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**Event-related potential correlates of emotion in a dichotic
listening task**

Erhan, Hulya Munibe, Ph.D.

City University of New York, 1994

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EVENT-RELATED POTENTIAL CORRELATES OF EMOTION IN A
DICHOTIC LISTENING TASK

By

Hulya Munibe Erhan

A dissertation submitted to the Graduate Faculty
in Psychology in partial fulfillment of the requirements
for the degree of Doctor of Philosophy, The City
University of New York

1994

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HULYA MUNIBE ERHAN

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This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

EVENT-RELATED POTENTIAL CORRELATES OF EMOTION IN A
DICHOTIC LISTENING TASK

by

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Auditory and visual modalities have been used to study lateralization of emotional perception. Studies using dichotic stimuli have supported the hypothesis of right-hemisphere dominance for emotional perception, whereas studies of facial emotion perception have provided evidence for the right hemisphere and valence hypotheses. A dichotic target detection task was developed with three aims: (1) acquisition of behavioral and event-related potential (ERP) measures for target emotion identification, (2) determination of the relationship between behavioral and ERP measures, and (3) study of behavioral and ERP effects in homogenous subgroups formed on the basis of ear-advantage and gender. The following predictions for the right hemisphere hypothesis were evaluated: greater accuracy and shorter reaction times for left- than right-ear emotion detection, greater P300 amplitudes over the right than left hemisphere for target stimuli, and an association between P3 amplitude asymmetries and left-ear advantages.

Nonsense syllables stated with seven emotional intonations were dichotically presented to 24 young adults, whose task was to respond to a specified target emotion (happiness, interest, anger or sadness) during four blocks of a dichotic detection task. ERPs were recorded from 14 scalp electrodes with a nose reference. ERP components included N100, a sustained negativity, a late positivity (P3), and a positive going slow wave.

Significantly greater left- than right-ear accuracy was obtained for target emotion identification. Subjects with a strong left-ear advantage (LEA) and women showed a trend for shorter reaction times for targets presented to the left than right ear. Hemispheric asymmetry was found for the N100 and sustained negativity, with greater negativity over the left than right hemisphere, and this asymmetry was largest for right-ear stimuli. The hemispheric asymmetry of N100 and sustained negativity was not significantly correlated with the left-ear advantage and may be related more to early phonetic processing than to emotional perception. Late positivity (P3) and slow wave amplitudes were symmetric and unrelated to behavioral ear advantages. Although, the behavioral data provided evidence for the right hemisphere hypothesis, there was no evidence of an ERP correlate of the behavioral asymmetry for emotional perception.

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I. INTRODUCTION

Examination of emotional functioning in unilateral brain-damaged patients, individuals with seizure disorders, as well as normal individuals, has resulted in the postulation of three major hypotheses regarding lateralization of 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 of positive emotions to the left hemisphere and experience of negative emotions to the right hemisphere (Borod & Koff, 1989; Ehrlichman, 1987; Sackeim, Greenberg, Weiman, Gur, Hungerbuhler, & Geschwind, 1982; Silberman & Weingartner, 1986). A variant of the valence hypothesis suggests that the right hemisphere (posterior region) is specialized for perception of positively- and negatively-valenced emotions and that, in the frontal areas of each hemisphere, there is hemispheric specialization for emotional expression or experience, which is based on the valence of the emotion (Borod, 1992; Davidson, 1984; Ehrlichman, 1987). A third notion associates the left hemisphere (frontal region) with approach emotions (i.e., action or ongoing activity) and the right hemisphere (frontal region) with avoidance emotions (i.e., inactivity or interruption of activity) (Davidson, 1984; Kinsbourne, 1982,

1989; Kinsbourne & Bemporad, 1984; Tucker & Frederick, 1989). Though several techniques have been implemented to test these hypotheses, the role of the left and right hemispheres in emotional functioning has not been fully delineated.

Two experimental techniques heretofore independently implemented to enhance our understanding of lateralization of emotional functioning include dichotic listening and event-related potentials (ERPs) to emotional stimuli. Studies using 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), or emotionally intoned neutral and nonsense sentences in competition with white noise or babble (Haggard & Parkinson, 1971; Hatta & Ayetani, 1985; Henry, 1983; Safer & Leventhal, 1977) have predominantly supported dominance of the right hemisphere for perception of emotion. The ERP studies examining hemispheric specialization for emotion have been predominantly in the visual modality and have resulted in various conclusions regarding hemispheric specialization for the perception of emotion. Laurian, Bafder, Lanares, & Oros (1991) interpreted their data as supporting the right hemisphere hypothesis, while Vanderploeg,

Brown, & Marsh (1987) suggested that each hemisphere was involved in distinct stages of emotional processing. According to these authors, 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 the emotionally expressive face (regardless of the valence of the emotion). Kestenbaum and Nelson (1992) reported evidence of lateralization in perception of facial expressions, such that at temporal recording sites, amplitude of the P300 was greater over the right than over the left hemisphere. The authors interpreted these findings as evidence that the right hemisphere was more activated during emotional perception than was the left hemisphere. This could be consistent with the right hemisphere hypothesis of emotional perception.

The present study was proposed to combine the dichotic listening and event-related potential techniques so as to provide converging evidence regarding lateralization of auditory emotional perception. Our expectation was that incorporation of basic methodological improvements in both techniques, in the context of a dichotically presented emotion target detection task, would result in more robust findings than have previously been reported. Specifically, the number of emotional categories from which each participant made

his/her selection was increased from the usual three or four categories to seven categories, with three positively-valenced and four negatively-valenced emotions. Also, the use of 14 scalp electrode placements during ERP acquisition enabled comparison of P300 amplitudes, both within and between hemispheres. Finally, use of a target detection task provided behavioral laterality measures for response time and accuracy, which were then related to more direct measures of hemispheric asymmetry in ERPs.

Given the wide range of support for the right hemisphere hypothesis vis-à-vis emotional perception, the main hypotheses of this study were: (1) participants would demonstrate a left-ear advantage for the identification of target emotions, (2) the P300 amplitudes to target items would be greater over the right parietal region than over the left parietal region, and (3) reaction time to targets presented to the left ear would be shorter than those presented to the right ear for all target emotions.

Although this task was created with the intention of studying emotional perception, rather than experience or expression, there may nonetheless have been an experiential component to it. Two possibilities may account for the experiential component. First, the emotional stimuli ranged

from 600-1000 milliseconds in duration. Davidson (1984) has reported that emotion can be induced in a matter of seconds. Second, each participant listened to stimulus presentations during four 20-minute blocks. It is conceivable that attention to one target emotion in each block may have led to thoughts about events associated with that emotion and may have induced experience of that particular emotion. Thus, results might have been in keeping with the valence hypothesis. The valence hypothesis would have predicted (1) a left-ear advantage for negatively-valenced emotions and a right-ear advantage for positively-valenced emotions, (2) greater P300 amplitudes over the right than left hemisphere to negatively-valenced target items and greater P300 amplitudes over the left than right hemisphere for positively-valenced target emotions, and (3) shorter reaction time measures for negatively-valenced targets presented to the right hemisphere (left ear) and for positively-valenced target items presented to the left hemisphere (right ear).

II. Specific Aims

This project is designed to examine lateralization of emotional perception via dichotic listening and electrophysiological measures. Improvements in several aspects of the studies already conducted with these techniques will help to provide greater insight into the role of the left and right hemispheres in emotional processing. Specifically, the proposed project aims:

- 1) To relate behavioral laterality and electrophysiological findings. Converging evidence will provide more robust information about hemispheric specialization of emotional perception;
- 2) To evaluate two major hypotheses regarding emotional perception: (1) the right hemisphere hypothesis and (2) the valence hypothesis, with regard to emotion detection;
- 3) To increase the number of positively- and negatively-valenced emotions presented to participants. Previous studies have usually included only one positively- and typically two negatively-valenced emotions. The positive emotion most often studied is happiness, while the negative emotions often included are sadness and anger (Herrero & Hillix, 1990; Ley & Bryden, 1982; Saxby & Bryden, 1984;

Shipley-Brown et al., 1988). This study uses three positively-valenced emotions: happiness, pleasant surprise, and interest, and four negatively-valenced emotions: anger, fear, sadness, and disgust. Only four of these emotions are selected as targets. However, the wider array from which to detect the target makes the task more challenging, thereby preventing the ceiling effect;

- 4) To increase the number of electrode placements from which event-related potentials will be recorded so that comparisons between the left and right hemispheres, as well as between anterior and posterior portions within each hemisphere, can be made. Most studies examining emotional processing have used a smaller number of electrodes not permitting such comparisons (Johnston, Miller, & Burleson, 1986; Lang, Nelson, & Collins, 1990; Vanderploeg et al., 1987);
- 5) To use a nonverbal response that provides both accuracy and reaction time measures to target items (This reduces the possibility of over-activation of a left hemisphere and interference with elicitation of the left-ear advantage by the emotional stimuli which could result from a verbal response modality.);

- 6) To examine hemispheric asymmetries of ERPs while the participant is engaged in an **auditory** emotional detection task. The evoked potential studies examining laterality of emotional perception have used visual stimuli. In fact, all of the ERP studies examining emotional perception in normal individuals have used materials in the visual modality (Johnston, Miller, & Burleson, 1986; Kestenbaum & Nelson, 1992; Lang et al., 1990; Laurian et al., 1991; Vanderploeg et al., 1987).

III. LITERATURE REVIEW

Lateralization of Emotion

Brain-Damage and Emotion

Experience/Expression

As early as the beginning of the twentieth century, changes in emotional functioning as a result of unilateral brain damage had been noted (Bear, 1983). Since that time, emotional changes following unilateral brain damage have been examined from several perspectives. The most obvious changes have involved emotional behaviors described as "catastrophic reactions" in left brain-damaged patients (LBDs) and the euphoric or "indifference reactions" observed in right brain-damaged patients (RBDs) (Sackeim, 1991). The former is usually described as tearfulness and deep frustration experienced in the face of disability or failure to complete tasks, while the latter refers to the jocular or even euphoric attitude demonstrated by RBDs which usually accompanies minimization of disability or denial of illness (Gainotti, 1972; Sackeim, 1991; Sackeim, Greenberg, Weiman, Gur, Hungerbuhler, & Geschwind, 1982).

Observations of post-stroke emotional behavior have led to the generation of hypotheses regarding lateralization of emotional functioning. The great display of negative affect

resulting from left-hemisphere damage suggested that the intact right hemisphere was responsible for the mediation of negative emotions. Conversely, the indifference reaction secondary to right-hemisphere damage pointed to the mediation of positive emotions by the intact left hemisphere. Thus, in each case, it was thought that the expressed emotion was a function of the intact hemisphere (Heilman & Bowers, 1990; Sackeim et al., 1982). Models of intra-hemispheric release phenomena have also been promoted to explain these emotional changes. The intra-hemispheric release model is based on the idea that interconnected regions within a hemisphere may exert inhibitory forces on one another. Thus, damage to a region that has inhibitory forces on another site would result in the disinhibition or activation of the site which was once inhibited. If this model is correct, the catastrophic reaction demonstrated by LBDs would not be a result of intact right hemisphere functioning, but would be a result of activation of a region of the left hemisphere which was inhibited prior to the left-hemisphere stroke. Studies involving hemispherectomies were not supportive of such models (Sackeim et al., 1982), rather they were supportive of interhemispheric release. Thus, left-hemisphere damage would enable greater disinhibition or "release" of right-hemisphere mediated negative emotions and right-hemisphere damage would disinhibit left-hemisphere mediated positive emotions (for a

more comprehensive review see Sackeim, 1991).

Mood

In addition to these gross behavioral changes in emotional functioning, many investigators have noted differences in the incidence of post-stroke depression in LBDs and RBDs. For example, Robinson, Kubos, Starr, Rao, and Price (1983) reported that 11 of 28 LBDs experienced minor depression and 7 of 28 experienced major depression two weeks after their stroke. In contrast, only 3 of 20 RBDs experienced minor depression, only 1 of 20 experienced major depression, and yet 6 of the 20 demonstrated a hypomanic state. Another report by Robinson and Starkstein (presentation, 1987) indicated that 25% of LBDs who suffered a single stroke developed major depression, 19% a minor depression. However, examination of a group of patients who developed mania post-brain injury found that 12 of the 17 patients studied were RBDs. Others have not found such differences. For example Gordon, Hibbard, Egelko, Riley, Simon, Ross, and Lieberman (1991) reported that 68% of RBDs and 56% of LBDs met DSM-III criteria for depression.

There may be several reasons that reports of depression follow both right- and left-hemisphere damage (Sackeim, 1991). For example, the location of the lesion within a hemisphere

plays an important role in determining whether post-stroke depression occurs. Lesions closer to the frontal pole of the left hemisphere and to the posterior pole of the right hemisphere have been associated with post-stroke depression (Robinson & Starkstein, 1990). Time of post-stroke onset also seems to be a determinant of whether depression is reported following a unilateral stroke. The nature of depressive symptomatology may also play a role in the discrepancies found between studies. Finally, there is no reason to suppose that one hemisphere or the other is solely responsible for regulating mood. Thus, closer analysis of the discrepancies across different studies and control of these factors may help to understand the role of each hemisphere in the occurrence of post-stroke depression and the regulation of affect.

Perception

In studies of perception of emotion, utilizing the facial, prosodic, and lexical channels (for review, see Borod, 1992), the dichotomy based on emotional valence (left hemisphere/positive emotions, right hemisphere/negative emotions) does not hold. Most perceptual studies support the right hemisphere hypothesis.

Prosodic perception. Several studies examining prosodic perception in brain-damaged patients have found that RBDs are

significantly impaired in their ability to identify emotional intonation and that their performance is worse than that of LBDs (See Joannette, Goulet, & Hannequin, 1990 for a review). For example, Heilman, Bowers, Speedie, and Coslett (1984) reported that patients with RBD did worse than LBDs in correctly identifying the emotional tone of sentences stated with emotional tones of happiness, sadness and anger. A separate study by Bowers, Coslett, Bauer, Speedie, and Heilman (1987) also supported the notion that the right hemisphere mediates perception of emotion regardless of the valence of the intonation. Lalande, Braun, Charlebois, and Whitaker (1992) also reported that RBDs were impaired, relative to LBDs, in perceiving "pure prosody," or what they defined as "prosody without lexical properties" (p. 18). The conclusion drawn from these and similar studies (Heilman, Scholes, & Watson, 1975; Tucker, Watson, & Heilman, 1977) is that, regardless of the valence of the emotion, it is the right hemisphere which mediates prosodic perception.

A study that did not find a difference in the abilities of LBDs and RBDs to identify the emotional intonation used in stating emotional sentences was conducted by Van Lancker and Sidtis (1992). In this study, both populations did worse than normals, but their performance levels did not differ. However, errors made by LBDs and RBDs were qualitatively

different. RBDs tended to identify negative intonations as positive intonations; LBDs did not. This could be interpreted as partial support for the valence hypothesis.

Facial perception. An examination of the perception of emotions in groups of left-brain damaged (LBD) and right-brain damaged (RBD) individuals found that the RBDs were less accurate in identifying negative facial expressions than LBDs or controls (Borod, Koff, Lorch, & Nicholas, 1986). However, the ability of RBDs to identify positive emotions did not differ from that of LBDs or controls. This was interpreted as evidence for right hemisphere specialization for the perception of emotion of negative valence. In a separate study examining the ability of schizophrenics and right-brain damaged (RBDs) subjects to identify and discriminate different facial emotional expressions (Borod, Martin, Alpert, Brozgold, & Welkowitz, 1993), schizophrenics and RBDs had greater difficulty than the control subjects in identifying negatively-valenced emotions. However, their ability to identify positively-valenced emotion did not differ from the control group. The relative sparing of positive emotion identification and impairment in negative emotion identification in the RBDs provide partial support for the valence hypothesis. Other studies have not supported hemispheric differences based on valence. Rather, they report

that right-hemisphere damage more often results in impairment of facial emotional perception than left-hemisphere damage (Dekosky, Heilman, Bowers, & Valenstein, 1980; Etcoff, 1984).

Seizure Disorders and Emotion

Expression

Changes in emotional functioning have also been noted in individuals with seizure disorders. Both short-term ictal and long-term inter-ictal alterations have been reported (Bear & Fedio, 1977; Sackeim et al., 1982). A review of 98 cases by Sackeim et al. (1982) indicated that gelastic epilepsy (uncontrollable outbursts of ictal laughter) is associated twice as often with left-sided epileptic foci than with right-sided foci. While they examined only a small number of dacrystic epileptic cases (epilepsy accompanied by uncontrollable crying), in most cases, the epileptic foci were in the right hemisphere. As several studies reviewed by Sackeim et al. (1982) have found that a variety of symptoms associated with epilepsy have been a result of alteration of brain activity in regions ipsilateral to the focus of seizure activity, Sackeim et al. (1982) suggest that "emotional outbursts in gelastic and dacrystic epilepsy are a result of excitation of regions ipsilateral to foci (p.216)." Based on these findings it appears that the left hemisphere houses positive emotional expression while the right hemisphere is

responsible for the expression of negative emotions (for a more comprehensive review, see Sackeim, 1991).

Mood

A survey of interictal personality characteristics has demonstrated that longstanding emotional functioning may be a function of epileptic foci lateralization (Bear & Fedio, 1977). Using self- and observer-report scales, behavioral traits of patients with seizures of unilateral foci were documented. Bear (1983) describes how such long-term changes might take place:

"Based on contrasting features of the Kluver-Bucy syndrome and behavioral changes in temporal lobe epilepsy, Fedio and I have suggested that the interictal behavior syndrome reflects enhanced affective associations resulting from increased functional connectivity between sensory association cortices and limbic structures, such as the amygdala, within the temporal lobe. For example, the kindling effect of a discharging epileptic focus may bring about fortuitous sensorilimbic connections that are the converse of sensorilimbic disconnections affected by temporal lobectomy or amygdalectomy" (p.197).

Results from the questionnaire indicated that right temporal lobe epileptics reported more elation than left temporal lobe epileptics who reported more anger and paranoia. Discrepancies between self-report and observer reports lead the authors to describe individuals with right foci as demonstrating "external emotive" behaviors, with a tendency

to deny negative qualities such as depression or other socially sanctioned qualities. In contrast, those with left-sided foci exhibited more "intellectual tendencies," and while minimizing their positive qualities, they exaggerated negative traits. From these findings, Bear and Fedio abstracted analogies between the emotional functioning found in RBDs and LBDs with that found in individuals with right-sided and left-sided seizure foci, respectively. Given their interpretation, it appears that both adult ictal (Sackeim et al., 1982) and interictal (Bear & Fedio, 1977) emotional functioning lend support to the valence hypothesis with regard to emotional experience and expression.

Perception

Unlike the literature on emotional expression and experience in seizure disorders, prosodic perception in children with left and right temporal lobe epilepsy seems to be in keeping with the right hemisphere hypothesis (as is also reported in normal children and adults). Cohen, Prather, Town, & Hynd (1990) presented 15 sentences with three emotional tones: (1) happy, (2) sad, and (3) mad. Those children with right-sided foci performed significantly worse than normal children for all emotional categories. The performance of children with left-sided foci was not significantly different from normal. Thus, as in the brain-

damaged literature, observations regarding lateralization of emotional processing of seizure disordered individuals are dependent on whether results are from studies on emotion experience/expression or perception.

Normal Individuals and Emotion

Although both studies of perception and expression have been used to investigate hemispheric specialization of emotional processing, recent studies have focused on emotional expression and/or experience (Ahern & Schwartz, 1985; Davidson, in press; Davidson, Ekman, Saron, Senulis, Friesen, 1990; Davidson & Tomarken, 1989; Ehrlichman, 1987; Martin, Borod, Alpert, Brozgold, & Welkowitz, 1990; Moreno, Borod, Welkowitz & Alpert, 1990; Schwartz, Ahern, & Brown, 1979). However, this shift has taken place without adequate resolution of the question of lateralization of emotional perception. While the majority of studies suggest that emotional perception is mediated solely by the right hemisphere (Borod, 1992; Borod & Koff, 1989; Ley & Strauss, 1986), other studies have provided evidence in support of left-hemisphere specialization for the perception of positively-valenced emotions and of right-hemisphere specialization for the perception of negatively-valenced emotions.

Much of the evidence in support of the valence hypothesis for emotional perception comes from facial perception studies, reviewed quite thoroughly by Davidson (1984). For example, Suberi and McKeever (1977) reported that recognition of facial expressions of sadness produced a strong left visual-field advantage, while recognition of facial expressions of happiness and anger produced the least left visual-field advantage in a reaction time paradigm. A separate study (Ley & Bryden, 1979) demonstrated that greater errors were made in the perception of positive schematic facial expressions presented in the left visual-field than in the perception of negative expressions presented in the left-visual field (cited in Davidson, 1984). A different paradigm administered by Dimond and Farrington (1977), in which negative and positive film clips were shown to each hemisphere separately, resulted in heart rate changes which were interpreted as evidence for left hemisphere processing for positive emotional information and right hemisphere processing for negative emotional information (cited in Kinsbourne & Bemporad, 1984). Reuter-Lorenz, Givis, and Moscovitch (1983) also demonstrated that it was easier to identify the visual field of presentation of the emotional expression of sadness when it was presented to the left visual-field and to identify the visual field of presentation of the facial expression of happiness when it was presented to the right visual-field (cited in Silberman and

Weingartner, 1986). All of these studies, with the exception of the one which found a right visual-field advantage for both happiness and anger, provide evidence which may be interpreted to support the valence hypothesis. These findings were obtained from "normal" individuals without psychiatric or neurological disorders.

More recent studies examining perception of facial emotion have not reported evidence in support of hemispheric differences for accuracy in target detection (Erwin, Gur, Gur, Skolnick, Mawhinney-Hee, & Smailis, 1992; Sackeim, Putz, Vingiano, Coleman, & McElhiney, 1988). However, when a different type of measure was used (e.g., response bias), Sackeim et al. (1988) reported that subjects rated sad facial expressions as more sad when presented to the left than right visual field. No hemifield/hemisphere effects were obtained in rating the intensity of positively-valenced facial expressions. This was regarded as partial evidence in support of the valence hypothesis.

Thus, much of the evidence in support of the valence hypothesis for emotional perception has been demonstrated for facial perception (and has been limited to the visual modality), and all the literature on prosodic perception in normals has been supportive of the right hemisphere hypothesis

(Borod, 1992; Borod & Koff, 1989; Joannette et al., 1990), but not of the valence hypothesis. One study using auditory presentation of lexical materials reported asymmetry of emotional perception when the focus of the task was on word content. Wexler, Schwartz, Warrenburg, Servis, and Tarlatzis (1986) presented words with "positive emotional value" and those with "negative emotional value", in separate blocks, using a dichotic fused-word technique (the words had either a negative connotation [e.g., die], or a positive connotation [e.g., pie]). They found a greater left-hemisphere advantage in blocks of trials in which the positive words were presented, compared to blocks of trials in which negative words or neutral words were presented. The findings were interpreted as evidence that exposure to words of positive valence led to activation of the left hemisphere and an enhanced right-ear advantage for the verbal material, while exposure to words of negative valence enhanced right hemisphere activity and resulted in a smaller than expected right-ear advantage for the verbal material. It should be noted that this paradigm is not merely a perceptual paradigm as the words presented were rated by subjects as also inducing an emotional experience.

Dichotic Listening and Perception of Emotion

Important Considerations in the Dichotic Listening Technique

Anatomical characteristics of the auditory system which underlie the ear preferences elicited via dichotic listening procedures include the size of and routes taken by the ipsilateral and contralateral fibers in conveying information to the brain (Bryden, 1988; Springer, Sidtis, Wilson, & Gazzaniga, 1978). The contralateral pathway is composed of a greater number of fibers and projects directly to the contralateral hemisphere. If the information which originally arrives at the contralateral hemisphere needs to be processed by the ipsilateral hemisphere, then information must be transferred across the corpus callosum. The ipsilateral pathway is composed of fewer fibers (Bryden, 1988). It is thought that under conditions of hemispheric competition, the combination of these two factors (size of pathway and route of information transfer) results in suppression of information arriving from the ipsilateral pathway. Thus, if verbal information is presented to both ears at the same time, information from the right ear would go directly to the left hemisphere via the large contralateral tracts, minimizing the ipsilateral input of the left ear. Information from the large contralateral fibers arising from the left ear would have to go first to the right hemisphere and then be transferred to

the left hemisphere for verbal processing. Thus, verbal material presented to the right ear would be more readily processed and accurately reported than the information from the left ear.

Given that approximately 99% of right-handers demonstrate left hemisphere language lateralization, the failure to obtain the REA at the same rates (usually the rate obtained is about 80%) (Mondor & Bryden, 1992) has raised questions about the roles of factors other than hemispheric specialization in the occurrence of ear advantages to specific types of stimuli. Another finding raising this question is poor test-retest reliability that has been reported in some dichotic tests (Borod & Goodglass, 1980). Other dichotic tests have proven to have moderate to high test-retest reliability (Bruder, 1988). Several factors affecting the size of ear advantage (REA) obtained in dichotic listening tasks have been identified. Some of these factors include: (1) gender of the subject, (2) attentional strategies employed by the subjects, (3) the memory load required to respond to the item, (4) intensity of stimulus materials, and (5) task difficulty (Mondor & Bryden, 1992). These factors are very important for the interpretation of what ear advantages reflect about the processes (such as language or emotion perception) being studied.

Perception of Emotion and Dichotic Listening

Several investigators have used dichotic listening paradigms to examine perception of prosodic emotion. For example, Saxby and Bryden (1984) presented emotionally-intoned sentences to children. They demonstrated a dissociation of ear advantages for prosodic intonation and the content of the presented sentences. A right-ear advantage was obtained for the verbal content while a left-ear advantage was obtained for prosodic identification. In adults, Herrero and Hillix (1990) also found a left-ear advantage in the prosodic identification of a neutral sentence stated with the emotional tones of being mad, glad, and sad, as did Ley and Bryden (1982) and Shipley-Brown et al. (1988). In these three experiments, the basic procedure was the same: neutral sentences (some studies used a single sentence, others used four different sentences) were stated with three emotional tones: anger, sadness, and happiness. The sentences were rated by a group of raters, converted to digital form via computer, and in some cases, after being rerated for accuracy, were dichotically presented to subjects.

Hatta and Ayetani (1985) used a slightly different procedure. They presented nonsense sentences, rather than real sentences, which had been uttered in a positive tone or a negative tone. They paired each sentence with white noise

rather than with a second nonsense sentence. The subject's task was to indicate positivity or negativity of the sentence on a 9-point scale. They found that ratings of positivity were higher for sentences presented to the left ear than for those presented to the right ear. No significant ear differences were found for sentences stated with a negative tone of voice. They also found that ratings of positivity or negativity were higher when stimuli were presented to the left ear than to the right ear. The latter findings also seem to be in keeping with the right hemisphere hypothesis.

Bryden and MacRae (1989) created yet another form of a dichotic listening task similar to the Wexler et al. (1986) word-fusion technique. They constructed a task in which two of four words having the same spelling with the exception of the initial consonant (bower, dower, power, tower), which had been stated in each of four tones (happy, angry, sad, or neutral), were paired together. Participants were presented with two different tasks. In the first task, they were asked to indicate whether or not they had heard a target word. In the second task, they indicated whether or not they had heard a target emotion. A right ear advantage was obtained for the accurate detection of target words, while a left ear advantage was obtained for the accurate detection of target emotional tones. The latter finding was marginally stronger for

negatively-valenced emotions than for positively-valenced emotions ($p < .06$). These findings were interpreted as being in keeping with the right hemisphere hypothesis for emotional perception. However, the trend for greater left-ear advantage for negatively- than for positively-valenced emotional tones could be interpreted as partial evidence for the valence hypothesis.

Results from these and other dichotic listening studies are supportive of the right hemisphere hypothesis. However, there are a few methodological shortcomings which, if improved upon, may improve our understanding of hemispheric specialization for emotional processing. These shortcomings include the limited number of emotions presented to participants as well as the use of digitized stimuli which were edited and not subsequently rerated. In addition, the use of sentences with varying semantic context and phonemic sounds with durations longer than one second may not be eliciting true hemispheric competition in the same way that the use of nonsense syllables provides (Sidtis, personal communication, May 31, 1992). Qualitative improvements in the dichotic listening technique may provide a more accurate understanding of the role of the right and left hemispheres in emotional perception.

Evoked Potentials and Emotion

Evoked Potentials as Measures of Complex Cognitive Processes

Behavioral data from dichotic listening tasks have demonstrated primarily a right-hemisphere advantage for the perception of emotional stimuli. Until the present time, electrophysiological data have not been collected during the execution of this task. However, such measures are interesting as they could provide information about electrophysiological activity during the perception of emotion. Event-related potentials provide measures of electrophysiological correlates of cognitive processing. Some of the components that have been associated with cognitive processes are the N100, P300, and the slow wave. These components are thought to reflect mental processes such as attention, memory and decision making (Hillyard, 1985).

N100 reflects processing of information at the sensory-attentional level. It can be influenced by stimulus characteristics, such as intensity. The N100 is also modulated by selective attention, in that its magnitude increases to attended stimuli. This increase in negativity to attended stimuli can be elicited in the auditory modality by a variety of stimuli, such as tone pips and speech sounds (Hillyard, 1985). The most commonly used method of

quantifying attention-related negativity is to subtract the evoked potential obtained during an attend condition from that obtained from a nonattend condition (Hillyard, 1985). This difference wave, interpreted as representing attentional events, is called "processing negativity," or sometimes, the "difference wave." Attention-related negativity is largest over frontocentral brain regions.

The P300 component has been studied in many paradigms, yet definition of this component in terms of scalp distribution, amplitude, and latency characteristics, as well as the cognitive processes that it is thought to represent, is not unitary or uniform. Squires, Squires, and Hillyard's (1975) demonstration of two different positive deflections (P3a and P3b, the former occurring in response to infrequent unattended stimuli and the latter to infrequent attended stimuli) is a clear example of the difficulty that arises in trying to characterize the P300 as one component or process. Johnson (1989,1993) strongly promoted the notion that P300 activity is not a single, uniform entity with a single locus of origin, but rather that it depends on stimulus modality and subject expectations, as well as to task conditions. Johnson has also provided evidence that the P300 is generated by different brain regions.

The P300 is associated with cognitive processes, such as stimulus evaluation in working memory and is commonly described as occurring in response to infrequently occurring stimuli. According to Woods (1990), "Frequent stimuli are processed through a comparison with a representation in short term memory that bypasses P300 generation. By contrast, infrequent, P300 producing stimuli usually require a search of LTM [long term memory]" p.191. For this reason, an "oddball" paradigm is often used to elicit the P300. In this paradigm, the listener is presented with a train of frequently occurring stimuli in which an infrequently occurring stimulus is embedded in a random fashion. The listener's task is to detect and indicate the occurrence of the infrequent stimulus (the target), usually by pressing a button (Regan, 1989). As the latency of P300 is often longer than reaction time measures, P300 does not reflect response set parameters (Hillyard, 1985).

In a commentary, Donchin and Coles (1988) reviewed the meanings ascribed to the P300 component over the years. These include resolution of participant uncertainty, information conveyed by stimulus probability, expectancy, and task relevance. In conclusion, they define P300 as a "manifestation of activity occurring whenever one's model of the environment must be revised (p.357)." Verleger (1988),

on the other hand, defined the P300 as reflecting "phasic physiological deactivation of...tertiary areas" (p.354). Tertiary areas refer to areas of the brain that integrate perceptual information from all sensory modalities.

The P300 complex begins between 300 and 600 milliseconds (ms) post-stimulus onset (Kutas, McCarthy, & Donchin, 1977). There are several parameters which affect the latency and amplitude of the component. These must be considered in constructing a task used to elicit the P300. Factors such as "stimulus quality" and "memory set size" can affect the latency of P300 (Hoffman, 1990). Factors that may affect P300 amplitude include stimulus probability, stimulus quality, and attention or task relevance of the stimulus (Hoffman, 1990). According to Johnson (1993), P300 amplitude is determined by the "subjective probability" and "stimulus meaning" of an event, and these factors are also affected by other elements such as: "global stimulus probability", "sequential expectancies", "task complexity," and "stimulus complexity".

Evoked Potentials and Perception of Emotion

Brain Damaged Patients

Though ERPs have not been used to examine emotional perception in conjunction with dichotic listening tasks, they have been recorded in a variety of other paradigms. In a

study reported by Twist, Squires, Spielholz, and Silverglide (1991), patients with unilateral brain damage, as well as a control group, participated in an "oddball" paradigm involving three different conditions: (1) tone discrimination, (2) prosodic discrimination, and (3) semantic discrimination. The prosodic discrimination task involved detection of a target item, consisting of neutral words (names of pieces of furniture) stated in the emotional tone of surprise, interspersed among nontarget items made up of these same items stated in a monotone voice. The P300 to the target items was significantly smaller in the patients with right-hemisphere damage (RBD) compared to the P300s obtained from patients with left-hemisphere damage (LBD) and control subjects. Conversely, the LBDs had smaller P300s for the target items in the semantic discrimination task than the RBDs or normal control subjects. This distinction between RBDs and LBDs based on hemispheric lesion and the concomitant reductions in P300 amplitudes was interpreted as evidence that the ERP, particularly the P300 component, could reflect cognitive functioning that is associated predominantly with either the left or the right hemisphere. However, hemispheric **asymmetries** in P300 amplitudes in response to tasks assessing tonal, prosodic (emotional), or semantic processing were not obtained in RBDs or LBDs. Thus, while P300 amplitudes in the brain-damaged subjects were smaller than those obtained from

normal participants engaged in the same tasks, support for lateralization of prosodic processing was not obtained.

Psychiatric Patients

A separate study was conducted in autistic adults who had intelligence levels in the average range (Erwin, Van Lancker, Guthrie, Schwafel, Tanguay, and Buchwald, 1991). An oddball paradigm was used to examine perception of neutrally stated nonsense syllables ("ba" and "pa"), the name "Bob" stated with linguistic prosody (with intonation contours reflecting a statement and a question), and prosodic perception of emotionally intoned stimuli (the name "Bob" stated with the emotional tones of happiness and anger). As individuals with autism experience interpersonal communication difficulties, the questions of interest were whether such individuals demonstrate a deficit in the perception of emotional stimuli, whether there might be a concomitant psychophysiological reflection of such a deficit, and whether the possible deficit was lateralized. Event-related potentials were recorded from central (Cz), left- and right-parietal (P3, P4) and left- and right-temporal (T5, T6) sites. Amplitude and latency measurements were determined only for the central electrode. Possible laterality effects were probed by an analysis of variance, in which hemisphere was a factor, with the factor scores obtained from a Principal Components Analysis.

They found that the performance level of autistic individuals was the same as the performance levels of normal individuals for identification of target items in the emotional prosodic identification task. In addition, both the normal subjects and the autistic subjects demonstrated similar differences in the P300 amplitudes elicited in the target versus nontarget trials (target P300 - Nontarget P300). A finding that caught the attention of the investigators was that the P300 amplitudes were significantly greater for the stimuli stated with the emotional intonation of anger than for the other stimuli. This, together with the significantly shorter latency for the P300 in the detection of the anger items, suggested to the authors that "the P3 generator system preferentially processes emotionally biased sound" (p.570). However, they found no evidence for differences in ERPs as a function of hemisphere.

Normal Individuals

Other investigators have examined the changes in P300 associated with affectively-charged stimuli in individuals without brain damage or any psychiatric condition. It has been proposed that "emotional value is a major determinant of P3 amplitude" (p. 684) (Johnston et al., 1986). These investigators collected ERPs in a paired associate learning task requiring the subject to learn the association between

nonsense syllable presentation and presentation of pictures with emotional valence ranging from pleasant to unpleasant (pictures were those of "ordinary people," "male models," "female models," "babies," and "dermatological slides" which had been rated by the subjects for their emotional valence). Event-related potentials were recorded from midline electrode sites. Two components examined were P300 (defined as having a maximum peak no later than 300 msec post-stimulus onset) and P400 (defined as having a maximum peak no later than 540 msec post onset). They consistently found that the P300 and P400 components were significantly greater for those stimuli rated as having emotional value (pleasant or unpleasant) than for those of neutral stimuli.

The oddball paradigm has been used in both children and adults (Lang et al., 1990; Nelson & Nugent, 1990) to examine the changes in ERPs associated with facial emotion discrimination. Lang et al. (1990) measured the changes in P300 associated with the detection of target facial expressions from four midline electrode sites: frontal, central, parietal, and occipital. The two target expressions were happiness and anger. The subject's task was to count the number of target items. Significant differences were obtained for P300 amplitude (defined within the window ranging from 290 msec to 800 msec) and P300 area. The P300 amplitude

difference was due to a larger P300 obtained for the angry face than the happy face (amplitudes were greater at the parietal electrode placement than for the central placement for both targets). Two possible explanations provided for this effect were that: (1) the angry expression may be more intense than the happy expression, and (2) the angry expression may be more salient and thus results in greater attention to and arousal associated with that type of stimulus. However, no empirical measures of intensity, attention, or arousal were obtained during the task; thus, these interpretations are speculative. Also, the area of the P300 wave was significantly greater for the happy expression than for the anger expression. This was due to an earlier resolution of P300 to baseline in response to anger slides than to happy slides. No explanation was provided for this result. Thus, while this study could not make a comment regarding hemispheric specialization for perception of emotion, it demonstrated that the amplitude of the P300 could be altered by the emotion category being processed.

In a similar study conducted with children (Nelson & Nugent, 1990), evoked potentials were recorded from electrodes placed at midline in children between the ages of four and six. Each child's task was to call out the name of the target emotional expression every time the target face occurred. The

target emotions used in this study were happiness and anger. In the first experiment, the target item occurred in 20% of all trials, while in the second, the target occurred in 80% of the trials. The findings from this study were that the P300 for target items were greatest at the parietal and central electrode placements. Also, the significant factor in determining the amplitude of P300, in both experiments with children, was the probability of the stimulus event, not the emotion conveyed by the stimulus. Thus, the P300 was greater for items of low probability, such that in the second experiment, in which the target occurred more frequently than the nontarget, P300s were greater for the nontarget items. This differed from the adult findings and was thought by the authors to reflect differences in "attentional allocation" which may exist in children and adults.

In all of the studies with normal subjects reviewed so far, the electrode placements were limited to midline locations. In three other studies (Laurian, et al., 1991; Kestenbaum & Nelson, 1992; Vanderploeg, et al., 1987), the number of placements was increased to provide information about possible laterality differences that may occur during emotional perception. In addition to a larger array of electrode placements, Laurian et al. (1991) used a wider emotional stimulus array comprised of one positive emotion

(happiness) and four negative emotions (fear, anger, disgust, and sadness). They also included a control task to ensure that any significant electrophysiological effects could be specified to emotional processing and not to visuospatial processing. At all leads, the P300 amplitude was measured at the latency of P300, which was obtained from the PZ lead (ranging from 330-350 msec). Positively- and negatively-valenced faces elicited the largest P300 differences (target vs. nontarget difference waves) at the right centroparietal lead, while neutral faces produced similar P300 differences in both hemispheres. Another interesting finding was that positive faces produced a greater difference wave at the left frontal lead compared to neutral faces. As similar differences were not found in the right hemisphere for negative faces, the authors did not promote this as evidence for the valence hypothesis. Rather, their interpretation of findings from this study was that the right centroparietal region is more engaged in emotional perception than other brain regions. This is in keeping with the notion of right hemisphere specialization for emotional processing. Another important conclusion was that ERPs were affected by the emotional content of stimuli, and that this reflected some mental processing of the emotional aspect of stimuli.

The left-hemisphere effect found in the study of Laurian et al. (1991) for the positively-valenced emotions should not be overlooked, as it may be interpreted as partial evidence for the valence hypothesis. Another possibility, however, is that exposure to the facial expressions caused the subjects to experience the emotion portrayed by the poser, and that this was more intense for the positively-valenced emotions than for the negatively-valenced emotions.

Kestenbaum and Nelson (1992) recorded ERPs in both adults and children (aged seven) from midline and lateral electrodes (T5,T6) in response to detection of facial target emotions. The facial expressions presented as slides were happiness, surprise, fear and anger. Reaction times were obtained to target emotions (happiness and anger items) on faces in the proper orientation, and in another set of stimuli, to faces that were inverted. P300 peak amplitudes and area measurements were greater to happy facial expressions than to anger facial expressions in adults. In addition, onset of P300 was earlier to happy items than to anger items. At the temporal electrode placements (T5 and T6) target items resulted in greater area measurements and peak amplitudes of P300 over the right placement than over the left placement. This effect was not found in the children participants.

Not all investigators studying the P300 have found significant changes in this component associated with emotional processing. Vanderploeg et al. (1987) asked subjects to rate the perceived "emotional connotation" (p. 194) (positive, negative, or neutral) of sketches of faces and verbal stimuli (words). They focused on the effects of perceived emotional valence on P300, which they described as falling within the range of 240 - 450 ms, and the slow wave, defined as occurring between 448 - 616 ms. They reported that the P300 was greater from left-hemisphere and midline leads for neutral stimuli and smaller for positively- and negatively-rated stimuli. In addition, slow wave amplitudes were significantly greater when recorded from right-hemisphere and midline leads. These findings are quite different from those in the other studies reviewed. Explanations suggested for these findings were that perhaps the initial discrimination of the emotional or nonemotional nature of a stimulus is mediated by left hemisphere processing and occurs earlier (at P300 as they describe it) and that the categorical distinction between emotional valence (positive, negative or neutral) of the stimuli requires further processing and is limited, with facial stimuli, to the right hemisphere (in keeping with its specialized function for facial recognition). The conclusion of the investigators was that the P300 and slow wave are not unique to emotional processing, but that

emotional processing may be reflected by changes in these components.

The information provided by prior ERP studies of emotional processing is tenuous. This is a result of the differences in the paradigms used by many investigators, limited number and location of electrode sites, limited categories of emotions studied, and the varied definitions of ERP components in terms of peak latency or area. In addition, many of these studies have confounded hemispheric differences by having subjects respond verbally when identifying target items. Improvements can be made by using montages that permit analysis of both inter- and intra-hemispheric changes in ERPs, by using a wider emotional stimulus array, and by using response methods which will not confound response parameters with parameters of perception and discrimination. Such improvements may provide a better understanding of ERPs in the processing of emotional stimuli.

Dichotic Listening and Event-Related Potentials

Event-related potentials to dichotic stimuli have been studied as early as 1974 (Haaland, 1974; Neville, 1974). Some of the stimulus materials presented included verbal materials (CVC syllables) (Haaland, 1974), verbal and nonverbal materials in two separate dichotic tasks (digits and clicks)

(Neville, 1974), as well as a single dichotic task combining verbal (sentences) and nonverbal (clicks) material (Mononen & Seitz, 1977). The objectives of these studies were largely to determine the physiological or cognitive bases for the right-ear advantage for verbal material. Their studies reported results regarding latencies and amplitudes of components such as N100, P200, or P300 components obtained from between nine and twelve participants. In these studies, recordings were obtained from a small number of recording sites (2-5) with various placements. For example, Haaland (1974) recorded from left- and right-temporal (T3,T4) and frontal (F7,F8), as well as central (Cz) placements. Neville (1974) recorded from what she described as right- and left-temporal placements (C6,C5), while Mononen and Seitz (1977) recorded from what they considered left- and right-parietal regions (C3, C4).

The findings from these studies were varied. Neville reported shorter N1 and N2 latencies over the left hemisphere and greater N1 amplitudes over the left hemisphere for verbal dichotic presentation of stimuli. Haaland only reported amplitude asymmetries---with P300 being larger over the right hemisphere than over the left. Mononen and Seitz (1977) reported similar findings for a positivity in the time period often used to describe the P300, regardless of ear of stimulus

presentation. Mononen and Seitz (1977) also reported that ERPs in response to contralateral ear presentation were shorter than those to ipsilateral presentation of dichotic stimuli. None of these studies correlated behavioral data with ERP information.

Two more recently published studies examined the relationship between demonstrated behavioral asymmetry to dichotically-presented stimuli and ERPs. Some of the improvements provided by these studies included: (1) examination of ERP components occurring later than N100, P200 and P300 (Van de Vijver, Kok, Bakker, & Bouma, 1984; Tenke et al., 1993); (2) use of a larger array of electrodes to examine ERP distribution across the scalp (Tenke et al., 1993); and (3) the subgrouping of participants into those showing the expected ear advantage to stimulus materials and those who show the reverse or no advantage (Van de Vijver et al., 1984; Tenke et al., 1993). As individual differences in the presence or absence of behavioral asymmetries have been found in a variety of studies examining hemispheric specialization of function (Levy, Heller, Banich, & Burton, 1983), this third methodological improvement is important. This step provides homogeneous samples of individuals who show the expected ear advantage as well as those who do not. If there is a relationship between behavioral asymmetry and lateralized

brain processing (as indicated by ERP measures), then a homogenous group of individuals with a given ear advantage should permit a more reliable analysis of this relationship than a heterogenous group in which some participants demonstrate the ear advantage and others do not. This is particularly important when analyzing the electrophysiological data, as increased variability across subjects may diminish any differences that could be obtained with a more homogenous group (Tenke et al., 1993). Likewise, those without the ear advantage might be expected to exhibit different patterns of ERP activity across (and/or within) hemispheres.

Although Van de Vijver et al. (1984) did not describe precisely how subgroupings were made, Tenke et al. (1993) did describe their subgrouping technique. Laterality quotients were calculated (by using the formula described in the Results Section p. 85) to determine the size of the left-ear advantage (LEA) to tonal stimuli for each participant. The median left-ear advantage was used to divide the participants into two subgroups: those with the LEA and those with little or no LEA. This type of division ensures an equal number of subjects in each subgroup and reduced variability in electrophysiological data within subgroups (Tenke et al., 1993). Results from both the Van de Vijver et al. (1984) and Tenke et al. (1993) study showed a strong association between the appropriate ear

asymmetry for their respective dichotic listening tasks and corresponding hemispheric asymmetries in later cognitive components. Van de Vijver et al. (1984) report associations between ear asymmetry and a sustained positivity, while Tenke et al. (1993) report associations between ear asymmetry and two late positivities. The correspondence between ear advantage and hemispheric asymmetries enabled statements to be made regarding hemispheric advantages for processing of specific types of information (e.g., verbal or tonal).

Gender Issues

Gender differences in emotional perception and expression have been examined in a variety of contexts (Hall, 1978; Borod, Koff, & Buck, 1986; Borod, Koff & White, 1983). Surveys of a large number of studies conducted in the sixties and seventies (Hall, 1978) and more recently (Shields, 1991) indicate that women are better at decoding nonverbal emotional cues. However, it is important to note that there have been some although fewer studies indicating that men are better at decoding emotional information (Hall, 1978; Shields, 1991). In studies of emotion and hemispheric specialization, valence by hemisphere interactions are more pronounced for females than for males (Borod, Koff & Buck, 1986).

Although it was not a major purpose of this study, it was of interest to determine the presence of gender effects in terms of both the behavioral data and the electrophysiological data. Heller (1993) noted the paucity of studies examining gender differences in terms of psychopathology and neuropsychological functioning. If this procedure is to be used with psychiatric populations, such as depressed individuals, it would be of interest to know about gender-related differences in overall performance, as well as possible gender-related differences in ear advantages demonstrated on the dichotic task. In a similar vein, there are few analyses by gender reported in the ERP literature (Taylor, Smith, & Iron, 1990). It is not clear whether this is due to a failure to investigate this issue or a result of nonsignificant differences and subsequent failure to report such findings. The advantage of looking at the relationship between behavioral performance and ERPs as a function of gender is that it may provide evidence concerning the mechanisms underlying gender differences in emotional perception.

The bulk of dichotic listening studies with both adults and children have not found gender differences in left-ear advantage for emotional stimuli (Carmon & Nachson, 1973; Herrero & Hillix, 1990; King & Kimura, 1972; Ley & Bryden,

1982; Mahoney & Sainsbury, 1987; Shipley-Brown et al., 1988). Some studies reported gender-related effects. For instance, Saxby and Bryden (1984) reported that, while both males and females showed an LEA for emotional stimuli, girls tended to show a greater laterality effect. In addition, Hatta and Ayetani (1985) reported that females rated negative stimuli more negatively than did males, yet no gender-related differences related to ratings of positive emotions were found. It should be noted that this study reported a significant left-ear advantage only for stimuli of positive valence. This brief survey of emotional dichotic listening tasks suggests that both males and females should demonstrate the left-ear advantage to the emotional stimuli presented in the current study.

Four of the five studies examining the relationship between ERPs and emotional perception did not report analyses for gender effects (Kestenbaum & Nelson, 1992; Lang et al., 1990; Laurian et al., 1991; Vanderploeg et al., 1987). This may have been due to the fact that some studies included only male subjects (Laurian et al., 1991; Vanderploeg et al., 1987), while other studies had unequal number of males and females in their studies (Kestenbaum & Nelson, 1992; Lang et al., 1990). The only study that reported gender effects (Johnston et al., 1986) found a poser by viewer gender

interaction, with late positivities (P300 and P400) being larger for the poser of the opposite sex for both males and females.

IV. HYPOTHESES/PREDICTIONS

As the majority of the studies examining emotional perception have found a right-hemisphere advantage for stimuli of both positive and negative valence, there is a greater likelihood of obtaining evidence in support of this hypothesis. If so, the following predictions follow:

- 1) Accuracy of detection of target emotions presented to the left ear is greater than accuracy of detection of target emotions presented to the right ear for target emotions of both positive and negative valences (i.e., there is a left-ear advantage for detection of target emotions of both positive and negative valences).
- 2) Presentation of target items of both positive and negative valences to the left ear results in shorter reaction times than presentation of the same target items to the right ear. If the right hemisphere is in fact the hemisphere responsible for emotional perception, quicker transmission of information via the contralateral pathway and ipsilateral pathway suppression enables a quicker response to target items presented to the left ear than to the same items presented to the right ear.
- 3) The P300 amplitudes to target items are greater for

measures obtained from leads placed on the right than the left hemisphere and they are greatest at the parietal lead. Although this is a task involving auditory processing, it is expected that P300 amplitudes are greater at the parietal site since right-parietal brain regions are associated with the complex cognitive processes involved in emotional processing.

- 4) A stronger left-ear advantage (determined by a laterality quotient defined in the Methods Section, p. 80) is positively correlated with differences in P300 amplitudes between the left and right hemispheres (Left - Right hemisphere differences are more negative when P300 is greater over the right hemisphere).

Given the possible experiential component of this experiment, evidence for the valence hypothesis may be obtained. In this case, the predictions that follow include:

- 1) A left-ear advantage is obtained for the detection of negatively-valenced emotions and a right-ear advantage results for positively-valenced emotions.
- 2) Shorter reaction time measures result from presentation of negatively-valenced target items

to the left ear and positively-valenced target items presented to the right ear.

- 3) The P300 amplitudes to target items are greatest at the parietal lead over the right hemisphere for negatively-valenced target emotions and greatest at the left-parietal lead for positively-valenced emotions.
- 4) A stronger left-ear advantage is positively correlated with differences in P300 amplitudes between the left and right hemispheres for **negatively-valenced** emotions; a stronger right-ear advantage (positive value obtained by using the laterality quotient defined in the Results Section, p. 85) is positively correlated with differences in P300 amplitudes between the left and right hemispheres for **positively-valenced** emotions (left - right hemisphere differences are more positive when P300 is greater over the left hemisphere) (See Table 1).

Table 1.

Layout of ear advantages expected for each emotion
for the two hypotheses considered.

	LEA	REA
Right hemisphere hypothesis	Happiness, Interest, Anger, Sadness	
Valence hypothesis	Anger, Sadness	Happiness, Interest

V. METHODS

The experiment involved acquisition of behavioral (accuracy and reaction time) and event-related potential measures while the participant was engaged in a dichotic listening task requiring the detection of a target emotion.

Creation of Emotional Stimuli

Six nonsense (consonant-vowel) syllables: ba, ta, ga, pa, da, ka, (Bryden, 1988) were recorded in each of eight emotional tones including three of positive valence: happiness, interest, pleasant surprise; and five of negative valence: anger, sadness, disgust, fear and unpleasant surprise (Borod, Welkowitz, Obler, Whalen, Erhan, & Grunwald, 1992). Consonant-vowel syllables were used in this experiment for the following reasons. Using a paired syllable paradigm reduces memory and attentional bias present when multiple words or sentences are presented. The nonsense consonant-vowel syllables selected for use in this study have commonly been used in dichotic listening paradigms as it has been found that consonants produce a greater right-ear advantage (REA) than vowels alone (Bryden, 1988). Also, this REA is more consistent if it is at the beginning of the syllable than at the end. Stop consonants have rapid onsets and are "the sounds most encoded in terms of the acoustical signal." Thus, onset of stimuli can be more accurately aligned. These

characteristics enabled construction of a dichotic task in which competition between the two hemispheres is effectively elicited by the simultaneous presentation of syllables to the two ears.

The emotional utterances were prepared in accordance with what is known about the pitch patterns associated with the utterances of different emotional intonations (Scherer, 1979, 1981, 1984, 1989; Sobin, 1989) and in accordance with the instructions developed by Borod, Erhan, Welkowitz, Obler, et al. (1994). One female voice was used to produce a final set of 196 utterances, ranging in duration from 500 to 1500 ms, which were recorded in a sound-proof booth. The production was based on method acting in which the person used her imagination to put herself back into a situation in which the emotion in consideration had been experienced. The larger pool of utterances from which the 196 were subjectively selected by the investigator, to be used in the accuracy rating sessions, was created in two different ways. In the first production session, a single syllable was stated in each of the eight emotional tones (four repetitions for each emotion) before the next syllable was produced. In the second production session, a single emotion was uttered with all of the 6 different syllables (four repetitions for each syllable) before going on to the next emotion. Both of these production

methods were used so as to control for the effects of the order of syllable or emotion on the production of the intended emotion. All of the utterances produced in these sessions were carefully screened by the investigator. Four utterances for each syllable, stated with each of eight emotional tones, were subjectively selected as those that were most intense or accurate in portraying the intended emotion. These items were then used to produce the presentation tape comprising 196 trials. Of those items, 118 were selected from items produced with during the first production session, and 78 were selected from items produced during the second production session.

In summary, the 196 trials presented to subjects for rating consisted of four unique productions of each of six nonsense syllables (ba, ta, ga, pa, da, ka) stated in each of eight different emotional tones (happiness, interest, pleasant surprise, unpleasant surprise, anger, sadness, fear and disgust) (this actually came to a total of 192 trials). An additional four trials were included, coming to a total of 196. Order of syllable and emotion presentation was randomized. Three blocks of 72, 72 and 52 trials were presented to subjects over a session that lasted approximately 90 minutes. Order of block presentation was randomized across rating sessions (latin square design) to control for fatigue effects. The inter-stimulus-interval between trials was 8

seconds to provide ample time for subjects to select their response from the eight possible categories.

These utterances were categorized into one of the eight emotional categories listed above by 21 undergraduates at Queens College. The participants included 13 females and 8 males. These raters were right-handed by self report; were native speakers of English or were fluent in English by age 7; had no history of substance abuse, a neurological disorder or a psychiatric disorder; and were between the ages of 17 and 28 years ($M=18.9$, $SD=2.51$). Native English speakers were selected to control for intonation and tonal qualities of other languages that might influence the perception and/or interpretation of these emotions.

Participants were asked to listen to each item presented through two loud-speakers and to select one of the eight emotions they thought best represented the tone used in making the utterance. Responses were recorded by each subject on response sheets which were then used to tally the percent agreement across raters. Two different forms of the response sheets were used within the experiment. One form listed the possible emotions from left to right while the second form listed the same emotions in the reverse order. This was done to control for any effect that the order in which the emotions

were listed might have had on the response selection. Rating sessions were conducted with 4 or 5 raters per session.

Items receiving an accuracy of categorization of 60% or higher were digitized using a program written for an IBM compatible computer of the Speech and Hearing Sciences Computing Laboratory of the Graduate Center of CUNY. As there were eight different categories to select from, the chance level of correct categorization was 12.5%. A cutoff level of 60% was incorporated to ensure that included items received a majority of the tallies for the emotion that was determined a priori. Items receiving ratings below 60% could receive equal ratings (e.g., 50%, 50%) in two categories, and this would reduce the reliability and validity of the items included in the task. The Neuroscan SOUND software package (Neuroscan, Inc., Neurosoft Inc. Co. 1991) was used to edit these files so that the exact time of onset and offset could be determined and used to clearly delimit the utterance.

In addition, intensities of each utterance were standardized to a level of 73.5 dB SPL. To do this, the following procedure was followed. The root mean square (RMS) of the intensity of each stimulus file was determined with a basic program and compared with the RMS levels of a 1000 Hz square wave tone with an intensity level of 73.5 SPL, by using

the following formula: $10 \times \log (1000)/(\text{RMS for each utterance})$. The resulting value was the dB to be added or subtracted from the intensity levels of each stimulus to equate it with 73.5 dB SPL. The corrected intensity level was entered into the Neuroscan Sound presentation SET UP file. Intensity levels of stimuli presented through each earphone was confirmed with a QUEST ELECTRONICS PERMISSIBLE SOUND CALIBRATOR and SOUND LEVEL METER. This value of 73.5 dB SPL was selected as it proved to be a satisfactory level of intensity as determined by a complex tone listening task (Tenke et al., 1993). In addition, other studies using the dichotic listening technique with emotional stimuli have used intensity levels ranging from 65 to 85 dB SPL (Bryden & MacRae, 1989; Hatta & Ayetani, 1985; Ley & Bryden, 1982; Saxby & Bryden, 1984; Shipley-Brown et al., 1988). The intensity level of each stimulus was standardized so as to reduce stimulus characteristics, other than emotional tone, which might influence behavioral and electrophysiological measures.

Those items which had received an accuracy rating of greater than 60% were then recopied onto tape and rerated in the same manner described for the first rating session. Ten new raters (6 females and 4 males), with an age range of 17-23 years ($M=19.0$, $SD=1.49$), were presented with these items to confirm that digitization had not significantly altered the

emotional quality of the utterances. Those items receiving 60% accuracy of categorization rating or more were selected to make final pairs. As none of the accuracy ratings for items previously rated as unpleasant surprise reached the criterion level of 60%, this category was dropped.

Items from each of the remaining seven emotional categories were paired with items from every other category for a total of 21 unique combinations (Table 2). The number of items available in each positively-valenced category were: (1)happiness=4, (2)pleasant surprise=4, (3)interest=6. The number of items available in each negatively-valenced category were: (1)anger=5, (2)disgust=12, (3)fear=16, (4)sadness=23. Despite the abundance of items in some of the categories, several restrictions lead to the use of a limited number of items in making the 21 pairs (See Table 3).

Three or four items were selected from each category so as to match as closely as possible across categories for several stimulus characteristics. First, each item was to be repeated approximately the same number of times throughout the task. Happiness and pleasant surprise categories had only four items which could be used. As a result a maximum of four items could be selected from the other categories. Second, pairs were created such that the maximum difference between

Table 2.

Possible unique combinations of seven emotions.

H-PS	PS-I	I-A	A-F	F-D	D-S
H-I	PS-A	I-F	A-D	F-S	
H-A	PS-F	I-D	A-S		
H-F	PS-D	I-S			
H-D	PS-S				
H-S					

Table 3.
Frequency of item use in preparing pairs.

Emotional Category	Filename	Frequency of Use in Making Pairs
Happiness	EDAH60	1
	ETAH122	2
	EGAH183	2
	EKAH97	1
Pleasant Surprise	EBAPS176	1
	EDAPS39	3
	EBAPS62	2
Interest	EKAI96	2
	EGAI110	2
	EBAI156	1
	EPAI132	1
Anger	EKAA116	2
	EBAA41	2
	EKAA83	2
Sadness	EKAS131	1
	ETAS134	2
	ETAS12	2
	EPAS157	1
Fear	EKAF89	2
	EGAF18	1
	EBAF119	2
	ETAF125	1
Disgust	EKAD49	2
	ETAD126	2
	EBAD146	1
	EDAD100	1

item duration within a pair did not exceed 7% of the duration of the shorter item (See Table 4). The average difference for the positively-valenced pairs was 3.41% of the duration of the shorter item in the pair, for positively- and negatively-valenced pairs was 1.83%, and for negatively-valenced pairs was 1.14% (See Table 5). In addition, items within each pair were matched as closely as possible for accuracy ratings (See Table 4). The average difference in accuracy ratings for the positively-valenced pairs was 10%, for the positively- and negatively-valenced pairs was 10.83%, and for negatively-valenced pairs was 15.0% (See Table 5). The average category accuracy ratings for each category and across positively- and negatively-valenced emotions are listed in Table 6. Happiness items had an average accuracy of 73.33 (SD=13.66), pleasant surprise had a mean of 70.00 (SD=0.0), while interest items averaged 85.00 (SD=8.37). Thus, the overall mean accuracy rating for positively-valenced emotions was 76.11 (SD=6.62). Mean accuracy ratings for negatively-valenced emotions were as follows: (1) anger M=70.00 (SD=8.94), (2) sadness, M=83.33 (SD=5.16), (3) fear, M=86.67 (SD=12.11), (4) disgust, M=78.33 (SD=9.83). This resulted in an overall mean accuracy rating of 79.58% (SD=6.41) for the negatively-valenced emotions. Thus, the positively- and negatively-valenced items were fairly closely matched for accuracy ratings. These levels are satisfactory as they prevent a ceiling effect and yet permit

Table 4.
Pairs presented in the dichotic listening task.

Pair	%Accuracy	Duration	Difference in Duration	Accuracy Difference
H-I	100 90	770 735	35	10
H-PS	70 70	805 800	5	0
H-A	70 60	930 935	5	10
H-D	70 80	930 965	35	10
H-F	60 70	687 690	3	10
H-S	70 90	805 810	5	20
PS-F	70 100	770 730	40	30
PS-S	70 80	865 860	5	10
PS-D	70 80	865 870	5	10
PS-A	70 70	770 720	50	0
PS-I	70 90	770 735	35	20
I-A	90 80	720 720	0	10
I-D	80 80	890 879	20	0
I-F	70 80	620 620	0	10
I-S	90 80	720 725	5	10

Table 4.
Continued

A-F	80	720	10	20
	100	730		
A-D	60	935	30	20
	80	965		
A-S	70	720	5	10
	80	725		
F-D	90	595	1	0
	90	596		
F-S	80	620	5	10
	90	625		
D-S	60	865	5	20
	80	860		

Table 5.

Average difference of duration and accuracy ratings (SD) for positive-positive, positive-negative, and negative-negative pairs.

Pair Type	Average Duration Difference (%)	Average Accuracy Difference
P-P (N=3)	X=3.4 SD=2.4	X=10.0 SD=10.0
P-N (N=12)	X=1.8 SD=2.3	X=10.8 SD= 7.9
N-N (N=6)	X=1.1 SD=1.1	X=15.0 SD= 5.5

Table 6.

Average accuracy ratings (SD) for items selected in each category.

Category	Mean Accuracy Rating(%)		Mean Duration(ms)	
Happiness	73.33	(13.66)	821.17	(94.69)
Pleasant Surprise	70.00	(0.00)	806.67	(46.65)
Interest	85.00	(8.37)	736.67	(86.81)
Positive Valence Emotions Overall	76.11	(6.62)	788.17	(37.96)
Anger	70.00	(8.94)	791.67	(111.02)
Sadness	83.33	(5.16)	767.50	(92.56)
Fear	86.67	(12.11)	664.17	(60.03)
Disgust	78.33	(9.83)	856.67	(135.77)
Negative Valence Emotions Overall	79.58	(6.41)	770.00	(70.75)

the possibility of categorization of the items exclusively to one category.

Screening Procedures

Participants were obtained from a pool of volunteers available through the New York State Psychiatric Institute Control Pool under the direction of Diane Schechter. These individuals were screened for a history of psychiatric disorders, neurological disorders or substance abuse with the Schedule for Affective Disorders and Schizophrenia-Lifetime Version. In addition, Manhattan residents were recruited with ads placed in local neighborhood newspapers. These individuals were also screened for the criteria listed above by administration of the SADS-L by the experimenter, who was trained to use this structured interview by Dr. Larry Sharp of the Psychiatric Institute. The Edinburgh Handedness Inventory (Oldfield, 1971) was used to determine handedness. Hearing thresholds for each ear and inter-ear threshold differences were determined by administration of audiometric screening procedures that tests the hearing threshold at 500, 1000 and 2000 Hz, by presentation of these tones at 5 dB intervals until they are no longer perceived.

Subjects

As few as 11 or 12 subjects have been adequate to demonstrate within group laterality effects (Tenke et al., 1993) in dichotic listening tasks. Thus, 24 (13 male, 11 female) 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. This age group was selected because it matched that used to rate the stimulus materials. Participants' education ranged from 13 to 20 years ($M=16.08$; $SD=1.98$). They were also right-handed as determined by self-report on the Edinburgh Handedness Inventory ($M=76.70$; $SD=22.47$). English speakers were selected so as to eliminate any influence that the tonality of other languages might have on emotional perception and identification. Other inclusion criteria were the absence of a history of psychiatric or neurologic disorders or of substance abuse (determined by use of the SADS-L as described in the Screening Procedures Section). As described in previously conducted auditory discrimination (Bruder et al., 1992) and dichotic listening tasks (Tenke et al., 1993), individuals with hearing thresholds above 25 dB HL or inter-ear threshold differences of greater than 10 dB HL, as determined by methods described in the screening section, were excluded. As the factors of interest in this study included measures of laterality and ear advantages, any discrepancies at the sensory level had to be

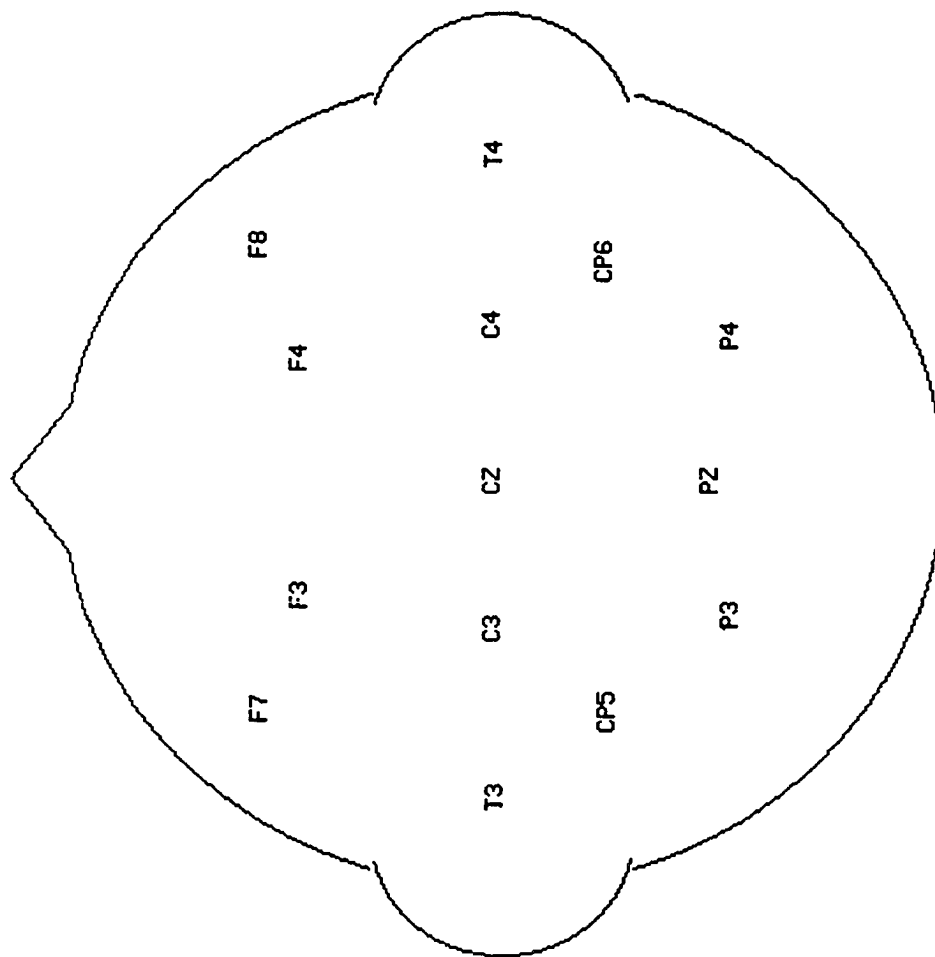
eliminated.

Acquisition of Event-Related Potentials

Electrode array

The Electro-cap (Neuroscience model) with tin electrodes were used to record from 14 electrode placements with a slight modification of the I-10-20 system (See Figure 1). The following scalp placements were used as recording sites: (1) frontal: F3,F4,F7,F8; (2) central: Cz,C3,C4; (3) temporal: T3,T4; (4) parietal: Pz,P3,P4 and (5) centroparietal (CP5,CP6). These placements enabled comparison between left- and right-hemisphere activity, as well as between the anterior and posterior regions within each hemisphere. A tin electrode placed at the tip of the nose was used as the reference and an electrode placed at the left mastoid was used as the ground (Tenke et al., 1993). Horizontal and vertical eye movements were monitored by Ag/AgCl electrodes placed at each canthus and above and below the orbit of the right eye. Trials with excessive eye movement were rejected from the ERP data prior to averaging the data. The Neuroscan Edit program scanned each trial of the EEG file for the amplitudes of the vertical eye movements and deleted any trials with eye movement amplitudes exceeding the cutoff of 100 (μ V) (root mean square). EEG data were recorded using a 16-channel Grass Neurodata system at 10 K gain, with a .01-30 Hz bandpass, with

Figure 1. Placement of electrodes from which event-related potentials were recorded.



Electrode Array

a sampling rate of 100 samples/sec. The cutoff of 30 Hz was used to exclude artifactual electrical activity (any frequency not associated with brain activity such as 60 cycle noise). The acquisition system involved use of two IBM compatibles with a continuous digitization system. One computer was used for stimulus delivery and/or timing and coding of events, while the second one was dedicated to the acquisition of data and stimulus-response timing information.

Presentation paradigm

A target detection paradigm comprising 30% target items and 70% nontarget items was the method of stimulus presentation. Though the most widely used ratio in the oddball paradigm is 20% targets to 80% nontargets, a minimum of 30 target items was necessary in this experiment to enable production of an average waveform for each target, even if a number of trials needed to be rejected due to artifacts such as eye movement. A separate block of trials was presented for the detection of each of four different target emotions. 210 trials were presented in each block. Thirty percent of these trials (60 trials) were made up of 10 repetitions of the six pairs available for a target emotion. Each of these six pairs was repeated in a randomized fashion throughout the 210 trials. Five repetitions occurred in the right ear, and the other five occurred in the left ear. The remaining 150 trials

were the nontarget items (15 pairs each also presented 10 times). As with the target items, each nontarget pair was heard five times so that one item of the pair was presented to the right ear and the other to the left ear. They were also heard another five times with the order of ear presentation reversed.

Sample Presentation

Each subject heard a binaural presentation of each of the 26 items, which were used to create the 21 unique pairs. The subject was asked to listen carefully to each item and to try to identify the emotional tone conveyed by each utterance. No response was required of the participant. This presentation was used to familiarize the participants with the items and to give them some idea of what each of the seven emotional categories sounded like. It also provided an opportunity for them to ask the experimenter questions.

Instructions to the participant in this section were as follows: "You will hear a nonsense syllable, stated with one of seven different emotional tones of voice, in the center of your head. Please listen carefully and see if you can tell which tone of voice is being used to say each syllable. You may hear one of seven emotions: happiness, interest, pleasant surprise, anger, fear, sadness, disgust."

Practice Session

Each participant was presented with a 10-minute practice session. If a person was to start their session with a positively-valenced emotion block, the practice session administered involved presentation of the block in which pleasant surprise was the target emotion. If the participant was to start with a negatively-valenced block, the practice session administered involved presentation of the block in which fear was the target item. These two emotions were selected from the seven emotional categories heard by each participant because they had not been selected as target emotions for the experiment proper. The instructions presented to each participant were as follows: " You will hear two nonsense syllables at the same time, one in each ear. Each syllable will be stated with a different emotional tone of voice. For this first block, I would like you to respond to any syllables that you think are being stated in the pleasantly surprised/fearful tone of voice. You may hear this tone of voice in either your left ear or your right ear. Please respond as quickly as you can, when you have heard a pleasant surprise/fear item, by pushing this button."

Experimental Session

The experiment consisted of a divided-attention condition in which the target item occurred in either the right ear or

the left ear. Subjects were asked to keep their eyes on a fixation light throughout each trial and to try not to blink until after they had made their response. This was done to diminish eye movement. The Neuroscan software program GENTASK was used to generate the stimulus files on line. A binaural cue of 1000 Hz frequency was presented for 100 ms to the center of the head one second prior to onset of a dichotic pair which was matched for duration and intensity. Each pair of dichotic stimuli was presented at an intensity of 73.5 dB SPL. The inter-trial interval (ITI) was 2.5 seconds. The ITI was determined during pilot work, which indicated that this was the minimum interval necessary for subjects to make their responses prior to presentation of the following trial. Reaction time (RT) was measured as the subject responded to a target item by pressing a hand held response button. The order of the hand (right or left) used in making responses was counterbalanced across subjects. A total of 840 trials was presented over 4 20-minute blocks separated by breaks of 2 minutes. The duration of this portion of the experiment was approximately 2 hours. It should be noted that in this portion of the experiment, the probability of a target item occurring in each ear was 15%. The probability of a target item occurring throughout the entire block was 30%. The instructions used were the same as those described in the practice session section.

Each subject responded to four different target emotions across four separate blocks of stimulus presentation. Originally, each subject was to be presented with seven separate blocks, examining ability to identify seven separate target emotions. However, administration of seven blocks to pilot subjects indicated that participants could not reliably or comfortably complete more than four blocks. Thus, four blocks which matched most closely in terms of accuracy ratings and stimulus duration (See Table 4) were selected for administration: two positive and two negative emotions. Thus, the participants responded to the target emotions of happiness, interest, anger and sadness in four separate blocks. Order of block presentation was randomized across subjects.

Statistical Analyses

General Summary

Behavioral and electrophysiological data were analyzed in three ways. Initially, an overall analysis with all subjects was conducted. Separate analyses were also conducted after subgrouping participants into those who demonstrated a left ear advantage and those who did not (as described by Tenke et al., 1993). A third analysis was conducted to examine possible gender differences. One additional analysis using vector scaled data was conducted with the electro-

physiological data. This will be described in greater detail in the following sections.

Behavioral Data

Overall accuracy scores and accuracy scores for each emotion were obtained by calculating the percent of target items correctly detected. These values were then used in subsequent analyses such as repeated-measures ANOVAs (the methods employed are discussed and described in detail in the results section). Significant interactions were followed up with post-hoc t-tests (Dixon, 1985) to better determine the nature of the interaction. Laterality quotients were calculated based on accuracy. These laterality quotients were subsequently used in correlational analyses in conjunction with the electrophysiological data. Reaction time measures, obtained in milliseconds, were standardized by log transformation (base 10) so that parametric statistical procedures could be used to analyze the data.

Electrophysiological Data

Separate repeated-measures analyses of variance were used to examine the characteristics of four ERP components elicited by this paradigm: (1) N100, (2) early negativity¹, (3) late

¹ A priori hypotheses were not made regarding the early negativity as its occurrence was not expected. However, characteristics of this component match those of a component described by Picton and Proulx (1978a, 1978b) as the sustained

positivity, and (4) slow wave. Factors used in the analysis included subject grouping based on existence or absence of a left-ear advantage, valence of emotion, ear of stimulus presentation and electrode site. The same analysis with subject gender as the grouping variable was also conducted. More detailed descriptions of each analysis conducted will be provided in the Results Section (pp. 79-173). The dependent measures used were the mean amplitudes for each component of interest, which were computed by a program developed by Neuroscan Incorporated in the following way. Amplitudes obtained at every 10-millisecond sampling interval, within the time window designated for each component (e.g., 50-175 ms for N100), were averaged. These measurements were obtained separately for averages of waveforms collected for trials representing specific conditions such as: left hits (correct detection of target items presented to the left ear), right hits, and overall hits for each target emotion, as well as correct rejections from blocks for each target emotion.

In addition to examining differences in absolute amplitudes of individual components and possible differences in the amplitudes across hemispheres or within a hemisphere,

potential or sustained negativity. Thus, although this component is called an early negativity throughout the dissertation, it probably corresponds to the sustained potential which is described in more detail in the discussion. It is not a new phenomenon or component.

the same repeated measures were conducted on data following vector scaling procedures (McCarthy & Wood, 1985). This procedure enables one to determine if amplitude differences at various electrode sites are attributable to independent underlying generators or whether they reflect changes in the strength of one signal generated by a single source. Thus, while we wanted to know if there were absolute amplitude differences between and within hemispheres, it was also of interest to determine the topographic profile of components involved. This information helps determine the significance of each component as it relates to brain structure and emotional processing. The particular scaling procedure used was a simple ratio procedure. The amplitude obtained at each electrode site was divided by the square root of the sum of the squares of the amplitudes obtained at each electrode placement.

VI. RESULTS

Behavioral Data

Accuracy Measures

A repeated-measures analysis of variance (ANOVA) (BMDP P4V) was conducted to determine whether a left-ear advantage had been obtained in this task, and to see whether this ear advantage changed as a function of valence or of the discrete emotion. An ANOVA with the two within-factors defined as Valence (2 levels: positive, negative) and Ear (2 levels: left, right) indicated that accuracy in the detection of target emotions presented to the left ear ($M=74.6$; $SD = 17.8$) was greater than accuracy in detection of target items presented to the right ear ($M=68.4$; $SD=18.1$) [$F(1,23)=10.46$; $p=.0037$] (See Table 7). There was no overall VALENCE main effect (See Table 8). Although accuracy for detection of positively-valenced target emotions ($M=73.4$; $SD=13.9$) was better than accuracy for the detection of negatively-valenced emotions ($M=69.6$; $SD=13.7$) (See Table 7), this difference did not reach significance [$F(1,23)=1.97$; $p=.1733$]. In addition, the EAR X VALENCE [$F(1,23)=1.43$; $p=0.2446$] interaction was not significant. Thus, ability to detect target items presented to the left ear was better than ability to detect the same items presented to the right ear, regardless of the emotional valence.

Table 7.

Mean percent accuracy (SD) of target emotion detection.

EMOTION	LEFT EAR	RIGHT EAR	OVERALL
HAPPINESS	67.50 (21.50)	63.61 (21.15)	65.56 (21.15)
INTEREST	83.89 (11.32)	78.75 (9.82)	81.32 (10.80)
POSITIVE	75.69 (14.19)	71.18 (13.58)	73.44 (13.93)
ANGER	70.42 (19.44)	63.20 (16.64)	66.80 (18.27)
SADNESS	76.39 (13.11)	68.19 (19.21)	72.29 (16.79)
NEGATIVE	73.40 (12.61)	65.69 (13.99)	69.55 (13.74)
TOTAL	74.55 (17.75)	68.44 (18.10)	71.49 (18.14)

Table 8. F and p values for repeated-measures ANOVAs conducted on behavioral data
(two separate analyses with no between-factors and two within-factors).

REPEATED MEASURES ANOVA		F.	ACCURACY D.F.	P	F.	REACTION TIME D.F.	P
1. WITHIN FACTORS: VALENCE(2), EAR(2)							
VALENCE		1.97	(1,23)	.1733	0.01	(1,23)	.9218
EAR		10.46	(1,23)	.0037**	0.62	(1,23)	.4380
VALENCE X EAR		1.43	(1,23)	.2446	0.65	(1,23)	.4271
2. WITHIN FACTORS: EMOTION(4), EAR(2)							
EMOTION		7.13	(2.55,58.55)	.0007**	3.98	(2.42,55.63)	.0180*
EAR		10.46	(1,23)	.0037**	0.62	(1,23)	.4380
EMOTION X EAR		0.53	(2.59,59.46)	.6365	0.96	(2.65,60.84)	.4074

A separate ANOVA, with two within-factors defined as Emotion (4 levels: happiness, interest, anger, sadness) and Ear (2 levels: left, right), indicated that some target emotions were easier to detect than others, as supported by the main effect of emotion [$F(2.55, 58.55) = 7.13$; $p = .0007$]. Post-hoc t-tests (Dixon, 1985) indicated that accuracy in identification of interest target items ($M = 81.3$; $SD = 10.8$) was significantly greater than accuracy of identification of happiness target items ($M = 65.6$; $SD = 21.2$: $t(23) = -4.36$; $p < .0001$), anger target items ($M = 66.8$; $SD = 18.3$: $t(23) = 4.28$; $p = .0001$), and sadness target items ($M = 72.3$; $SD = 16.8$: $t(23) = 3.18$; $p = .004$). Some of the interest items were stated as a question, and this feature actually may have made identification of interest items easier than identification of the other items.

Reaction Time Measures

To determine whether effects obtained from accuracy measures were also obtained from reaction time measures, a repeated-measures analysis of variance (ANOVA) (BMDP P4V) (Dixon, 1985) with the same within factors as specified for the accuracy measures were conducted. Unlike the findings for the accuracy data, RTs for detection of target emotions presented to the left and right ears were not significantly different [$F(1, 23) = 0.62$; $p = .44$]. A repeated-measures ANOVA

with the two within-factors defined as Valence (2 levels: positive, negative) and Ear (2 levels:left, right) did not show differences in RT as a function of valence. The mean RT for the identification of positively-valenced emotions of 1.176 seconds (SD = 1.170) was not significantly different from the mean RT for detection of negatively-valenced target emotions ($M=1.174$; $SD = 1.192$) [$F(1,23)=.01$; $p=.9218$] (See Table 8). In a separate analysis with the two within-factors defined as Emotion (4 levels) and Ear (2 levels), a main effect of emotion [$F(2.42,55.63)=3.98$; $p < .02$] indicated that RTs for the detection of some target emotions were shorter than RTs for the detection of others (See Table 8 and Table 9). Post-hoc t-tests (Dixon, 1985) indicated that RTs to interest target items were significantly shorter than RTs to happiness items [$t(23)=3.06$; $p=.006$], as well as to sadness items [$t(23)=-2.33$; $p=.029$] (See Tables 8 and 9). This is in keeping with the higher accuracy for interest items and suggests that greater accuracy is associated with shorter reaction times.

It was of interest to determine the presence of a relationship between accuracy levels and response time. Pearson product-moment correlations between accuracy measures and reaction time measures (separately for left-ear accuracy and reaction time measures and right-ear accuracy and reaction

Table 9.

Mean reaction time measures (SD) for target emotion detection (seconds).

EMOTION	LEFT EAR	RIGHT EAR	OVERALL
HAPPINESS	1.240 (1.220)	1.221 (1.189)	1.230 (1.202)
INTEREST	1.114 (1.186)	1.136 (1.178)	1.125 (1.180)
POSITIVE	1.175 (1.177)	1.178 (1.166)	1.176 (1.170)
ANGER	1.151 (1.236)	1.160 (1.225)	1.156 (1.228)
SADNESS	1.174 (1.169)	1.210 (1.193)	1.192 (1.180)
NEGATIVE	1.162 (1.186)	1.185 (1.201)	1.174 (1.192)
TOTAL	1.169 (1.205)	1.181 (1.196)	1.175 (1.200)

time measures) were nonsignificant. The correlations between left-ear accuracy and RT measures ($r = -.176$) and between right-ear accuracy levels and RT measures ($r = -.348$) were not significant. The negative values of the correlation indicated that reaction times were longer at lower accuracy levels, particularly for right-ear stimulus presentation (but not significantly so).

Laterality Quotients and Participant Subtyping

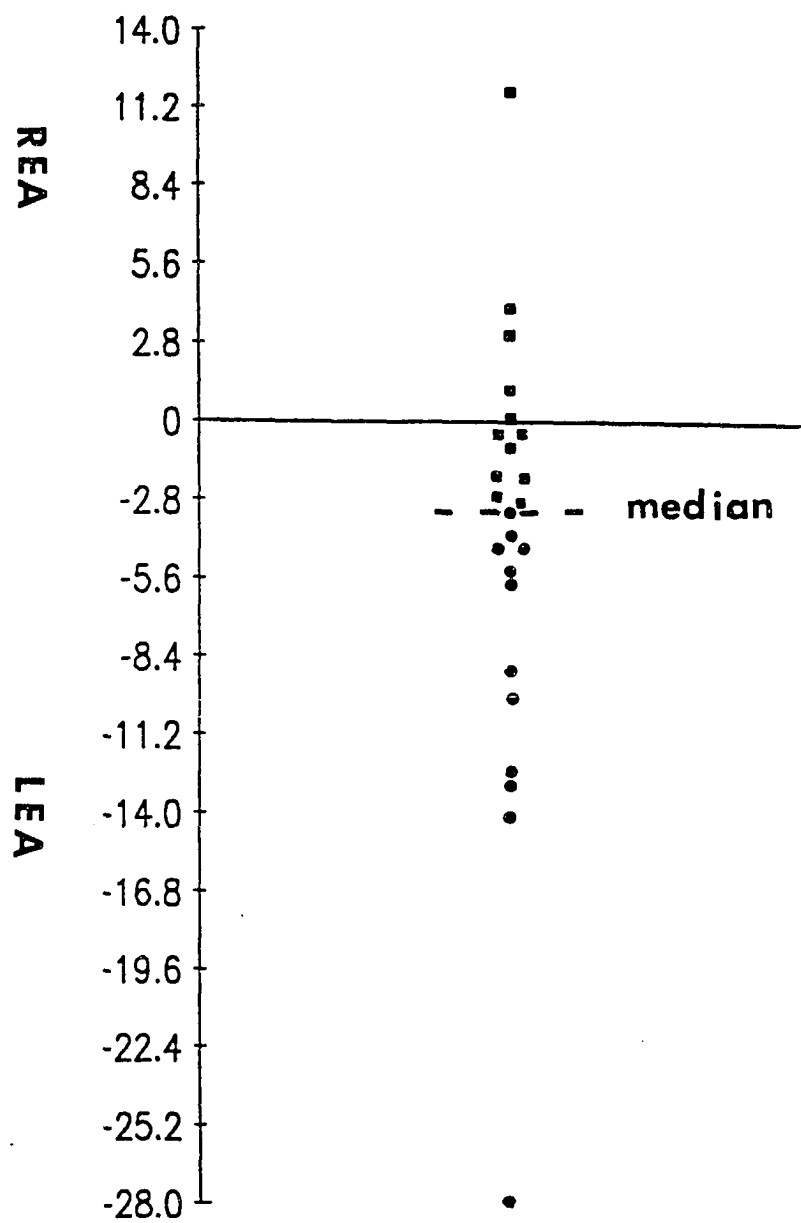
As described in the Methods Section, subjects were divided into two groups: those with laterality quotients more negative than the median value of -3.15 (a relatively large left-ear advantage) (LEA), and those with laterality quotients less negative than the median value (a relatively small or no left-ear advantage, or a right-ear advantage) (NOLEA) (Tenke et al., 1993). This breakdown was used primarily to enable inspection of the relationship between behavioral laterality and ERP findings. Since Sidtis (1981) indicated that accuracy measures were more consistent indicators of laterality effects than were reaction time measures, accuracy measures were used to make this breakdown. Laterality quotients (LQ) for each participant were calculated by applying the following formula to the accuracy data:

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

Other formulas for calculating asymmetry indices have been generated to address issues regarding differences in overall performance levels (Bruder, 1991). However, many of the asymmetry indices are highly correlated and provide similar results. This particular formula was selected to be in keeping with the Tenke et al. (1993) study. Separate LQs for each emotion and an overall LQ were calculated for each participant. A survey of these LQs indicated that the sample was indeed comprised of two subgroups distinguished by the presence or absence of an LEA for detecting emotional stimuli. Thus, the median of the LQ values (-3.15) was used to divide the sample into left-ear advantage (LEA) (N=12) and no left-ear advantage (NOLEA) (N=12) subgroups (See Figure 2). It is of note, however, that some of the subjects (N = 7) included in the NOLEA group did have negligible left-ear advantages. The mean LQ of the LEA subgroup (M=-10.00; SD=7) was significantly different than the NOLEA mean LQ of (M=0.65; SD=4) [$t(22)=4.37$; $p=.0002$].

The subject characteristics and behavioral data were then reexamined for the two subgroups of participants. Comparison of the subject characteristics of age, years of education, and handedness determined by self-report on the Edinburgh Handedness Inventory (Oldfield, 1971) with between-group t-tests, indicated that there were no significant differences

Figure 2. The distribution of Laterality quotient scores for all participants (REA = right ear advantage, LEA = left ear advantage) (N=24).



between the NOLEA and LEA groups on these characteristics (See Table 10).

An ANOVA with a between factor defined as Grouping (2 levels) and the two within-factors defined as Valence (2 levels: positive, negative) and Ear (2 levels: left, right) was conducted (See Table 11). This verified that the subgrouping based on behavioral asymmetry scores (LQ) was valid. A significant EAR X GROUPING interaction [$F(1,22)=21.72$; $p=.0001$] indicated that while the NOLEA group demonstrated comparable performance in target emotion detection with both the left ($M=71.3$; $SD=15.76$) and right ($M=71.80$; $SD=13.23$) ears, for the LEA group, mean left-ear accuracy ($M=77.57$; $SD=9.79$) was significantly higher than right-ear accuracy ($M=65.07$; $SD=13.95$) (Table 12 & 13). There was, however, no significant difference in overall accuracy between the LEA and NOLEA groups for the left ear [$t(22) = -1.32$; $p = 0.201$] or right ear [$t(22) = 1.51$; $p = 0.146$]. Matched t-tests confirmed that the difference in accuracy level between ears was significant in the LEA group [$t(11) = 5.17$; $p = .0003$], but not in the NOLEA group [$t(11) = .224$; $p = .8343$]. A significant GROUPING X VALENCE X EAR interaction (See Table 11) [$F(1,22)=5.40$; $p=.0298$] suggested that for the LEA group, but not for the NOLEA group, the left-versus right-ear difference ($M=16.94$) for negatively-valenced

Table 10.
Demographic statistics for the LEA and NOLEA groups.

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

Table 11. F and p values for repeated-measures ANOVAs conducted on behavioral data.
(two separate analyses with one between-factor and two within-factors)

REPEATED MEASURES		ACCURACY			REACTION TIME		
ANOVA	F.	D.F.	P	F.	D.F.	P	
1. BETWEEN: GROUPING (NOLEA,LEA)							
WITHIN: VALENCE (2) X EAR (2)							
GROUPING	0.01	(1,22)	.9365	3.94	(1,22)	.0597	
VALENCE	1.90	(1,22)	.1820	0.01	(1,22)	.9179	
EAR	19.88	(1,22)	.0002**	0.68	(1,22)	.4178	
VALENCE X EAR	1.70	(1,22)	.2059	0.66	(1,22)	.4256	
VALENCE X GROUPING	0.12	(1,22)	.7338	3.39	(1,22)	.0791	
EAR X GROUPING	21.72	(1,22)	.0001**	3.17	(1,22)	.0889	
VALENCE X EAR X GROUPING	5.40	(1,22)	.0298*	1.19	(1,22)	.2875	
2. BETWEEN: GROUPING (NOLEA,LEA)							
WITHIN: EMOTION (4) X EAR (2)							
GROUPING	0.01	(1,22)	.9365	3.94	(1,22)	.0597	
EMOTION	6.94 (2.55,56.13)		.0009**	4.11 (2.47,54.41)		.0153*	
EAR	19.88	(1,22)	.0002**	0.68	(1,22)	.4178	
EMOTION X EAR	0.55 (2,50,54.93)		.6164	0.96 (2.57,56.51)		.4076	
EMOTION X GROUPING	0.39 (2.55,56.13)		.7277	1.77 (2.47,54.41)		.1716	
EAR X GROUPING	21.72	(1,22)	.0001**	3.17	(1,22)	.0889	
EMOTION X EAR X GROUPING	1.98 (2.50,54.93)		.1370	0.90 (2.57,56.51)		.4322	

Table 12.

Mean accuracy (SD) in target detection by ear of stimulus presentation for the NOLEA and LEA groups.

GROUP	LEFT EAR	RIGHT EAR
NO LEA	71.53 (15.76)	71.81 (13.32)
LEA	77.57 (9.79)	65.07 (13.95)

Table 13.

Mean percent accuracy (SD) for identification of target emotions for NOLEA and LEA groups for each ear.

EMOTION	NOLEA		LEA	
	LEFT EAR	RIGHT EAR	LEFT EAR	RIGHT EAR
HAPPINESS	67.223 (20.490)	67.778 (19.916)	67.778 (23.240)	59.444 (22.375)
INTEREST	81.944 (13.594)	79.444 (9.082)	85.833 (8.660)	78.055 (10.865)
POSITIVE	74.584 (15.861)	73.611 (13.062)	76.805 (12.919)	68.750 (14.214)
ANGER	63.056 (23.158)	66.945 (15.792)	77.777 (11.664)	59.445 (17.283)
SADNESS	73.891 (14.622)	73.056 (18.881)	78.889 (11.488)	63.332 (19.071)
NEGATIVE	68.473 (15.722)	70.000 (13.908)	78.333 (5.685)	61.388 (13.236)
TOTAL	71.530 (15.760)	71.810 (13.320)	77.570 (9.790)	65.07 (13.950)

emotions was about twice as large as the left- versus right-ear difference ($M=8.05$) for the positively-valenced emotions (See Figure 3 & Table 13 & 14). Matched t-tests indicated that this difference in ear-advantage size for negatively- versus positively-valenced emotions was marginally significant [$t(11) = 2.13$; $p = 0.0567$] in the LEA group, but was not significant in the NOLEA group [$t(11) = .975$; $p = .351$]. This effect was not solely due to right-ear performance level differences for positively- and negatively-valenced emotions since these accuracy levels were comparable [$t(11) = 1.56$; $p = .147$] in the LEA group.

Analysis of the accuracy data with a repeated-measures ANOVA, with the between factor defined as Grouping (2 levels: LEA, NOLEA) and two within-factors defined as Emotion (4 levels) and Ear (2 levels), was also conducted to determine if accuracy scores of one particular emotion within each valence accounted for the valence interactions described above. The GROUP X EMOTION and GROUP X EMOTION X EAR interactions were not significant and indicated that accuracy of target emotion detection did not significantly differ in the LEA and NOLEA groups for left- and right-ear stimulus presentation when accuracy scores were broken down by discrete emotion categories (See Table 13).

Figure 3. Accuracy of detection of positively- and negatively-valenced emotions for NOLEA and LEA groups as a function of ear.

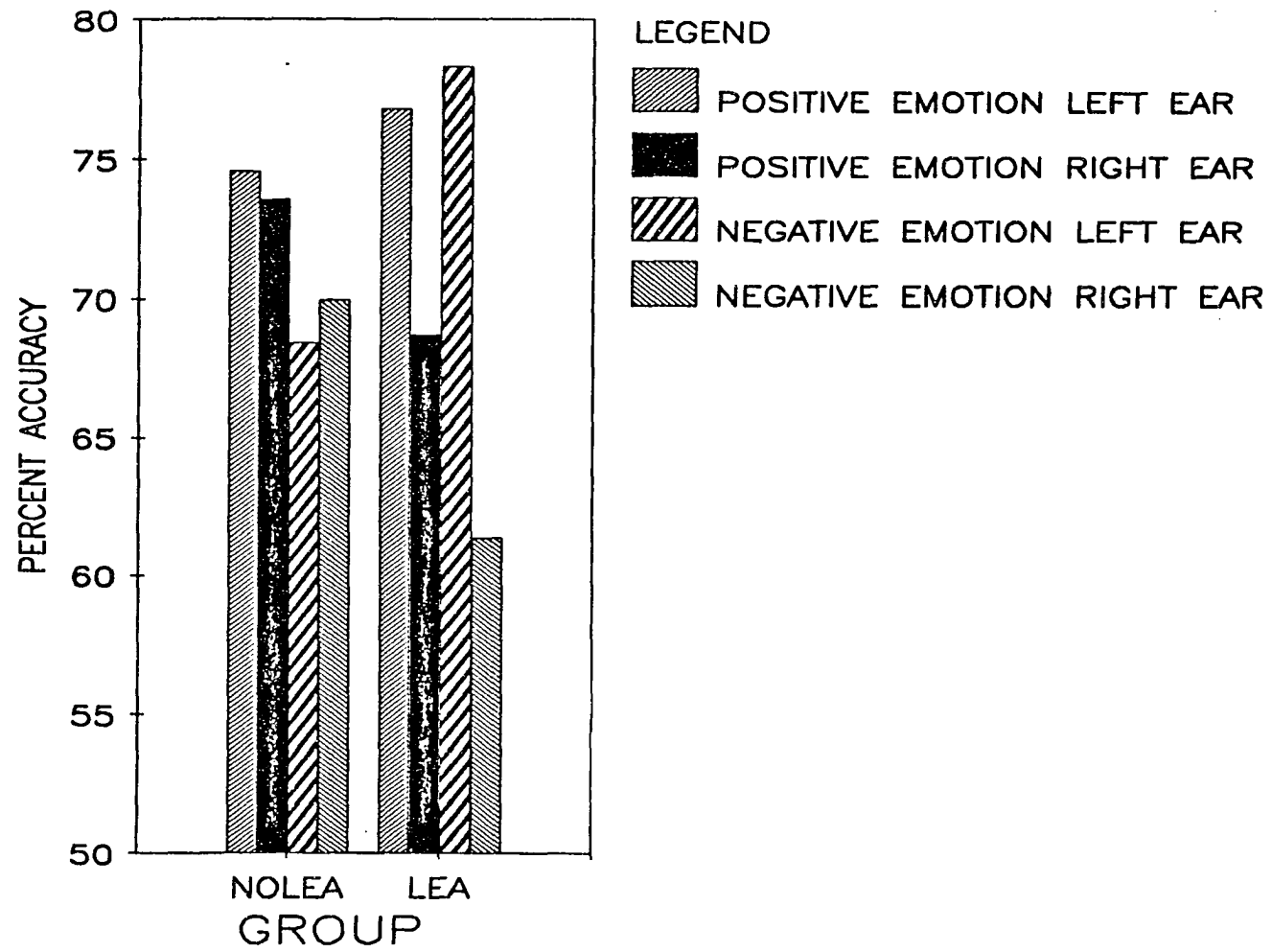


Table 14.

Accuracy in identifying positively- and negatively-valenced emotions for the NO LEA and LEA groups (means and standard deviations).

GROUP	POSITIVE VALENCE		NEGATIVE VALENCE	
	LEFT EAR	RIGHT EAR	LEFT EAR	RIGHT EAR
NO LEA	74.58 (15.86)	73.61 (13.06)	68.47 (15.72)	70.00 (13.91)
LEA	76.80 (12.92)	68.75 (14.21)	78.33 (5.68)	61.39 (13.24)

The two repeated-measures ANOVAs described in analyzing the accuracy measures were applied to the reaction time measures to determine whether the NOLEA and LEA subgroups differed in their reaction time characteristics. A marginal EAR X GROUPING interaction [$F(1,22)=3.17$; $p=0.089$] (See Table 15), which was followed up by post-hoc t-tests, indicated that there was a trend for reaction times of LEA subjects to be shorter for items presented to the left ear than to the right ear [$t(11) = 2.13$; $p = .057$]. In the NOLEA group, while reaction times were shorter to right- than left-ear stimulus presentation, the difference between ears was not statistically significant [$t(11) = .69$; $p = .559$]. It is also interesting to note that, while there were no significant differences in the reaction times for items presented to the left ear for the NOLEA and LEA groups [$t(22) = -1.48$; $p = .152$], reaction times for right-ear stimulus presentation were significantly shorter in the NOLEA than in the LEA group [$t(22) = -2.11$; $p = .0230$] (See Table 15). Thus, the EAR x GROUPING effect seemed to rest on the fact that, in the LEA group, RTs to right-ear stimulus presentation were longer than RTs to left-ear stimulus presentation. There was also a marginally significant VALENCE X GROUPING interaction [$F(1,22)=3.39$; $p=0.079$]. Post-hoc t-tests revealed that this was due to shorter RTs for negatively-valenced emotions for the NOLEA participants than for the LEA participants [$t(22)$

Table 15.

Mean reaction time (SD) for target detection
by ear of stimulus presentation for the
NOLEA and LEA groups (seconds).

GROUP	LEFT EAR	RIGHT EAR
NO LEA	1.115 (1.178)	1.101 (1.152)
LEA	1.225 (1.168)	1.267 (1.178)

= -2.48; $p = .021$] (See Table 16). RTs to positively-valenced emotions were not significantly different between groups [$t(22) = -1.27$; $p = .218$]. Unlike the findings for the accuracy data, the VALENCE X EAR X GROUPING interaction was not significant.

Gender Effects

A repeated-measures ANOVA with a between-factor defined as Gender (2 levels: males [$N=13$], females [$N=11$]) and two within-factors defined as Valence (2 levels) and Ear (2 levels), as described above, was applied to the accuracy data to examine whether the overall left-ear advantage changed as a function of gender or valence. This analysis indicated that women tended to be more accurate in identifying target emotions ($M=74.17$; $SD=16.89$) than were men ($M=69.23$; $SD=18.92$), but this effect did not reach statistical significance [GENDER EFFECT: $F(1,22)=1.38$; $p=.253$] (See Table 17). While the overall effect of ear was significant as in the initial analysis, the GENDER X EAR interaction was not significant (See Table 18). Although women tended to show a stronger left-ear advantage for identification of target emotions (8%) than did male participants (4%), a post-hoc t -test indicated that this difference in ear advantage was not statistically significant [$t(22) = -1.01$; $p = .324$] (See Table 19 for accuracy scores and Table 22 for F and p values when

Table 16.

Mean reaction time measures in seconds (SD) for identification of positively- and negatively-valenced emotions for the NOLEA and LEA groups.

GROUP	POSITIVE VALENCE		NEGATIVE VALENCE	
	LEFT EAR	RIGHT EAR	LEFT EAR	RIGHT EAR
NOLEA	1.136 (1.172)	1.125 (1.167)	1.094 (1.190)	1.078 (1.139)
MEAN	1.130 (1.166)		1.086 (1.162)	
LEA	1.215 (1.182)	1.232 (1.157)	1.235 (1.162)	1.303 (1.201)
MEAN	1.224 (1.166)		1.268 (1.180)	

Table 17.

F and p values for repeated-measures ANOVAs conducted on behavioral data examining gender effects (two separate analyses with one between-factor and two within-factors).

REPEATED MEASURES		ACCURACY			REACTION TIME		
ANOVA	F.	D.F.	P	F.	D.F.	P	
1. BETWEEN: GENDER (2)							
WITHIN: VALENCE (2) X EAR (2)							
GENDER	1.38	(1,22)	.2528	0.92	(1,22)	.3469	
VALENCE	2.05	(1,22)	.1663	0.01	(1,22)	.9231	
EAR	10.46	(1,22)	.0038**	0.64	(1,22)	.4335	
VALENCE X EAR	1.38	(1,22)	.2531	0.63	(1,22)	.4374	
VALENCE X GENDER	1.87	(1,22)	.1850	0.30	(1,22)	.5897	
EAR X GENDER	1.02	(1,22)	.3244	1.50	(1,22)	.2342	
VALENCE X EAR X GENDER	0.22	(1,22)	.6461	0.02	(1,22)	.8915	
2. BETWEEN: GENDER (2)							
WITHIN: EMOTION (4) X EAR (2)							
GENDER	1.38	(1,22)	.2528	0.92	(1,22)	.3469	
EMOTION	7.16 (2.51, 55.19)		.0008**	3.92 (2.40, 52.80)		.0196*	
EAR	10.46	(1,22)	.0038**	0.64	(1,22)	.4335	
EMOTION X EAR	0.52 (2.56, 56.22)		.6400	0.93 (2.64, 58.03)		.4235	
EMOTION X GENDER	1.10 (2.51, 55.19)		.3486	0.68 (2.40, 52.80)		.5383	
EAR X GENDER	1.02	(1,22)	.3244	1.50	(1,22)	.2342	
EMOTION X EAR X GENDER	0.63 (2.56, 56.22)		.5725	0.14 (2.64, 58.03)		.9191	

Table 18.

Mean percent accuracy (SD) for detection of target emotion by ear of stimulus presentation for MALES and FEMALES.

GROUP	LEFT EAR	RIGHT EAR
MALES (N=13)	71.411 (14.747)	67.051 (14.113)
FEMALES (N=11)	78.258 (10.600)	70.076 (13.825)

Table 19.
Mean percent accuracy (SD) for identification of target emotions for MALES and FEMALES for each ear.

EMOTION	MALES		FEMALES	
	LEFT EAR	RIGHT EAR	LEFT EAR	RIGHT EAR
HAPPINESS	65.642 (25.581)	65.900 (25.098)	69.697 (16.157)	60.909 (16.062)
INTEREST	82.307 (14.363)	77.691 (11.656)	85.758 (6.340)	80.000 (7.452)
POSITIVE	73.974 (15.514)	71.795 (16.672)	77.727 (9.318)	70.454 (9.460)
ANGER	68.461 (20.531)	61.025 (13.499)	72.726 (18.786)	65.759 (20.115)
SADNESS	69.232 (11.797)	63.589 (17.506)	84.849 (9.119)	73.636 (20.519)
NEGATIVE	68.847 (11.494)	62.307 (9.392)	78.788 (12.181)	69.698 (17.651)
TOTAL	71.411 (14.747)	67.051 (14.113)	78.258 (10.600)	70.076 (13.825)

female data was analyzed separately). Post-hoc comparison of the means indicated that there was no difference in left [$t(22) = -1.50$; $p = .147$] or right [$t(22) = 2.68$; $p = .524$] ear accuracy levels between males and females. Accuracy in target identification was significantly better for the left than right ears in women [$t(10) = 2.68$; $p = .023$]; men showed a similar nonsignificant trend [$t(12) = 1.85$; $p = .088$].

There was no GENDER X VALENCE interaction for accuracy in detection of target emotions (See Table 17 for F and p values and Table 20 for accuracy levels). However, application of this same ANOVA to male (See Table 21) and female (See Table 22) groups separately showed that while males had a trend toward better accuracy in the detection of positive emotions than negative emotions [$F(1,12)=3.33$; $p=0.093$], females did not show such a trend. Post-hoc t -tests indicated that males and females had comparable accuracy levels for detection of positively-valenced target emotions, but males had a trend for lower accuracy scores for detection of negatively-valenced emotions than women [$t(22) = -1.67$; $p = .062$]. This is consistent with some of the results reported by Erwin et al. (1992); men demonstrated lower accuracy for identification of negatively-than positively-valenced emotions in facial expressions of women, while they showed no difference in the identification of both valences in men.

Table 20.

Mean percent accuracy (SD) in detection of positively- and negatively-valenced target emotions for MALES and FEMALES.

GROUP	POSITIVE VALENCE		NEGATIVE VALENCE	
	LEFT EAR	RIGHT EAR	LEFT EAR	RIGHT EAR
MALES (N=13)	73.974 (17.514)	71.794 (16.672)	68.847 (11.494)	62.307 (9.393)
MEAN	72.884(16.790)		65.577(10.811)	
FEMALES (N=11)	77.278 (9.318)	70.454 (9.460)	78.788 (12.181)	69.698 (17.651)
MEAN	74.091(9.890)		74.243(15.513)	

Table 21.

F and p values for repeated-measures ANOVAs conducted on behavioral data (analyses for the MALES with no between- and two within-factors).

REPEATED MEASURES ANOVA		F.	ACCURACY D.F.	P	F.	REACTION TIME D.F.	P
1. WITHIN FACTORS: VALENCE(2), EAR(2)							
VALENCE		3.33	(1,12)	.0929	0.36	(1,12)	.5582
EAR		3.44	(1,12)	.0883	0.04	(1,12)	.8436
VALENCE X EAR		1.72	(1,12)	.2137	0.35	(1,12)	.5672
2. WITHIN FACTORS: EMOTION(4), EAR(2)							
EMOTION		3.09	(2.25,27.05)	.0562	1.26	(2.07,24.82)	.3035
EAR		3.44	(1,12)	.0883	0.04	(1,12)	.8436
EMOTION X EAR		0.87	(2.34,28.10)	.4457	0.50	(2.09,25.04)	.6189

Table 22.

F and p values for repeated-measures ANOVAs conducted on behavioral data (analyses for the FEMALES with no between- and two within-factors).

	REPEATED MEASURES	F.	ACCURACY	P	REACTION TIME		
	ANOVA		D.F.		F.	D.F.	P
1. WITHIN FACTORS:	VALENCE(2),EAR(2)						
	VALENCE	0.00	(1,10)	.9669	0.07	(1,10) .7925	
	EAR	7.20	(1,10)	.0230*	4.27	(1,10) .0657	
	VALENCE X EAR	0.17	(1,12)	.6925	0.31	(1,10) .5929	
2. WITHIN FACTORS:	EMOTION(4),EAR(2)						
	EMOTION	6.38	(2.61,26.13)	.0030**	2.89	(1.88,18.85) .0829	
	EAR	7.20	(1,10)	.0230*	4.27	(1,10) .0657	
	EMOTION X EAR	0.32	(2.36,23.58)	.7612	0.55	(2.27,22.68) .6034	

A repeated-measures ANOVA with a between-factor defined as Gender (2 levels) and two within-factors defined as Emotion (4 levels) and Ear (2 levels), was applied to the accuracy data to determine whether males and females demonstrated a different pattern of left-ear advantage for the four discrete emotions. The GENDER X EMOTION and GENDER X EMOTION X EAR interactions were not significant, indicating that the performance of males and females did not differ across the four emotion categories overall or for left- and right-ear stimulus presentation.

To determine whether reaction time measures provided results similar to the accuracy data, reaction time measures were submitted to the same analyses. An analysis with one grouping factor (sex of subject) and two within-factors defined as Valence (2 levels) and Ear (2 levels) indicated that there were no reaction time differences as a function of valence of emotion for neither males nor females (See Table 17). The other repeated-measures ANOVA, with one between-factor (Gender) and two within-factors [Emotion (4 levels), Ear (2 levels)], showed that there were no gender differences in reaction time measures for detection of discrete target emotions (See Tables 17, 23 & 24).

Table 23.

Mean reaction time (SD) for target detection by ear of stimulus presentation for the MALES and FEMALES (seconds).

GROUP	LEFT EAR	RIGHT EAR
MALES (N=13)	1.211 (1.164)	1.206 (1.171)
FEMALES (N=11)	1.121 (1.190)	1.153 (1.196)

Table 24.

Mean reaction time measures in seconds (SD) for identification of positively- and negatively-valenced emotions for the MALES and FEMALES.

GROUP	POSITIVE VALENCE		NEGATIVE VALENCE	
	LEFT EAR	RIGHT EAR	LEFT EAR	RIGHT EAR
MALES (N=13)	1.225 (1.157)	1.208 (1.157)	1.197 (1.176)	1.203 (1.191)
MEAN	1.216(1.154)		1.200(1.180)	
FEMALE (N=11)	1.118 (1.191)	1.143 (1.179)	1.123 (1.198)	1.164 (1.221)
MEAN	1.131(1.181)		1.143(1.205)	

The analyses described above were applied to male and female subject groups independently (Tables 21 and 22). Results from the ANOVA with two within-factors defined as Valence and Ear, showed no trends for differences in reaction time based on valence of emotion for neither males nor females. However, females (see Table 22) showed a trend for shorter reaction times for emotions presented to the left than right ear (See Table 23). There was no such trend for males (See Tables 21 & 23).

Electrophysiological Data

Overview

The ERP recorded in response to the dichotic presentation of consonant-vowel syllables stated in one of seven emotional tones has four prominent components (See Figure 4). Two negative components, the N100 and Early Negativity (which seems to correspond to the sustained negative potential described by Picton and Proulx, 1978a, 1978b) are most negative at the frontal and central placements and become less negative or diminish at parietal placements (See Figure 5). The late positive complex which is composed of two somewhat overlapping positive going deflections (late positivity and slow wave) differs in its scalp distribution such that it is smallest at frontal sites, increases at central sites, and is maximum at parietal placements. The features of each of these

Figure 4. Wave forms to hits and correct rejections and their major components.

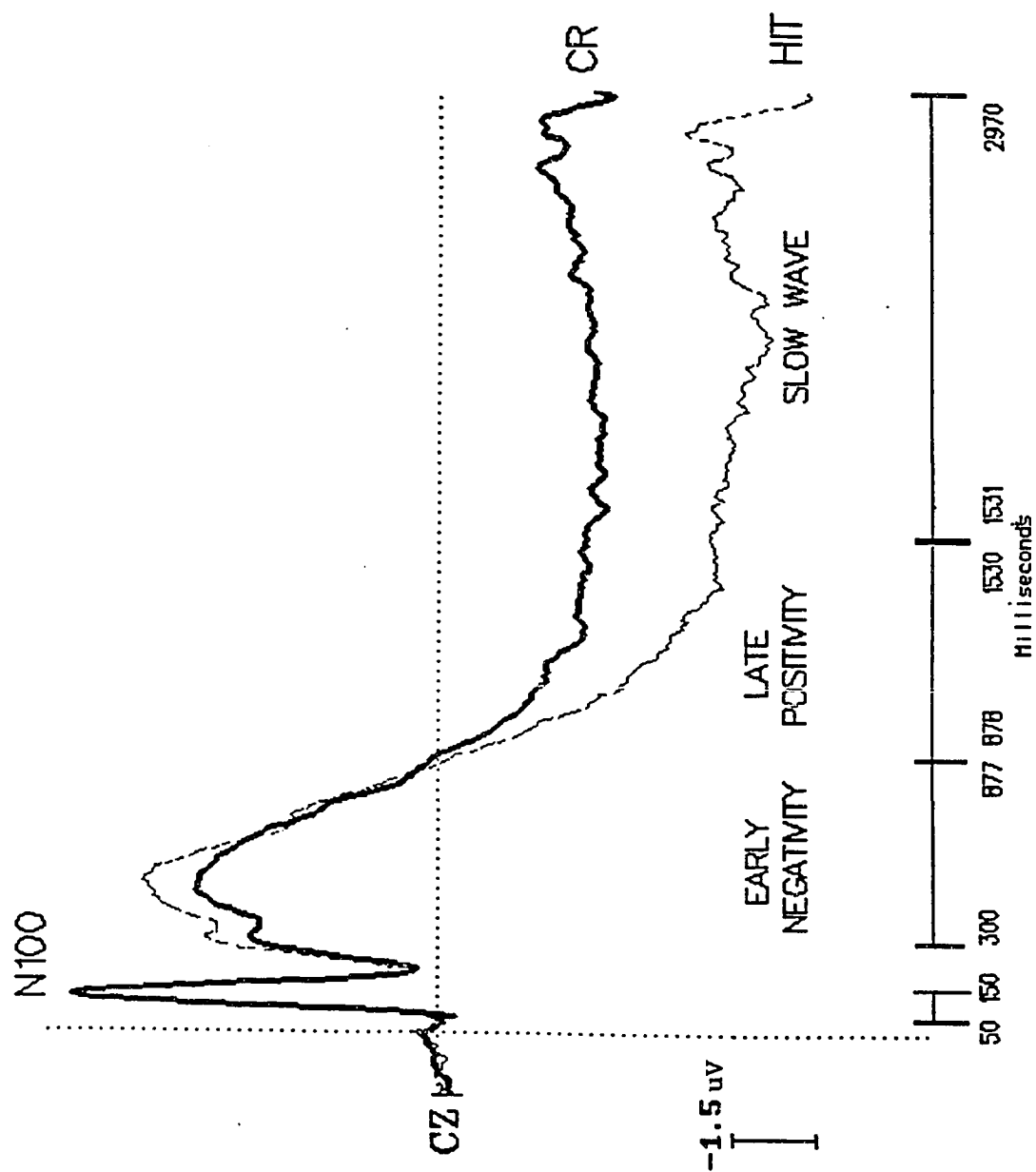
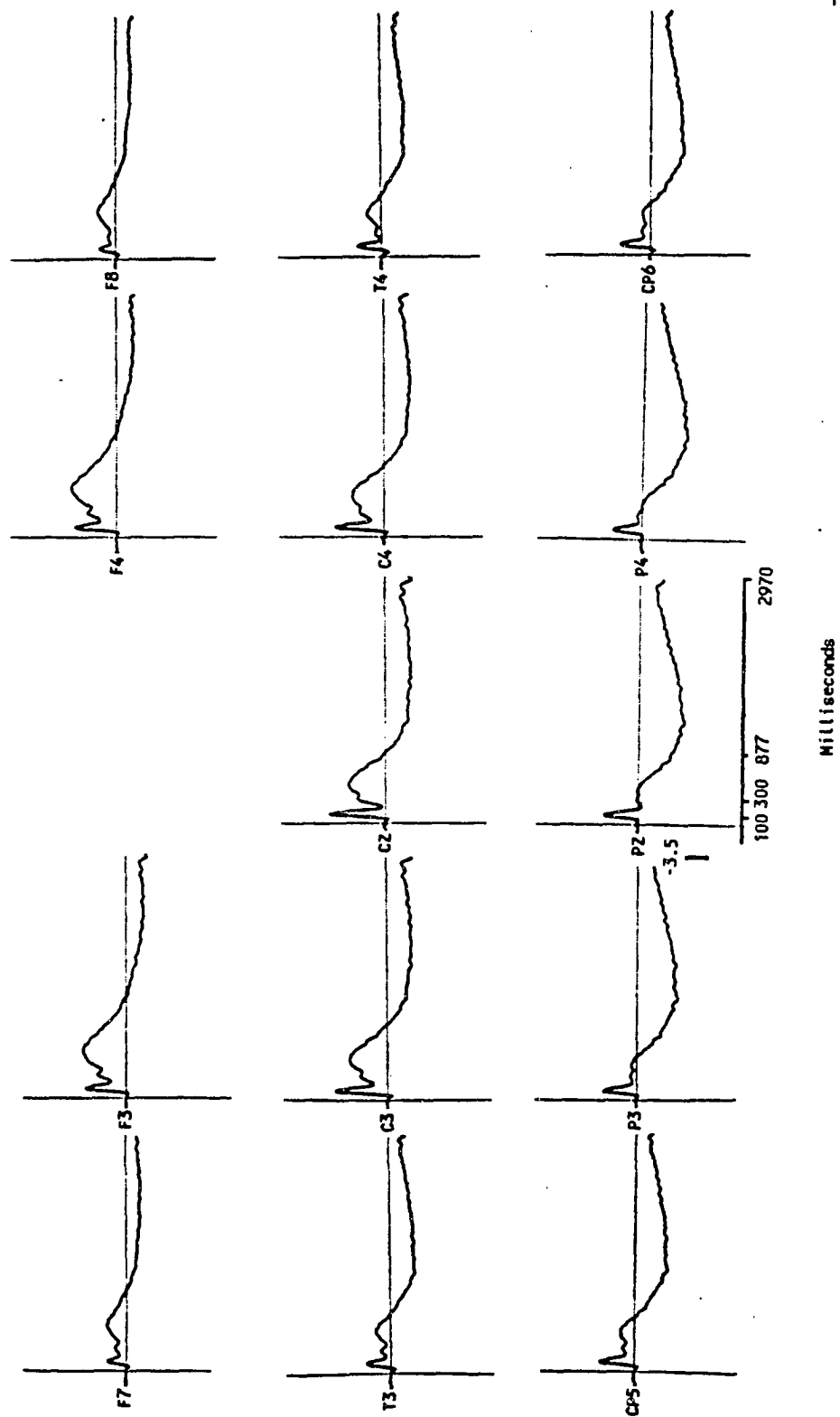


Figure 5. Overall scalp distribution of the event-related potentials recorded while participants were engaged in emotional target identification (microvolts).



components will be examined and described in detail in the following sections.

Selection of Component Windows

After close inspection of individual data, it became very apparent that the onset and duration of the early negative component and the late positive complex was not uniform due to: (1) the variable duration of stimulus materials, (2) across-subject variability, and (3) within-subject variability in identification of target items across trials. With the help of a Principal Component Analysis, which is described in detail in the Appendix (pp. 201-206), the following windows were used in measuring average amplitudes for each of three components: early negativity (sustained negative potential), 300-877 milliseconds (msec); late positivity, 878-1530 msec; and slow wave, 1531 - 2970 msec. A component accounting for a negligible portion of variance, yet still of interest, is the N100. The window for area measurements of this component was determined by a survey of all participant's waveforms and by windows described in other studies. The window implemented for this component was 50 to 175 msec post-stimulus onset.

Summary of Analysis Procedures

The ERPs analyzed by using their area measurements as dependent measures included the N100, early negativity (EN),

late positivity (LP), and slow wave (SW). A separate ANOVA was conducted for each component. Initially, a repeated-measures ANOVA with the between-factor defined as Group i.e., presence of LEA or NOLEA for identification of target emotions, and the within-factors defined as: Condition (2 levels: hits, correct rejections), Valence (2 levels: positive, negative), and Electrode (14 levels: F7, F8, F3, F4, T3, T4, C3, C4, CP5, CP6, CZ, P3, P4, AND PZ) was conducted. This analysis indicated whether there were significant differences in amplitudes of components as a function of electrode site. Then, to probe the possible hemispheric differences in component amplitudes, a repeated-measures ANOVA with the between-factor defined as the grouping based on the presence (LEA) or absence (NOLEA) of a left-ear advantage for identification of target emotions, and the within-factors defined as: Condition (2 levels: hits, correct rejections), Valence (2 levels: positive, negative), Hemisphere (2 levels: left, right), and Electrode (6 levels: FL [F7,F8], F [F3,F4], T [T3,T4], C [C3,C4], CP [CP5,CP6], P [P3,P4]) was conducted. Results from this analysis indicated that amplitudes of average wave forms obtained from hits (correct detection of target items) had features of interest that needed further analysis independent of averages obtained from correct rejections. Thus, a separate ANOVA was conducted with the between-factor defined as Grouping (2 levels: LEA, NOLEA) and

the within-factors defined as Valence (2 levels: positive, negative), Ear (2 levels: left, right), Hemisphere (2 levels: left, right), and Electrode (6 levels: FL, F, T, C, CP, P). This analysis was of particular interest because of the additional within-factor of EAR not present in the first analysis described. Many of the effects obtained were consistent across both analysis procedures (i.e., inclusion of only correct hits vs. inclusion of both correct hits and correct rejections in the analyses). Except where a unique factor is being inspected and unless otherwise specified, the findings reported are from the analysis of hits only. Greenhouse-Geisser corrections were used for the F-tests obtained with repeated-measures ANOVA to reduce the number of spurious significant effects that could occur from analyses involving psychophysiological measures (Keselman & Rogan, 1980).

A separate analysis with the between-factor defined as Grouping and the within-factors defined as Emotion, Ear, Hemisphere and Electrode was not conducted. This was due to the fact that some participants had very few available trials for averaging waveforms under specific conditions, e.g., only two correct trials for the correct detection of happy target items presented to the left ear. The small number of trials lead to a very small signal to noise ratio, and the data were

essentially not valid. It should be noted, however, that this small trial number was not due to poor performance levels, but often due to rejection of trials during the averaging process as a result of excessive eye movements or other artifactual recordings.

Findings

These analyses were conducted with 24 subjects (all subjects). Table 25 lists the F-values, degrees of freedom, and p-values obtained from analyses for each component, with one between-factor (Grouping) and four within-factors (Valence, Ear, Hemisphere, and Electrode). Table 26 lists the values of the average amplitudes for each component at each electrode site.

N100

Although we had not hypothesized hemispheric asymmetries for this component, it was important to determine the inter- and intra-hemispheric differences in this component. If they existed and were in keeping with findings associated with the predicted late positivity and slow wave changes, it would help to explain the processes underlying obtained effects. A significant ELECTRODE effect demonstrated that the N100 area amplitude peaked at the central electrodes [$F(1.97, 43.48) = 39.60$; $p < .0001$] (See Figure 5 and Table 26). A significant

Table 25.

F and p values for each component obtained from a repeated-measures (NOLEA, LEA), and four within-factors (valence, ear of stimulus electrode).

Effect	N100			Early Negativity			Late Negativity
	F VALUES	D.F.	P VALUES	F VALUES	D.F.	P VALUES	F VALUES
GROUPING	2.15	(1,22)	.1570	5.82	(1,22)	.1340	1.34
VALENCE	2.63	(1,22)	.1189	0.41	(1,22)	.5308	1.99
EAR	0.43	(1,22)	.5188	0.03	(1,22)	.8661	0.74
HEMISPHERE	20.11	(1,22)	.0002**	1.75	(1,22)	.1997	1.36
ELECTRODE	39.60	(1,22)	.0000**	65.02	(2,22)	.0000**	119.68 (2,22)
VALENCE X GROUPING	0.20	(1,22)	.6560	0.02	(1,22)	.8899	0.95
EAR X GROUPING	1.58	(1,22)	.2225	1.90	(1,22)	.1822	0.79
HEMISPHERE X GROUPING	0.37	(1,22)	.5515	0.87	(1,22)	.3605	0.83
ELECTRODE X GROUPING	1.15	(1,22)	.2921	0.19	(1,22)	.6512	0.32 (2,22)
VALENCE X EAR	1.00	(1,22)	.3281	1.24	(1,22)	.2769	2.03
VALENCE X HEMISPHERE	4.70	(1,22)	.0412*	0.36	(1,22)	.5553	0.02
VALENCE X ELECTRODE	1.22	(1,22)	.2765	0.51	(1,22)	.4730	0.82 (1,22)
EAR X HEMISPHERE	0.39	(1,22)	.5363	13.61	(1,22)	.0013**	4.49
EAR X ELECTRODE	1.43	(1,22)	.2407	0.85	(1,22)	.3623	0.97 (2,22)
HEMISPHERE X ELECTRODE	5.25	(1,22)	.0032*	3.82	(1,22)	.0133*	1.78 (2,22)
VALENCE X EAR X GROUPING	0.33	(1,22)	.5689	0.02	(1,22)	.8764	0.00
VALENCE X HEMISPHERE X GROUPING	1.56	(1,22)	.2254	0.29	(1,22)	.5967	1.95
VALENCE X ELECTRODE X GROUPING	0.30	(1,22)	.5788	0.43	(1,22)	.5049	0.60 (1,22)
EAR X HEMISPHERE X GROUPING	1.61	(1,22)	.2175	1.91	(1,22)	.1810	2.82
EAR X ELECTRODE X GROUPING	2.74	(1,22)	.1071	3.55	(1,22)	.0418*	0.31 (2,22)
HEMISPHERE X ELECTRODE X GROUPING	2.44	(1,22)	.1260	3.35	(1,22)	.0206*	0.53 (2,22)
VALENCE X ELECTRODE X HEMISPHERE	0.48	(1,22)	.4962	0.01	(1,22)	.9080	2.05
VALENCE X EAR X ELECTRODE	1.16	(1,22)	.2921	0.74	(1,22)	.3967	0.45 (2,22)
VALENCE X HEMISPHERE X ELECTRODE	1.33	(1,22)	.2575	0.48	(1,22)	.4922	0.82 (2,22)
EAR X HEMISPHERE X ELECTRODE	2.10	(1,22)	.1513	7.83	(1,22)	.0003*	6.63 (2,22)
VALENCE X EAR X HEMISPHERE							
X GROUPING	0.08	(1,22)	.7827	0.00	(1,22)	.9680	1.18
VALENCE X EAR X ELECTRODE							
X GROUPING	0.69	(1,22)	.4117	1.35	(1,22)	.2687	0.30 (2,22)
VALENCE X HEMISPHERE X ELECTRODE							
X GROUPING	1.89	(1,22)	.1631	1.43	(1,22)	.2424	0.83 (2,22)
EAR X HEMISPHERE X ELECTRODE							
X GROUPING	2.29	(1,22)	.0893	0.72	(1,22)	.3991	0.34 (2,22)
VALENCE X EAR X HEMISPHERE							
X ELECTRODE	1.26	(1,22)	.2945	0.28	(1,22)	.6134	0.64 (2,22)
VALENCE X EAR X HEMISPHERE							
X ELECTRODE X GROUPING	0.49	(1,22)	.4915	1.03	(1,22)	.3801	2.98 (2,22)

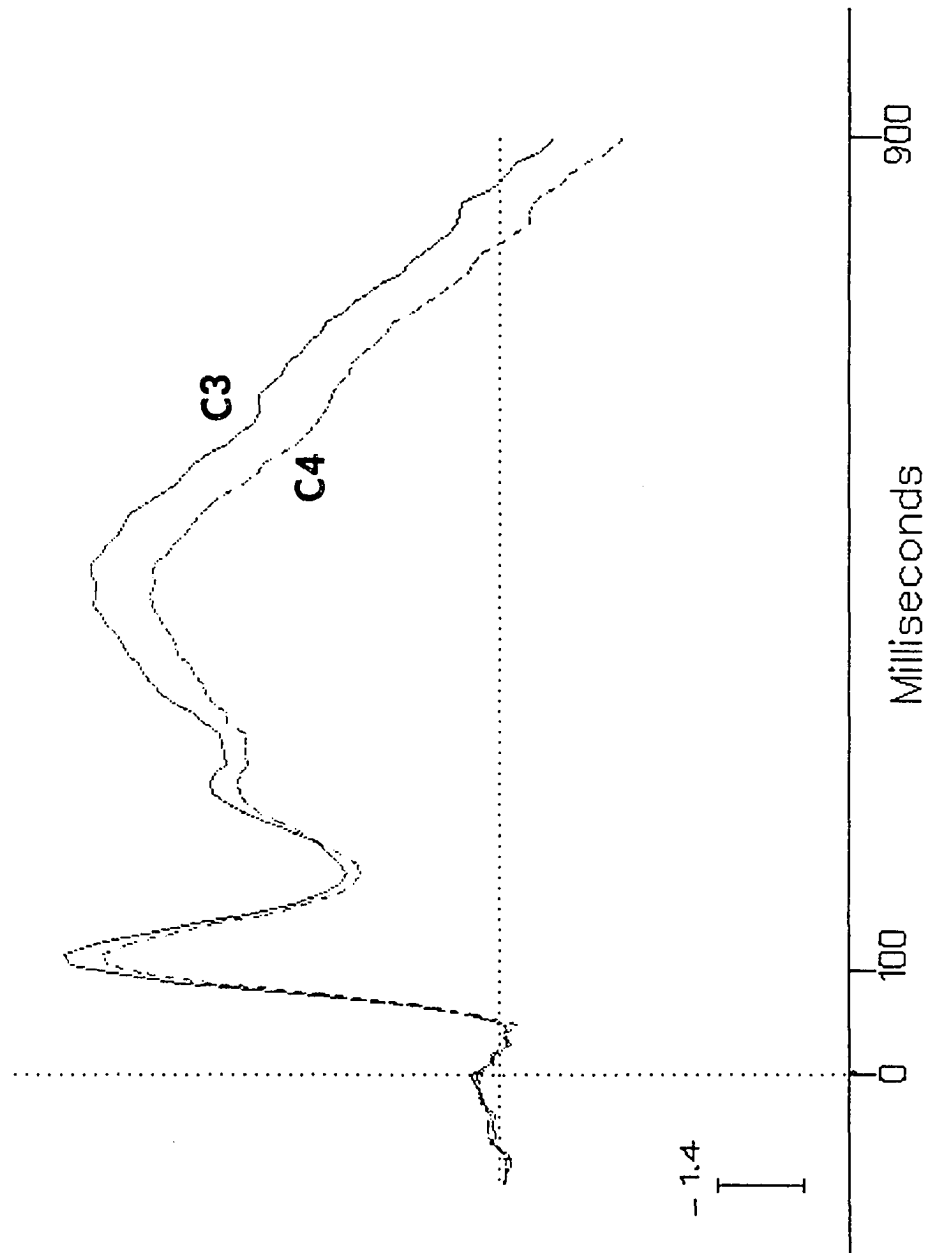
Table 26. Mean amplitude (μV) and SD of each component at all electrode sites ($n=24$) (EN = early negativity, LP = late positivity, SW = slow wave).

LEFT HEMISPHERE ELECTRODES					MIDLINE ELECTRODES					RIGHT HEMISPHERE ELECTRODES				
	<u>N100</u>	<u>LN</u>	<u>LP</u>	<u>SW</u>		<u>N100</u>	<u>LN</u>	<u>LP</u>	<u>SW</u>		<u>N100</u>	<u>LN</u>	<u>LP</u>	<u>SW</u>
F7	-1.64 (1.57)	-2.87 (3.34)	-0.16 (3.80)	1.63 (4.77)						F8	-1.19 (1.80)	-2.57 (3.19)	0.34 (3.73)	1.90 (5.00)
F3	-3.65 (2.13)	-5.40 (4.19)	-0.70 (4.74)	2.83 (4.89)						F4	-3.61 (2.33)	-5.34 (4.45)	-0.48 (5.02)	2.56 (5.29)
T3	-1.73 (1.79)	-1.44 (4.06)	3.13 (4.06)	3.65 (4.72)						T4	-1.12 (1.85)	-1.58 (3.78)	3.10 (4.11)	3.91 (5.26)
C3	-5.52 (2.46)	-3.78 (4.90)	2.87 (5.54)	4.37 (4.85)	CZ	-4.93 (2.59)	-3.23 (4.90)	3.67 (6.30)	5.33 (5.36)	C4	-4.14 (2.46)	-2.92 (4.50)	3.77 (5.34)	4.60 (5.09)
CP5	-2.68 (2.06)	-0.31 (4.67)	5.19 (4.68)	4.98 (5.18)						CP6	-1.89 (2.09)	0.02 (4.48)	5.32 (4.53)	5.16 (5.39)
P3	-2.71 (2.25)	2.16 (4.98)	7.79 (4.70)	6.46 (5.02)	PZ	-2.81 (2.26)	3.10 (5.08)	8.57 (5.02)	7.03 (5.34)	P4	-2.26 (2.22)	2.67 (4.93)	8.05 (4.63)	6.70 (5.28)
M	-2.99 (1.44)	-1.94 (2.68)	3.02 (3.21)	3.99 (1.69)		-3.87 (1.50)	-0.06 (4.48)	6.12 (3.46)	6.18 (1.20)		-2.37 (1.25)	-1.62 (2.74)	3.35 (3.16)	4.14 (1.75)

HEMISPHERE effect indicated that the N100 was significantly more negative over the left hemisphere ($M=-2.82$; $SD=2.29$) than over the right hemisphere ($M=-2.37$; $SD=2.42$) [$F(1,22)=20.11$; $p=.0002$](Figure 6). The greater N100 over left-hemisphere regions may indicate greater activation of left- than right-hemisphere regions. However, when interpreting hemisphere asymmetries of ERPS, caution must be taken. Since brain waves are being recorded from the scalp and since neural tissue has several characteristics which affect the orientation of the dipoles created by electrical activity, neuronal activity from several areas may interact to create the appearance of greater or smaller amplitude. However, one cannot say with certainty that the increased or decreased activity in one particular area is responsible for these changes. First, negativity over the left hemisphere could reflect not only underlying activity, but activity at other sites. Second, greater negativity over left-hemisphere sites could just as well be interpreted as less positivity at these sites compared to the right-hemisphere sites.

Thus, increased negativity could be reflecting several processes. If, in fact, it is the case that greater N100 reflects greater activity over the left hemisphere, it may be that characteristics of the consonant vowel-stimuli may activate the left hemisphere more than the right hemisphere.

Figure 6. Hemisphere effect obtained for the N100 (Dotted line = right hemisphere, Solid line = left hemisphere) (N=25).



In addition, there may be attentional factors or other information-processing factors with onsets beginning within the region of N100 and continuing beyond N100 (Naatanen & Picton, 1987). According to Naatanen and Picton (1987), what McCallum and Curry have called the N1a (a type of N100) is reportedly larger over the left hemisphere than over the right hemisphere for right-handed subjects. All of our subjects were right-handed.

A significant HEMISPHERE X ELECTRODE interaction indicated that the hemispheric difference in N100 amplitudes (left hemisphere - right hemisphere) was greatest at the temporal (-0.6096 uV) and centroparietal (-0.7917 uV) electrode sites. This is not surprising since the task involves perception and integration of auditory information. In addition, a VALENCE X HEMISPHERE interaction (See Table 25) revealed that the difference between left- and right-hemisphere amplitudes was greater for negatively-valenced emotions (-.5584 uV) than for positively-valenced emotions (-.3457 uV). Since all stimulus pairs were matched for intensity, this valence-dependent difference in asymmetry should reflect something other than perception of intensity differences that might occur when ordinarily expressing positively-valenced and negatively-valenced emotions.

Early Negativity

This component was not anticipated. Therefore, hypotheses regarding lateralization or amplitude differences as a function of discrete emotion or valence were not presented at the opening of the study. However, as with the N100, analyses used were applied to the early negativity because a correspondence between effects obtained for this and other components might help to explain the mechanisms underlying the observed effects. The early negativity may represent spreading of activation that occurs initially in the auditory cortex (represented by N100 at central electrodes) to more frontal regions involved in the initial analysis of emotional content. The main effect of ELECTRODE was significant [$F(2.22, 48.92) = 65.22$; $p < .0001$] for the early negativity (EN). Figure 5 shows that EN had its most negative area measurements at the frontal electrode. This negativity was smaller at central electrodes and diminished at parietal electrodes. A significant HEMISPHERE X ELECTRODE interaction [$F(5, 18) = 3.43$; $P = .0238$] (See Table 27) indicated that the amplitude of the early negativity at the central electrode placement was more negative over the left hemisphere (C3) than over the right hemisphere (C4), whereas that was not evident at other sites (Figure 7). This asymmetry was in the same direction as the asymmetry of N100. An EAR X HEMISPHERE interaction [$F(1, 22) = 13.61$, $p = .0013$] (See Table 28) showed

Table 27.

Mean Amplitude (SD) of early negativity over the left and right hemispheres at different electrode sites (microvolts).

ELECTRODE	LEFT HEMISPHERE	RIGHT HEMISPHERE
FL	-2.87 (3.34)	-2.57 (3.19)
F	-5.40 (4.19)	-5.34 (4.45)
T	-1.44 (4.06)	-1.58 (3.78)
C	-3.78 (4.91)	-2.92 (4.50)
CP	-0.31 (4.67)	0.02 (4.48)
P	2.16 (4.98)	2.67 (4.93)

Figure 7. The Hemisphere X Electrode effect obtained for the Early negativity.

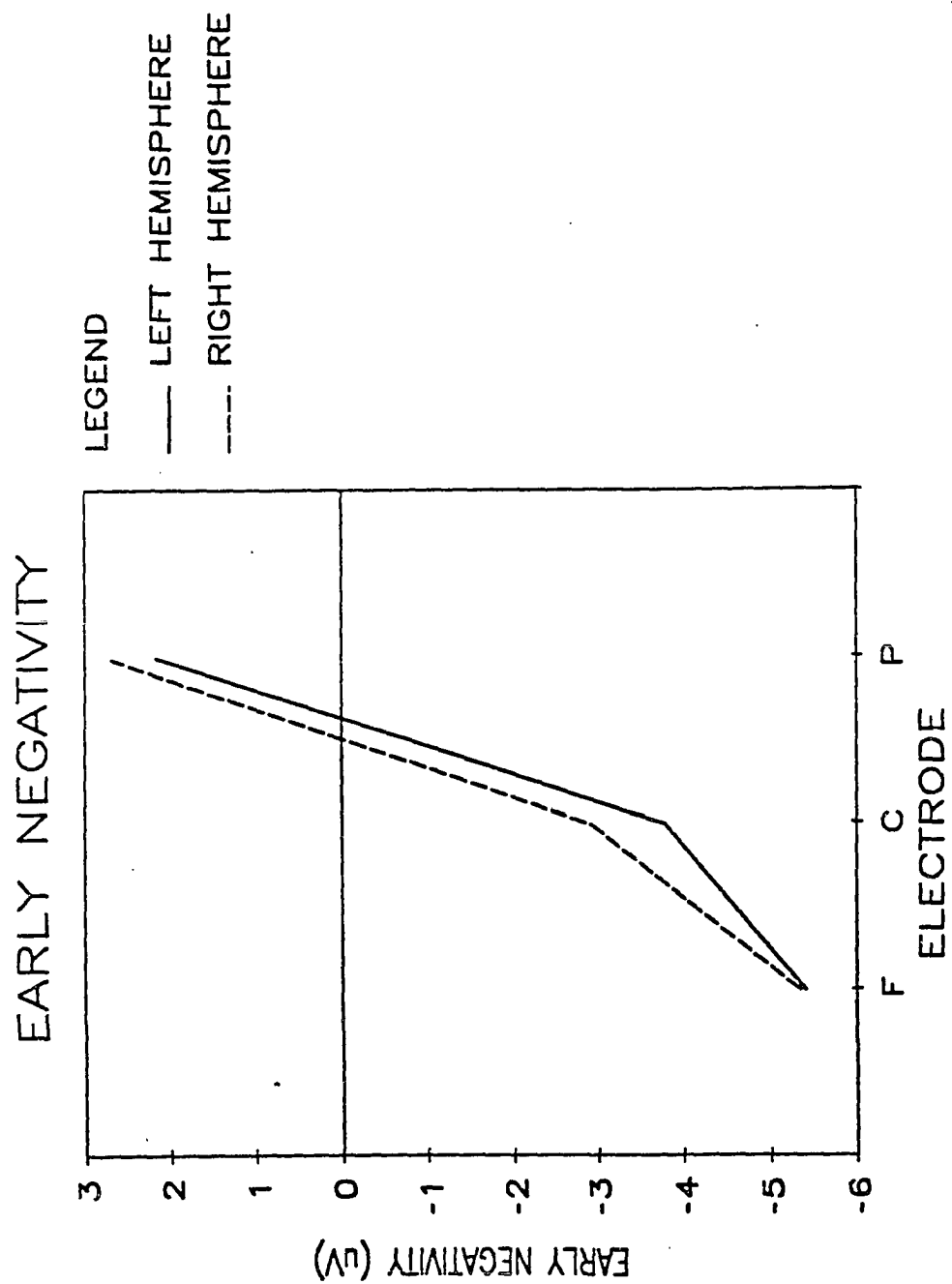


Table 28.

Early negativity amplitudes (SD) as a function of ear of presentation and hemisphere (N=24) (in microvolts).

	LEFT HEMISPHERE	RIGHT HEMISPHERE
LEFT EAR	-1.76 (5.09)	-1.74 (5.01)
RIGHT EAR	-2.12 (4.94)	-1.50 (4.85)

that the early negativity in response to stimulus items presented to the right ear was significantly more negative over the left hemisphere than over the right hemisphere; while the same stimulus items presented to the left ear resulted in comparable early negativity amplitudes over both hemispheres. Thus, differences between left- and right-hemisphere early negativity amplitudes were elicited by right-ear stimulus presentation (left-right hemisphere amplitude was $-.6162$ uV) and not by left-ear stimulus presentation (-0.0185). The EAR X HEMISPHERE X ELECTRODE interaction [$F(2.68, 58.98) = 7.83$; $p = .0003$] encompassed the HEMISPHERE X ELECTRODE and EAR X HEMISPHERE interactions and provided additional information that the difference between left and right hemispheres for items presented to the right ear was greatest at the central electrodes (Figure 8 & Table 29). It is interesting that the asymmetry of early negativity is primarily at central not frontal sites. This could represent continuation of initial asymmetry beginning at N100 and may be a result of initial processing the verbal aspect of the consonant-vowel stimulus because of the assumed contralateral advantage for this type of processing.

A significant GROUPING X HEMISPHERE X ELECTRODE interaction [$F(3.26, 71.63) = 3.35$; $p = .0206$] indicated that for the NOLEA group, the left hemisphere early negativity

Figure 8. The Ear X Hemisphere X Electrode effect for both the early negativity and late positivity at frontal, central and parietal electrodes (left hemisphere is represented by the dotted line, right hemisphere is represented by the solid line).

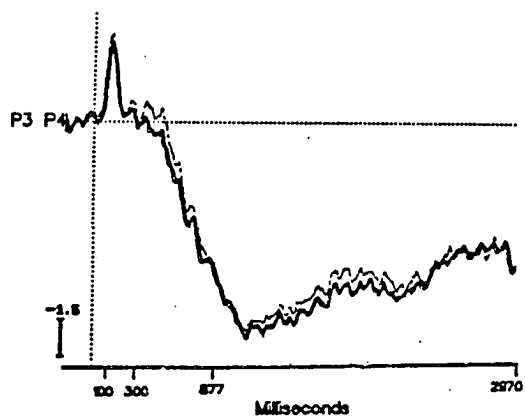
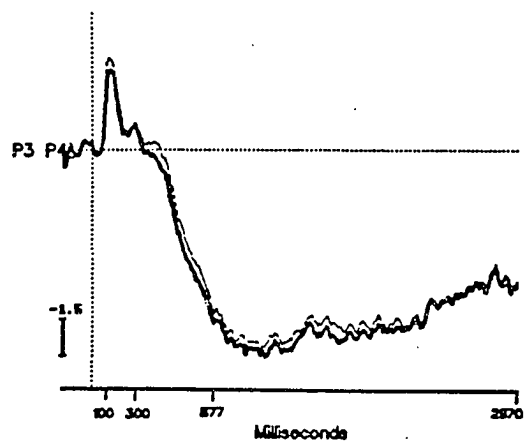
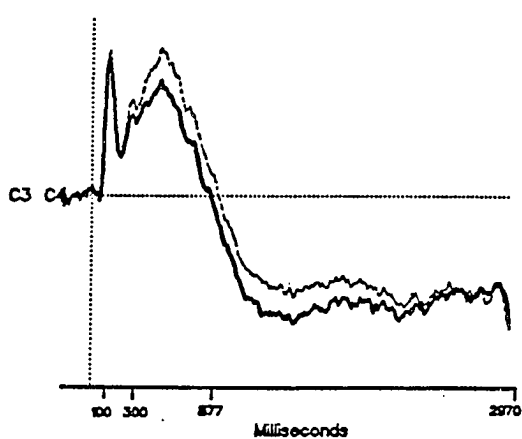
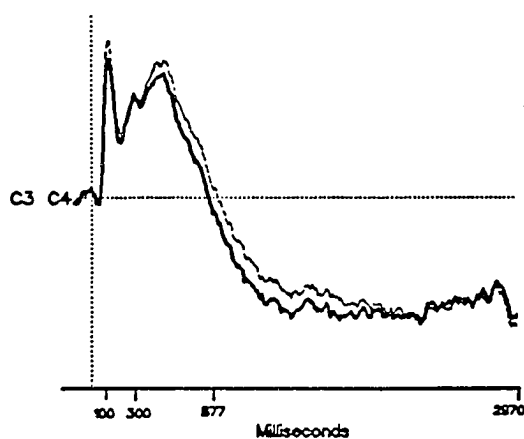
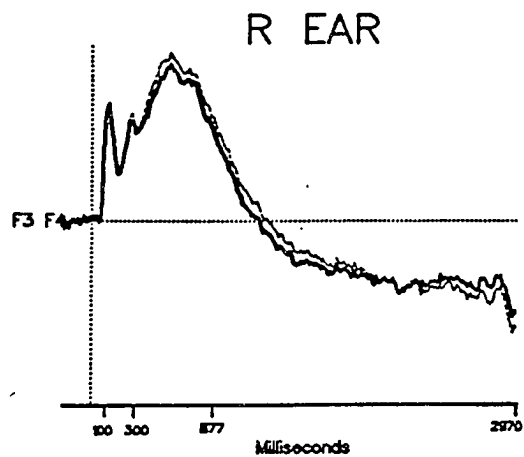
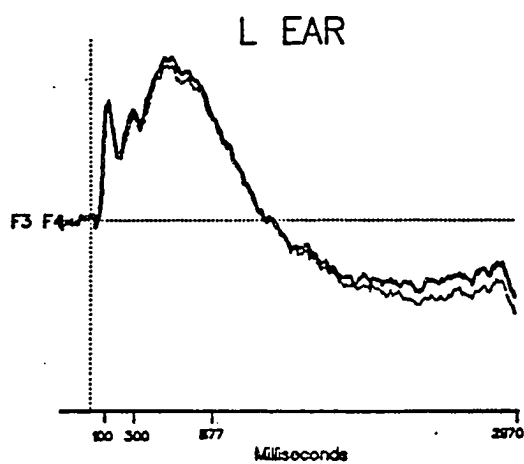


Table 29.

Mean early negativity amplitudes (SD) as a function of ear of stimulus presentation, hemisphere and electrode placement (in microvolts) (N=24).

	LEFT EAR		RIGHT EAR	
	LEFT HEMISPHERE	RIGHT HEMISPHERE	LEFT HEMISPHERE	RIGHT HEMISPHERE
FL	-2.68 (3.36)	-2.89 (3.13)	-3.07 (3.35)	-2.56 (3.25)
F	-5.22 (4.31)	-5.49 (4.53)	-5.58 (4.09)	-5.20 (4.42)
T	-1.22 (5.04)	-1.85 (3.73)	-1.65 (3.93)	-1.31 (3.85)
C	-3.62 (4.80)	-2.99 (4.64)	-3.93 (4.81)	-2.86 (4.41)
CP	-0.11 (4.80)	-0.04 (4.59)	-0.51 (4.58)	0.07 (4.42)
P	2.28 (5.07)	2.80 (4.99)	2.04 (4.94)	2.54 (4.92)

amplitude was more negative across all electrodes than at the right-hemisphere sites (See Table 30). In contrast, the LEA group exhibited larger negativities over the left hemisphere at the central electrodes, but showed greater negativity over the right hemisphere at the temporal placements. Thus, the NOLEA group showed a constant asymmetry across all electrodes, but the LEA group showed an asymmetry that was different across sites (See Figure 9). The most remarkable difference in the LEA group was the shift from greater early negativity amplitudes over the left hemisphere at central sites to the greater amplitudes over the right hemisphere at temporal electrode placements. Thus, the left-ear advantage of the LEA group may be related to this increased negativity over the right hemisphere which is absent in the NOLEA group.

Late Positivity

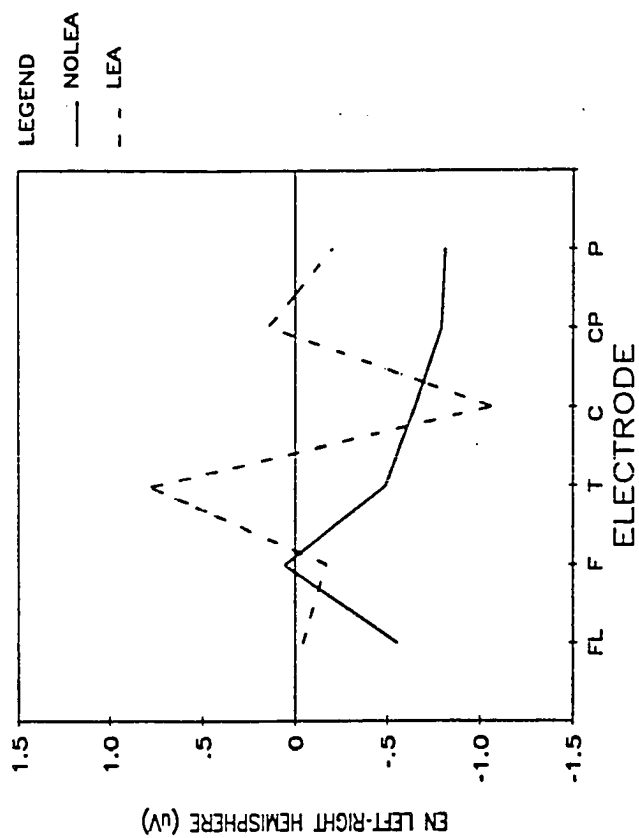
To determine whether the hypothesized hemispheric asymmetries in late positivity amplitudes existed and to what extent this was affected by factors such as the valence of the emotion and electrode, the analyses described at the opening of the FINDINGS section (p. 120) were conducted. The distribution of this component was such that it was most positive at the parietal electrode (main effect of ELECTRODE: $F(2.42, 53.30) = 119.68$; $p < .0001$). The EAR X HEMISPHERE effect indicated that hemispheric asymmetries were greatest for items

Table 30.

Mean early negativity amplitudes (SD) as a function of absence (NOLEA) or presence of (LEA) a left-ear advantage, hemisphere and electrode placement (in microvolts) (N=24).

	NOLEA GROUP		LEA GROUP	
	LEFT HEMISPHERE	RIGHT HEMISPHERE	LEFT HEMISPHERE	RIGHT HEMISPHERE
FL	-4.07 (3.50)	-3.51 (3.26)	-1.68 (2.73)	-1.64 (2.86)
F	-6.27 (4.31)	-6.33 (4.47)	-4.53 (3.91)	-4.36 (4.26)
T	-2.88 (4.11)	-2.39 (3.60)	0.01 (3.49)	-0.77 (3.82)
C	-4.84 (4.47)	-4.19 (4.04)	-2.72 (5.13)	-1.66 (4.63)
CP	-1.86 (4.13)	-1.06 (3.93)	1.23 (4.72)	1.09 (4.77)
P	0.71 (3.89)	1.52 (3.76)	3.61 (5.54)	3.82 (5.68)

Figure 9. The Grouping X Hemisphere X Electrode interaction obtained for the early negativity (N=24).



presented to the right ear and that the asymmetry took the form of a greater positivity over the right hemisphere (3.7 uV) than over the left hemisphere (3.1 uV). Left-ear stimulus presentation resulted in comparable late positivity (LP) amplitudes over the right (3.0 uV) and left (3.0 uV) hemispheres. A significant EAR X HEMISPHERE X ELECTRODE interaction [$F(2.77, 60.86) = 6.63$; $p = .0008$] indicated that this difference in hemisphere asymmetry of LP for right- and left-ear stimuli was most pronounced at the central electrode (See Figure 8 & Table 31). A simple effects ANOVA, analyzing each of the factors used in the analysis and their interactions, separately for each EAR, supported the conclusion that right-ear stimulus presentation produced larger hemispheric asymmetries than left-ear stimulus presentation. The hemisphere effect was significant for the right ear [$F(2.96, 68.05) = 2.70$; $p = .0531$] but not for the left ear [$F(2.96, 49.02) = 2.40$; $p = 0.0983$], although there was a trend in the same direction. This difference in asymmetry is most marked at the frontal and central electrodes.

Smaller P300 amplitudes have been associated with greater difficulty in task completion. Thus, if this difference in asymmetry reflects processing attributable to P300, then one possibility is that greater late positivity to right-ear items over the right hemisphere indicates greater ease of right-

Table 31.

Mean late positivity amplitudes (SD) as a function of ear of stimulus presentation, hemisphere and electrode placement (in microvolts) (N=24).

	LEFT EAR		RIGHT EAR	
	LEFT HEMISPHERE	RIGHT HEMISPHERE	LEFT HEMISPHERE	RIGHT HEMISPHERE
FL	-0.14 (4.02)	-0.36 (3.82)	-0.18 (3.61)	1.03 (3.55)
F	-0.77 (4.94)	-0.83 (5.13)	-0.63 (4.58)	-0.14 (4.93)
T	3.05 (4.26)	2.66 (4.28)	3.21 (3.89)	3.54 (3.94)
C	2.75 (5.51)	3.55 (5.42)	3.00 (5.63)	4.00 (5.31)
CP	5.12 (4.65)	5.11 (4.75)	5.26 (4.75)	5.53 (4.33)
P	7.66 (4.61)	7.95 (4.57)	7.92 (4.84)	8.14 (4.73)

hemisphere processing of the information presented to that ear. However, what we know about processing of information presented to the ipsilateral ear (i.e., the fact that information must be transferred across the corpus callosum and the presence of contralateral suppression) does not support this conclusion. The other possibility, however, is that the carry over of larger negativity over the left hemisphere to stimuli presented to the right ear is influencing the amplitude of the late positivity. The fact that this asymmetry is most prominent over the frontal and central electrodes, where the early negativity is greatest, supports this interpretation. Left-ear stimulus presentation does not seem to create this hemispheric difference in processing ability as indexed by the late positivity.

A five-way (GROUPING X VALENCE X EAR X HEMISPHERE X ELECTRODE) interaction [$F(2.88, 63.43) = 2.98$; $p = .0399$] was also obtained. This interaction was very difficult to interpret in a meaningful fashion and will not be discussed.

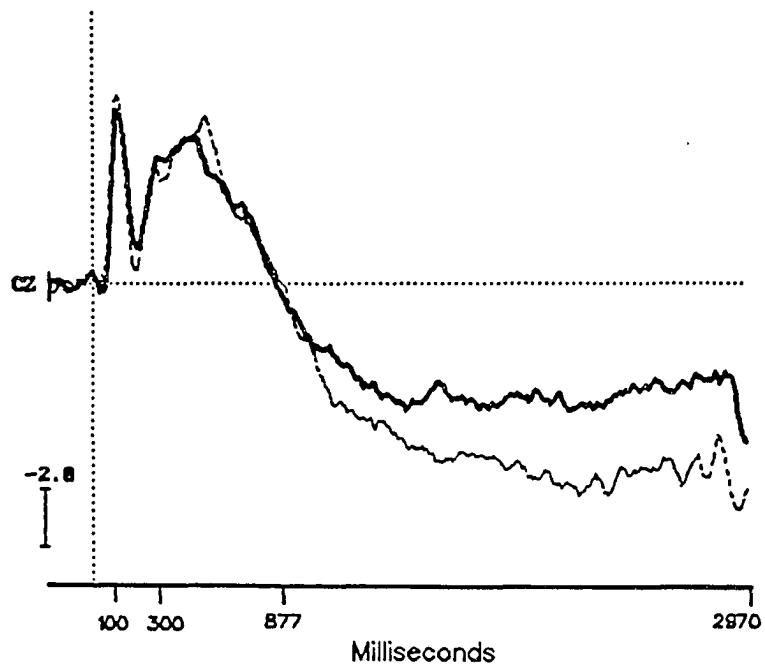
Slow Wave

Slow wave (SW) amplitudes are thought to reflect further processing of complex stimuli. Smaller positive slow waves are associated with greater facility in completing task demands and lower difficulty levels (Ruchkin, Johnson,

Mahaffey, & Sutton, 1988). A repeated-measures ANOVA was done on the average slow wave amplitudes to determine whether there was an asymmetry in this component and whether the possible asymmetry was a function of ear-advantage characteristics of the subject (grouping), the valence of the emotion, or the electrode site used to make the recordings. A significant ELECTRODE effect [$F = 55.58$; $P = .000$] confirmed that slow wave amplitudes were smallest at frontal sites and increased to its maximum values at parietal sites. In addition, slow wave amplitudes were significantly greater for negatively-valenced emotions ($M=5.1$; $SD=4.7$) than for positively-valenced emotions ($M=3.0$; $SD=5.6$) (VALENCE effect: $F(1,22)=6.57$; $p=.0177$) (Figure 10). This suggested that it was more difficult to identify or discriminate negatively-valenced emotions than positively-valenced emotions. Although there were no statistically significant differences in the accuracy of identification of negatively-valenced emotions, accuracy scores for identification of positively-valenced emotions ($M=73$) were slightly higher than identification of negatively-valenced emotions ($M=70$) (See Table 7).

As seen for the late positivity, the analysis of the SW data also resulted in a five-way GROUPING X VALENCE X EAR X HEMISPHERE X ELECTRODE interaction. Again, this interaction could not be interpreted in a meaningful way and will not be

Figure 10. The slow wave to negatively-valenced emotions is greater than the slow wave to positively-valenced emotions (dotted line represents negatively-valenced emotions, solid line represents positively-valenced emotions) (Targets only; N=24).



discussed here.

Gender Effects

Gender effects were probed with an overall repeated-measures ANOVA with the grouping factor defined as Gender and within-factors defined as Valence, Ear of presentation, Hemisphere, and Electrode. This analysis was done with a sample size of 24 including 13 males and 11 females. Table 32 provides the F-values, degrees of freedom, and p-values for each of the four components resulting from the ANOVA.

No main effects of GENDER were found for any of the components; two significant interactions involving gender were found. A significant EAR X GENDER interaction was obtained for the slow wave (See Table 33 & Figures 11 & 12). Males had comparable slow wave amplitudes for target stimuli presented to the left and right ears, although the amplitude was slightly smaller for items presented to the right than left ear. However, females had a smaller slow wave in response to target items presented to the left ear than to the right ear. A simple effects analysis indicated that the ear difference in slow wave was significant for females [$F(1,22)=6.10$; $p=0.022$], but not for males [$F(1,22)=1.58$; $p=0.222$]. This was an interesting finding because females also had a stronger behavioral left-ear advantage than males for target detection.

Table 32.

F and p values for each component obtained from a repeated-measures (gender) and four within-factors (valence, ear of presentation, hemisphere of presentation, and electrode)

Effect	M100			Early Negativity			Late Negativity
	F VALUES	D.F.	P VALUES	F VALUES	D.F.	P VALUES	F
GENDER	0.05	(1,22)	.8314	1.83	(1,22)	.1895	0.00
VALENCE	2.72	(1,22)	.1134	0.41	(1,22)	.5288	1.92
EAR	0.44	(1,22)	.5129	0.03	(1,22)	.8640	0.84
HEMISPHERE	19.87	(1,22)	.0002**	1.68	(1,22)	.2079	1.36
ELECTRODE	40.84	(2,04,44.88)	.0000**	67.28	(2,11,46.35)	.0000**	120.77 (2.3)
VALENCE X GENDER	0.92	(1,22)	.3479	0.24	(1,22)	.6310	0.08
EAR X GENDER	2.26	(1,22)	.1468	2.66	(1,22)	.1172	3.71
HEMISPHERE X GENDER	0.10	(1,22)	.7601	0.03	(1,22)	.8627	0.94
ELECTRODE X GENDER	1.88	(2,04,44.88)	.1643	0.89	(2,11,46.35)	.4228	0.52 (2.3)
VALENCE X EAR	1.06	(1,22)	.3140	1.34	(1,22)	.2591	2.09
VALENCE X HEMISPHERE	4.41	(1,22)	.0473*	0.35	(1,22)	.5574	0.02
VALENCE X ELECTRODE	1.30	(2,57,56.56)	.2840	0.52	(1,58,34.83)	.5598	0.82 (1.6)
EAR X HEMISPHERE	0.39	(1,22)	.5366	13.07	(1,22)	.0015**	4.00
EAR X ELECTRODE	0.20	(1,99,43.82)	.8174	0.75	(1,77,38.92)	.4647	0.98 (2.2)
HEMISPHERE X ELECTRODE	4.84	(2,76,60.75)	.0054**	3.44	(2,99,65.73)	.0217*	1.79 (2.3)
VALENCE X EAR X GENDER	1.77	(1,22)	.2049	1.78	(1,22)	.1961	0.65
VALENCE X HEMISPHERE X GENDER	0.11	(1,22)	.7431	0.04	(1,22)	.8360	0.01
VALENCE X ELECTRODE X GENDER	1.63	(2,57,56.56)	.1974	0.83	(1,58,34.83)	.4177	0.56 (1.6)
EAR X HEMISPHERE X GENDER	1.58	(1,22)	.2216	0.96	(1,22)	.3377	0.08
EAR X ELECTRODE X GENDER	0.52	(1,99,43.82)	.5971	0.45	(1,77,38.92)	.6172	0.49 (2.2)
HEMISPHERE X ELECTRODE X GENDER	0.51	(2,76,60.75)	.6621	0.84	(2,99,65.73)	.4780	0.75 (2.3)
VALENCE X EAR X HEMISPHERE	0.54	(1,22)	.4713	0.02	(1,22)	.8960	2.05
VALENCE X EAR X ELECTRODE	1.13	(2,47,54.36)	.3371	0.71	(2,17,47.80)	.5100	0.45 (2.0)
VALENCE X HEMISPHERE X ELECTRODE	1.24	(2,11,46.39)	.2990	0.46	(3,13,68.95)	.7223	0.80 (2.7)
EAR X HEMISPHERE X ELECTRODE	1.94	(2,69,59.25)	.1186	7.74	(2,70,59.38)	.0003*	6.80 (2.7)
VALENCE X EAR X HEMISPHERE X GENDER	2.78	(1,22)	.1098	6.18	(1,22)	.0210*	1.19
VALENCE X EAR X ELECTRODE X GENDER	0.13	(2,47,54.36)	.9168	0.29	(2,17,47.84)	.7650	0.30 (2.0)
VALENCE X HEMISPHERE X ELECTRODE X GENDER	0.36	(2,11,46.39)	.7126	0.24	(3,13,68.95)	.8726	0.43 (2.7)
EAR X HEMISPHERE X ELECTRODE X GENDER	0.45	(2,69,59.25)	.7006	0.45	(2,70,59.38)	.6956	0.94 (2.7)
VALENCE X EAR X HEMISPHERE X ELECTRODE	1.34	(2,91,63.94)	.2703	0.30	(2,65,58.20)	.8037	0.59 (2.7)
VALENCE X EAR X HEMISPHERE X ELECTRODE X GENDER	1.84	(2,91,63.94)	.1509	2.52	(2,65,58.20)	.0737	0.71 (2.7)

Table 33.

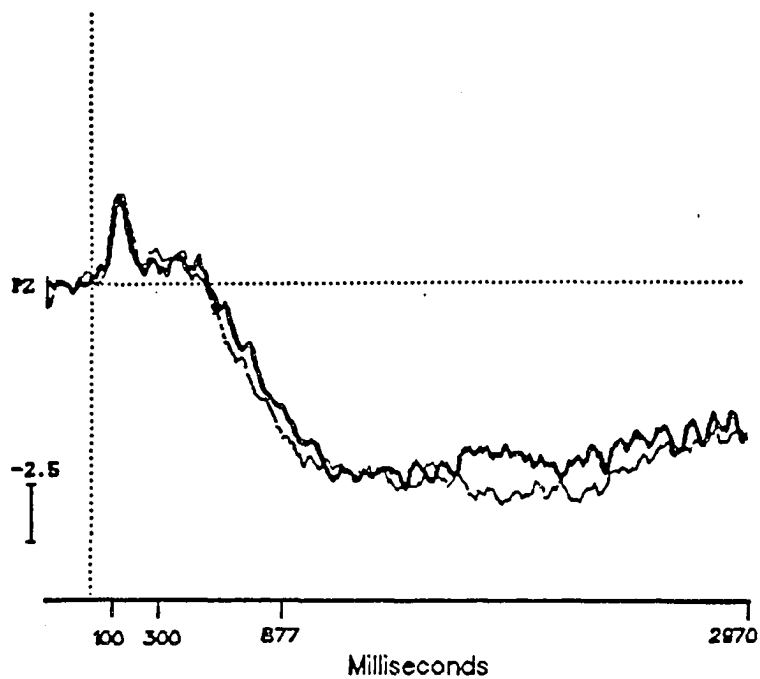
Means (SD) of slow wave amplitudes as a function of ear of presentation and gender of participant (in microvolts) (N=24).

	LEFT EAR	RIGHT EAR
MALES (N=13)	5.4 (4.3)	4.5 (4.4)
FEMALES (N=11)	2.0 (5.9)	3.9 (6.0)

Figure 11. The Ear X Gender interaction obtained for the slow wave (N=24) (Dashed line represents the left ear, Solid line represents the right ear).

MALES

150



FEMALES

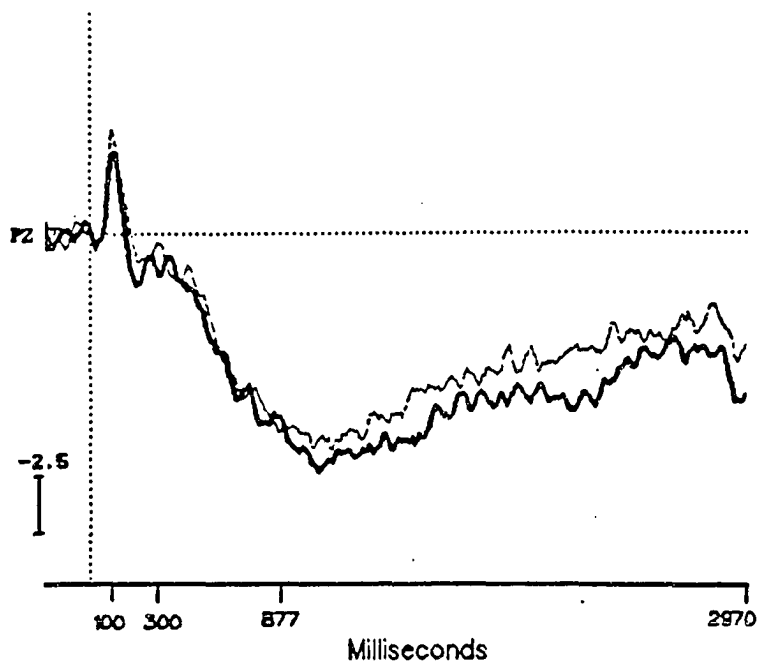
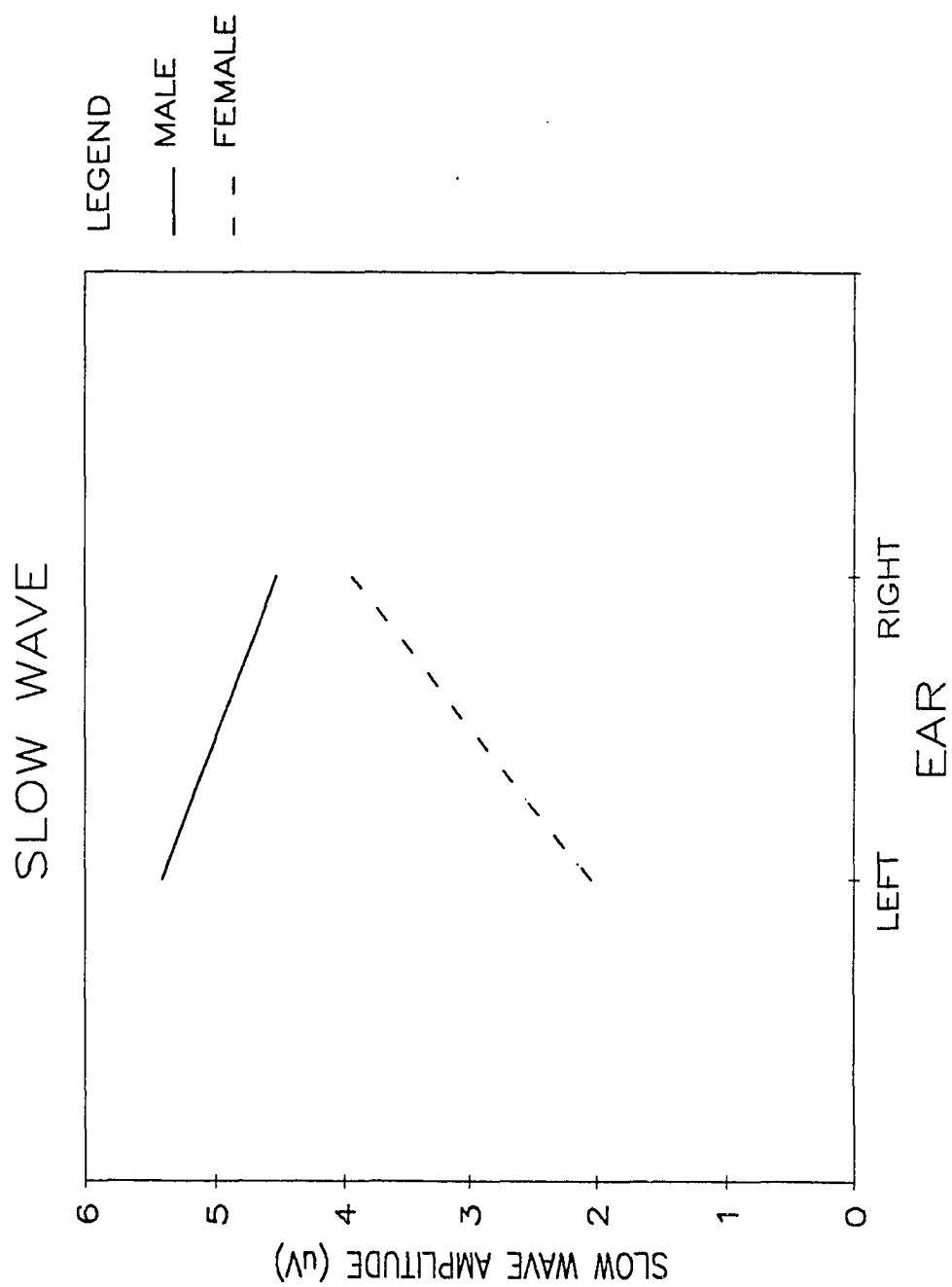


Figure 12. The Ear X Gender interaction obtained for the slow wave (N=24).



The smaller slow wave for left-ear items and the behavioral advantage obtained for females in target emotion detection suggested that the smaller slow wave amplitude reflected greater ease in processing of emotions presented to the left ear. In contrast, males showed a smaller behavioral left-ear advantage, and a corresponding lack of significant slow wave differences as a function of ear.

For the early negativity, a significant effect involving gender was the GENDER X VALENCE X EAR X HEMISPHERE interaction (See Figure 13 & Table 34) [$F(1,22)=6.18$; $p=0.021$]. Figure 13 indicates that, for the early negativity, females showed a comparable asymmetry (with left hemisphere being more negative than the right hemisphere) for positive items presented to both left and right ears. However, for negative emotions, females showed a much larger asymmetry for items presented to the right ear than to items presented to the left ear. In males, negatively-valenced emotions presented to the left and right ears produced comparable hemispheric asymmetries. In contrast, right-ear presentation of positively-valenced emotions produces greater asymmetry than left-ear presentation. It should be noted that for both males and females, right-ear presentation produced more asymmetry (greater negativity over left hemisphere than right hemisphere) than did left ear presentation. It is not clear

Figure 13. Early negativity amplitudes for target items presented to the left and the right ears (Dashed line represents right ear, Solid line represents left ear; Triangles represent males, circles represent females) (Gender X Valence X Ear X Hemisphere).

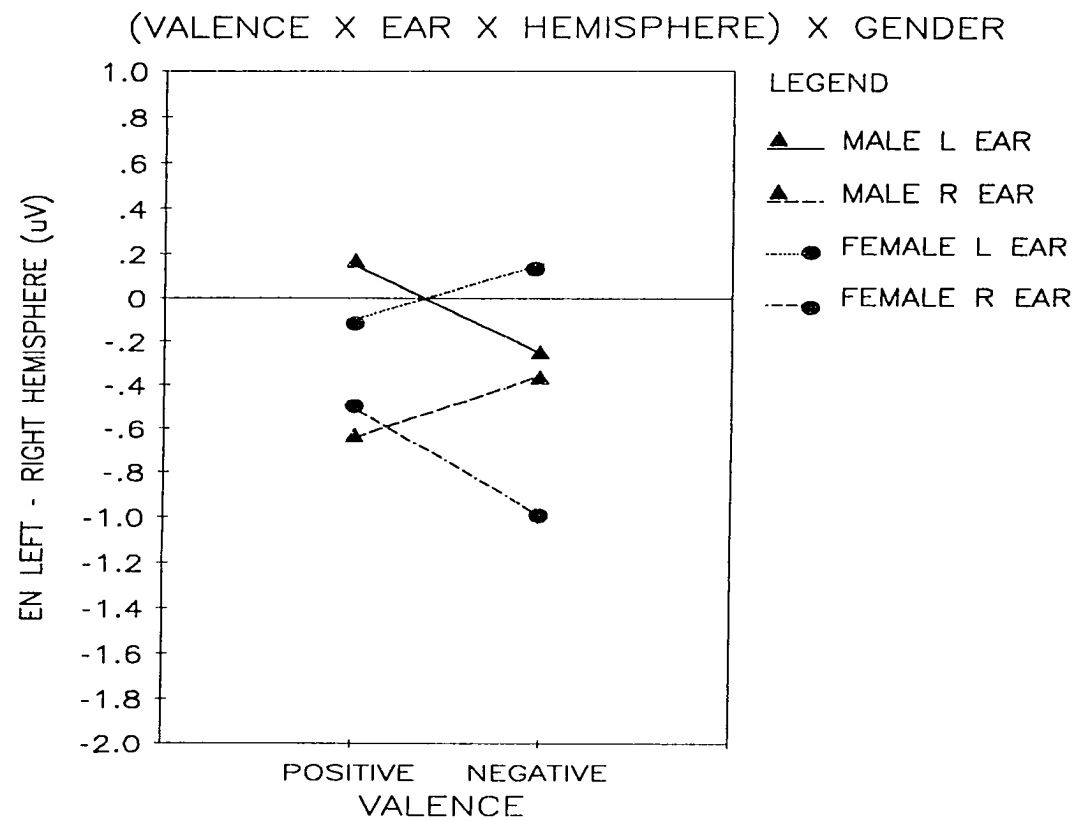


Table 34.
Means (SD) of early negativity amplitudes as a function of gender, valence of stimulus, ear of presentation and hemisphere from which recording was made (in microvolts) (N=24).

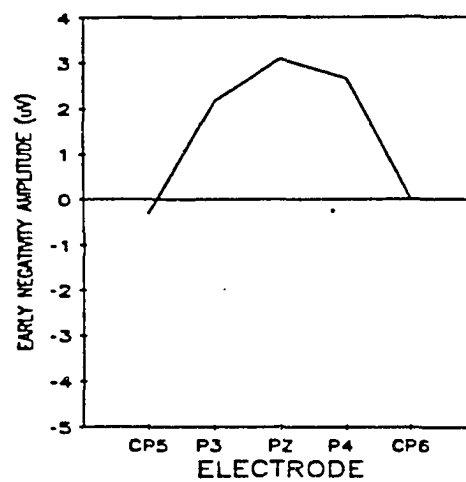
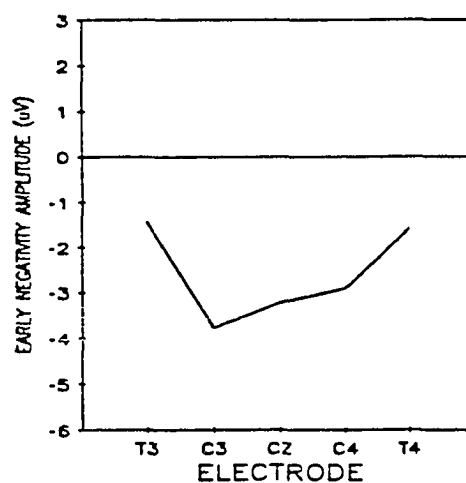
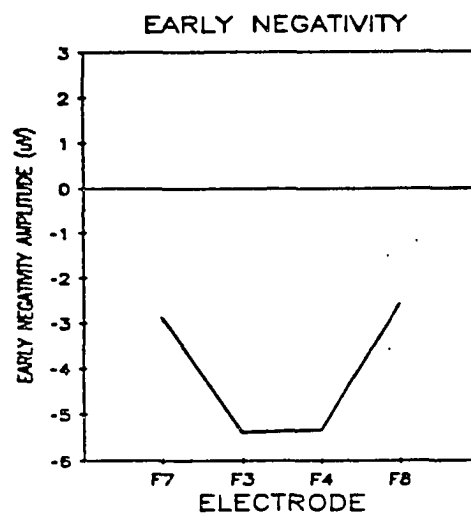
MALES				
	POSITIVE EMOTIONS		NEGATIVE EMOTIONS	
	LEFT HEMISPHERE	RIGHT HEMISPHERE	LEFT HEMISPHERE	RIGHT HEMISPHERE
LEFT EAR	-2.34 (4.72)	-2.49 (4.48)	-2.58 (4.50)	-2.33 (4.37)
RIGHT EAR	-3.27 (4.80)	-2.62 (4.92)	-3.21 (4.82)	-2.85 (4.60)
FEMALES				
	POSITIVE EMOTIONS		NEGATIVE EMOTIONS	
	LEFT HEMISPHERE	RIGHT HEMISPHERE	LEFT HEMISPHERE	RIGHT HEMISPHERE
LEFT EAR	-0.33 (5.50)	-0.23 (5.63)	-1.54 (5.53)	-1.68 (5.40)
RIGHT EAR	-0.96 (4.71)	-0.46 (4.36)	-0.62 (4.92)	0.37 (4.78)

what this higher order interaction represents. However, lack of a statistically significant correlation between behavioral ear advantage and asymmetry of early negativity (as will be discussed in a subsequent section) suggests that it may have little to do with emotional perception per se and may have more to do with the phonemic aspect of the stimuli.

Topography

Closer inspection of the topography of the components elicited after N100 may help clarify these findings. To characterize the topography of each component, in addition to plotting the entire wave for each electrode site (Figure 5), overall amplitudes of each component have been separately plotted for frontal, central and parietal electrode placements. The early negativity shown in Figure 14 had a fairly symmetric frontal distribution with amplitudes being greatest for more midline placements than for fronto-lateral placements. At central sites, amplitudes were greater closer to the center of the head than more parasagittally. In addition, one can see in Figure 14 that the negativity was greater over the left-central than the right-central placements and was less evident at the temporal site. At parietal placements, this component was either absent or actually inverted so that obtained amplitudes became positive. It resembled the P300 and though an asymmetry existed, it

Figure 14. Topography of the early negativity in response to target items.



appeared to be less pronounced than at central sites.

The amplitude of the late positivity was negative at frontal placements. It was clearly positive at central and temporal placements. One can see in Figure 15 that the positivity was greater over the right hemisphere than over the left hemisphere for central sites. This component had its greatest amplitudes at parietal leads (See Figure 15). The smaller late positivity amplitudes at the left-central and temporal sites may be an indication that this component overlapped with the early negativity to some extent and that the late positivity was riding on the early negativity.

The slow wave obtained in this paradigm was one that was positive at frontal, central and parietal leads. The striking feature of this component was that, at central and parietal placements, the slow wave was quite symmetrical unlike the early negativity and late positivity (See Figure 16). And as with the late positivity, slow wave amplitudes were greatest at parietal leads.

Factors Affecting Amplitudes of Components and Implications For Generators. Two of the most interesting and consistent findings with regard to the ERPs included the EAR X HEMISPHERE X ELECTRODE interactions for both the early

Figure 15. Topography of late positivity in response to target items.

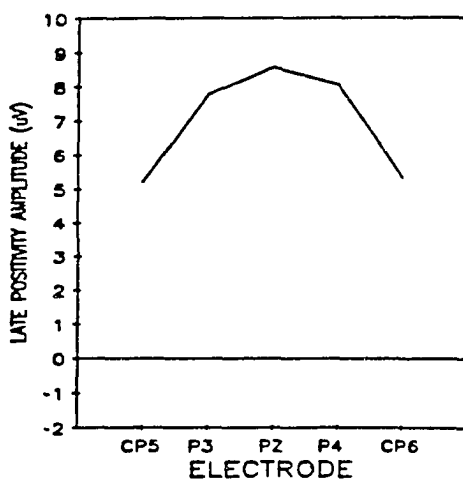
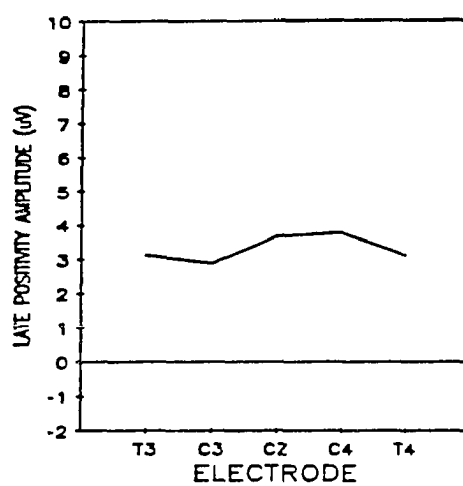
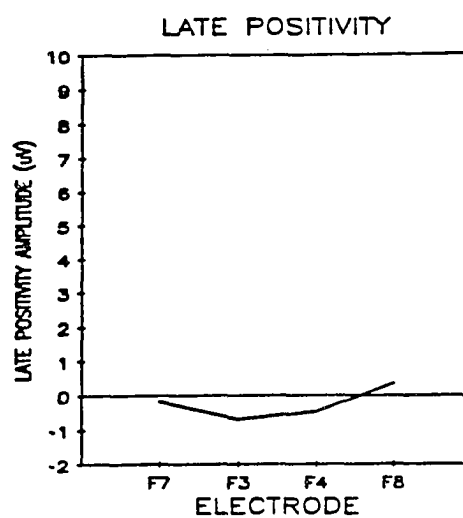
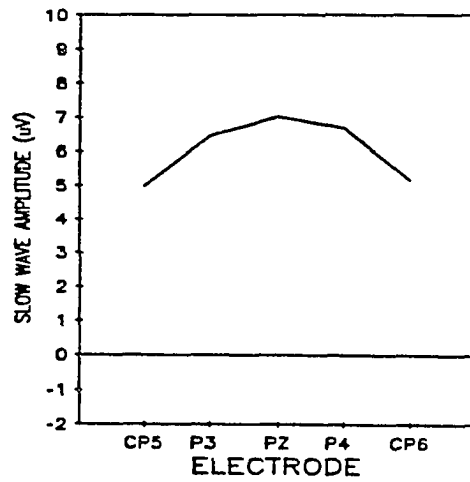
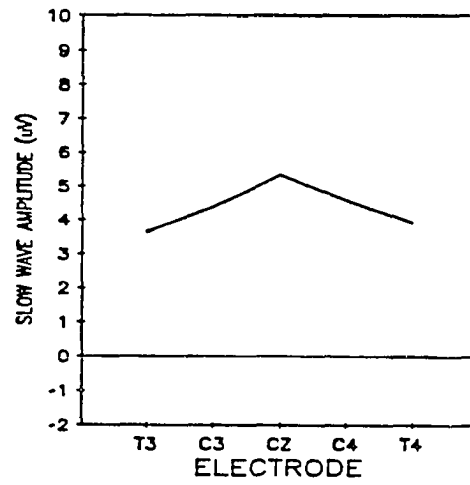
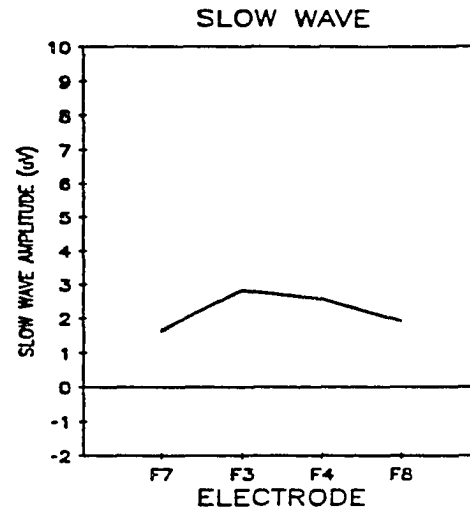


Figure 16. Topography of slow wave in response to target items.



negativity and late positivity (See Figures 17 & 18). Figure 17 clearly demonstrates that the topography of the early negativity depended on the ear of stimulus presentation. For instance, at frontal sites, right-ear stimulus presentation resulted in an early negativity that was greater over the left hemisphere (F3) than over the right hemisphere (F4), while left-ear stimulus presentation resulted in greater negativity over the right-frontal site (F4) than over the left-frontal site (F3). An essential feature of this figure is that it also demonstrates that the larger early negativity over the left hemisphere was greatest at the central electrode (C3) for items presented to the right ear.

Figure 18 also demonstrates that the degree of hemispheric asymmetry between the left and right hemispheres for the late positivity was a function of the ear of stimulus presentation. For this component, at frontal electrode placements, right- and left-ear stimulus presentation resulted in comparable late positivity amplitudes over the left hemisphere. In contrast, the late positivity in response to right-ear items was more positive than those elicited in response to left-ear items, particularly over the right hemisphere. These findings were maintained after analyses with vector scaled component amplitudes were carried out.

Figure 17. The early negativity in response to target items presented to the left and right ears (Topography).

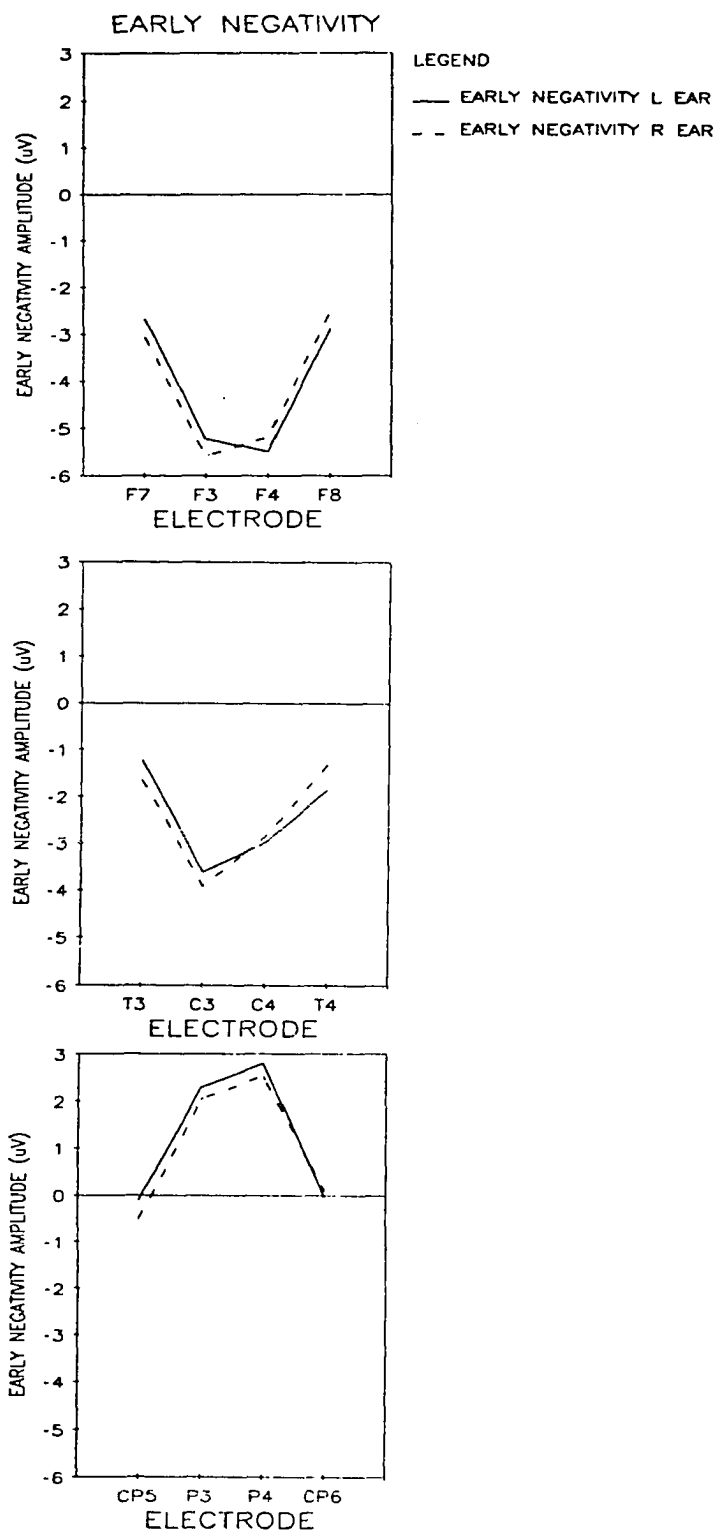
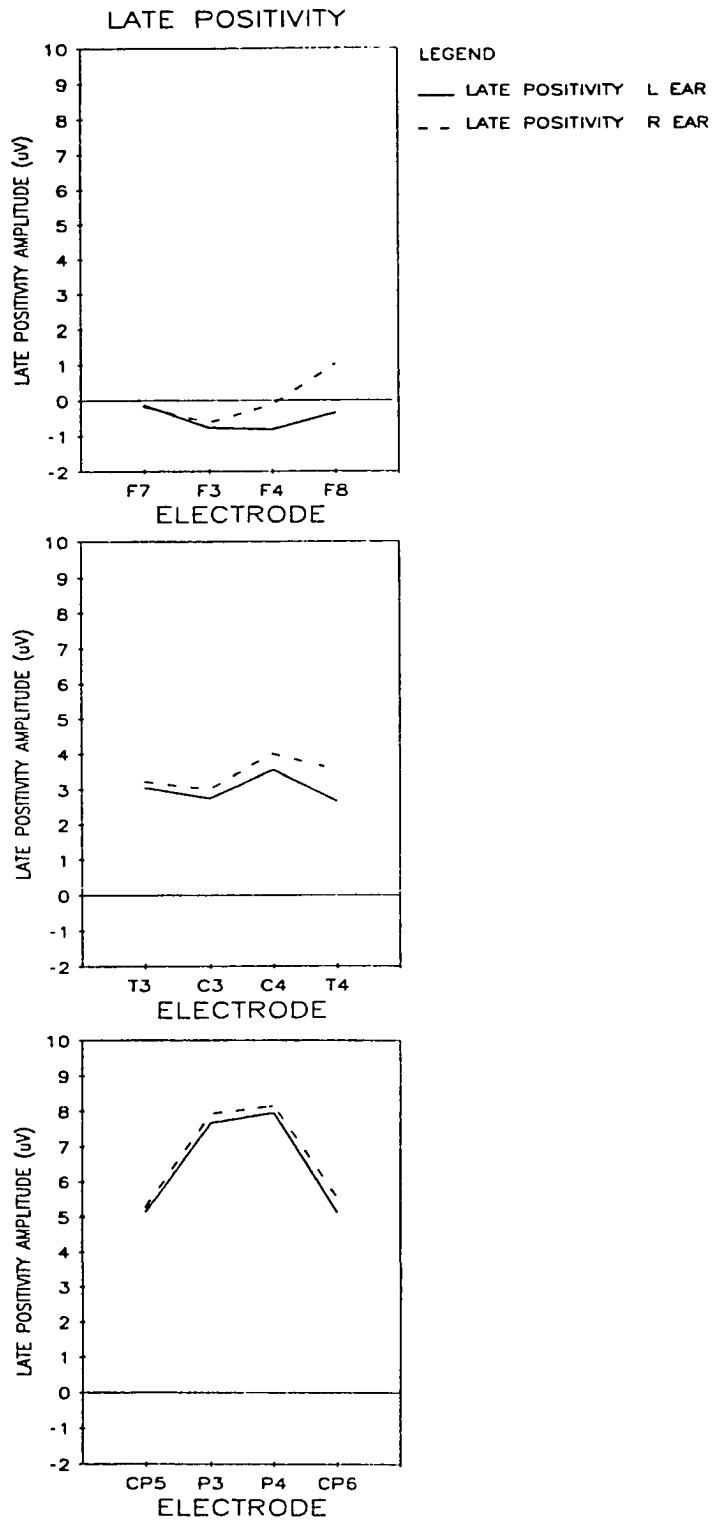


Figure 18. The late positivity in response to target items presented to the left and right ears (Topography).



The variation in distributions of each component across the scalp under differing conditions indicated that the pattern of neural activity had changed with those conditions. Johnson (1989, 1993) has shown that different subunits of neural activity represented by ERPs are associated with different variables. In this case, the factor influencing the early negativity and late positivity components would be ear of stimulus presentation. This suggests that the pattern of neural activity reflected by early negativities and late positivities elicited by the left ear were not the same as the pattern elicited by the right ear. This may rest on the organization of the auditory system, with greater excitation of contralateral brain regions resulting from the greater number of contralateral fibers projecting from each ear.

Correlations Between Behavioral Data and Event-Related Potential Measures

Overall Analyses

Behavioral ear advantages were correlated with electrophysiological data to determine whether there was a relationship between the behavioral ear advantage and hemispheric asymmetries of the ERP components. Though correlations between the laterality quotients and ERP asymmetries were conducted for each component, of particular interest were the correlations between the behavioral

asymmetry scores (LQ) and hemispheric asymmetries in the amplitudes of the late positivity and the slow wave. As there were no significant overall ear effects in the RT data, these correlations were conducted only with accuracy data.

As the ANOVAS indicated that EAR, HEMISPHERE, and ELECTRODE were factors which significantly affected component amplitudes, the correlations were conducted between the LQ and hemispheric differences in component amplitudes, separately for items presented to the left and right ears, and separately for the different electrode sites. For example, for the early negativity, differences in this component's amplitudes over the left and right hemisphere obtained for homologous electrode pairs were calculated separately for target items presented to the left ear and target items presented to the right ear. A Pearson product-moment correlation was then calculated to examine the relationship between the behavioral ear advantage obtained as described in the results section with these calculated hemispheric difference amplitudes for all subjects (N=24) (See Table 35).

In the Hypothesis Section (pp. 44 ~ 47) it was hypothesized that there would be a positive correlation between LQ and left minus right hemisphere late positivity amplitudes (i.e., a correlation between greater left- than

Table 35. Pearson product-moment correlations between Laterality Quotient for each subject and hemispheric differences in amplitudes for the early negativity and late positivity. This analysis examines the relationship between behavioral and electrophysiological data, taking into account three factors: ear of stimulus presentation, hemisphere and electrode (N=24; none of the correlations were significant at or below the .05 level).

LEFT-RIGHT HEMISPHERE	LEFT EAR		RIGHT EAR	
	EN	LP	EN	LP
FL	-0.15	0.00	-0.14	0.10
F	-0.05	-0.12	-0.01	0.13
T	-0.18	-0.03	-0.05	0.16
C	0.02	0.17	0.07	0.26
CP	-0.19	-0.13	-0.16	0.02
P	-0.14	-0.09	-0.10	0.08

right-ear accuracy and greater right than left late positivity amplitudes). This was not obtained when the entire sample ($N = 24$) was examined. The correlations obtained were small and nonsignificant (See Table 35). The lack of significant correlations may be due to a variety of factors. It may be that the correlation of two difference scores, rather than actual accuracy levels or amplitudes may have reduced the possibility of obtaining a significant correlation. In addition, it may be that the statistical analyses being used do not have enough power because of the relatively small number of subjects in the sample. This may have resulted in a type II error. It is noteworthy, however, that another study using samples as small as 15 subjects has been able to demonstrate a correlation between behavioral and ERP asymmetries (Van de Vijver et al., 1984). One other interpretation of these nonsignificant correlations is that there is no relationship between hemispheric asymmetry in ERP components and behavioral ear advantage for emotional stimuli. The studies that have demonstrated a relationship between these two measures have used cognitive tasks involving verbal (Van de Vijver et al., 1984) and tonal discrimination (Tenke et al., 1993).

VII. DISCUSSION

Behavioral Data

Two hypotheses regarding emotional perception, the right hemisphere hypothesis and the valence hypothesis, were investigated in this study. As was predicted by the right hemisphere hypothesis, there was an overall left-ear advantage in the accuracy of detecting target emotions. This finding is in keeping with previously reported left-ear advantages for accuracy of detection of 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 significant Valence by Ear interactions for accuracy measures provides more support for the right-hemisphere hypothesis than for the valence hypothesis. However, it is of interest to note that in the group of subjects with a left-ear advantage, this ear advantage was present for both positively- and negatively-valenced emotions, but was stronger for the negatively-valenced emotions. This finding is in keeping with the findings of Bryden & MacRae (1989). They reported that the left-ear advantage was marginally stronger for negatively- than positively-valenced emotions. These findings could be interpreted as partial evidence for the valence hypothesis. However, strong support for the valence hypothesis would have

taken the form of a left-ear advantage for negatively-valenced emotions and a right-ear advantage for positively-valenced emotions. This result did not occur.

Reaction time measures were included in this study to provide additional information regarding lateralization of perception of emotion. None of the previous dichotic listening studies examining emotional perception acquired or reported RT data (Carmon & Nachshon, 1973; Hatta & Ayetani, 1985; Herrero & Hillix, 1990; King & Kimura, 1972; Ley & Bryden, 1982; Mahoney & Sainsbury, 1987; Shipley-Brown et al., 1988). The RT data, overall, did not provide additional support for the right hemisphere hypothesis, as RTs to items presented to the left and right ears were comparable. The large variability of RT measures could account for this finding. This is in agreement with Sidtis's (1981) report that reaction time measures were less consistent ear-advantage markers than accuracy measures for tonal stimuli. However, it should be noted that individuals with a left-ear advantage tended ($p=0.06$) to show shorter RTs to items presented to the left ear (1.23 seconds) than to the right ear (1.27 seconds), as did women ($p=0.07$) (left ear = 1.21 seconds, right ear = 1.15 seconds). Thus, findings from the RT data are in the same direction as the accuracy data. With a larger sample of women or participants having a left-ear advantage or women,

this effect might become significant and might further support the right-hemisphere hypothesis. There was no support for the valence hypothesis. Reaction times to positively- and negatively-valenced emotions presented to the left and right ears were comparable.

As is often the case with dichotic listening tasks, not every participant demonstrated the anticipated left-ear advantage. In fact, the distribution seemed to be a continuum with 16.7% of the individuals demonstrating a right-ear advantage, 4.1% no ear advantage, and 79.2% a left-ear advantage. Similar individual differences in dichotic ear advantages have been seen for nonverbal stimuli such as complex tones (Tenke et al., 1993). It is noteworthy that the percentage of individuals demonstrating the LEA for the emotional dichotic perception task is comparable to the right-ear advantage often observed in response to consonant-vowel stimuli (Hughdahl, 1988). When divided into the LEA and NOLEA subgroups, demographic variables and degree of right-handedness were similar across groups. The differences in ear advantage between groups may reflect differences in the methods deployed during execution of the task. The consistently greater left than right early ERP negativity in the NOLEA group may represent an attentional bias favoring the right side that prevented the left-ear advantage in this

group.

Both accuracy and RT data reflected the greater ease in detection of interest target items over the other target emotions. This was probably due to differences in stimulus characteristics. One of the four interest items used in pair construction was stated as if it were a question. This feature could have enhanced the ease of recognition of this particular interest item and, thus, the overall accuracy level and RT measure of the interest category.

While women tended to have higher accuracy scores than men, as well as greater differences in left- and right-ear accuracy levels than men, for the identification of target emotions, a significant main effect of GENDER and a GENDER X EAR interaction were not obtained overall. When each group was analyzed separately, the females showed a significant left-ear advantage ($p = .0230$), and males showed a trend in the same direction ($p = .0883$). This finding is consistent with those of Saxby and Bryden (1984) who reported a stronger left-ear advantage for girls than for boys. Many of the other studies reported no differences in ear advantage as a function of gender (Carmon & Nachshon, 1973; Herrero & Hillix, 1990; King & Kimura, 1972; Ley & Bryden, 1982; Mahoney & Sainsbury, 1987; Shipley-Brown et al., 1988). Although the results in

this regard are not conclusive, the accuracy findings from our study are not inconsistent with other studies that show stronger right-hemisphere dominance in women than in men for tasks requiring emotional processing (Heller, 1993; Lavadas, Umilta, & Ricci-Bitti, 1980; Strauss & Moscovitch, 1981).

No gender effects were obtained for the RT data. However, when analyzed separately, females showed a trend for shorter RTs for target emotions presented to the left ear than to those presented to the right ear; a similar trend was not obtained for males. Thus, the current study provides some support for the suggestion that right-hemisphere lateralization for aspects of emotional perception may be stronger for women than for men.

In summary, the behavioral data reported in this study pointed to an overall right-hemisphere superiority for the identification of target emotions, which is supportive of the right hemisphere hypothesis. This is in contrast to a number of findings reported from facial emotional perception tasks (See literature review above), but replicates findings from auditory emotional perception tasks. One possible explanation for the discrepancies may be Sackeim's (1988) postulation that there are different aspects or elements involved in processing emotionally-laden information. He suggests that studies on

different aspects of processing may provide support for either the right hemisphere or the valence hypotheses. For example, one aspect of emotional processing is category accuracy. The other aspect is "response bias" which has to do with processing information not only regarding discrete emotion, but also intensity of emotion. Sackeim points to the fact that some of the studies providing support for the valence hypothesis use the response bias measure, while the majority of studies supporting the right hemisphere hypothesis use accuracy measures. It may be that subjects' ratings of emotion intensity led to a mild experiential element. Thus, the perceptual studies reporting evidence in support of the valence hypothesis may be reporting findings that are based on mild emotional experience rather than emotional perception.

Erwin et al. (1992) addressed this possibility by asking subjects to view slides of happy, sad, and neutral facial expressions and to rate the intensity of observed emotion on a seven-point scale ranging from very happy to very sad, with neutral as the midpoint. The ratings of happy and sad faces were done in two separate blocks. Happy and neutral slides were presented (one at a time) in one block, while sad and neutral slides were presented in the other block. Upon presentation of a slide of a white question mark, which was interspersed among the slides of facial expressions (this

occurred several times in each block) subjects were asked to rate their own emotional state on the same seven-point scale. The investigators found that emotional state ratings did not differ for the happiness-neutral and sad-neutral blocks. As a result, they concluded that exposure to happy and sad faces did not induce corresponding mood states in each respective block. Thus, other factors may account for the valence effect.

Electrophysiological Data

Summary

There was no evidence from the ERP data to support or refute either the right hemisphere hypothesis or the valence hypothesis. Contrary to the hypotheses, there was no asymmetry of the late positive components. In addition, there were no overall hemispheric asymmetries in amplitudes of the slow wave, a component that may indicate further processing of complex information. The only overall hemisphere asymmetry was found for N100, with greater negativity over the left than right hemisphere. This and the more complex asymmetries observed for the early negativity (dependent on such factors as ear of stimulus presentation), with greater left- than right- hemisphere amplitudes, may have had little to do with emotional perception per se and may have reflected responses to verbal stimulus characteristics or attentional biases of

the participants.

Contrary to expectations, the correspondence between behavioral asymmetries and hemispheric asymmetries in the late positivity amplitudes did not reach statistically significant levels as was postulated by the hypotheses. This may have to do with the fact that, overall, hemispheric asymmetry for this component was not obtained. The behavioral ear advantage for emotion may not be related to hemispheric asymmetry for late positive components. The studies that have found a relationship between these measures have all used cognitive not emotional discrimination.

N100

One of the most consistent ERP findings in this study was the greater negativity of N100 over the left hemisphere than over the right hemisphere. According to Naatanen and Picton (1987), the negativity in this component can be due to six separate factors: three separate N100 components generated in three separate cortical regions (auditory cortices, association areas of temporal and parietal cortex, and motor and premotor areas) (p.375), as well as separate processes (detection of mismatches in a stimulus sequence, attention-related processes). Although studies have found N100 amplitudes to be larger over the hemisphere contralateral to

the ear of presentation, this finding has been reported to be stronger for the left hemisphere (and right ear) and weaker or absent for the right hemisphere (Naatanen & Picton, 1987). These authors suggest that such N100 asymmetries result from asymmetry in pathways to auditory cortical regions in each hemisphere.

The overall hemisphere asymmetry effect found in our study for N100 suggests that, regardless of ear of presentation, the left hemisphere was more activated (as indicated by larger N100 amplitudes) than the right hemisphere in response to stimuli. It may be that in trying to balance hemispheric activation in this task, by the inclusion of stimuli composed of both syllables and emotional intonation, the consonant-vowels succeeded in activating the left hemisphere more than the emotional intonation was able to activate the right hemisphere. In fact, a study conducted by Wood, Goff, and Day (1971) (as reviewed in Naatanen & Picton's 1987 paper on N100) showed that when participants had to discriminate the stop-consonant factor of a consonant-vowel N100 was greater over the left hemisphere than when the subjects were asked to discriminate the tonal aspect of the stimulus. N100 amplitudes over the right hemisphere did not change as a function of which stimulus characteristics the subjects were to attend to. 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, but rather, reflects some aspect of left hemisphere processing of language stimuli.

A review of the studies that recorded ERPs to dichotically-presented verbal stimuli did not unequivocally confirm this interpretation. Two of the studies (Neville, 1974; Van de Vijver, 1984) involved dichotic presentation of digit sequences. Neville reported that in the dichotic condition N100 amplitudes were greater over the left than right hemisphere. Van de Vijver (1984) made no mention of asymmetries of this component. In the experiments involving dichotic presentation of consonant-vowels (Ahonniska et al., 1993) or consonant-vowel-consonants (Haaland, 1974), the former did not address issues related to N100 and the latter reported a lack of N100 asymmetry. Thus N100 asymmetries have not been consistently elicited in verbal dichotic tasks. Thus, while the asymmetries in the early negative components in the present study may be a result of the phonemic processing of the syllables, there is also room for other interpretations.

Early Negativity

The most robust and stable finding for the early negativity was the EAR X HEMISPHERE X ELECTRODE interaction, in which right-ear stimulus presentation resulted in greater hemispheric asymmetry (with the left hemisphere being more negative than the right) than did left-ear presentation. Although it is not clear what this negative potential represents, its fronto-central maximal distribution and duration suggest that it is akin to what has been called the sustained potential or negativity (Picton, Woods & Proulx, 1978a). This component has been elicited by long duration auditory stimuli. Its duration seems to correspond to the duration of the stimuli. The component has greatest amplitudes at frontal and central electrode sites. In addition, it is more negative than the N100 component at the frontal electrodes (N100 in response to auditory stimuli usually has its greatest amplitude at central electrodes). Increased neural activity is usually associated with greater negative sustained potentials (Picton et al., 1978a). This auditory sustained potential might derive from cortical negative potentials generated in the primary auditory cortex or in frontal association areas. The sustained negativity in response to binaural stimulation is not asymmetric. In addition, stimuli made up of tones of lower frequency elicit a bigger sustained negative potential than tones of higher

frequency (Picton et al., 1978b). It is thought that this negativity reflects a long duration sensory response.

Since this sustained negativity is symmetrical under conditions of binaural tonal stimulation, there must be some other factor resulting in the hemispheric asymmetry of this component observed in the present study. During the target detection task, throughout each block, the subject had a list of emotional categories, used in making the utterances, in front of them. This became necessary as participants often became confused as to which target emotion they had to attend to and how many they could select from when making their decisions. Thus, perhaps some subjects performed this task by expecting emotions with specific verbal labels. This additional processing of verbal information may have enhanced the negativity over the left hemisphere relative to the right.

Another possibility is that the greater negativity in the left-central regions reflects greater activation of the left hemisphere. The fact that the asymmetry is greatest at the central electrode (where N100 has its maximum amplitude) suggests that this early negativity asymmetry is a continuation of the asymmetry that began at N100. It may reflect spreading of activation from the central sites to the frontal sites concomitant with further processing of the

stimuli. This greater activation may be associated with emotional experience. Davidson and Tomarken (1989) have shown that left frontal activation (determined by EEG recordings) is a concomitant of emotional experience. Since this is a task requiring emotional identification for prolonged periods of time, subjects may have experienced the target emotion throughout each block. However, if the asymmetry was due to emotional-experiential components, the early negativity asymmetry should have been greatest at frontal electrode sites.

The difference in the pattern of early negativity asymmetry for the NOLEA and LEA groups may be meaningful. In the NOLEA group, the early negativity was consistently more negative over the left than right hemisphere, and their accuracy in identification of left- and right-ear targets was equivalent. However, in the LEA group, the early negativity was greater over the **right** hemisphere for the temporal electrode site. This negativity over the right hemisphere might have been associated with attentional factors that enabled the LEA group subjects to more accurately identify the emotional targets presented to the left ear.

Some studies that acquired ERP data to verbal dichotic stimuli have reported asymmetries in a negative component that

followed N100. This component was often labelled N200, but little explanation was provided regarding the cognitive process represented by this component. Although Neville (1974) reported an asymmetry in the N100 amplitude, with left hemisphere amplitudes greater than right hemisphere amplitudes, she reported no asymmetry for the N200 component. In contrast, Ahonniska et al. (1993) found that the N200 amplitudes were greater over the left (C3) than right (C4) central electrode sites in individuals who demonstrated a left-ear advantage to the verbal dichotic consonant-vowels. In our study, individuals with a left-ear advantage for target emotion identification also demonstrated greater early negativity amplitudes at left (C3) than right (C4) central electrode sites. The early negativity obtained in the present study may not correspond precisely to the negativities reported in the earlier studies; however, there may be some element of similarity, particularly the verbal aspect of the stimuli, which results in greater left hemisphere negativity in early ERP components in general.

The asymmetries in the early negative components (N100 and early negativity) obtained in the present study, though not anticipated, make an important point regarding the role of attentional factors in the production of ear-advantages. Kinsbourne (1978) has suggested that an attentional bias by

the left hemisphere to the right hemifield occurs in orientation and consummatory behaviors, and that this is governed by an organism's motivational state. More specifically, he suggests that attentional factors interact with hemispheric specialization to produce the right-ear advantage observed in verbal dichotic listening tasks. In the ERP literature, attention-related processing is usually indicated by negativities superimposed on early components such as the N100. In the present study, the early negative components were greater over the left hemisphere. Behaviorally, if Kinsbourne's notion of attention-driven ear-advantages is correct, the left-hemisphere negativities should have been accompanied by a right-ear advantage. This effect was not obtained for our emotional detection task. However, it is likely that a right-ear advantage would have been obtained had we also had subjects do a syllable detection task (See Bryden & MacRae study, 1989).

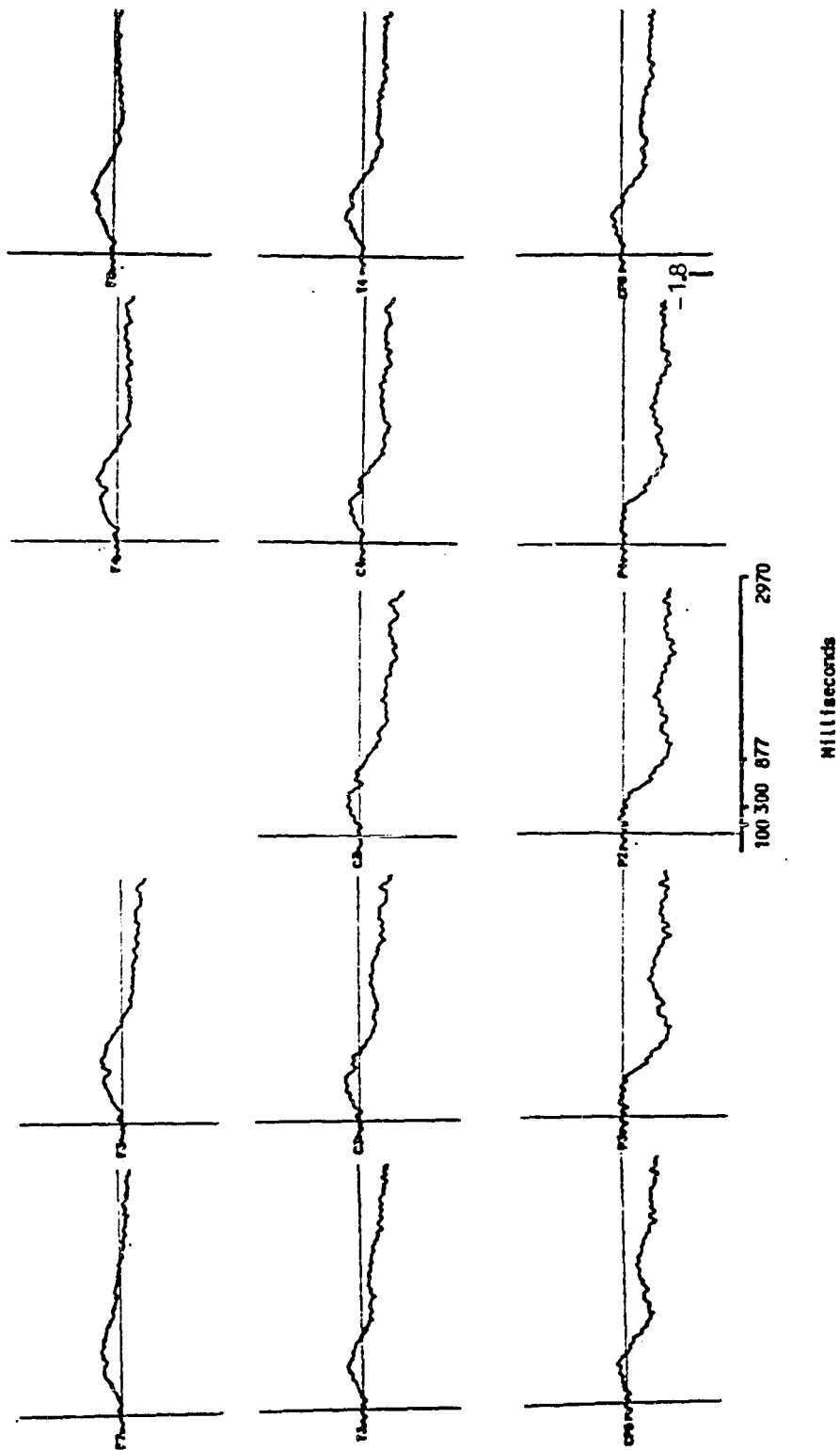
Late Positivity

The findings related to the late positivity are very similar to those obtained from the early negativity. The EAR X HEMISPHERE X ELECTRODE interaction had demonstrated that the left-hemisphere positivity to right-ear stimuli was smaller than the right-hemisphere positivity to right-ear stimuli. For left ear stimulus presentation, there was no apparent

asymmetry in this positivity over left and right hemispheres. This reduction in positivity over the left hemisphere may merely reflect the fact that this late positivity was superimposed on a larger (or longer lasting) early negativity. Thus, the greater early negativity and smaller late positivity over the left hemisphere to right-ear stimuli may be reflecting a unitary change that is continuous over the time domains selected for the determination of component amplitudes.

This late positivity seems to correspond to a P300 for several reasons. It is much larger to target items, which occur infrequently (30%), than to nontarget items, which occur more frequently (70%). Figure 19, which shows a difference wave of targets minus nontargets (correct rejections) clearly demonstrates this. In addition, the component had maximum amplitudes at posterior placements. Although there may be some overlap of this late positivity with the slow wave, lack of similar effects for analyses conducted for each of these components suggests that they are independent of one another. Again, the lack of an overall hemispheric asymmetry for the late positive (P3) component does not provide additional support for the right hemisphere hypothesis or the valence hypothesis.

Figure 19. Difference wave form obtained by subtracting target trials (correct detection) from nontarget trials (correct rejections) (microvolts).



Several ERP studies have reported a lack of asymmetries in late positive ERP components in response to emotional stimuli. In the auditory modality, in a task involving binaural emotional tone presentation, Twist et al. (1991) did not find a greater P300 over the right than left hemispheres in normal controls. RBDs, demonstrated smaller P300s than control subjects overall, yet, this effect was not lateralized.

In some studies involving the visual modality, acquisition of ERPs only from midline electrode placements did not permit investigators to address the issue of lateralization (Lang et al., 1990; Nelson & Nugent, 1990). However, three other groups of investigators did record ERPs over both left and right hemispheres, as well as from midline sites, while subjects were engaged in emotional perception of visual stimuli (Laurian et al., 1991; Kestenbaum & Nelson, 1992; Vanderploeg et al., 1987). They reported varied results. Laurian et al. (1991) found greater target minus nontarget differences for P300 amplitudes over the right centroparietal regions for perception of facial emotion. This effect was not obtained for neutral faces. In addition, they found that positively-valenced faces produced greater left frontal difference wave forms (target - nontarget) than did neutral or negatively-valenced faces. They interpreted these

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 appeared to issue, 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 and area measurements over the right hemisphere, but only at temporal electrode sites. This is unusual, as the task is one of facial perception and emotion discrimination, and greatest asymmetries in such instances should be at more posterior regions. Vanderploeg et al (1987) did not provide evidence of lateralized P300 differences, but reported larger slow wave amplitudes over the right than left hemisphere, regardless of emotional valence. If slow wave amplitude is inversely related to discrimination difficulty, this is contrary to expectation if the right hemisphere is more facile with emotion perception. Thus, the reports regarding lateralization for perception of facial expression are not consistent. The findings from the current study in the auditory modality do not deviate substantially from what has been reported for both facial and auditory emotional

perception.

Slow Wave

As thoroughly reviewed by Ruchkin et al. (1988), the slow wave occurs in response to several task demands. It was suggested by these investigators that slow waves with negative values are elicited when scanning and mental imagery are involved and that "positive slow waves are associated with memory storage, rule learning, and perceptual operations" (p.341). They also indicated that the slow wave amplitude is related to perceptual difficulty with greater positivity reflecting greater task difficulty. The slow waves obtained in response to emotional identification in the present experiment did not show a hemispheric asymmetry. It should be noted that a larger slow wave was obtained in response to negatively-valenced target items than to positively-valenced items. The greater slow wave amplitude to negative emotions may have to do with the negatively-valenced emotions having greater salience than positively-valence emotions. It may also have been due to greater difficulty in identification of negatively-valenced (accuracy of 70%) than positively-valenced emotions (accuracy of 73%); however, differences in accuracy levels were not statistically significant.

Women exhibited smaller slow wave amplitudes to items presented to the left ear than to the right ear, suggesting that it was easier for them to process emotional information presented to the left ear than to the right ear. Males did not show this effect. Although there were no statistically significant correlations between behavioral accuracy and slow wave amplitude across subjects, other studies have found correlations between these measures (these tasks were not emotional tasks) (Bruder, Towey, Friedman, Erhan, Jasiukaitis, & Tenke, 1992). As mentioned earlier, the small number of subjects may have resulted in low power of the statistical tests, thus resulting in type II errors. Thus, it may be concluded that while the slow wave appears to be involved in the processing of emotional information, it is not unique to emotional processing, and is not manipulated only by factors related to emotional processing.

Conclusion

The emotional dichotic listening task developed in this study was successful in eliciting a left-ear advantage, for accuracy measures, which confirms prior findings for dichotic emotion perception tasks. The behavioral results obtained were in keeping with right-hemisphere dominance for perception of emotion. However, as in other studies looking at behavioral advantage for dichotically presented stimuli

(Ahonniska et al., 1993; Tenke et al., 1993; Van de Vijver et al., 1984), not all individuals showed this effect. In addition, women tended to show a stronger lateralization for emotional perception than did males. Overall reaction time measures did not provide additional information regarding the right hemisphere or valence hypotheses, although in the LEA and women subjects, a trend for a left-ear advantage lent support to the right hemisphere hypothesis. The left-ear advantage for emotional discrimination was independent from the overall ERP asymmetry effects found for N100 and from the more complex interactions with hemisphere found for the early negativity and late positivity. This is contrary to the strong relationships between behavioral and event-related potential asymmetries for tasks involving discrimination of dichotically-presented complex tones (Tenke et al., 1993) and nonsense syllables (Van de Vijver et al., 1985). This could be related to the difference in task demands (emotional versus cognitive discrimination) or to insufficient statistical power in the present study.

The main ERP asymmetry found in this study was for N100, and there was no overall asymmetry for the late positive component (P300), which had been hypothesized. This may have been due to the relatively mild intensity of the emotional utterances used. Items with emotional ratings as high as 95

to 100 percent accuracy might produce the expected ERP hemispheric asymmetries. However, the problem with using stimuli with such high accuracy levels is the possibility of the ceiling effect, which would make calculation of ear asymmetries implausible.

There were hemispheric differences in the early negativity component and these asymmetries depended on ear of stimulus presentation and electrode site; the negativity was greater over the left than right hemispheres, particularly for right-ear stimulus presentation, and most notably at the central electrode site. Event-related potential findings from our study did not provide additional support for the right hemisphere hypothesis and suggest that stimulus characteristics other than emotional content were driving the amplitudes and hemispheric asymmetries for the early negative components. One very strong possibility is that the left hemisphere was more actively engaged than the right hemisphere by the phonemic aspect of the stop consonants present in the CV syllables. For instance, temporal characteristics in the initial burst onset of the consonant vowels presented may activate the left hemisphere more than the right hemisphere. Tallal, Stark, and Mellis (1985) report that it may be the "rapidly changing acoustic cues...that underlies left-hemisphere superiority for speech processing" (p.321). Thus,

even though subjects were instructed to focus on the emotional content, they may have nonetheless processed other temporal or acoustical informational changes. However, inconsistent findings from previously conducted experiments acquiring ERPs in response to verbal dichotic stimuli indicate that this explanation needs further investigation.

In summary, this study has replicated the previously reported left-ear advantage for auditory perception of emotion. It provided information regarding reaction times measures which had not been reported before in the dichotic listening paradigm used to examine emotional perception. It appears that reaction time measures could provide some useful information regarding lateralization of emotional perception, particularly in individuals with a strong left-ear advantage and in women. This study also provided gender-related findings which have not been commonly reported in the dichotic listening and event-related potential literature. There are many potential applications of this newly developed dichotic listening task. For instance, it may prove useful in understanding changes in hemispheric functioning in psychiatric populations. It may also be helpful in understanding gender-related differences in affective disorders, as well as disruptions in affective functioning in schizophrenics with flat affect.

Future Directions

To control for effects other than emotional content that may have affected the outcome of this study, two recommendations are made for future research. This task could be done with altered instructions to determine whether the hemispheric asymmetry of early negativity is indeed in response to the phonemic aspect of the stimuli. The subject's task would be to respond to a target syllable rather than a target emotion. Thus, subjects would listen to the same items used in the emotional dichotic listening task and respond to a target syllable such as "ba" or "ga". If the hemispheric asymmetry of the early negativity is a result of phonemic or acoustic aspects of the stimuli, there should be greater asymmetry when the participant is actively attending to this phonemic aspect of the stimulus than when the subject is asked to detect target emotions. This study poses the question whether the greater left-hemisphere negativity is a function of the attentional demands of the task. In other words, if subjects attend to the consonant-vowel, will the early negativity get larger over the left hemisphere? It is also possible that the asymmetry of early negativity asymmetry reflects an automatic process. In this case, the asymmetry of early negativity would remain unchanged.

At the behavioral level, it would be of interest to determine whether the left-ear advantage obtained in the divided-attention condition could be maintained in a directed-attention condition that uses a pull cue preceding each trial (Mondor & Bryden, 1991, 1992). In fact, a version of the directed-attention task was developed for this study. However, the additional time taken by the divided-attention condition prohibited administration of both tasks to subjects. In addition, we wanted to initially confirm that a left-ear advantage would indeed occur in response to emotional stimuli. In the directed-attention paradigm, a cue serves to pull the attention of the listener to the desired ear. Mondor and Bryden (1991, 1992) have found that this procedure reduces the ear advantage obtained to both verbal and nonverbal stimuli. Thus, if attention does play a role in producing the left-ear advantage observed for emotional stimuli, then the left-ear advantage should be reduced in the directed-attention condition. This measurement of behavioral ERPs in the directed-attention paradigm would be a reasonable next step in this research.

Appendix A

This appendix contains a description of the Principal Component Analysis procedure used as an objective tool to assist in the determination of appropriate time windows for the definition and measurement of ERP components described in the text. In order to objectively determine the time windows appropriate for computing the average amplitude of the components, ERPs averaged separately for six conditions (happy hits, interest hits, anger hits, sadness hits, all left hits and all right hits) for each participant were submitted to a cross-products matrix principal components varimax (PCVA) procedure (BMDP P4M; Dixon, 1985). These six conditions were submitted to permit an analysis of the contribution of each emotion (i.e., happiness, interest, anger, sadness) and ear of stimulus presentation to the variability that might occur in the average ERP wave forms. Though inclusion of these conditions involves some redundancy, it is unlikely that this would affect the outcome of the PCA analysis. If all possible wave forms had been included in the analysis (such as left happy hits, right happy hits, etc.), the size of the data file submitted to the PCA would have been prohibitive. Thus, those wave forms best representative of the factors of emotion and ear of stimulus presentation were selected.

The use of PCVA has been criticized by Wood and McCarthy (1985) primarily because the procedure does not guarantee that

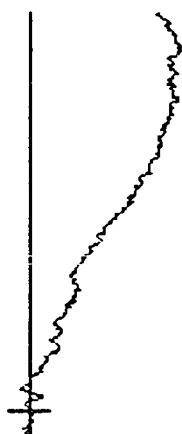
independent components extracted by the procedure do not overlap to some extent. However, there is not yet a better method to assist in such endeavors at this time (Mocks and Verleger, 1986). Wood and McCarthy point out that there are ways to determine if the overlap between components remains following PCA analysis. Keeping these hints in mind will enable avoidance of errors in data interpretation that could occur. In addition, it should be noted that PCA was not the sole determinant of the components defined and analyzed in this study. In addition to this, each individual's data were closely reviewed and the polarity, number, and peaks of visible components were noted.

Three components shown in Figure 20 accounted for 94.37 percent of the overall variance. The first factor, with a wave form and scalp distribution (positivity increasing from frontal to parietal electrode placements) in keeping with a late slow wave, accounted for 21.37 percent of the variance. The second factor, with a wave form and scalp distribution (factor scores negative at frontal sites and positive at central and parietal sites) in keeping with the P300 (which is called a late positivity throughout this paper owing to an onset much later than 300 milliseconds post-stimulus onset), accounted for 26.70 percent of the variance. Finally, a third factor, with a negative going wave form and scalp distribution

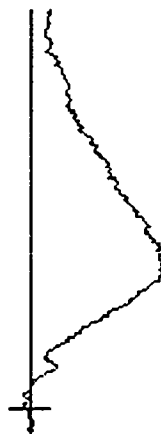
Figure 20. Three components obtained from factor loadings of Principal Component Analysis accounting for more than 30% of the variance.

PCA

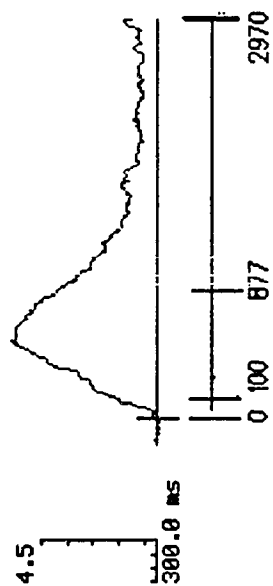
FACTOR 1



FACTOR 2



FACTOR 3



in keeping with the sustained negative potential (most negative at frontal and central sites and positive at parietal sites) accounted for 21.37 percent of the variance. The three factors described above overlap to some extent. Their points of intersection were used to help determine the windows over which average amplitudes for each component would be made.

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