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Event Related Potentials (ERP) and Behavioral Responses: Comparison of Tonal stimuli to speech stimuli in phonological and semantic tasks.

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Abstract

Event Related Potentials (ERPs) were recorded from 20 young subjects to auditory target stimuli while they were performing three different tasks, using an odd-ball paradigm; 1. Tones: Subjects were instructed to respond to a 2kHz tone, and ignore a 1kHz tone. 2. Phonological: Subjects were instructed to respond only to words that had a specific ending ("f"). 3. Semantic: Subjects were instructed to respond to words that belonged to a specific category (name of alphabetic letters). EEG was recorded from 19 electrode sites. Peak amplitude of the early component (N100) did not differ significantly across the three tasks, while peak latency differed significantly across stimuli. In contrast, the later endogenous component (P300) was stimulus- and task-dependent. P300 latency differed significantly across stimuli and tasks; 327 ms to target tones; 668 ms to the phonological targets; and 706 ms to target words in the semantic task. P300 amplitude was significantly larger to tones than to linguistic stimuli. P300 peak amplitude recorded from electrode sites over the left hemisphere to the tonal target stimuli did not differ significantly from that recorded over the right hemisphere. In contrast, P300 amplitude recorded to both the phonological and semantic targets was significantly larger over the left hemisphere than over the right hemisphere. The present results can aid in our understanding of how humans process linguistic stimuli. These findings emphasize the importance of using similar experimental protocols for a broad comparison of the ERP response to a variety of stimuli and tasks.

Introduction

The process of auditory speech perception requires the use of sensory information in conjunction with linguistic knowledge. Event related potential recordings which have been increasingly used in the research of human cognitive processes, can provide information on the patterns of cortical activity that underlie different modes of processing various kinds of auditory and linguistic information.

The use of P300 for auditory presented tonal stimuli is well known. Studies have compared the ERP responses to tonal stimuli to vowels (Tiitinen et al 1999), syllables (Kayser et al 2001) or words (Lovrich et al 1988) and reported prolongation of latency as well as decrease in amplitude. These differences reflect the involvement of different processes in tonal and speech stimuli.

Using tonal stimuli Polich (1997)) reported an asymmetry in P300 amplitude with right hemisphere dominance specifically at the frontal and central electrode sites. They interpreted the data as reflecting the allocation of attention. Other researchers (Bruder et al 1999, Breier et al 1999) did not observe any laterality effect. Using speech stimuli a left hemisphere advantage was observed for phonemes, syllables (Kayser et al 2001, Alho et al 1998) and word stimuli (Breier et al 1999).

Studies have examined ERP morphology and topography using linguistic stimuli (Novick et al 1985, Henkin et al 2002). There seems to be an agreement among researchers that while phonological processing is characterized by a left hemisphere advantage, semantic processing is less localized, since it involves the activation of distributed networks in the brain (Lovrich et al 1988, Thierry et al 1998, Angrilli et al 2000).

In the present study, we used the oddball paradigm to generate a clear P300 component. We suggest that this paradigm, and specifically the P300 component, is appropriate to compare the ERP to a variety of target stimuli that lie along a continuum of auditory processing, from basic sensory discrimination of auditory features (tones) to cognitive language processing (e.g. phonology and semantics).

Methods

Subjects:

Twenty University students ranging in age from 20-26, mean age 22.5 (10 male and 10 female) participated in the study as part of their course requirement. Written informed consent was obtained, and the Bar Ilan University Ethic committee approved all experiments.

All subjects reported they were right handed, native Hebrew speakers, healthy and had no history of neurological or psychiatric disease. All passed a hearing screening test performed in a quiet room using the Madsen OB 822 audiometer.

Stimuli:

Three different auditory tasks were tested using the oddball paradigm. One task consisted of tonal stimuli, and the other two tasks consisted of speech stimuli:

Tones: Subjects were instructed to respond to a 2kHz pure tone target and ignore the standard 1kHz tone. The tone duration was 50ms with rise/fall time of 10ms, and an interstimulus interval (onset to onset) of 2 sec.

Speech stimuli: High frequency Hebrew monosyllabic short words were chosen as stimuli. The duration of word stimuli ranged between 450-500ms. The same initial phonemes were used for both targets and nontargets so that discrimination between the targets and nontargets was only possible if the subject attended to the last phoneme. For example: If the target was “kaf” (alphabetic letter), the nontargets were “kal” (easy) or “kar” (cold). In a series of pilot experiments, we attempted to record ERPs using 11different target stimuli. The waveform in the expected P300 window was extremely spread with no clear peak. Consequently, in the present experiment we used three different targets and twelve nontarget stimuli to generate a clear P300 (See figure 1).

Two linguistic tasks were included in the experiment:
Phonological: Subjects were instructed to respond only to words that had a specific ending ("f").
Semantic: Subjects were instructed to respond to words from a specific category (name of Alphabetic letter).

The exact same target and nontarget words were used in the two speech tasks so that we could compare the behavioral and ERP responses to the same target stimuli in the two different linguistic tasks.

The oddball paradigm was programmed on a PC with the Audio task editor, Orgil medical equipment. In all experimental tasks conducted, a total of 180-195 stimuli were presented, thus the probability that a stimulus would be a target was 0.2. Stimuli were presented binaurally at 60 dBSL.

Procedure:

During the experiment subjects were instructed to fixate on a point located 1.5meters distant on the wall facing them, while keeping eye movement, blinks and general body movement to a minimum.
Subjects were instructed to press a button when detecting the target stimuli. A practice run was used to ensure that all individuals understood the task. Presentation order of the different conditions was counterbalanced across subjects. The entire session (of all 11 tasks not all reported here) lasted not longer than 3.5 hours.

The recording system:

The electroencephalogram (EEG) was recorded from 19 sites on the scalp according to the International 10-20 system referenced to back of neck. A ground electrode was placed on the right mastoid. An additional electrode placed below the right eye recorded electrooculogram (EOG) to monitor eye movement. The impedance measured for each electrode was lower than 7k ohm. The EEG program used to collect the data was Ceegraph IV Digital EEG system Biologic Corp. Raw data was continuously recorded with a band pass filter at 0.1-100Hz, sampling rate was 256Hz. Signals were amplified and digitized on line with a 4ms step.

All data underwent analysis using BPM Orgil medical equipment. Recordings were first segmented into epochs that were time locked to the stimuli and extended from 200ms pre-stimulus to 1800ms post-stimulus. Behavioral reaction time and accuracy were measured. The data were referenced to a common 100 ms pre-stimulus base line. Trials containing eye blinks or movements, excessive muscle activity artifacts were corrected or rejected. If more than 15 of the 35-40 sweeps of a given target were rejected for any reason, then all of the data in that condition for that subject was rejected. Thus, each ERP was based on a minimum of 20-25 sweeps.

Recordings to the target were averaged separately from recordings to the standard stimuli. The responses to standards preceding the targets were averaged and used as the comparison. ERPs were originally analyzed for correct response only. Because there were no differences between the averaged ERPs for correctly detected targets and those for all targets, further analysis was based on the later.

In a collateral behavioral experiment eight young naive subjects were instructed to write down exactly what they heard. Target words were cut and segmented in 25 ms intervals from 200ms to 500ms. All the segments were rearranged and randomly presented. The earliest cut off point where at least six subjects recognized the word correctly was defined as the point of identification for that word (e.g. "taf" was identified at 300ms). The results indicated that although the length of the words in the present experiment ranged from 450-500ms, all the words were correctly identified within the range of 275-350ms after word onset. ERP recording analysis were time-locked both to stimulus onset, and also to the point of identification based on the behavioral judgments. Using averaging to behavioral point of identification rather than to the onset of stimuli showed no significant difference in P300 peak latency and amplitude.

The measurements:

Behavioral measures of reaction time and performance accuracy were recorded as well as electrophysiologic measures. ERP's were quantified in terms of peak latencies and peak amplitudes of the maximum negative or positive values within specific time windows. The time window for the different components was determined by visual inspection of the grand averages over all subjects. N100 was identified as the most negative point between 50 and 180ms post-stimulus. P300 peak amplitude was identified as the maximum positive point between 250 and 450ms for tones and 550 to 900ms for the speech stimuli.

Statistical analysis

Latency and amplitude values as well as behavioral measures were subjected to repeated measures analysis of variance (ANOVA) with 3 levels of task as well as 6 levels of electrode site as within subject factors. The level of significance was set to p<0.05.

Correlation tests were preformed between tasks, between behavioral and electrophysiological components.

Results:

Behavioral results:

The accuracy and reaction time data were analyzed (each separately) by a one-way analysis of variance (ANOVA) with task as a repeated variable. Accuracy measured as percent of target detection was not significantly affected by task. Task had a significant effect on reaction times to target stimuli ($F[2,36]=109.426$, $p<0.001$). Post hoc analysis revealed that the response to the target tones was always shorter than to the target speech stimuli ($p<0.001$), with no significant differences in RT within the speech stimuli (Table 1).

Table 1: Behavioral results of accuracy and reaction time averaged from all 20 subjects.

		tone	phonology	semantic
Accuracy (%)	Mean SD	93.74 8.04	93.94 9.87	90.1 11.82
Reaction time (ms)	Mean SD	459.95 87.46	829.67 92.27	869.3 98.72

Electrophysiological results:

Latency: Latency values (N100 and P300) were analyzed separately by a repeated measure analysis of variance (ANOVA) with 3 levels of task as a within subject factor. Both N100 and P300 latencies showed a significant main effect of task (N100 $F[2,38]=12.35$, $p<0.001$; P300 $F[2,38]=217.561$, $p<0.001$) (Table 2). Post Hoc analysis showed that N100 latency to the target in the tonal task was significantly shorter than to targets in both speech tasks ($p<0.001$). However, there were no significant differences in N100 latency to targets in the phonological task versus targets in the semantic task. Post hoc analysis revealed that P300 peak latency was significantly shortest to tonal stimuli ($p<0.001$), and within the speech stimuli, P300 latency to targets in the semantic task was significantly longer than to the targets in the phonological task ($p<0.044$) (Figure 1).

There were no significant correlations between any of the behavioral and electrophysiological measurements.

Table 2: N100 and P300 latency results averaged from all 20 subjects

		tone	phonology	semantic
N100 latency (ms)	Mean SD	91.48 29.14	129.48 25.51	124.4 22.53
P300 latency (ms)	Mean SD	327.5 18.76	668.71 78.4	705.58 74.34

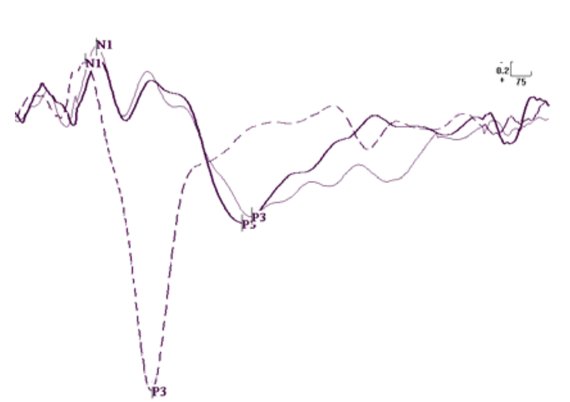

Figure 1: Grand average from all 20 subjects for the 3 tasks recorded at the Pz electrode. As can be seen, N100 latency was shorter for the tonal targets (dashed line) than the phonological (thick) and semantic (thin) targets. The P300 was shortest in latency and had larger amplitude to tonal targets as compared to speech targets.

Amplitude and Topography: A general repeated measure ANOVA with 5 levels for electrode site (frontal, central, parietal, occipital and temporal) revealed P300 amplitude was largest in parietal electrodes (Main effect of electrode site $F[4,76]=9.023$, $p<.001$). Further statistical analyses were performed on selected sets of scalp sites. On the basis of the observed distributions, the statistical analysis of ERP was limited to the central and parietal electrode sites (C4, Cz, C3, P3, Pz, P4).

Peak amplitude of N100 and P300 were analyzed separately by a two-way repeated measures analysis of variance (ANOVA) with 6 levels of electrode site and 3 levels of task as within subject factors.

N100: N100 amplitude showed a main effect of electrode site ($F[5,92]=144.194$, $p<0.001$) and did not show any significant effect of task. Post hoc analysis indicated that N100 peak amplitude was largest over the central electrode sites ($p<0.001$).

The degree of hemispheric asymmetry was computed by subtracting N100 peak amplitude recorded over the right hemisphere from that recorded over the left hemisphere (see Bellis et al 2000 for use of a similar index). As seen in

Figure 2 there was no significant difference in N100 amplitude recorded from the electrode sites over the left hemisphere (c3, p3) as compared to the electrode sites over the right hemisphere (c4, p4), for targets in either tonal, phonology or semantic tasks.

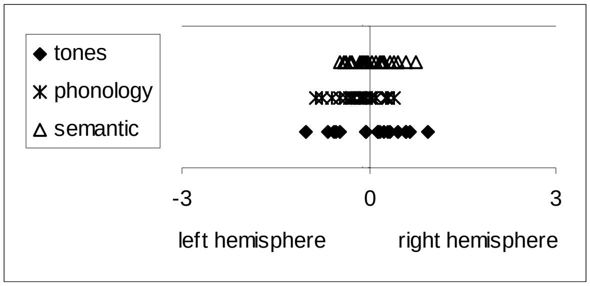

Figure 2: Degree of hemispheric symmetry in N100 amplitude. Results indicate responses were essentially symmetrical across all tasks.

P300: P300 peak amplitude was significantly affected by two of the variables, task and electrode site ($F[2,38]=21.08$, $p<0.001$; $F[5,95]=61.256$, $p<0.001$ respectively) as well as a two-way interaction of task X electrode site ($F[10,195]=3.021$, $p<0.001$). Post hoc analyses showed that the largest P300 amplitude was recorded over the parietal sites ($p<0.001$), and when comparing the tasks the largest P300 amplitude was recorded to targets in the tonal task ($p<0.001$).

P300 amplitude to targets in the tonal task were distributed symmetrically over the electrode sites. There was no significant difference in P300 amplitude recorded to tonal targets from the electrode site over the left hemisphere as compared to the comparable electrode site over the right hemisphere. In contrast, for both the phonological and semantic speech tasks, P300 amplitudes recorded from the parietal electrode site (p3) over the left hemisphere was significantly larger than P300 amplitude recorded from the parietal electrode site (p4) over the right hemisphere (phonology $t[18]=2.551$ $p<0.02$; semantics $t[18]=4.392$ $p<0.001$). (Figure 3).

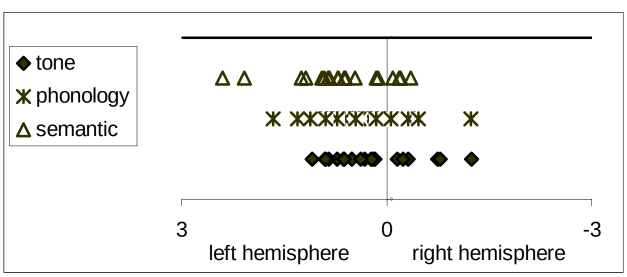

Figure 3: Degree of asymmetry for P300 amplitude. While for the tonal stimuli responses were essentially symmetrical, a significant degree of asymmetry can be seen for both speech stimuli, most pronounced in the semantic task, favoring the left hemisphere.

At the central electrode sites the distribution of P300 was symmetrical.

Discussion

Behavioral

The average accuracy scores for the 3 tasks ranged between 90-94% (Table 1). The high level of accuracy may have caused a ceiling effect and resulted in the inability to differentiate among the three tasks (Henkin et al 2002). In contrast, RT was sensitive to the different tasks. RT to targets in the tonal task was significantly shorter than to the targets in the two speech tasks. Although we did not find significant differences in RT to the targets in the phonological task versus targets in the semantic task, earlier studies did report such a difference (Novick et al 1985, Henkin et al 2002). The present study differs from the two earlier studies in that the construction of the targets in both the phonological and semantic tasks was such that subjects could not differentiate targets from nontargets unless they attended to the last phoneme. This may have presented a more difficult task than either of the earlier studies whose stimulus construction allowed for discrimination of targets from nontargets at an earlier stage of stimulus processing.

N100

The largest N100 peak amplitude was recorded over the central electrode sites. There were no significant differences between N100 recorded to targets and to nontargets in any of the tasks. Furthermore, there was a significant correlation between N100 to target and non-target in each of the tasks. These findings support the hypothesis that N100 represents obligatory primary sensory processing dependant upon the arrival of any stimuli at the auditory cortex, but does not by itself indicate any sort of discrimination or any of the task requirements (Martin et al 1999).

The N100 latency to the tonal stimuli was always shorter than to the speech stimuli, but there were no significant differences in N100 latency between the two speech stimuli. Similar results were previously reported (Wunderlich and Cone-Wesson 2001). Since N100 is an exogenous wave, it is sensitive to changes in the basic physical characteristics of the stimuli.

P300

As noted above, the P300 paradigm was chosen as the experimental technique so that the same electrophysiological components might be compared across a variety of stimuli and tasks.

In the present study P300 latency showed significant differences between the responses to tones and to the speech stimuli (327ms versus 668-706ms). The increase in latency for speech stimuli compared to tonal stimuli was reported previously (Tiitinen et al 1999, Kayser et al 1998). We tested the hypothesis that the difference in P300 peak latency to tonal targets as compared to speech targets was due to the specific construction of the speech stimuli which required attention to the last phoneme before discrimination was possible. Subjects could only discriminate the target from the nontargets after hearing the last phoneme of the word while they could theoretically begin the process of discriminating the tone target from the tone nontargets beginning with stimulus onset. Furthermore, the duration of the tonal stimuli was 50ms, while the duration of the speech stimuli ranged between 450-500ms. This would mean that the difference in P300 peak latency to targets in the tonal task versus targets in the speech tasks should be directly related to the duration of the speech stimuli necessary to discriminate the words (Woodward et al 1990). In an adjunct experiment, we found that the average word identification point ranged between 275-350ms after word onset. Note the additional amount of time required for identification of speech stimuli (approximately 325ms) coincides with the time difference between P300 latency of tones (327ms) and P300 latency of speech stimuli (668-706ms).

Alternatively, it is possible that processing speech stimuli takes longer than processing tones. Therefore, the difference in P300 peak latency to tone targets versus speech targets also included the differences in processing time to the two types of stimuli (Bentin et al 1999).

The present findings can be related to the ongoing debate concerning the identity of the late ERP potential recorded to speech stimuli within the 500-750 ms time window, the "identity" thesis. Coulson et al (1998) argued that ERPs recorded in complex cognitive tasks are basically identical to (or are just modifications of) waves found in simpler conditions. Particularly, the P600 component of the scalp recorded event-related brain potential related to syntactic violation processing is just a delayed P300 similar to that recorded in simple oddball tasks (both are sensitive to probability manipulations and are similar in their respective scalp distribution). Kotchoubey and Lang (2001) used a paradigm in which subjects discriminated infrequent targets from frequent standards based on a semantic feature (e.g. animals versus other common nouns), this paradigm elicited a positive parietal wave in the 600 ms window frame. They argued that the P600 is an oddball delayed P300 component elicited in a semantic oddball experiment to more complex stimuli.

The alternative view states that there exist specific ERP waves manifesting brain mechanisms of language processing (Osterhout et al 1994, Frisch et al 2003). The late positive wave P600 recorded in response to syntactically anomalous words manifests specific brain mechanisms of syntactic processing.

Comparison between speech tasks: P300 latency to target stimuli in the phonology word tasks was significantly shorter than to targets in the semantic tasks. Similar results have been reported (Novick et al 1985, Cobianchi and Giaquinto 1997)

Topographical distribution

Tones: In our study both N100 and P300 peak amplitude in the tonal task were distributed symmetrically over the two hemispheres. These results are similar to previous reports using pure tones (Breier et al 1999) as well as complex tones (Bruder et al 1999, Kayser et al 2001).

Speech tasks: In the present study, While N100 peak amplitude distribution was symmetrical over the two hemispheres, P300 peak amplitude to the targets in the two speech tasks, was significantly larger when recorded from the parietal electrode over the left hemisphere (p3) as compared to the right hemisphere (p4). Similar results were reported in other studies using phonemes, syllables (Kayser et al 2001, Alho et al 1998) and words (Breier et al 1999). It is important to note that the change from hemispheric symmetry in tonal stimuli to hemispheric asymmetry in speech stimuli was found only for the P300 component and not for the N100 component (compare Fig 2 and 3). This dissociation of the two ERP components further emphasizes their different electrophysiological representations and may point to a dynamic change of hemispheric interaction in the processing of speech stimuli over time.

Phonology vs. semantics: A number of imaging and ERP studies have concluded that while phonological processing is more confined to regions of the left hemisphere, the semantic processing is less localized, since it involves the activation of distributed networks in the brain. (Ferlazzo et al 1993, Cobianchi and Giaquinto 1997, Thierry et al 1998, Angrilli et al 2000, Connolly et al 2001). For example, imaging studies demonstrated that phonological processes are related to Broca's area and the left inferior frontal gyrus (Demonet et al 1992, Becker at al 1999). However, during lexical-semantic tasks there is a wider cortical distribution of activation, not confined only to the left temporal and inferior frontal areas (Zatorre et al 1992, Kareken et al 2000, Zahn et al 2000). In the present study we found hemispheric asymmetry favoring the left hemisphere to targets in both the phonological and semantic tasks and did not find a significant difference in the hemispheric asymmetry of P300 peak amplitude favoring either the targets in the phonological or semantic tasks. These results are in line with several imaging studies (Poldrack et al 1999, Johnson et al 2001) that point to a greater activation of left hemisphere neural systems for both semantic and phonological tasks.

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