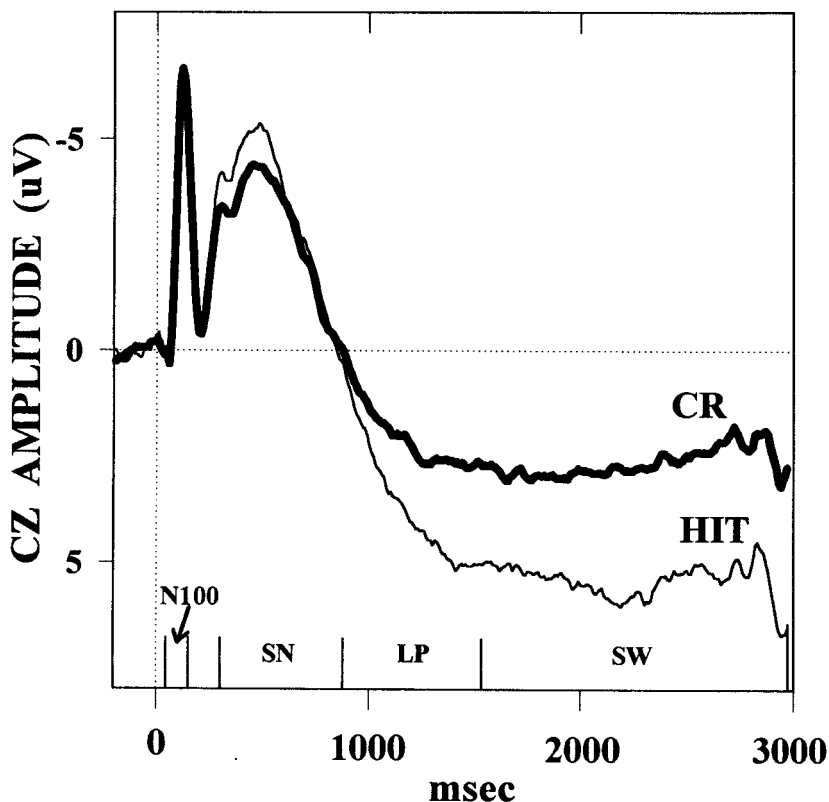


FIG. 2. The event-related potentials, including hits and correct rejections, to dichotic presentation of emotionally intoned nonsense syllables. N100, sustained negative potential, late positivity, and slow wave in response to target detection are clearly depicted.

NOLEA group, the sustained negativity was greater over left than right hemisphere at all electrode sites (Group \times Hemisphere \times Electrode: $F[3.26,71.63] = 3.35, p = .05$). In contrast, larger sustained negativity over the left than right hemisphere in the LEA group was observed at *central* electrodes, but reversed with right greater than left hemisphere negativity at the *temporal* site. Decreased ear advantage may therefore be related to hemispheric asymmetry of sustained negativity at temporal electrodes.

Late positivity. As can be seen in Fig. 3, the late positive component was largest at parietal electrodes (Electrode: $F[2.42,53.30] = 119.68, p < .0001$) and was greater over the right than left hemisphere. Hemispheric asymmetries were greatest for items presented to the right ear (Ear \times Hemisphere: $F[1,22] = 4.49, p < .05$; simple effect for right ear, $F[2.96,68.05] = 2.70, p = .05$), although there was a trend in the same direction for the left ear (simple effect for left ear, $F[2.96,49.02] = 2.40, p = .10$). This difference

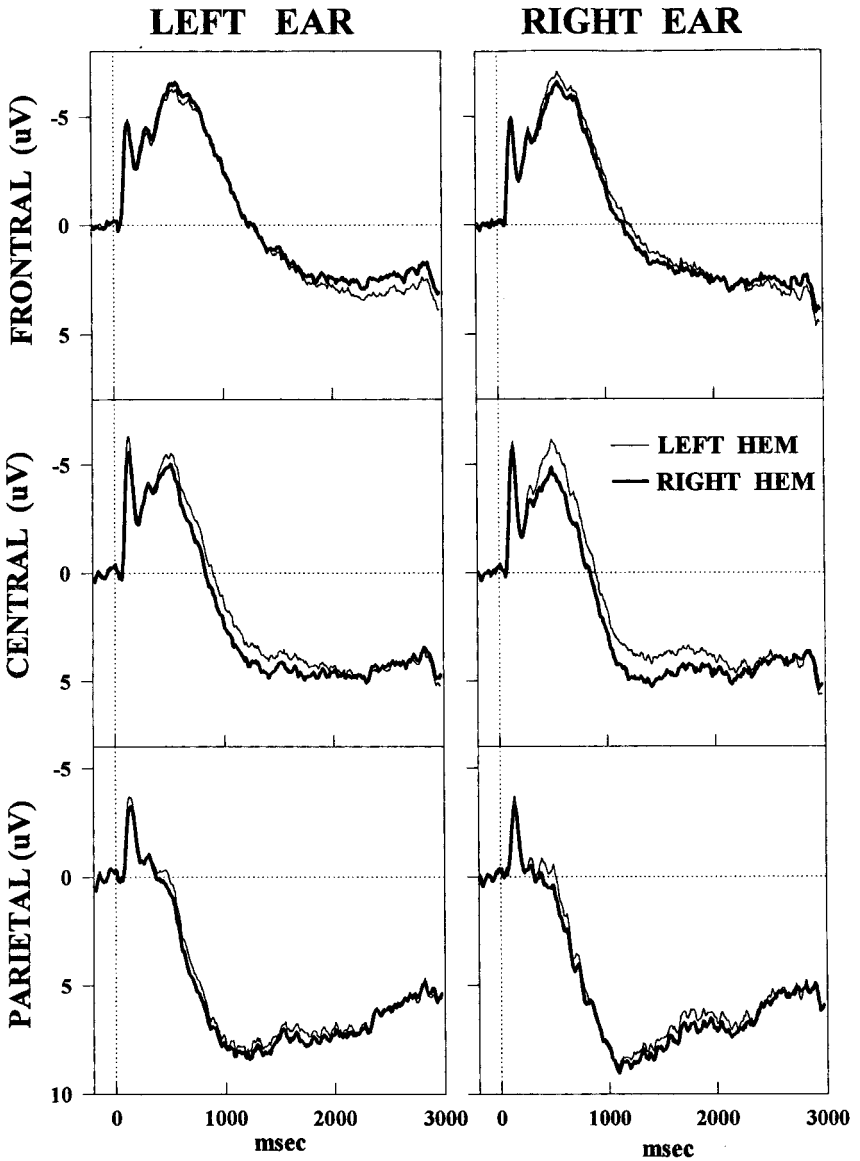


FIG. 3. The Ear \times Hemisphere \times Electrode effect for both the sustained negativity and late positivity at frontal, central, and parietal electrodes (left hemisphere is represented by the fine line, right hemisphere is represented by the bold line).

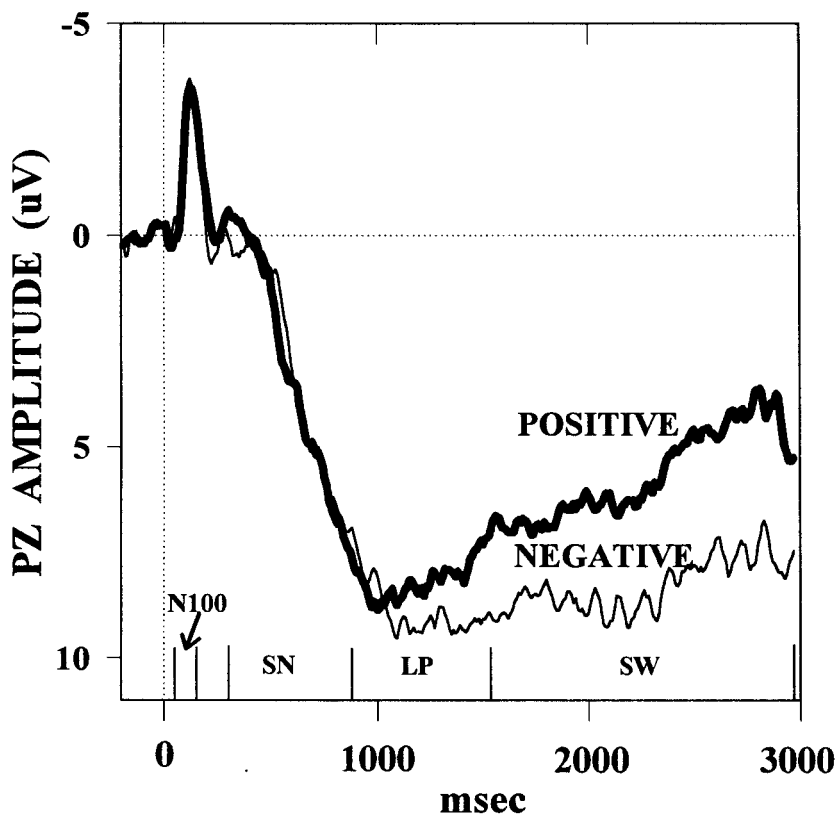


FIG. 4. The slow wave to negatively valenced emotions is greater than the slow wave to positively valenced emotions (fine line represents negatively valenced emotions, bold line represents positively valenced emotions) (Targets only; $N = 24$).

in hemispheric asymmetry of late positivity for right- and left-ear stimuli was most pronounced at the central electrode (Ear \times Hemisphere \times Electrode: $F[2.77, 60.86] = 6.63$, $p < .001$; See Fig. 3).

Slow wave. Slow wave amplitudes were smallest at frontal sites and largest at parietal sites (Electrode effect: $F[55.58]$, $p = .0001$; see Fig. 4). As can be seen in Fig. 4, a clear valence difference developed in the late positive window, reaching a maximum in the slow wave region (1500 and 3000 ms). Slow wave amplitude was substantially greater for negatively than positively valenced stimuli (Valence: $F[1, 22] = 6.57$, $p = .025$). A review of the behavioral data indicated that this was not due to differences in difficulty levels between positively and negatively valenced stimuli as there was no significant valence effect for accuracy levels.

The Relationship between Behavioral Data and Event-Related Potential Measures

Pearson product-moment correlations were calculated separately for items presented to the left and right ears and separately for different electrode sites. No significant correlations were found between behavioral ear asymmetries and hemispheric asymmetries of any of the ERP components.

DISCUSSION

Behavioral Data

Two hypotheses regarding emotional perception, i.e., right-hemisphere and valence hypotheses, were investigated. As was predicted by the right-hemisphere hypothesis, there was an overall left-ear advantage in the accuracy of detecting target emotional tones. This finding is in keeping with previously reported left-ear advantages for detecting prosodic emotional stimuli presented dichotically (Carmon & Nachshon, 1973; Hatta & Ayetani, 1985; Herrero & Hillix, 1990; King & Kimura, 1972; Ley & Bryden, 1982; Mahoney & Sainsbury, 1987; Saxby & Bryden, 1984; Shipley-Brown et al., 1988). The absence of a significant Valence by Ear interaction for the accuracy measure provided more support for the right-hemisphere hypothesis than for the valence hypothesis.

Of note was the finding that in the subgroup of subjects with a left-ear advantage, the ear advantage tended to be stronger for negatively than positively valenced emotions. This finding is in keeping with that reported by Bryden and MacRae (1989). Taken together, these results could be interpreted as offering partial evidence for the valence hypothesis. Support for this hypothesis has been provided by studies of emotional experience or expression (Davidson, 1993; Davidson & Tomarken, 1989). Although the task used in the present study was created with the intention of studying emotional perception, there may nonetheless have been an experiential component to it. Each participant listened to stimulus presentations during four 20-min blocks. This prolonged exposure to emotional stimuli in each block may have induced experience of that particular emotion and could have contributed to this partial valence finding.

The reaction time data did not provide additional support for lateralization; reaction times to items presented to the left and right ears were comparable. This finding is in agreement with the findings of Sidtis (1981), who also reported that accuracy was a more consistent marker of ear advantage for complex tone stimuli than reaction time.

Electrophysiological Data

N100. In the present study, the N100 was greater over the left than the right hemisphere, regardless of the ear of presentation. This replicates the finding of Neville (1974) who found greater N100 amplitudes over the left

than the right hemisphere for verbal dichotic stimuli. It may be that in trying to balance hemispheric activation in this task by including stimuli composed of both syllables and emotional intonation, consonant–vowels succeeded in activating the left hemisphere more than emotional intonation activated the right hemisphere. This, together with the lack of correlation between N100 hemispheric asymmetry and behavioral asymmetry for emotional target detection, suggests that the N100 asymmetry had little to do with emotional processing per se. Instead, the asymmetry may reflect an early left hemisphere superiority for processing dichotic consonant–vowels, possibly related to the voice onset properties of the consonants used in the current study. Tallal, Stark, and Mellis (1985) reported that it may be the rapid change in acoustic features that is responsible for left hemisphere superiority for speech processing. The finding of greater N100 amplitudes over the left hemisphere for the phonemic aspect of the consonant–vowel syllables is consistent with other reports of greater left than right hemisphere ERP components in response to language processing (Nelson, Collins, & Torres, 1990). In contrast, information required for the emotion category classification may have been primarily revealed in the later portion of the consonant–vowel utterance, which ranged from 595 to 965 ms. Further experimentation with the stimuli used in this study, in which the task requirement would be identification of CV syllables rather than the emotional tone of the syllables, would enable dissociation of ERP findings related to discrimination of temporal–phonemic characteristics of the stimuli from those related to emotion perception.

Sustained negativity. The distribution and duration of the sustained negative component, with its fronto-central maximal distribution, is similar to that described by Picton, Woods, and Proulx (1978a). The duration of this component is thought to correspond to stimulus duration. Increased neural activity is usually associated with greater negative sustained potentials (Picton et al., 1978a). In the current study, the window used to measure the amplitude of sustained negativity (300–855 ms), which was determined by principal component analysis (PCA), very closely corresponds to the range of stimulus item duration (595–965 ms). Therefore, the sustained negativity may in fact reflect a long duration sensory processing of the emotionally intoned syllables.

The most robust and stable finding for sustained negativity was the Ear \times Hemisphere \times Electrode interaction in which right-ear relative to left-ear stimulus presentation resulted in greater hemispheric asymmetry, with the left hemisphere being more negative than the right. The greater negativity obtained over the left-central regions may reflect greater activation of the left hemisphere. To ensure that this asymmetry was in no way a result of the hand used to make the response (e.g., Starr, Sandroni, & Michalewski, 1995), analysis of variance with between factors defined as group and response hand were conducted. There was no significant effect of hand overall, nor were there any interactions between response hand and group or hemi-

sphere. The asymmetry of the sustained negativity was greatest at the central electrode (where N100 has its maximum amplitude), suggesting a similarity with the N100 asymmetry. Picton et al. (1978a, 1978b) suggested that the auditory sustained potential may derive from cortical negative potentials generated in the primary auditory cortex or frontal association areas. It may therefore reflect the spread of activation concomitant with sensory and perceptual elaboration related to the further processing and categorization of the stimuli. Cuthbert et al. (1993), who described a component of similar amplitude, duration, and scalp distribution, noted that it was greater for neutral than negatively valenced stimuli and greater for negatively than for positively valenced stimuli. They concluded that this component reflected a process important for discriminating valence categories.

The asymmetry of sustained negativity had different scalp topography for subjects with LEA and NOLEA. In the NOLEA group, sustained negativity was consistently greater over the left than right hemisphere regions, and identification accuracy was equivalent for left- and right-ear targets. However, in the LEA group, the sustained negativity was greater over the *right* hemisphere at the temporal electrode site. The LEA group also demonstrated a larger left-ear advantage for negatively than positively valenced emotion but the NOLEA group did not. The enhanced sustained negativity over the right temporal site in the LEA group, which was absent in the NOLEA group, may reflect a process related to emotional valence discrimination similar to that reported by Cuthbert et al. (1993). Thus, the greater sustained negativity over the right temporal site may be associated processing that enabled the LEA group subjects to more accurately identify the target emotions presented to the left ear.

Late positivity. The late positivity appears to be the classical P300 component. It was much larger to infrequent target items and had maximum amplitude at parietal sites. Although there may be some overlap of this late positivity with the slow wave, the ANOVA results suggest that they are independent. The findings for the late positivity are very similar to those obtained for the sustained negativity. Left-hemisphere positivity was smaller than the right-hemisphere positivity for right-ear stimuli, but for left-ear stimulus presentation, there was no significant hemispheric asymmetry. The smaller positivity over the left hemisphere may merely result from the late positivity being superimposed on a larger (long lasting) sustained negativity. Thus, the larger sustained negativity and smaller late positivity over the left hemisphere to right-ear stimuli may reflect a single process that has similar effects on the two components. On the other hand, greater P300 over the right hemisphere has been found in studies examining event-related potentials during nonverbal oddball tasks (Alexander et al., 1995; Bruder et al., 1998). Thus, the asymmetry in P300 obtained in the current study may in part represent a general aspect of the nonverbal oddball nature of the task, rather than some process specific to emotional perception.

Previous studies examining hemispheric ERP differences during emotion perception have also reported P300 asymmetries. Laurian et al. (1991) found greater target minus nontarget differences for P300 amplitudes over the right centroparietal regions. They also found that positively valenced faces produced greater left frontal difference wave forms (target–nontarget) than did neutral or negatively valenced faces. They interpreted their findings as support for the right-hemisphere hypothesis, although, clearly, the left frontal finding for the positively valenced emotions could have been interpreted as partial evidence for the valence hypothesis. Moreover, the frontal location of this effect suggests that the left-frontal findings may have resulted, not from emotional perception alone, but from a concomitant experiential effect occurring during facial emotion perception. Kestenbaum and Nelson (1992) also reported greater P300 amplitudes over the right hemisphere to visual stimuli, but only at temporal electrode sites. Vanderploeg et al. (1987) reported that P300 over the left hemisphere was greater for neutral visual or verbal stimuli than for similar stimuli of either positive or negative valence. Vanderploeg et al. (1987) also reported asymmetry in the slow wave component, with greater slow wave amplitudes over midline and right-hemisphere sites than from left-hemisphere sites for visual stimuli.

Slow wave. As thoroughly reviewed by Ruchkin et al. (1988), slow wave activity occurs in response to several task demands. It was suggested by these investigators that negative slow waves are elicited when scanning and mental imagery are involved, while positive slow waves are associated with memory storage, rule learning, and the performance of difficult perceptual tasks. Although we observed a larger positive slow wave in response to negatively than positively valenced target items, there was no evidence of hemispheric asymmetry for this component. The valence finding in the current study emerged at the later positive components and was greatest during the slow wave. This difference in amplitude for positively and negatively valenced items starts much later than the response time and continues to the end of the recording epoch, i.e., 3 s after stimulus onset. Cuthbert et al. (1993) also reported greater positive slow wave amplitudes in response to negatively valenced visual stimuli than to positively valenced stimuli. The amplitude finding may be related to the greater salience of negatively than positively valenced emotions for survival, as the slow wave has been associated with further information processing (Bruder, Towey, Friedman, Erhan, Jasiukaitis, & Tenke, 1992). Thus, the valence effect is a long lasting effect which may reflect lingering emotional arousal or activation and which may be related to the long latency at which emotional processing takes place relative to initial stimulus evaluation.

CONCLUSIONS

Identification of the emotional tone of dichotically presented consonant vowels produced a left-ear advantage, reversing the commonly elicited right-

ear advantage obtained during identification of consonant–vowels. This finding supports the right-hemisphere hypothesis for emotional perception and is consistent with accuracy data from other studies. However, not all individuals displayed a left-ear advantage for the identification of emotional prosody. Those individuals with a relatively strong left-ear advantage tended to show greater left-ear advantage in identifying negatively than positively valenced target emotions. This could be interpreted as partial support for the valence hypothesis.

The left-ear advantage for emotional perception was not accompanied by prominent ERP hemisphere asymmetries. Ear advantage was not related to hemispheric asymmetry found for N100. The greater N100 amplitude over the left than right hemisphere indicates that the early processing of the CV syllables involved left hemisphere mechanisms that are responsible for language dominance (Tallal et al. 1985). Ear advantage was also unrelated to interactions involving hemisphere found for sustained negativity and late positivity ERP components. Characteristics of the sustained negativity, which peaked in the region of 300 to 900 ms after stimulus onset, suggested that this component was associated with emotion categorization in individuals with a strong left-ear advantage, as is consistent with the findings of Cuthbert et al. (1993). Greater slow wave in response to negative stimuli suggested that negatively valenced emotions may require more extended periods of processing than positively valenced emotions.

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