To the Graduate Council:

I am submitting herewith a dissertation written by Celia Sue Bessel Hume entitled "Neurophysiological Correlates of Meaningful and Nonmeaningful Sentence Processing." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Speech and Hearing Science.

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The Graduate School

NEUROPHYSIOLOGICAL CORRELATES OF MEANINGFUL AND NONMEANINGFUL SENTENCE PROCESSING

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Celia Sue Bessel Hume

June 1984

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DEDICATION

This dissertation is dedicated to the memories of my father, Albert G. Bessel, and uncle, the Honorable Fred B. Cramer, who believed in the pursuit of higher education and always encouraged my academic goals.

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ABSTRACT

Event related potentials (ERPs) were utilized to investigate the influences of sex and presentation on meaningful and nonmeaningful sentence processing. Amplitude and latency values were recorded from a central (Cz) and left parietal (P3) electrode location beginning with the onset of the last (Key) word or nonsense syllable in the sentence. The ERPs were recorded for approximately 1000 msec, and peaks were recorded within three different time windows: 52.5 to 170.0 msec (N100), 172.5 to 285.0 msec (P200) and 290.0 to 580.0 msec (P300). Two of the amplitude measures, P200 and P300, were referenced to the N100 component by measuring the peak-to-peak amplitudes resulting in N100P200 and N100P300 measures. Peak latencies corresponding to the N100, P200, and P300 amplitudes were also computed.

Seven young female adults and seven young male adults listened to two identical presentations of ten randomized recordings of each of the ten stimulus sentences (200 total sentences). The ten different sentences consisted of five pairs with each semantically inappropriate sentence differing from its cognate sentence in the final (Key) word or element. Two of the semantically inappropriate sentences contained real words inappropriately placed in the final position. The other three (phonemic) semantically inappropriate sentences contained a nonsense CVC which differed from its cognate sentence in the final phoneme of the CVC.

Subsequent analyses of variance and planned comparison testing indicated the following results:

1. Females manifested significantly more positive N100P300 amplitudes than males at Cz and P3. These amplitude differences between females and males were also statistically significant at N100 and N100P200 for Cz, but not for P3.

2. Semantically inappropriate sentences were generally significantly more negative (N100) or more positive (N100P200, N100P300) than the semantically appropriate sentences at Cz and P3.

3. N100P200 amplitude was significantly more positive for the semantically inappropriate sentences with the real words tall and teeth for Cz and P3.

4. N100P300 amplitude reflected statistically significant differences between the phonemic-semantically inappropriate and phonemic-semantically appropriate sentences.

5. Latencies were generally shorter for the semantically inappropriate sentences, however, these differences were not as pronounced nor as consistent as the amplitude differences.

6. Although there were no significant differences in the main effect Presentation, ERPs for the first presentation generally manifested more positive waveforms than did the second presentation.

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CHAPTER I

INTRODUCTION

Brain-language relationships have traditionally been formulated from surgical and postmortem studies comparing particular areas of damage in the brain with resulting linguistic behaviors. However, with recent advances in Event Related Potential (ERP) research, it is now possible to study ongoing neural activity related to language processes. Molfese (in press) summarized the state of the art of language related ERP studies in his chapter, "Event Related Potentials and Language Processes," in Gaillard and Ritter's (Eds.) Tutorials in ERP Research in Endogenous Components. According to Molfese, ERP measures do appear to be sensitive to various language relevant stimulus manipulations including phonological cues, such as voicing and place of articulation (Molfese, 1980a, b; Dorman, 1974, 1978a); syntactic/denotative semantic manipulations (Brown et al, 1973, 1976, 1980); and connotative meaning manipulations (Begleiter and Platz, 1969; Chapman et al, 1977). However, Molfese also cited numerous methodological flaws and the absence of a theoretical framework as limiting factors in the contribution of this work. He stressed the need for stricter control of stimulus influences (e.g. rise/decay times, loudness level, masking) as well as use of a strong theoretical model.

In time ERP techniques may not only offer new insights into the study of neurolinguistics but may also become powerful clinical tools. Refined computer technology and more sophisticated methods of central nervous system (CNS) stimulation have contributed to the more recent

applications of ERPs in the clinical neurosciences (Greenberg and Ducker, 1982). The routine use of Brainstem Evoked Response Audiometry is one instance of clinical application of the early, or exogenous, components. Neurophysiological correlates to behavioral measures would also be invaluable in the study of language development, language functioning, and recovery of language functioning. ERP techniques not only provide correlates to behavioral measures but also have the potential to provide new evidence concerning the temporal structure of the intervening events between a stimulus and the subject's overt response (Neville, 1980). By recording from different scalp locations, ERP information concerning the sequence, nature, and timing of processing tasks can theoretically be obtained. Since ERP techniques are painless and noninvasive, they permit frequent serial studies with little or no risk to the subject.

Current research studies are directed, for the most part, toward isolating ERP correlates of acoustic, semantic, syntactic, and phonologic processing. To investigate these aspects of information processing, most researchers have focused their attention on variables influencing the endogenous components. One endogenous component which has received considerable attention is "P3" or "P300." P300 is a positive voltage component which occurs in adults approximately 300-500 msec following onset of a stimulus event. P300 has been shown to be generated in the posterior temporo-parietal association cortex (Vaughan and Ritter, 1970), an area considered important for language functioning because of its strategic location between the cortical association areas of the visual, auditory, and somesthetic systems (Friedman et al, 1977). P300

is thought to reflect modality nonspecific brain processes since a P300 wave can be elicited by unexpected stimuli in any sensory modality (Simson et al, 1977). Because P300 is so highly dependent on attention and discrimination, it has become increasingly important in neurophysiological studies of cognitive and linguistic processing.

In order to expand present knowledge concerning neurophysiological aspects of linguistic processing, the present study was undertaken. The investigation described in the following chapters was designed to examine late cortical potential responses (especially P300) to semantically appropriate and semantically inappropriate sentences in a group of normal young adults. The processing tasks (meaningful and nonmeaningful sentences varying semantically and phonemically) were presented auditorily (two separate presentations) to a group of young adults (males and females). Measures of (a) the differences of ERPs to semantically appropriate versus semantically inappropriate sentences, (b) differences in responses by males and females, and (c) differences in responses to presentation order were obtained. Recording sites were a central (Cz) and a left parietal (P3) location.

CHAPTER II

REVIEW OF THE LITERATURE

Two major breakthroughs in event-related potential research have contributed significantly to the current state of ERP technology. The first, in 1959, was Clynes' development of a digital signal averager which converted a device used in nuclear physics to the Mnemotron Computer of Average Transients (Clynes and Kohn, 1960). Prior to this time, research efforts were minimal since lack of proper technology precluded effective signal averaging. Some researchers, such as Dawson (1947) performed human evoked potential studies and attempted to average responses by photographically superimposing traces of EEGs. However, this technique was crude and cumbersome and contributed to the general lack of interest in evoked responses. With the advent of computerized signal averaging techniques, however, research in ERPs rapidly escalated.

The second major breakthrough occurred in 1964-1965 when it was determined that besides the "hard wired" early potential responses to sensory input in receiving areas, the brain generated potentials related to cognitive/information processing at high levels of performance (Donchin, 1979). The "discovery" of P300 (Sutton et al., 1965) diverted attention from the obligatory or exogenous components and focused on this unique component which has been implicated in human information processing. Identification of the contingent negative variation (CNV) by Walter in 1964 as an electrophysiological correlate of conditional expectancy also increased interest in the cognitive components.

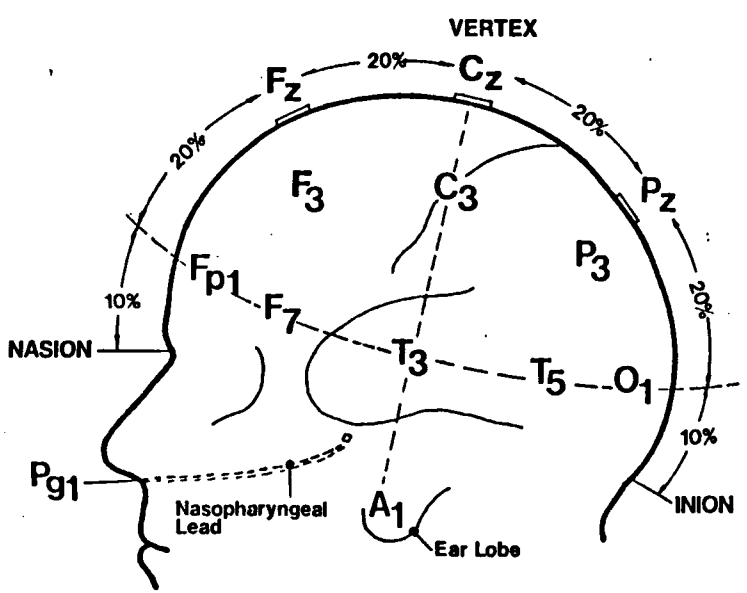
Although many of the results of the early ERP studies (1965-1975) have since been revised or put in better perspective with improved technology, insights gained from these studies suggest mechanisms whereby the neural tissues process information. In addition to providing a tool for examining a working brain actively engaged in information processing, ERPs may also provide an effective methodology for detecting abnormal neurophysiological conditions.

The present review examines neurophysiological correlates of information delivery, decision making, and cognitive/linguistic processing. Specific studies related to speech vs. nonspeech stimuli, semantic, phonetic, and sentence processing will be reviewed. The general nature and structure of ERP components, as well as nomenclature and conventions, will also be reviewed as background information.

A. Nomenclature of ERPs

The International 10-20 System (Jasper, 1958) is commonly used to specify electrode placement. This is illustrated in Figure 1. Letters define the general areas on the head and correspond to the cortical lobes while numbers specify more exact locations. Right-side electrodes are designated by even numbers while left-side electrodes are designated by odd. The letter Z is used to indicate a midline position. Thus, Cz is a central midline position, P3 a left parietal, and F2, a right frontal.

The polarity of a wave is indicated by the letter (N or P) while modal latency of the peak or trough is indicated by the number. Since latencies of several endogenous components are known to vary over a



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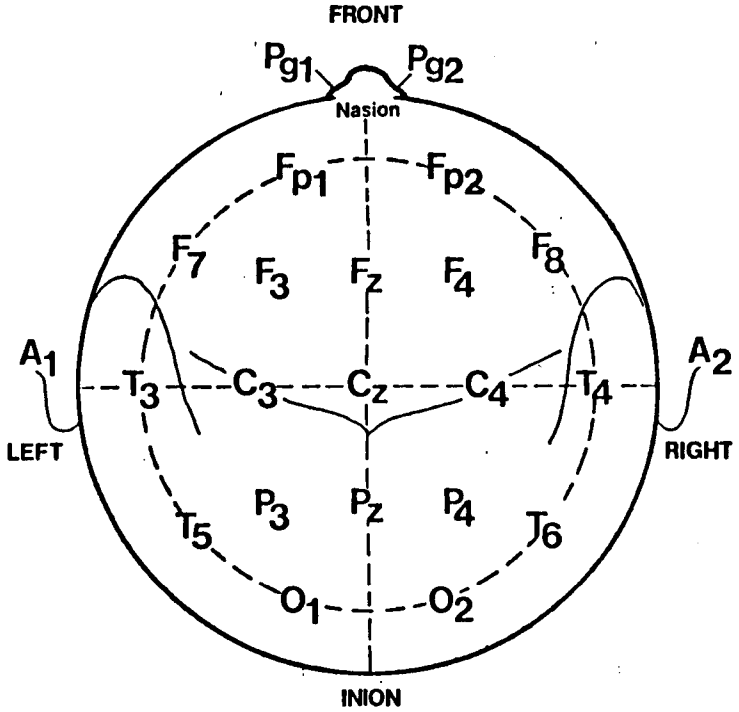

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INTERNATIONAL (10-20) ELECTRODE PLACEMENT

Figure 1. International 10-20 electrode system used to specify electrode placement. (from Grass Instrument Co.)

wide range, an average latency is usually adopted. Occasionally an ordinal system is used when simpler, unambiguous waves are referenced.

Confusion concerning the graphing of ERPs still exists. Some graphs depict positive as an upgoing spike, while others depict negative as upgoing. Although in physics and mathematics positive is up and negative is down, in electrophysiology negative is sometimes up, possibly because negative-going action potentials were the earliest peaks identified by neurophysiologists. Callaway (1975) also attributed this confusion to the fact that downgoing spikes on an oscilloscope became upgoing spikes when a one-step paper-backed photograph was made.

B. Nature and Structure of ERPs

In addition to electroencephalography (EEG) which provides a measure of brain electrical activity, the event-related potential (ERP) is also an indicator of brain function. ERPs can basically be defined as the brain's immediate or short-term response to a stimulus and are generally identified by their most salient features--amplitude and latency of the various peaks and troughs (Shabsin, 1982). These peaks and troughs represent electrical activity of the cortex and underlying structures and can be evoked in most stimulus modes. However, the majority of studies involving language/information processing have utilized the auditory and visual modes.

Early researchers generally regarded the ERP as a global response of the cortex and tended to ignore particular features of waves modulated by the experimental variables. Over the years, however, this

trend was replaced by a tendency to view the ERP as a sequence of overlapping components, each possibly representing activity of different populations of nerve cells and each component representing differential responses to experimental variables (Donchin, 1979). The establishment of Brainstem Evoked Response Audiometry as a valid measure of neural activity along the auditory pathway was instrumental in contributing to the search for other specific neurological correlates to processing.

C. Obligatory Exogenous Components

The terms exogenous and endogenous were suggested by Sutton et al. in 1976. (Donchin and McCarthy, 1979). They referred to an obligatory component evoked by an external stimulus as exogenous since its variance is controlled by the physical characteristics of the stimulus. The waveform composed of brainstem potentials elicited by an auditory stimulus is a prototypical exogenous component. The potentials are representative of neural activity in the early phases of auditory processing from the auditory nerve up to the medial geniculate (Jewett et al., 1970) and are observed over the first 12 msec after the stimulus onset. To visualize these components the presentation of many hundreds of stimuli must be averaged; however, the waveforms are very reliable as long as the pathways are intact. Because of these features, brainstem audiometry has become an important diagnostic technique, especially among noncommunicative patients. Figure 2 illustrates typical human brainstem responses to click stimuli.

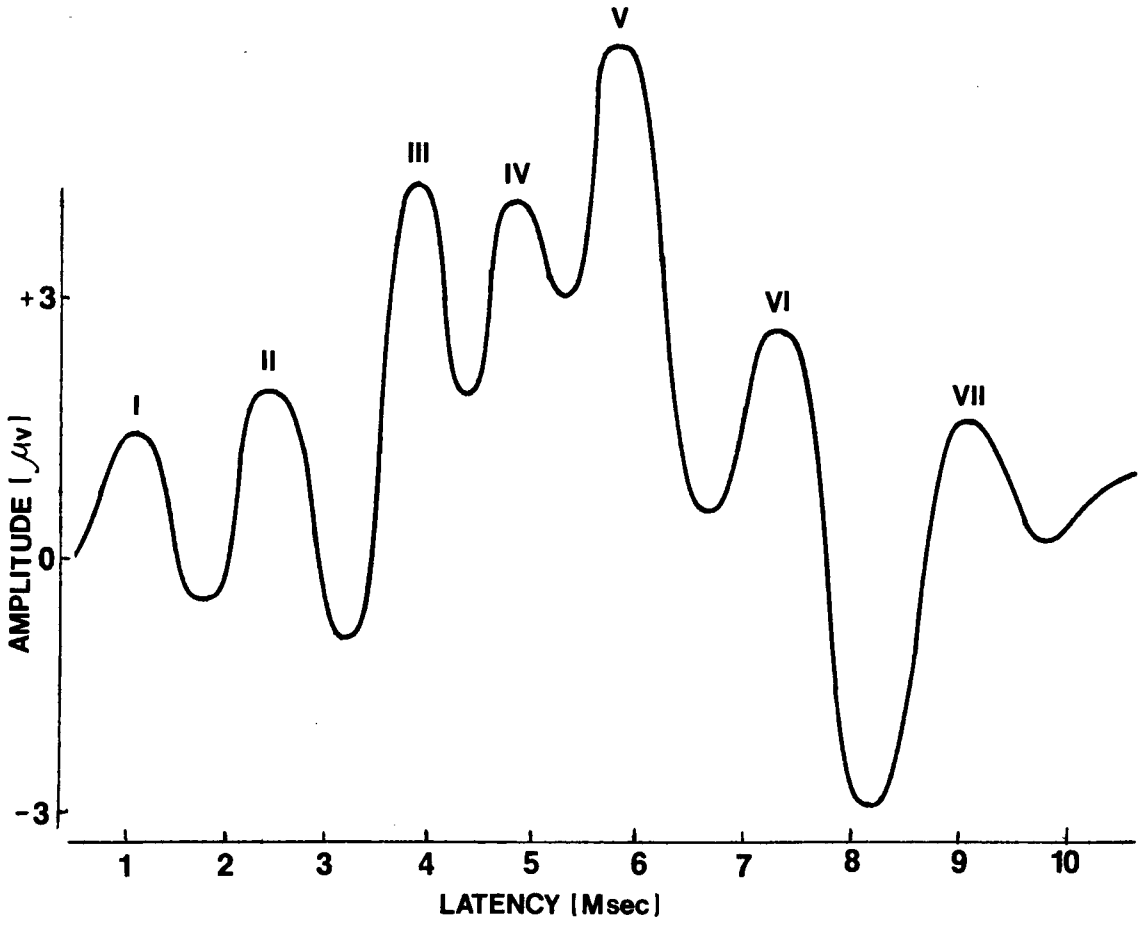

Figure 2. Typical human auditory brain stem response to click stimuli. Positive peaks represent structures from the 8th cranial nerve (Wave I) to the auditory radiations (Wave III) (Davis, 1976).

These earliest waveforms are followed by several mid-latency exogenous components which can be observed from 30-100 msec following onset of a click stimulus (Donchin, 1979). Although the origin of these components is uncertain, they have been attributed to thalamic activity and have found some use in audiometry (Davis, 1976).

Following the middle components are a number of larger peaks and troughs. The most commonly identified are a large negative (N1 or N100) peak which occurs approximately 100 msec after onset of a click and a large positive peak (P2 or P200) which occurs approximately 200 msec after onset. Figure 3 illustrates typical human cortical evoked potentials to repeated presentations of auditory or visual stimuli.

These earliest components represent obligatory responses to an external physical stimulus. The components from 100-200 msec may reflect simple attention while later components may reflect more complex recognition and discrimination. N100 appears to be related to stimulus set, an early stage of selective attention in the auditory, visual, somatosensory modalities. P200 has been related to the perception of visual form. Most cortical components from 75 msec on do show effects of attention. Earlier components (before 200 msec) seem to be affected by simpler functions of attention (i.e. recognizing the stimulus as being in the relevant modality). The later components (200 to 400 msec) are most affected when more complex processes are involved.

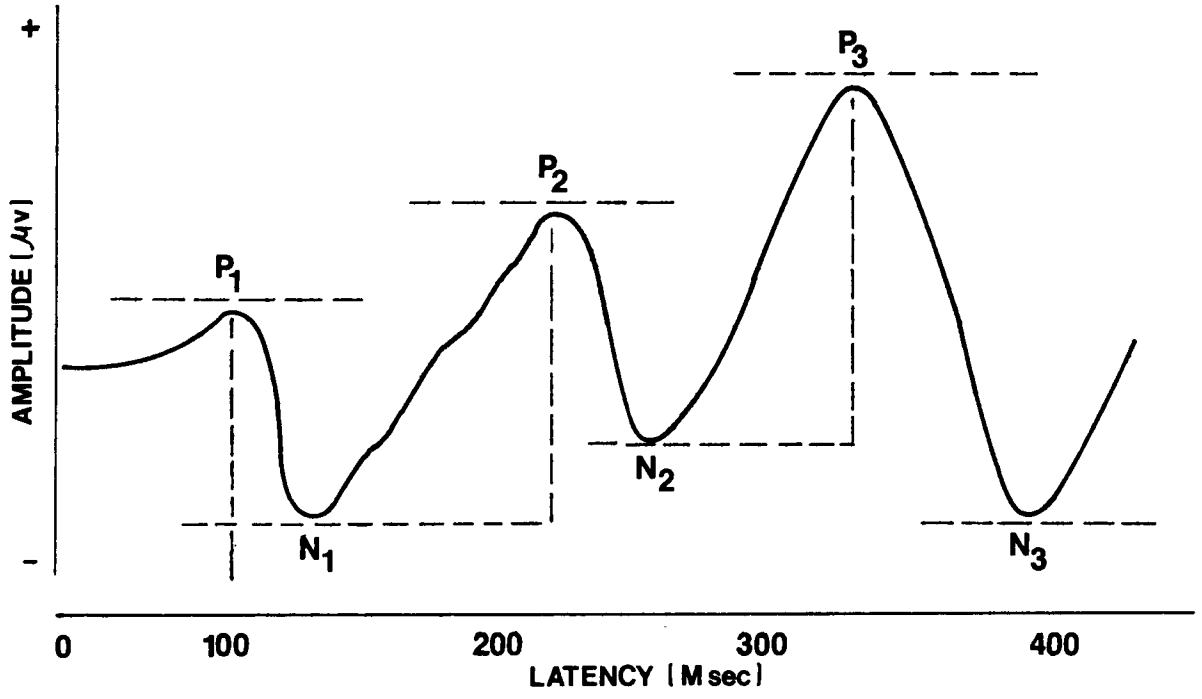

Figure 3. Schematic of human cortical evoked potential to repeated presentations of an auditory or visual stimulus. Peak latency and peak-to-peak amplitude measures are also shown (Shabsin, 1982).

D. Endogenous Components

Unlike the early exogenous components, the later components (P300 etc.) are labile and entirely idiosyncratic (Callaway 1975). According to Donchin and McCarthy (1979), endogenous components are elicited by the processing demands of a task and depend primarily on the meaning the stimuli have for an individual. The amplitude and latency of these endogenous components depend on the psychological circumstances under which the stimuli were presented rather than on the physical nature of the stimulus. Since endogenous components are not obligatory responses to a stimulus, the same physical stimulus may or may not elicit a response. P300 can also be elicited without the presence of an external physical stimulus (Klinke et al., 1968).

Since the late components are anything but stable, identification of specific components is often very difficult and confusing. Callaway (1975) suggested that some late waves occur in various evoked-response studies frequently enough to be named; however, he cautioned against definitive naming of all late components because of their inherent instability. Rosenfeld et al. (1969), for example, used an operant conditioning technique and trained subjects to control the polarity and amplitude of evoked potentials 200 msec post stimulus, a wave labeled by Allison (1962) as wave 5. The question of whether a potential which can be positive or negative can be representative of some constant neural activity must be considered. The variable latencies of endogenous components also present a problem. Even when two waves are observed with about the same latencies and with the same

polarities, the longer the latencies are the harder it is to be sure such waves all represent the same neural events. Regardless, all waves from 30 msec on are not equivalent.

P300

P300, undoubtedly the most well-defined endogenous component, is said to have been "discovered" on a particular day in 1963 by Sutton and his colleagues. The experimenters were so impressed by the size and clarity of this component in guessing designs that the typical evolutionary pattern of scientific advances was bypassed. Since that day much has been learned about this particular component and event related potentials in general. Research emphasis has shifted to the role of P300 in cognitive, linguistic processing, and while many questions have been answered many more have arisen.

Vaughan and Ritter (1970) demonstrated that P300 is generated in the posterior temporoparietal association cortex, an area considered to be important for language function because of its strategic location between the cortical association areas of the visual, auditory, and somesthetic systems (Friedman et al., 1977). Donchin et al. (1975) indicated that P300 is largest in the parietal sites and is quite small in the frontal areas. P300 is not modality specific and is thought to reflect modality non-specific brain processes since a P300 wave can be elicited by unexpected stimuli in any sensory modality (Simson et al., 1977). Donchin et al. also indicated that P300 is associated primarily with predictability of a stimulus and is not affected by the presentation of a warning stimulus.

P300 can be elicited in a variety of decision making tasks at a latency of 250-500 msec following delivery of task relevant information (Callaway, Tueting, Koslow, 1978). The oddball paradigm which requires the subject to detect and report infrequent "target" stimuli is typically used in guessing or decision making designs. The target stimuli are interspersed randomly within a series of nontargets. According to Hillyard (1973) a P300 wave accompanies each target decision with the amplitude determined by the confidence of detection and the subjective likelihood of its occurrence. Duncan-Johnson and Donchin (1977) indicated that unpredictability is not sufficient to elicit P300 and that the subjects must also be "paying attention" to the stimuli or the stimuli must be "task relevant." They indicated that P300 appears to result from a combination of uncertainty resolution and task relevance.

Squires et al. (1976) examined the relationship between the amplitudes of P300 elicited by any stimulus and the specific sequence of stimuli that preceeded it. They concluded that P300 amplitude varies from trial to trial depending on the sequential structure of a series. They also concluded that P300 amplitude is proportional to the subject's surprise at the occurrence of an event.

Sutton's studies (Sutton et al., 1965) indicated that a late positive component of stimulus locked potentials (P300) was related both to the time and amount of uncertainty reduction. Sutton and his colleagues observed a large P300 component following presentation of a low probability stimulus compared with a smaller P300 elicited by a

high probability stimulus. Sutton also demonstrated that disconfirming events produced larger P300 waves than confirming events even when the probabilities of these outcomes were equal. Sutton et al. presented subjects with a series of tones. In some experimental conditions the subjects knew in advance which tone would be presented on each trial. At other times, the tones appeared in random order and subjects were required to predict prior to each trial which tone would be presented. The tones that appeared in a random order increased the subjects' uncertainty and elicited larger P300s. Tueting et al. (1971) also demonstrated that amplitude of P300 increases as probability associated with the eliciting stimulus decreases.

Exactly what P300 represents has yet to be determined; however, various researchers have offered explanations. Squires et al. (1973, 1975b) have proposed that earlier components of the auditory ERP to threshold level stimuli such as the N1 (N100) component reflect the "effective intensity of the stimulus," whereas the later P300 component reflects the actual detection of that stimulus. Hillyard et al. (1971) noted the high correlation between the amplitude of the late positive component and the recognition of a near threshold stimulus. Friedman et al. (1973) examined the relationship between P300 amplitude and subsequent pupil dilation and concluded that "P300 amplitude and pupilary dilation are inverse monotonic functions of the stimulus probability."

McCarthy and Donchin (1981) compared P300 latency and reaction time and manipulated stimulus discriminability and stimulus-response compatibility in an "additive factors" design. P300 latency and

choice reaction time were measured simultaneously for each trail. P300 latency was affected only by stimulus discriminability while reaction time was affected by both discriminability and stimulus-response compatibility. McCarthy and Donchin interpreted these data as confirmation of their hypothesis that P300 latency is sensitive to the duration of stimulus evaluation processes and relatively insensitive to response selection processes. Choice reaction time, however, appears to be strongly influenced by both.

Rohrbaugh et al. (1974) proposed that P300 reflects "some terminal aspects of the subject's judgment" . . . "by which time sensory properties have been extracted and analyzed." However, which aspect of processing is indexed by P300 is still uncertain. P300 appears to be an indication of selective attention. The question is where the selectivity indexed by P300 occurs--at the level of initial sensory processing, comparisons with memory, or decisions about target identity or response selection (Callaway, Tueting, Koslow, 1978).

E. Handedness and Sex Differences

The issues of handedness and sex in ERPs has not been directly addressed. However, in several instances, differences in components related to sex or handedness have been identified. The relationship of handedness to speech dominance has been investigated by many researchers, with many differing conclusions (Davis and Wada, 1977b, c). There is little direct evidence, however, since most of the studies involved patients with pathologies or patients in whom the speech process was interrupted surgically or pharmacologically.

Penfield and Roberts (1959) used electrostimulation of the exposed cortex and concluded that handedness and speech dominance are not related. They estimated that 98 percent of the right-handed population was left speech dominant (LSD) and 2 percent right speech dominant (RSD). For the left-handed population, they estimated 90 percent LSD and 10 percent RSD.

Branch et al. (1964) used the carotid amytal test and estimated 90 percent LSD and 10 percent RSD in the right-handed population and 50 percent LSD and 40 percent RSD in the left-handed population. Neither group of researchers considered bilaterality, however.

In a more thorough investigation involving ERPs and the carotid amytal technique, Davis and Wada (1974) performed a spectral analysis of visual and auditory evoked potentials for the 3-9 Hz maximum amplitude, frequency component of 500 msec ERPs. Responses to flash and click stimuli were recorded from left and right, occipital and temporal areas. Subjects included six left and five right speech dominant epileptics and 12 "pure" right-handed and 12 "pure" left-handed normal subjects. Speech dominance of the epileptics was ascertained by the carotid amytal test while "pureness" of the right- and left-handed normal subjects was established on the basis of 13 handedness criteria (Annett, 1967; Davis and Wada, 1974). Subsequent discriminant analysis of the spectral analysis results indicated that form asymmetries were related to speech dominance but amplitude asymmetries were not. Large ERP coherences within a hemisphere increased the probability that speech dominance was localized within the opposite hemisphere (Davis and Wada, 1974). The coherence asymmetry

correctly predicted the speech dominance of 10/11 patients. For the normal subjects, the equations grouped the 12 right-handed subjects into 8 LSD, 3RSD, and 1 bilateral, and the 12 left-handed subjects into 5 LSD, 1 RSD, and 6 bilateral. On the basis of these findings, Davis and Wada suggested that handedness and speech dominance are not related, however, left-handed subjects did show more of a trend toward bilaterality. They also concluded that ERP coherence or form similarities are significantly related to speech dominance; however, amplitudes are not. Another conclusion is that for the coherence asymmetries, only left minus right hemisphere difference is significantly related to speech dominance. The researchers suggested the technique of discriminant analysis of coherence asymmetries as a determinant of speech dominance in patients and in normal subjects.

Low et al. (1973) used the Contingent Negative Variation (CNV) to determine dominance. Low et al. reported CNV asymmetries in a group of 8 LSD and 3 RSD patients who had been tested with the carotid amytal technique. Using maximum CNV amplitude preparatory to speech as their index of laterality, they correctly predicted speech dominance of 8/8 LSD patients and 2/3 RSD patients. Low et al. also found a distribution of CNV asymmetries corresponding to 8 LSD, 1 RSD, and 2 bilateral in the right-handed normal subjects, and 3 LSD, 6 RSD, and 2 bilateral in the left-handed normal subjects. The right-handed distribution of Low et al. is similar to that of Davis and Wada (1974).

Although sex differences in regard to ERPs have received even less attention than handedness factors, differences in latencies and amplitudes have been reported. Given the differences in anatomical

factors such as skull thickness, head size, and deep body temperatures, these results are not surprising.

Bali et al. (1977) employed a coupling approach which compared signals from different regions of the scalp and examined changes in their relationships as a function of various tasks. One method involved sampling each channel every 4 msec and classifying the response on the basis of polarity (+ or -) and determining whether its voltage was greater (↑) or smaller (↓) than the previous sample from the same channel. This yielded four possible categories (+↑, +↓, -↑, -↓) and a 4 x 4 contingency table was tallied for each pair of channels for a fixed number of samples. Coupling between each pair of channels was computed from the contingency tables by comparing actual cell frequencies with expected cell frequencies.

Bali et al. (1977) measured coupling between parietal and frontal leads over each hemisphere while subjects were presented with a series of clicks or flashes. All 16 subjects exhibited higher left/right ratios for clicks than flashes. This result is consistent with findings which suggest that the left hemisphere is more specialized for language and therefore more strongly engaged by auditory than visual stimuli. Female subjects exhibited higher left/right ratios than males. Bali et al. related these findings to the fact that females score higher than males on verbal portions of standardized intelligence tests and males score higher on spatial tests.

Stockard et al. (1979) reported that the mean latency of the P100 component of the checkerboard reversal response was some 2.69 msec shorter in a group of 50 healthy women than in 50 healthy age-matched

men, the difference being statistically significant ($p < 0.03$). Halliday et al. (1982) confirmed a shorter latency of the response of 69 women to 65 men in a similar checkerboard reversal task. They also found a sex difference in the amplitude of response, with the mean amplitude of P100 for the females being between 4 and 5 uV greater than for the male group ($p < 0.01$). Halliday et al. speculated that the differences in mean latency and amplitude may be related to the smaller average head size and skull thickness in women (Johnston and Whillis, 1938; Parsons and Keene, 1919) and possibly due to the higher deep body temperature in women (Stockard et al., 1979). Shorter latencies in women for BSER (Michalewski, et al., 1980) and for the somatosensory potentials (Shagass, 1972) have also been reported. Marshall and Donchin (1980) have also recently demonstrated circadian variation in the latency of the BSER related to changes in deep body temperature.

F. Analysis Procedures

A choice exists among analysis procedures for measuring event-related potentials. However, since none of the techniques have a firm biological basis, selection among these techniques is essentially empirical at this time. Current analysis techniques either rely on human intuition and are therefore susceptible to bias, or they rely on explicit rules for computer or human scoring and may therefore fail to extract the desired ERP feature (Callaway, 1975). A review of the various techniques indicates that no one measure is inherently good or bad. Choice of analysis procedure depends, therefore, on the type of

data and the degree to which any given technique makes the data informative and answers the experimental questions.

Extraction of the ERP from the noise can be accomplished in one of several ways: median evoked potentials, pattern recognition with cross correlation, recurrence frequency functioning, Wiener filtering, etc. Statistical procedures commonly used with the extracted signal include multiple regression analysis, discriminant analysis, factor analysis, multiple and partial coherence and phase analysis, ANOVA, and MANOVA.

All techniques have their own inherent advantages and disadvantages and are clearly more applicable for certain types of data. Latency and amplitude measures are generally confounded. To measure the latency of a peak, the minimum amplitude needed to define a peak must first be determined. Conversely, to measure amplitude from peak-to-trough, the latency range must first be defined. Donchin and McCarthy (1979) caution against indiscriminant signal averaging since it cannot always distinguish amplitude changes from latency variability. This problem is especially acute for endogenous components whose latencies are under the subject's rather than the experimenter's control. Since these times are extremely variable in relation to the external stimulus, amplitude of a signal average might be artificially reduced by fluctuating latencies (Brazier, 1964). Linguistic or cognitive tasks which involve repetition of stimuli in order to obtain an average may be especially susceptible to semantic satiation.

Thatcher (1977b) proposed the use of "light averaging" (12 or fewer stimuli) and Donchin and McCarthy (1979), Friedman et al. (1977),

Ritter et al. (1972), and others have suggested the scoring of single-trial data especially in P300 experiments. Another proposed alternative in semantic studies is the use of several different words with no repetition (Chapman, 1974b).

Baseline Measures

Since all amplitude measures must be referenced to a value, baseline measurements are a necessity and often present a problem. Baseline can be defined as the average value over a portion of the recording epoch just preceding the stimulus that evoked the ERP (Callaway, 1975). However, the assumption that the average reflects a true "zero point" may not always be valid. Too much variation in the prestimulus baseline or event-related activities may confound the baseline measures. The problem of fluctuating baseline measures is sometimes alleviated by measuring peak-to-peak rather than base-to-peak (Callaway, 1975). Donchin et al. (1973) suggested using trimmed averages for baseline. These are obtained by eliminating all values in the upper and lower quartiles and then computing the average, thus eliminating any extreme deviations. Shucard et al. (1971) proposed an amplitude criteria based on an average of the prestimulus EEG. Baseline and amplitude limits are measured and then drawn out above and below the ERP. Any peak or trough exceeding these limits is counted. To offset problems caused by any large prestimulus artifacts, Hall et al. (1973) proposed a window that is 10 percent of the maximum peak-to-trough excursion. The window is moved along the wave and is centered on each peak or trough. If a more positive or negative value is not found in the window, that value is accepted.

Latency Measures

Latency measures of ERPs are generally variable. By changing the window size or amplitude limits, the identity of the peak and especially its latency may easily be changed. Since most automatic peak detection techniques are either too simple to be reliable or too complex, most researchers rely on visual inspection of the peaks. Frequency, rather than latency, measures have been suggested as a means of circumventing these difficulties. Since wavelength and frequency are both functions of time and are reciprocals of each other, a wavelength can easily be converted to a frequency measure. Freeman (1964) determined "dominant frequency" from the reciprocal of positive-going zero-cross and negative-going zero-cross latency measures.

Analog filters have also been used to decompose ERPs into frequency components, however, digital frequency analysis procedures are more commonly used. Digital procedures provide a series of times and an amplitude value associated with each time. Fourier analysis allows this time series to be converted into a series of frequencies and a pair of numbers associated with each frequency. Frequency analysis does not, however, remove all the ambiguities inherent in the original time-series data.

Amplitude Measures

Maximum peak measures can easily be quantified as the largest or smallest voltage values in an interval representing the latency range of the component being measured (Donchin and Heffley, 1978). Peak amplitude is usually referenced to either a baseline condition or some

other component. Peak measures can easily be expressed as linear combinations and lend themselves to ANOVA testing. An inherent assumption with peak analysis is that a single point can adequately quantify the magnitude of the component. However, since contributions from all components may be included at that time point, the measurement may be misleading. Peak measures are easily obtained and have the advantage of face validity. They are appropriate when the data exhibit clear differences in the ERPs.

Disadvantages of peak measurements include experimenter bias, difficulty defining waveforms, baselines, and reference peaks. Peak amplitudes are difficult to dissociate from CNV (Donchin et al., 1975) and are not applicable when measuring any slow potentials. Finally, since the measures are based on a single point, real differences can easily be obscured by nonsystematic variance.

Area measures under selected portions of the ERP curve can be computed by integrating the voltage relative to the reference baseline. Unlike peak measures, area analysis assumes that the amplitude of a component can be accurately measured by combining values measured at several time points (Donchin and Heffley, 1978). Area measures can also be expressed as linear combinations. Area measures involve relatively little computation and are more accurate representations of slow potentials. Since more time points are included, they are less susceptible to the effects of random variation.

However, determination of a reference point becomes more complicated when area measures are used. Dustman and Beck (1969) suggested summing the absolute differences between successive digitized values

over a predetermined value. Determination of the integration limits is also often difficult because of component overlap. Area measures also yield no information concerning the waveform of the component. Area measures are suggested for ERPs with independent, well-defined components and clearly defined baselines (Donchin and Heffley, 1978).

An alternative to peak analysis and area measurements, principal components analysis (PCA) is a technique for extracting a small number of components, each representing systematic influences on many time points. Since a waveform is essentially a sequence of voltages recorded at each of the points, it can be represented by an ordered set of numbers. Primary data vectors computed from the ERPs can be constructed with rows representing the ERPs and columns representing the time points. Since the number of variables depends on the sampling rate, multivariate statistical techniques are highly plausible (Tatsuoka 1971, Donchin, 1966). Principle components analysis first involves computation of a variance-covariance matrix. Principal components are then extracted from this matrix. This produces a component matrix which shows the influence of the principle components at each time point. Next a Varimax rotation (Kaiser, 1958) is performed to derive the basic ERP components. Finally each ERP vector is multiplied by a coefficient vector derived from the rotated loading vector for each component derived from the Varimax procedure.

The main advantage of PCA is that it provides information about amplitude variability and waveshape of components. This technique also can provide valuable information when components overlap but are not highly correlated. Analysis of variance measures can also be

employed to assess the effects of experimental variables on the independent components. Another advantage is the ability to handle fast and slow components. Disadvantages of PCA include the requirement of extensive computerization and the confounding of latency and amplitude variability.

Discriminant analysis is a classification procedure and is similar to PCA in that it provides a rule for developing a linear combination of the observations. However, in PCA, coefficients are obtained through an analysis of the total variance in the ERP data matrix. Discriminant analysis, however, assumes that ERPs can be objectively classified into two or more groups corresponding to values of the experimental variables. Step-wise discriminant analysis (SWDA) is a classification technique used to identify features of an observation which can then be used to decide its class membership. An algorithm uses labeled sets of observations, one set from each of the classes and develops a classification rule which tests new sets of labeled observations (Dixon, 1975; Donchin and Herning, 1975). SWDA has been applied to single-trial waveforms with some success (Squires and Donchin, 1976). Squires et al. (1977) applied SWDA to single-trial waveforms from an auditory oddball paradigm. Voltages from the P300 region of the waveforms in the classification rule (discriminant function) were used to correctly classify 80-90 percent of the single-trial data. The discriminant function refers to a set of coefficients for selected time points. The discriminant score results from the application of the function to any ERP and is a sum of several weighted amplitudes along the ERP epoch (Donchin and Heffley, 1978).

The technique involves selecting time points at which the amplitudes are to be measured and obtaining a relative weighting of these amplitudes. This is accomplished by providing maximal separation between two groups of ERPs. The discriminant function can be used to define a continuum along which an ERP can be assigned depending on its resemblance to the average of one group or another.

Principal advantages of discriminant analysis include its ability to objectively assess ERP differences along any independent dimension. Since the technique allows extraction of differences, it is applicable to single-trial ERP data. Another advantage is the existence of a statistical theory as a guideline. The main disadvantage of discriminant analysis is the necessity of having an independent basis for grouping ERPs and developing a discriminant function. Lachin and Schachter (1974) suggest the possibility that the analysis may differentiate between groups on the basis of random variation in the sample rather than on systematic differences. This problem can be overcome by using a large original sample or applying the function only to data not used in the training set.

Other analysis techniques include filtering phase-forcing, equipotential mapping, etc. Although confusing, the multitude of techniques allows one to view the same data from different vantage points. Since no solid theoretical framework associated with ERPs exists at this time, these waveforms need to be measured and defined in as many ways as is possible. In this way, hopefully, a more coherent and acceptable basis for neurophysiological measures will eventually evolve.

G. ERPs and Linguistic Processing

Early electrophysiological studies focused on interhemispheric differences in some parameter of the electroencephalogram (EEG) or event-related brain potential (ERP) and were directed toward providing evidence for the existence of a left hemispheric spatial or holistic processor (Donchin and McCarthy, 1979). While a number of these studies have supported the view that decoding of the linguistically significant features of speech occurs in the left hemisphere (Molfese, 1977; Morrell and Salamy, 1971; Marsh and Brown, 1977), the issue of ERP asymmetry to language and nonlanguage is still not resolved (Friedman et al., 1977). Shelburne (1972, 1973), Galambos et al. (1975) and Friedman et al. (1977) did not report asymmetry to linguistic and nonlinguistic stimuli in their studies and Friedman et al. suggested that some of the early studies in which asymmetries were found may have been influenced by methodological flaws.

Although the issue of cerebral localization of language function and its possible reflection in the evoked potential is certainly important, some researchers have expressed concern that the search for hemispheric asymmetries might obscure other useful ways in which such measures might be used to study language processing (Donchin and McCarthy, 1979). Consequently, research strategies have shifted in many cases toward isolating ERP correlates of phonologic, semantic, and syntactic processing. To investigate these aspects of cognitive processing, most researchers have focused their attention on variables influencing the endogenous components. The following sections will

review research in three areas of language related studies: speech/nonspeech stimuli, phonology, and semantics.

ERPs and Speech/Nonspeech Stimuli

Early research attempted to define differences between language-relevant speech sounds and various types of nonspeech sounds (Cohn, 1971; Morrell and Salamy, 1971; Molfese, 1972).

Friedman et al. (1977) conducted several experiments which employed linguistic and nonlinguistic stimuli and were unable to ascertain consistent ERP asymmetry. As a result, their research strategy shifted toward uncovering ERP correlates of semantic, syntactic, and phonologic information processing. They chose to look at the P300 wave since it has been shown to be closely related to cognitive information processing (Donchin and Lindsley, 1966; Desmedt, 1977b). Using visual and auditory stimuli and experimental linguistic paradigms designed to generate P300 waves and Contingent Negative Variation (CNV), they recorded ERPs using scalp electrodes. In the first experiment, subjects were presented visually with language and nonlanguage stimuli. Subjects had only to attend to the stimuli.

The purpose of this particular experiment was to determine whether evoked potentials differed for language stimuli and nonlanguage stimuli. In these experiments the language and nonlanguage stimuli produced visual evoked potentials (VEPs) of similar morphology and latency with no consistent hemispheric asymmetry. To ensure that the subjects were attending to the stimuli, subjects were next required to respond to each stimulus in a simple reaction time design.

However, there were no differences with respect to the no-response experiments. In another experiment, a "go, no-go" reaction time task in a CNV experiment was used. Subjects were cued as to whether the discrimination they would make at S2 would be verbal or nonverbal. Tones that carried cue value evoked large amplitude P300s whereas those that did not have cue values did not evoke P300s. This was thought to be related to the information-bearing nature of the tone in the cue condition (Sutton et al., 1965, 1967).

Friedman et al. (1975a) recorded ERPs from electrodes over P2 and midway between P2 and the mastoid (both sides of the head). Stimuli were five natural speech words and five nonspeech human sounds. During one task (Condition 1) the subjects listened to the stimuli, whereas in the next task (Condition 2) subjects were required to respond to the signal stimuli (five possible stimuli) with a finger lift. Left hemisphere amplitudes for N100 component were larger for the signal than for nonsignal stimuli. Latency of this component was also longer for words than for sounds. P300s were present for all stimuli, even though nonsignal stimuli do not usually evoke P300s (Ritter et al., 1972; Hillyard et al., 1973). P300 amplitude was largest to the signal, next largest to the nonsignal, and smallest to the no-task stimuli. Friedman et al. speculated that the presence of P300 waves to all stimuli was due to the engagement of the P300 system whenever language stimuli were used and the subject was engaged in a vigilance task.

In one of the earliest studies, Cohn (1971) recorded ERPs to clicks and consonant-vowel-consonant (CVC) words from electrodes

placed over the left and right side of the head. Approximately half of the 37 adult subjects produced larger left hemisphere (LH) ERPs between the first negative and positive peak in response to the words. A large positive component with a peak latency of 14 msec was reported over the right hemisphere (RH) leads in all subjects in response to the clicks. In a related study (Morrell and Salamy, 1971) ERPs were recorded to five natural speech nonsense syllables at bilateral frontal, rolandic, and temporo-parietal locations in seven adult subjects who were instructed to report the stimulus after a delay. The N90 component appeared largest over the left hemisphere temporo-parietal leads. A modified replication of this study (Grabow et al., 1980) failed to substantiate these results. The researchers attributed this in part to incorrect baseline measures by Morrell and Salamy.

In an attempt to identify changes in ERPs over different developmental periods, Molfese (1972) and Molfese, Freeman, and Palermo (1975) recorded ERPs (T3 and T4 locations) from 10 infants who were one week to 10 months old, 11 children 4 to 11 years old, and 10 adults 23 to 29 years old. Natural speech stimuli were CV syllables /ba/ and /da/ and monosyllabic words /bɔi/ and /dɔg/. Nonspeech stimuli were piano chords and white noise bursts. Stimulus duration and intensity were matched across stimulus sets. In general, larger left hemisphere amplitudes were measured for the speech stimuli in all three groups of subjects while larger right than left hemisphere amplitudes were measured for the nonspeech material. Amplitude measures were from N100-P160 component in adults, N143-P214 component in

children, and N454-P528 in infants. The researchers concluded that from infancy onward, ERP measures can distinguish speech and nonspeech material. A later study reported by Molfese (in press) reported similar effects in infants. ERP responses to click and speech (infants' names) stimuli were recorded from normal and malnourished infants. Larger left than right hemisphere ERPs to speech stimuli were recorded for the normal infants. Larger RH ERPs to nonspeech (click) stimuli were recorded for both groups of subjects.

Lawson and Gaillard (1981a) also attempted to distinguish responses to natural speech stimuli and tones. ERPs and reaction times (RT) were recorded to a 1 k Hz tone and 10 different consonants preceeding the vowel /e/. Reaction time and N100, (110-170) latencies distinguished one set of stimuli (tone, /pe, te, ke/) from a second group (/we, je, me ne, ve, fe/). N100-P200 peak amplitudes grouped the tone and /pe, te, ke, we/ responses together and distinguished them from the /fe, se/ stimuli. The researchers suggested that these results were due to acoustic rather than phonetic differences and concluded that the results were not affected by vowel onset.

In a related study (Galambos et al., 1975) ERPs were recorded to two natural speech stimuli and tones from electrodes placed at Cz, midway between T3-P5, and T4-T6. Latencies for N100 and P300 components differed for the speech and tone stimuli. Galambos et al. speculated that the shift in latency may have resulted from different processes being engaged in the identification of speech and nonspeech material.

Neville (1974) used a dichotic listening task, presenting speech (digits) and nonspeech (clicks) and recording from C5 and C6. Pairs of speech stimuli were presented in groups of three to each ear. In another condition, clicks were presented monotically. Behavioral measures for the dichotic task were consistent with earlier research (Kimura, 1967) reporting greater recall accuracy of stimuli presented to the right ear and therefore thought to be processed by the left hemisphere. Neville reported shorter peak latencies (N100, P200, N200) in the left hemisphere than in the right for speech stimuli (opposite of results reported by Friedman et al., 1975). Neville reported that larger latency differences were measured over the left hemisphere electrode site in response to both types of stimuli.

In a later study, Neville (1980) recorded ERPs from P3, P4, C3, C4 and one suborbital site during a series of tasks. In the first task, subjects were instructed to recall dichotically presented words. Recall accuracy of stimuli presented to the right ear (60%) was greater than the left ear (34%). Hemisphere effects were noted over parietal leads of late occurring baseline to N100 components. In Task 2 melodies were presented dichotically. No behavioral or electrophysiological effects were found. The third task required subjects to recall two different four letter words presented simultaneously to the two visual fields. Nine of the 12 subjects correctly reported more words presented to the right visual field. Amplitude asymmetries to the visual ERPs (baseline to N100 and N100 to P200) were reported only over the parietal leads with the left hemisphere leads manifesting the largest amplitude.

ERPs and Phonological Variables

In an effort to identify the organization and localization of brain activity in response to speech, several researchers have manipulated acoustic and phonological dimensions of vowels and consonants. Phonology refers to the specification of the units of sound (phonemes) which compose words (Caroll, 1967). Recent studies have focused on vowel contrasts (Molfese and Erwin, 1981); voicing contrasts (Dorman, 1974; Molfese, 1978a, 1980a; Molfese and Hess, 1978; Molfese and Molfese, 1979a); and place of articulation contrasts (Molfese and Molfese, 1979b, 1980; Molfese, 1978b, 1980b). Studies involving manipulation of phonological variables have indicated involvement of several right hemisphere as well as left hemisphere sites. These studies concerning vowel, voicing, and place of articulation contrasts will be reviewed in this section.

Molfese and Erwin (1981) investigated ERP responses to vowel perception. Three synthetic vowels /i,æ,ɔ/ and three nonspeech stimuli matched to the vowel stimuli in duration, rise time, peak intensity, and mean formant frequency were presented to 20 adults. ERPs were recorded from bilateral temporal and parietal sites. Principle components analysis indicated nine factors which accounted for 80 percent of the total variance. Analysis of variance indicated that bilateral anterior temporal electrode sites discriminated /i/ from /ae/. Bilateral parietal sites discriminated /i/ from /æ/ and /i/ from /ɔ/. Molfese and Erwin interpreted these findings to indicate that a single localized region is not responsible for vowel detection. Rather it appears that a number of discrete mechanisms located over different

regions of both hemispheres may be involved in the processing of vowels (Molfese and Erwin, 1981).

Generally, on most sensory dimensions, listeners can discriminate among many more stimuli than they can actually identify or label. However, in the case of speech, discrimination is generally no better than identification. For example, the consonants /pa/ and /ba/ differ in the voicing of the initial consonant. Voicing or voice onset time (VOT) is reflected acoustically by the temporal relationship between the initial consonant release and the subsequent sound made by the vibrating vocal folds during the production of a stop consonant. If VOT is varied over a range of values in synthesized speech sounds, adult listeners discriminate changes only to the extent that they can assign unique labels to these sounds (Liberman et al., 1974). Stop consonants with VOT values of 0 and +20 msec are identified as /ba/ while stimuli with +40 and +60 msec VOT values are identified as /pa/. However, stimuli with VOT values of +20 and +40 are distinguished as /ba/ and /pa/, respectively; that is, the changes in VOT appear to be categorical. The 20 msec difference in VOT between speech syllables is only detectible when stimuli are from different phonological categories. This close relationship between identification and discrimination has been termed categorical perception and has been consistently reported with adults (Lisker and Abramson, 1964, 1970; Liberman et al., 1958) as well as with infants in studies using heart-rate and sucking paradigms (Eimas et al., 1971). Studies of spectrographs have indicated that portions of the acoustic patterns for related phonetic segments often lie along an acoustic continuum (Studdert-Kennedy, 1975).

Molfese (1978a) studied VOT and ERPs in a phoneme identification task. Recording from T3 and T4, he presented 16 adult subjects with a series of randomly ordered synthesized consonant-vowel (CV) syllables. The CVs varied in VOT values of 0, +20, +40 and +60 msec. Subjects pressed a button after each stimulus presentation to indicate whether they heard /b/ or /p/. The CVs with VOT values of 0 and +20 msec were identified as /ba/ approximately 95 percent and 93 percent of the time, respectively. CVs with VOT times of +40 and +60 msec were identified as /pa/ 95 percent and 98 percent of the time, respectively. Subsequent analyses revealed two ERP components recorded from T4 which influenced N110 and P350 components and which varied systematically as a function of the phoneme category. Stimuli with VOT values of 0 and +20 msec elicited a different ERP waveform from the right hemisphere than did the +40 and +60 msec stimuli. No differences in ERPs were recorded between the 0 and +20 msec responses or between the +40 and +60 msec responses.

In a subsequent study Molfese (1980a) attempted to determine whether the laterality effects noted with the VOT stimuli could be elicited with nonspeech materials. He used four tone-onset-time (TOT) stimuli in which the two-tone stimuli differed from each other in onset time of the lower tone in relation to the higher tone. Sixteen college age females served as subjects. ERPs were recorded from four electrode sites over each hemisphere. Principle components analysis indicated that ERPs to temporal information were characterized by bilateral component changes in the first half of the ERP localized near temporal and parietal sites. An additional later occurring component was identified at all right hemisphere sites.

Molfese and Hess (1978) also recorded ERPs from left and right temporal sites of twelve four-year-old children. Stimuli were a random series of synthesized consonant vowel consonant syllables (/k,g/) varying in 20 msec VOT values. One late occurring ERP component which varied systematically as a function of phoneme category was identified. The component with a peak latency of 444 msec was from the right hemisphere electrode and was similar to the one identified in the case of Molfese's adult listeners. A second ERP complex with peak latencies of N198 and P342 was identified bilaterally and discriminated VOT values along phoneme boundaries.

Molfese and Molfese (1979a) later included infants and newborns in the VOT experiments. The same four consonant-vowel speech syllables (Molfese, 1978a) were presented to 16 infants, two-to-five months old, and 16 newborns under 48 hours of age. ERPs were recorded from T3 and T4. Principle components analysis of the infants' ERPs revealed a positive component in the right hemisphere (P920) which discriminated between VOT values from different phoneme categories. No evidence of the phoneme categorical VOT effect was found with the newborn population. On the basis of these findings, Molfese and Molfese suggested that the ability to discriminate VOT categorical stimuli is not inherent but rather develops after birth. Molfese (Gaillard and Ritter, in press) also concluded from these studies that several right and left cortical regions are involved in perception of VOT cues.

In one of the earliest ERP studies of VOT contrasts, Dorman (1974) used an ERP habituation paradigm and recorded from Cz. Fifty

adults (ten assigned to one of five groups) served as subjects and listened to computerized speech sounds 250 msec in duration. Three groups listened to a series of stimuli with a fixed VOT which was then changed by 20 msec. Group four heard stimuli from one category while group five listened to a randomly ordered series of stimuli from within as well as between phoneme categories. N100P200 peak to peak amplitude effects were noted for ERPs elicited by the shift stimuli when they were from a different phoneme category. On the basis of these results, Dorman suggested that ERPs could reflect the categorical perception effects of voicing contrasts.

Molfese, who was the principal investigator in most of these studies, (Gaillard and Ritter, in press) summarized his general findings indicating that ERPs may discriminate stimuli from different phoneme categories. His results also indicated that several cortical regions, including right hemisphere areas, may be involved in this type of perception. Additionally, ERPs recorded from temporal sites indicate that the components change with development.

The extent and duration of formant transitions are acoustic cues which have been identified in the perception of consonant place of articulation. Electrophysiological studies have indicated that ERPs may reflect perception of these cues.

Molfese (1978b) presented a series of synthesized CV syllables which varied in place of articulation (/b,g/). The second formant transition rose for /b/ and fell for /g/. ERPs were recorded from T3 and T4 from ten adults. Principle components analysis indicated six

major ERP components which accounted for 97 percent of the total variance. Two positive left hemisphere ERP components (170 msec and 430 msec) were identified which varied in response to changes in F2 transitions. Molfese (1980b) replicated and extended this work to include three vowels /i,æe,ɔ/ combined with the initial consonants /b,g/. ERPs were recorded bilaterally from temporal and parietal sites of 20 adult subjects. Principle components analysis indicated an early positive component (170 msec) over both hemispheres which reflected discrimination between /b/ and /g/. A positive peak (460 msec), recorded from the left hemisphere, was found to reflect the /b,g/ discrimination.

Studies by Molfese and Molfese (1979b, 1980) were undertaken to determine developmental aspects of electrophysiological responses to place of articulation contrasts. Sixteen newborn infants served as subjects in the first study. ERPs were recorded from T3 and T4 to two stop consonants which differed only in F2 transition and formant bandwidth. A late negative component (630 msec) over the left hemisphere differentiated the two consonants. A second negative component (192 msec) was identified over both electrode sites which also distinguished between the two stops.

Molfese and Molfese (1980) then included preterm infants and added nonphonetic as well as phonetic transitions. Eleven preterm infants with a mean conceptual age of 35.9 weeks were tested after birth. Results were similar to those of the full term infants. A left hemisphere component which distinguished between transition cues in stimuli with speech formant structure was identified. An additional

left hemisphere ERP component distinguished between only the non-phonetic stop consonants.

VOT and place of articulation contrasts both elicit bilateral discrimination responses. However, while voicing contrasts elicit additional right hemisphere activity, place of articulation contrasts evoke an additional left hemisphere response (Molfese, in Gaillard and Ritter, in press).

ERPs and Semantic Processing

In addition to phonological aspects of language, researchers have also focused on other linguistic processes. Morphology, the words and other basic meaningful forms (morphemes) of the language; syntax, specification of the patterns in which linguistic forms may be arranged; and semantics, specification of the meaning of linguistic forms and syntactical patterns in relation to objects, events and processes, have also been correlated with neurophysiological processes. Pragmatics, the use of context to determine an individual's interpretation of linguistic events (Bates, 1976), has also become increasingly important both in psycholinguistic research and also in neurophysiological studies. Recent studies have been directed toward determining ERP differences as a function of stimulus context (Brown et al., 1973, 1976, 1979; Teyler et al., 1973), ERPs to word (Bucksbaum and Fedio, 1969; 1970), and sentence meaning (Thatcher, 1977b; Matsumiya et al., 1972).

Early ERP studies related to word processing attempted to determine whether words can be discriminated from nonwords (either a series

of auditory speech sounds or nonword letters). Matsumuya et al. (1972) recorded ERPs from bilateral locations in nine adult subjects during four different conditions. During Condition 1 subjects counted the number of words intermixed with nonspeech sounds. Subjects counted the number of noises intermixed with words in Condition 2. In Condition 3, in which only mechanical sounds were presented, subjects counted the number of different sounds. In Condition 4 subjects were required only to listen to ten sentences. Peak-to-peak amplitudes were calculated as an R-value using a ratio of left hemisphere amplitudes to left hemisphere plus right hemisphere amplitudes. No differences were noted between conditions 1 and 2. More left hemisphere involvement was noted in Condition 4. Larger P60-N180 amplitudes were recorded for the more meaningful stimuli. Matsumuya et al. also suggested that the significance of the auditory stimuli may be more relevant to the occurrence of interhemispheric asymmetry.

Molfese (1979) attempted to determine whether ERP measures could differentiate meaningful versus nonmeaningful natural speech stimuli. Auditory ERPs were recorded from T3 and T4 to a randomly ordered series of consonant-vowel-consonant (CVC) words and nonsense syllables. Initial and final consonants of words and nonsense syllables were matched in terms of voicing and place of articulation and all stimuli contained the vowel /æ/. Ten adult subjects were required to press one of two buttons indicating they heard a word or nonsense syllable. Principle components analysis indicated ten factors that accounted for 93.2 percent of the variance. A subsequent analysis of variance indicated that four components, P60, N250, P300, and N370,

reflected whether the stimulus was a word or nonsense syllable. Molfese indicated that coarticulation effects may have been reflected by P60.

Shelburne (1972) utilized the "information delivery" paradigm of Sutton et al. (1967) in a visual study similar to Molfese's (1979). Shelburne recorded visual evoked responses (VERs) from Cz, P3, and P4 to word and nonword orthographic stimuli. Eight adult subjects viewed the words and nonsense syllables which were flashed one letter at a time at one second intervals. The third letter of the sequence of letters determined whether it was a word or nonword. Subjects were instructed to indicate whether they viewed a word or nonsense syllable. P300 waves were present to the critical third letter but not to the other two and were of similar amplitude whether the word was real or nonsense, thus demonstrating the information delivery effect but not uniquely reflecting anything related to language. In a second experiment the first letter determined whether the stimulus was a word. Amplitude for the first letter was larger than that for the third letter. Again, no differences between word and nonword stimuli were noted for any letter position.

Shelburne (1978) extended this study to include learning disabled children. He studied visual evoked potentials in children with reading disabilities with the aim of developing diagnostic neurophysiological techniques. He visually presented three letters at one-second intervals to subjects who had to indicate whether the stimuli formed a word or nonsense syllable. For each word there was a matching nonsense syllable having the same first two letters. Normal children who

were able to achieve a score of 95 percent or better on recognition indicated clear differences between the ERPs to the first letter and third position responses. Children with reading disabilities scored near chance level of 50 percent on the recognition task and did not show the first-third position ERP effect. Shelburne concluded that the difference appeared to be related to the subjects' ability to solve the problem and resolve the uncertainty.

Donchin and McCarthy (1979) investigated coding processes which do not require access to lexical memory. They presented subjects with pairs of English words and required subjects to decide whether the words rhymed. The purpose was to assess the degree to which the rhyming decision, which is essentially phonological, is affected by the interaction between phonological and graphemic aspects of words. The experimenters hypothesized that if words are directly coded into phonological representations, then graphemic information should not affect phonological decisions. Four classes of words were used: words that rhymed and whose orthography suggested they rhyme, words that rhymed but whose orthography were dissimilar, word pairs whose orthography suggested rhyming although they did not, and words that neither rhymed nor were orthographically similar. A reaction time paradigm was used with the evoked response recordings. The data recorded were quite complex. Among the findings were the differences in P300 latencies for the different conditions. Words that rhymed on a phonological basis only had distinctly longer latencies than words that rhymed and were orthographically similar. P300s for the other two conditions were essentially the same in terms of their latencies.

The experimenters suggested that the long RTs associated with the third condition coupled with the short P300 latencies reflected postencoding processes associated with the conflict of phonological and graphemic analysis.

Teyler et al. (1973) presented subjects with words that could be interpreted as nouns or verbs. ERPs were recorded at C3 and C4 from six female subjects. Prior to each recording, the subject was instructed as to the meaning of the stimulus words. Marked differences in waveforms of verb and noun forms were found. The differences in waveform could not be related to differential stimulus characteristics since the identical physical stimulus elicited the ERPs associated with each stimulus word meaning. Waveforms for a given stimulus word meaning were highly similar in the right and left hemispheres. However, larger amplitudes to the initial components were recorded in the left hemisphere.

Megela and Teyler (1978) recorded ERPs in two classes of words, synonyms and homonyms. They hypothesized that if ERPs reliably encode linguistic meaning, then synonyms should elicit potentials with similar waveforms and homonyms should elicit potentials with dissimilar waveforms. It was further hypothesized that semantic meaning would influence the P300 wave. Short phrases with the stimulus words occurring in the last position of the phrase were presented to six right-handed adult females. Results indicated that ERPs were more similar between words of different meanings but similar physical characteristics than between words of similar meanings but different physical characteristics. These results were true for N100, P200, P300

components and for both frontal and temporal ERPs. It was also noted that subjects were relatively passive in this particular study, and it was suggested that behavioral tasks be encorporated to actively engage the language processing centers. Correlational analysis revealed consistent patterns between homonyms only. Early and late components were also of higher amplitude over the left temporal hemisphere.

Thatcher (1976) designed an experiment to extend the match-mismatch paradigm beyond stimulus features to a semantic level. He used a delayed semantic matching paradigm using synonyms, antonyms, and neutral words and required the subject to indicate the semantic category of the second word in relation to the first. Results indicated significant differences in P400 amplitude between antonyms and neutrals, between synonyms and neutrals, and between second and first words. Maximal effects were recorded in posterior rather than anterior regions.

Bucksbaum and Fedio (1969, 1970) conducted two studies to determine whether verbal and nonverbal stimuli would elicit different visual evoked potentials (VEPs). Responses to familiar words, random dot patterns, simulated words, and designs of random dots were recorded over occipital areas, O1 and O2. Latency of the positive peak (190-280 msec) was significantly shorter for the words. Using a discrimination index computed from the left hemisphere site, "word" VEPs were discriminated best from the design VEPs. No between hemisphere effects were noted for the "word" stimuli.

Bucksbaum and Fedio (1970) next recorded VEPs to three-letter words and nonsense visual patterns presented to the right or left

visual fields. Both right and left occipital electrode sites discriminated the word from the dot patterns.

Begleiter and Platz (1969) conducted a study of connotative meaning related to ERPs. Visual evoked responses were recorded to taboo words, neutral words, and blank fields. Peak-to-peak amplitude measures were larger for the N100-P160 component elicited by taboo words. A larger N100-P160 amplitude was also recorded over all stimuli when the subjects were required to respond. The authors concluded that amplitude of components is affected by demand for a response as well as connotative meaning of the stimulus.

Much of the research concerning semantic meanings of words has its origin in Osgood's analysis of semantic meaning (Osgood, 1952). Using semantic differential measures on a large number of scales, it was found that a good portion of the total variance in judgments of verbal meaning could be accounted for by three underlying dimensions: evaluation, potency, and activity (E, P, A). Semantic meaning can therefore be specified by the location of a word on Osgood's E, P, and A dimensions. These concepts have been well defined, objectively measured, and have been determined to be valid in 23 different language groups (Chapman et al., 1977). Osgood's three dimensions are each bipolar so that words can have either positive or negative values on E, P, and A dimensions. Chapman et al. selected words which scored relatively high or low on one of the dimensions and presented them visually to a group of normal subjects. The basic premise of the study was that the neural components common to the words of a given semantic meaning class would appear in the average response, while those aspects of processing not common would cancel out.

A principle components analysis yielded evoked potential differences between semantic meaning classes. ERP effects were demonstrated by the success in classifying ERPs into high and low word classes using scoring templates. Chapman et al. concluded from their complex analyses that "internal representations of meaning can be assessed by analyzing brain responses."

Some researchers have attempted to assess neurophysiological responses to sentence processing. Papanicolaou (1980) recorded ERPs from bilateral frontal, temporal, and parietal locations of eight adults who listened to a meaningless sequence of words at a rate of 200 words per minute. Subjects received four different experimental conditions. Concrete nouns from the Rocsh (1975) category nouns, containing one of four specific consonants and occurring at one of two loudness levels, were presented at irregular intervals. A one Hz strobe light flash occurred throughout each passage. In addition to a control condition in which subjects ignored the passages, controls included: (1) a semantic condition in which subjects counted words from the same category; (2) a phonetic condition in which subjects counted words with a specific consonant; and (3) an acoustic condition in which subjects counted number of loud or soft words. Papanicolaou used a ratio of peak amplitude (P100N100) for each experimental condition divided by P100N100 control condition amplitude. An increase in left hemisphere activity during the processing tasks was reported.

Friedman et al. (1975b) also designed an experiment where visually flashed words comprised a sentence in which a key word delivered information either late in the sentence (condition 1) or early in the

sentence (condition 2). No consistent VEP asymmetries were reported. They also found that all words in the sentence evoked P300s. P300 to the last word in both conditions was significantly larger than the P300 to all the other words in the sentence, even though in condition 2 the second word delivered information. P300 latency to words which delivered information (last word in condition 1, second word in condition 2) were significantly longer than P300 latency to any of the other words in the sentence as well as to the same position word in the other condition. Friedman et al. noted that the major effect of information delivery was on P300 latency while "syntactic closure" had its major effect on P300 amplitude. The fact that evoked potentials to all words had P300 components was attributed to the engagement of P300 system whenever task-related language stimuli were used. The experimenters concluded that in language experiments, uncertainty has its greatest effect on P300 latency and not amplitude. The evoked potential to the word which ended the syntactic structure produced a larger P300 than all the other words in that structure. Friedman et al. called this effect syntactic closure and speculated that the brain processes language stimuli in terms of their meaning and syntactic structure simultaneously. According to this theory, when a syntactic structure such as a sentence ends, the brain presumably recognizes it as a language unit and reacts neurophysiologically.

Kutas and Hillyard (1980a, b, c) also reported a special ERP effect when the final word in a sentence resolved or failed to resolve the information contained in the sentence. Using a procedure similar to Friedman et al. (1975b), subjects viewed 160 different seven-word

sentences presented one word at a time. The majority of the sentences ended with a semantically appropriate final word; however, 20 sentences ended with a semantically inappropriate final word, 20 sentences ended with an appropriate final word presented in larger size type, and 20 sentences with an inappropriate final word in larger size type. A negative wave (400-500 msec) was identified which occurred for the incongruous seventh word only. Left hemisphere positive components were found to be larger than right hemisphere for all words in the sentence. The larger type stimuli produced a larger positive area centered around P560 (300-600 msec) across the semantic congruent/ incongruent dimensions. A larger P200 was recorded at Fz and Cz for large size type stimuli.

Goto et al. (1979) used three normal right handed adults, three mild aphasics, and one adult with auditory agnosia in their experiment. Three meaningful and three meaningless sentences (predicates exchanged) were presented visually or auditorily. Each sentence had five spoken syllables (Japanese) or four visually presented characters (two Kanji and two Kana). Subjects were able to determine the meaningfulness/ nonmeaningfulness of the sentences by understanding the key information (fourth syllable or third character). One second after the last word of the meaningless sentence a red lamp was lit in front of the subject as the imperative stimulus for the CNV task. The subject had to press a switch as fast as possible after the task signal. For the normal subjects, the auditory task-evoked potentials were obtained to each spoken syllable. Amplitude of N100 component of the evoked potential to the first syllable was the largest. Amplitudes

of P300 to the first and fourth syllables were larger than those to the others. In the visual task, the amplitude of N100 to each character was small. P200 was observed for every character. Amplitudes of P300 to the first and third character were larger than to the second or fourth characters. P300 latency to the third character was longer than any of the other P300 latencies. In both the auditory and visual experiments, CNV began to develop at the first information (first syllable or character) and continued until the subject pressed the switch in response to the meaningful sentence. However, when the subject was stimulated by the meaningless sentence, CNV began to develop at the first information, continued until the key information was given and then disappeared.

In the experiment with the visually presented sentences, P300 latency to the key (third) character was longer than that to the other characters. This finding agrees with that of Friedman et al. (1975b) who reported that P300 latencies to words which delivered information were longer than P300 latencies to any of the other words in the sentence. The aphasics' responses for all tasks were reported to be "confused." The subject with auditory agnosia responded similarly to the normals for the visual task but did not manifest waves for the auditory task.

Brown et al. (1973) recorded ERPs to auditorily presented three-word sentences in which the target was the final word. A control condition contained the same two words as the first word in the sentence. Experimental sentences were "Sit by the fire," "Ready, aim, fire," while control sentences were "Fire is hot," and "Fire the gun."

Sentences were presented in random order and subjects were instructed to "visualize" the meanings of the sentences. Results were similar to those reported by Teyler et al. (1973) in that differences in ERP waveforms over the left hemisphere electrode site were identified for the different contexts.

Brown et al. (1976), in a follow-up study, recorded ERPs while subjects listened to the sentence "It was led." Prior to presentation of the sentence, subjects were instructed to perceive the stimulus (last) word as either a noun or a verb. Several types of analyses, including principle components analysis, were applied to the data. Using PCA, a larger N150 component to nouns than verbs was recorded over left hemisphere leads. A second component (P230) indicated greater amplitudes for nouns than verbs at posterior electrode sites.

In another follow-up study, Brown et al. (1980) studied context effects across languages. Similar stimuli were presented in English and German. Principle components analysis identified components which were more positive anteriorly for nouns and more negative posteriorly than verbs. These data were consistent with those reported by Brown et al. (1979).

The series of studies reported by Brown et al. (1973, 1976, 1980, 1979) and Teyler et al. (1973) consistently reported ERP differences to noun versus verb stimuli. Crucial ERP components appear to be N100-P200 complex and later components (260-500 msec).

H. Summary

In an attempt to define brain-language relationships, many researchers have focused on event-related potentials. Endogenous components, which are elicited primarily by the processing demands of a task have been the primary focus of these studies since they appear to reflect aspects of uncertainty resolution, decision making, and cognitive/ linguistic processing. Although endogenous components are highly variable and depend primarily on the meaningfulness of stimuli to an individual, they do appear to be sensitive to various language relevant stimulus manipulations including phonological cues such as voicing and place of articulation contrasts. ERP measures have also demonstrated sensitivity to syntactic/semantic manipulations (Brown et al., 1973, 1976, 1980) and connotative meaning manipulations.

Early electrophysiological-linguistic studies attempted to define cerebral localization of language function and were directed toward providing evidence for the existence of a left hemispheric spatial or holistic processor (Donchin and McCarthy, 1979). However, results of these studies were generally equivocal, and research emphasis shifted toward isolating ERP correlates of phonologic, semantic, and syntactic processing. Molfese (1972) and Molfese et al. (1975) determined that from infancy onward, ERP measures can distinguish speech and nonspeech material. ERP sensitivity to phonological cues such as voicing and place of articulation contrasts has been demonstrated by responses from both hemispheres (Molfese and Molfese, 1979a). ERP components have also been determined to be sensitive to semantic manipulations

(Teyler et al., 1973; Thatcher, 1976; Freedman et al., 1975b) and syntactical variations (Brown et al., 1973, 1976, 1980). Several researchers have reported neurophysiological responses to semantically incongruous sentences which disconfirm subjects' expectancies. Since certain ERP components are known to be sensitive to expectancy and uncertainty reduction, disconfirming events such as semantically incongruous sentences may be an initial step in deciphering the coding systems engaged during linguistic processing. However, conclusive results have been hampered and confounded by many factors. In addition to their inherent variability, endogenous components also appear to be sensitive to task manipulations and acoustical characteristics such as frequency, formant structure, rise-decay time, duration, etc. Several researchers (Neville, 1974, 1980; Kutas and Hillyard, 1980a, b, c; and Hillyard and Woods, 1979) have also suggested that the manipulation of various listener tasks influences the ability of ERPs to detect differences in language-related stimuli.

Many studies have also failed to control for sex and handedness differences although differences in evoked response amplitudes and latencies have been determined for both factors. The issues of sex and handedness have not been directly addressed in ERP studies. This lack of systematic research and absence of a theoretical framework have greatly limited the contributions of these studies. Nevertheless, ERP techniques do appear to offer new insights into the study of neurolinguistics and need to be more systematically investigated.

I. Statement of Purpose

Areas of Experimental Interest and Design Rationale

The possibility of studying neural activity related to linguistic processing is a fascinating aspect of evoked potential research. Although the technique is still in its infancy and is undergoing many refinements, it does offer new insights into the study of neurolinguistics. Reports from numerous researchers studying language processes indicate that ERP measures do appear to be sensitive to various language relevant stimulus manipulations.

The present study was designed to add to the current knowledge concerning linguistic aspects of information processing and evoked potential parameters. To investigate this area, a design consistent with the preceding review of the literature was developed. Since ERP research regarding sex differences and linguistic processing has not been directly addressed, this factor was included in the design. Also, since many studies involve numerous repetitions of the stimuli for averaging, the effect of two separate successive recordings was also included as a factor in the study.

The evoked responses were recorded from Cz and P3, and each site was treated as a separate study during the analysis. Stimuli consisted of five semantically inappropriate and five semantically appropriate sentences. Each semantically appropriate sentence had an anomalous cognate sentence which differed in the final (Key) word or nonsense syllable. Key elements varied in one of two ways:

1. Phonemically--three of the pairs varied phonemically with only the final phoneme of the key element differing.

2. Semantically--two of the pairs varied semantically with an inappropriate meaningful word replacing the appropriate word for the semantically inappropriate cognate sentence.

Subjects were required to listen to each sentence and indicate immediately after each presentation whether or not the sentence made sense. A randomized list of ten presentations of each of the ten sentences was presented twice for a total of 20 presentations of each stimulus sentence. ERPs were obtained for stimulus words only. ERP responses between the first and second list were also compared.

Experimental Questions:

The design outlined above permitted statistical (analysis of variance) as well as descriptive analyses of a number of experimental questions relevant to the experimental areas. Following the preliminary analysis of variance of main effects and interaction effects, the method of orthogonal contrasts was used since it permited testing for the various treatment effects and interaction effects separately (Lindman, 1974).

Peak-to-peak amplitudes and their corresponding latencies were recorded within the following time windows: 52.5 to 170.0 msec (N100), 172.5 to 285.0 msec (P200) and 290.0 to 580.0 msec (P300). Two of the amplitude measures, P200 and P300, were referenced to the N100 component resulting in N100P200 and N100P300 measures.

For each of the eight amplitude and latency measures the following experimental questions were generated:

1. Do the effects of sentence and presentation on ERP (amplitude, latency) measures vary for male and female subjects?

2. Do the effects of sentence type and presentation differentially affect the ERP (amplitude, latency) responses?

3. Do ERP (amplitude, latency) responses vary as a function of sentence type for males and females?

4. Do ERP (amplitude, latency) responses vary as a function of presentation for males and females?

5. Do ERP (amplitude, latency) responses vary as a function of sentence type?

6. Do ERP (amplitude, latency) responses vary as a function of presentation?

7. Do ERP (amplitude, latency) responses vary for males and females?

Since there were two electrode locations, three amplitude measures, and three latency measures, 12 ANOVAs were initially completed. Following the initial ANOVAs a method of planned comparisons, orthogonal contrasts, was used to estimate and test for differences among the various sentences.

CHAPTER III

METHODS

Electrical activity was recorded from a central (Cz) and a parietal (P3) site, and from one inch above and to the side of the right eye and one inch below and to the side of the left eye. Electrical activity was recorded against a linked-ear reference and ground. ERPs recorded from Cz and P3 were analyzed and reported separately. The general design of the investigation, description of subjects, apparatus, and general procedures are discussed in this chapter.

A. General Design

The stimuli in this investigation consisted of five pairs of sentences which included five semantically inappropriate and five semantically appropriate sentences. The sentences were presented auditorily to female and male subjects. Three of the sentence pairs differed phonemically (final phoneme only) and two of the pairs, semantically (final word). ERPs were recorded from final (Key) elements only. The ten stimulus sentences are presented in Table 1.

College-age females and males served as subjects. The listening task consisted of two separate presentations of the ten sentences. Each sentence was presented randomly ten times during a listening condition for a total of 100 sentences per condition and a total of 200 sentences in all.

Each subject completed the experimental conditions in one session of approximately one-hour duration. Prior to the testing session

TABLE 1. The ten stimulus sentences used in this investigation presented in terms of phonemic/semantic pairs.

	Stimulus sentences
Phonemic Pairs	You'll catch cold if you don't wear a hat. You'll catch cold if you don't wear a /hædʒ/
	John fell down and broke his leg. John fell down and broke his /lep/
	I enjoyed reading the new book. I enjoyed reading the new /bʊf/
Semantic Pairs	The flowers smell good. The flowers smell tall.
	Wash your face and comb your hair. Wash your face and comb your teeth.

audiometric screening, handedness assessment, and case history information were completed.

B. Subjects

Fourteen young adults, seven females and seven males, served as subjects in this investigation. Age range of the female subjects was 21 to 24 years, with a mean age of 22.7 years. Age range of the male subjects was 21 to 28 years with a mean age of 24.4 years. All subjects were students at The University of Tennessee and were drawn from a population of volunteers. Subjects were not paid for their participation in this study. Criteria for selection as a subject included the following:

1. Right handedness. The Edinburgh Handedness Inventory (Oldfield, 1971) was administered to all subjects prior to experimental testing. Criterion for selection was a laterality quotient within or above the fifth decile for right handed individuals. Subjects were also questioned concerning any change in hand preference which may have occurred in childhood. Subjects who reported any change in hand preference were excluded from the study.

2. Hearing sensitivity within normal limits. A Beltone portable audiometer was used for audiometric screening. Testing was conducted in a quiet room. Criteria were responses no greater than 20 HL (calibrated to ANSI), bilaterally at 500, 1000, 2000, 4000, and 8000 Hz.

3. No history of neurological disorders, as indicated by subject report. Subjects were questioned concerning any history of epilepsy, tumors, neurological diseases or injuries.

4. No history of speech or language problems, as indicated by subject report. Subjects were questioned concerning any history of speech or language disorders. Articulation was also screened informally during conversation with the subject.

C. Stimuli

Stimuli consisted of ten sentences, five semantically inappropriate and five semantically appropriate. Each of the five semantically inappropriate sentences had a semantically appropriate cognate sentence which differed in the final (Key) word or CVC syllable. Three of the pairs varied phonemically with only the final phoneme of the Key element varying. In the other two sentence pairs, a meaningful word was used in an anomalous context. ERPs were recorded to the Key element only.

All stimulus tapes were prepared in the speech laboratory at The University of Tennessee. The ten sentences were recorded on a two channel tape recorder by an adult male with a general American dialect. The speaker was seated in a sound-treated room (Suttle, Model 224) six inches from a microphone (Electro Voice, Model RE20). The microphone output was connected to the microphone mixer (Shure, Model M67) which was connected to the tape recorder (Studer, Model B67). Three speech pathologists having Certificates of Clinical Competence listened to the tape and transcribed the ten sentences to verify that the sentences were produced correctly and were intelligible.

A 250 msec, 1000 Hz sinewave was recorded on the second channel of the tape, synchronous with the onset of the vowel of each Key

element. A Wavetek VCG/VCA (Model 136) was used to generate the trigger pulse, and a digital storage oscilloscope (Explorer II, Nicolet, Model 206) was used to help align the trigger pulse with the Key element. The ten recordings were analyzed on the Voice Identification Unit (700 series) using a high frequency shaping circuit and linear expand set at 0-4 K Hz. Spectrographic recordings of each of the ten sentences indicated that the trigger pulse was within $\pm$50 milliseconds (msec) of the onset of the vowel of each Key element. Duration of the Key elements ranged from 348 msec (hair) to 575 msec (/hædʒ/). Spectrographic measurements are presented in Table 2 and the actual spectrograms are included in Appendix A.

The list of ten sentences was then randomized ten times and re-recorded for a total of 100 sentences. Interstimulus interval was seven to nine seconds. Sound pressure level at the earphone (B & K Artificial Ear, Mic 4134 Pre Amp 2619) was 96-99 dB for the speech signal and 96.8 dB for the trigger tones.

D. Apparatus

A block diagram of the experimental apparatus is presented in Figure 4. For all testing the subject was seated in a comfortable lounge chair (upright position) within a sound attenuated, electrically shielded room. Ambient room temperatures were maintained throughout the study and average room lighting was maintained at 10 foot candles. Ambient noise level was judged to be 58 dB SPL using a Realistic Corporation sound level meter.

Scalp electrical activity was recorded from one central (Cz) and one left hemispheric (P3) location according to the International

TABLE 2. Duration measures (msec) of the Key elements and sentences and timing measures of the trigger pulse.

		Duration (msec)		
		Key Element	Sentence	Trigger Onset (msec)
1.	hat	435	1684	-24
2.	/hæedʒ/	575	2000	+24
3.	leg	424	1688	-50
4.	/lep/	375	1637	-50
5.	book	350	1524	-12
6.	/bʊf/	355	1450	+24
7.	good	355	1450	0
8.	tall	420	1500	-24
9.	hair	348	1688	-50
10.	teeth	355	1654	0
	$\overline{X}$	= 399.2	= 1627.5	= -16.2

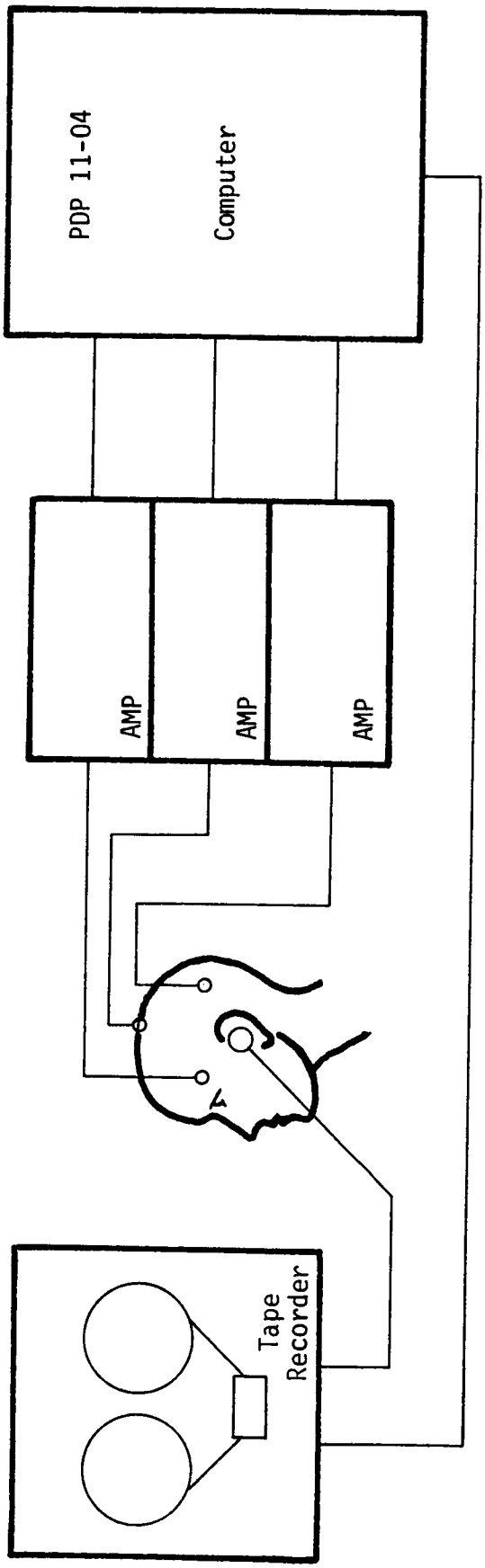

FIGURE 4. Block diagram of the instrumentation used to record the ERPs to the language stimuli used in the investigation.

Federation 10-20 electrode system (Jasper, 1958). Subjects wore a flexible lycra cap (Electro-cap, Model 1X) with Grass Miniature Ag/AgCl biopotential electrodes mounted in it. Recording sites (Cz, P3) in monopolar configuration were referenced to the right ear lobe. In addition to ERP data, electroocular (EOG) information was also collected from a pair of electrodes placed one inch above and to the side of the right eye and one inch below and to the side of the left eye. The computer (PDP 11/04 minicomputer) was set to indicate when EOG activity exceeded 60 microvolts (uv). ERPs containing more than 60 uv of EOG activity were flagged and excluded from the averaging. EOG activity was monitored to help control for eye movement contamination of the ERP. Electrode impedances were measured before and after testing using a Grass Electrode Impedance Meter (Model EZM4). Impedances were always below 10 K ohms and were typically below 5 K ohms.

A panel of electrode pin plugs (Grass Mini Electrode Board, Model IGMed-INT 25) was located on the right side of the subject's chair. All recording and monitoring electrodes were fitted into the plugs. The monitoring and recording equipment was located in a room immediately adjacent to the experimental room.

Three amplifiers (Grass EEG Amplifier for Data Processing, Model 7P511J) with band pass flat responses between .1 and 50 Hz were used to amplify the responses and send them to the computer. Collection and analysis of data was controlled on line by a Digital Equipment Corporation PDP 11/04 minicomputer. ERPs were sampled every 7.5 msec for a total of 134 time points during the 1000 msec time window.

Channel 1 of the audio tape containing the sentence stimuli was played to subjects on a Sony TC 377 tape recorder through TDH-39 stereophonic earphones. Channel 2 of the tape containing the trigger pulse was routed to the PDP 11-04 computer.

A warning light placed on a table in front of the subject appeared one second before the presentation of each sentence and remained on for 1½ seconds after the end of the sentence. Subjects responded by raising the appropriate finger after the light went off. Figure 5 illustrates the timing sequence of the warning light, Key element, and trigger pulse.

E. Procedures

Each subject was tested individually. Once the subject was comfortably seated, the areas to the right and left of the eyes were rubbed with fine grained sandpaper and then washed with acetate. Grass Instrument Co. ESSH gold electrodes were then attached with Grass Instrument Co. EC-2 Electrode Cream. A reference electrode was also filled with Grass Electrode Cream and then clipped to the subject's right ear lobe. Electrode impedance was measured, and adjustments were made, if necessary, to maintain resistance below 10 thousand (K) ohms.

The subject's head was then measured, and the appropriate flexible lycra cap was placed on the subject's head. Grass Instrument Co. Electrode Gel was injected into the Cz and P3 electrodes. Electrode impedance was again measured and appropriate adjustments made, if necessary, to maintain resistance below 10 K ohms.

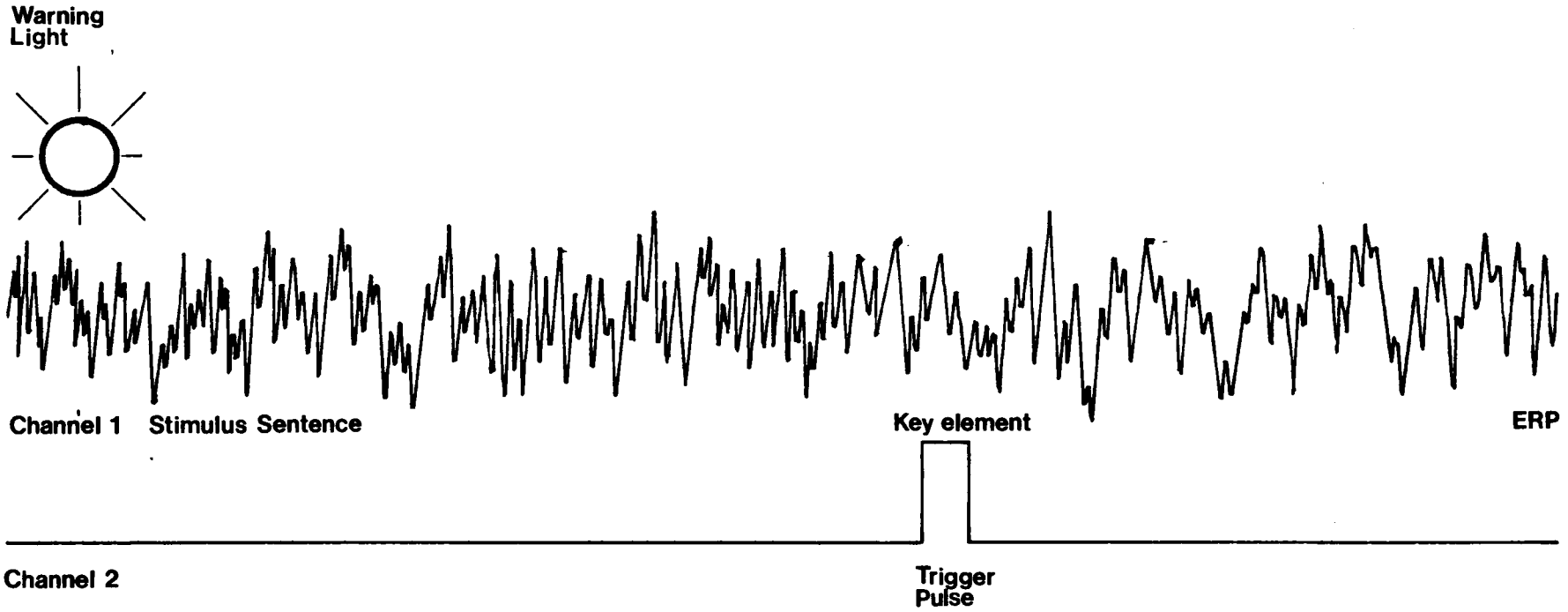

FIGURE 5. Waveform illustrating the timing sequence of the Key element.

After completion of the electrode preparations, the subject was seated in a recliner chair which was in an upright position. The active, reference and ocular electrodes were then plugged into the electrode panel. EEG activity from Cz, P3 and the ocular sites was then initially recorded and monitored. Subjects were instructed to face a blank display screen in front of them. A warning light was positioned immediately in front of the display screen. Subjects were instructed to remain as motionless as possible during data collection. Prior to the beginning of the experimental session, each subject was given individual instruction on the procedure to be used. During this instruction, the experimenter remained in the room with the subject while six practice sentences were presented. The subjects were instructed in body movement and position, muscle activity, relaxation, and eye movements. Subjects were instructed to listen to each sentence and to decide whether or not it made sense. Subjects were instructed to raise the right finger if the sentence made sense and to raise the left finger if the sentence did not make sense. Subjects were told that the warning light would appear before each sentence and to wait for the light to go out before responding. During this practice session, the experimenter answered any questions by the subjects and reinstructed them when necessary. Typewritten instructions for the listening tasks are presented in Appendix B.

Following the short training session, each subject participated in two listening sessions. The same order of presentation was used for each list of 100 sentences. Subjects were given a two-minute rest period after each presentation of 50 sentences. Subjects were given a

ten minute rest period between the first and second listening conditions. The entire listening session lasted approximately 30 minutes. Subjects were observed through a one-way glass, and testing was temporarily interrupted if the subject evidenced any signs of fatigue or discomfort. Following the test session, electrode impedances were again checked.

CHAPTER IV

RESULTS

The present investigation was conducted in order to examine the effects of semantically inappropriate and semantically appropriate sentence processing and stimulus presentation on the neurophysiological responses of female and male subjects. Two electrode sites, a central and a left parietal (Cz and P3, respectively) were selected for the recording of the ERPs. Each electrode site was treated as a separate study and was reported as such. Amplitude and latency values were recorded from each electrode beginning with the onset of the last (Key) word or nonsense syllable in the sentence. The ERPs were recorded for approximately 1000 milliseconds (msec), and peaks were measured within three different time windows: 52.5 to 170.0 msec (N100), 172.5 to 285.0 msec (P200) and 290.0 to 580.0 msec (P300). A peak was defined as the major positive or negative deflection originating during the specified time window after the stimulus presentation. Two of the amplitude measures, P200 and P300, were referenced to the N100 component by measuring the peak-to-peak amplitudes resulting in N100P200 and N100P300 measures. Peak latencies corresponding to the N100, P200, and P300 amplitudes were also computed. Latency measures were then adjusted by adding or subtracting the appropriate correction factor for the trigger pulse for each word (reported in Chapter III). For each amplitude or latency measure, a repeated measures three way analysis of variance was utilized to investigate the effects of Sex, Presentation, and Sentence Type. A

method of planned comparisons was employed when Sentence Type was determined to be significant to test for differences among the various sentences.

Subjects listened to two identical lists of ten randomized presentations of each of the ten stimulus sentences (200 total sentences). The lists were presented successively with a two-minute break between presentations. Subjects were asked to indicate whether the sentence was meaningful or nonmeaningful. A trigger pulse recorded on the second channel and aligned with the onset of the final word or nonsense syllable triggered the computerized recording of the evoked potentials. A sampling rate of 7.5 msec yielded 134 measurements for each sentence during the 1005 msec time window.

A. Central (Cz) Measures

The following amplitude measures were recorded from Cz: N100, N100P200, and N100P300. Latency measures corresponding to N100, P200, and P300 were also recorded resulting in six different analyses.

Peak amplitude and latency measures were recorded from each individual subject. Each subject's ERP reflected an average of ten repetitions of each sentence. The ERP tracings depicted in Figures 6 through 25, however, were computed from averages of each group of subjects for each presentation (First or second). Since amplitude and latency measures were confounded, many of the individual differences were obscured by the averaging process. The composite waves retained the basic waveshape, however, they failed to maintain the actual amplitude and latency measures recorded from each individual subject.

N100 Amplitude and Latency Measures

Mean microvolt N100 amplitudes of females and males for both presentations of all ten sentences are presented in Table 3. The mean N100 amplitude for both presentations of all ten sentences for the female subjects was -4.90 μv which was 1.07 μv more negative than the group mean (see Table 3). For the male subjects the mean N100 amplitude was -2.76 μv which was 1.07 μv's more positive than the group mean. The mean N100 amplitude of the first presentation of all ten sentences for males and females was -3.71 μv while the mean of the second presentation was -3.95 μv. Mean microvolt (μv) N100 peak amplitudes of female and male subjects for both presentations of each of the ten sentences are presented in Table 4. Mean N100 amplitudes of each of the five semantically inappropriate sentences were consistently more negative than the mean amplitudes of their semantically appropriate cognate sentences.

Table 3. Mean N100 peak amplitudes (μV) at Cz for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	-4.76	-2.65	-3.71
Presentation 2	-5.03	-2.86	-3.95
$\bar{X}$	-4.90	-2.76	-3.83

Table 4. Mean N100 peak amplitudes (μV) at Cz for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation		Males Presentation		$\bar{X}$
	1	2	1	2	
book	-3.56	-3.56	-1.76	-2.73	-2.90
/bʊf/	-3.70	-4.27	-2.60	-3.46	-3.51
hat	-5.00	-3.97	-2.44	-2.23	-3.41
/hæʤ/	-4.63	-4.50	-2.40	-2.37	-3.48
leg	-5.50	-5.31	-3.13	-2.73	-4.17
/lep/	-6.41	-6.64	-3.07	-3.23	-4.85
good	-2.34	-5.34	-2.94	-3.14	-3.44
tall	-5.90	-5.13	-3.60	-3.11	-4.44
hair	-4.99	-5.13	-2.31	-2.64	-3.77
teeth	-5.61	-6.44	-2.20	-2.97	-4.31

A repeated measures three way analysis of variance was used to test the effects of Sex, Presentation, and Sentence on N100 amplitude.

Results of the ANOVA, presented in Table 5, yielded statistical significance for the effects of Sex ($F = 17.59$, $df = 1$, $p = 0.0012$) and Sentence ($F = 2.15$, $df = 9$, $p = 0.0314$). These results indicated that N100 peak amplitude for all ten sentences was significantly more negative for the female subjects than for the males.

Table 5. Analysis of variance for N100 peak ampliude--Cz.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	4.10	1	4.10	0.65	0.4356
Presentation x Sex	0.04	1	0.04	0.01	0.9387
Sex	321.21	1	321.21	17.59	0.0012
Sentence	88.66	9	9.85	2.15	0.0314
Sex x Sentence	51.67	9	5.74	1.25	0.2716
Presentation x Sentence	30.32	9	3.37	0.54	0.8447
Presentation x Sex x Sentence	16.95	9	1.88	0.30	0.9724

To further test the effects of Sentence, the method of orthogonal contrasts was used to compare differences between the sentence pairs and between groups of sentences. According to Edwards (1964) it is possible to analyze the sum of squares for K treatments into K-1 component parts, each with one degree of freedom, such that the sum of these component parts is equal to the sum of squares for treatments.

Each of the component parts may involve a comparison between two or more of the treatments. Comparisons of two hypotheses are orthogonal if their associated linear combinations are statistically independent. Any linear function of the treatment means is called a comparison between the means if the sum of the coefficients is equal to zero. Table 6 contains the matrix of the eight sets of contrasts included in the planned comparisons of the present study. The rows represent questions (comparisons) while the columns represent various samples. The numbers in the cells are the weights assigned to a given sample mean for a given comparison. For example, to investigate the difference between book and /bʊf/ the weights of 1 and -1 would be assigned. Weights of zero are given to the other samples not being considered in a particular comparison. The sum of weights for each row is zero as it should be for comparisons among means. These contrasts were used for the amplitude and latency measures and included the five cognate sentence pairs differing in the final word or nonsense syllable; the average of the three phonemic semantically appropriate sentences (Key words = book, hat, leg) vs. the average of the three phonemic semantically inappropriate sentences (Key CVCs = /bʊf/, /hædʒ/, /lep/); the average of all five semantically appropriate vs. all five semantically inappropriate sentences, and a phonemic contrast based on final plosive stops vs. continuants (book + hat vs. (bʊf/ + /hædʒ/).

Results of the significance testing of N100 on the eight contrast sets indicated a significantly more negative N100 amplitude for all five semantically inappropriate sentences averaged together vs. the average of the five semantically appropriate sentences (F = 5.07, df =

Table 6. Matrix depicting orthogonal contrasts between the five cognate sentence pairs, the average of the three phonemic-semantically inappropriate and three phonemic-semantically appropriate sentences, the average of the five semantically inappropriate and five semantically appropriate sentences, and the plosives and continuants contrast.

Comparison	book	/bʊf/	hat	/hædʒ/	leg	/lep/	good	tall	hair	teeth
book vs. /bʊf/	1	-1	0	0	0	0	0	0	0	0
hat vs. /hædʒ/	0	0	1	-1	0	0	0	0	0	0
leg vs. /lep/	0	0	0	0	1	-1	0	0	0	0
good vs. tall	0	0	0	0	0	0	1	-1	0	0
hair vs. teeth	0	0	0	0	0	0	0	0	1	-1
book + hat vs. /bʊf/ + /hædʒ/	1	-1	1	-1	0	0	0	0	0	0
book + hat + leg vs. /bʊf/ + /hædʒ/ + /lep/	1	-1	1	-1	1	-1	0	0	0	0
book + hat + leg + good + hair vs. /bʊf/ + /hædʒ/ + /lep/ + tall + teeth	1	-1	1	-1	1	-1	1	-1	1	-1

1, p = 0.0264). No significant differences in N100 amplitude were found between any of the five individual sentence pairs or between the stops vs. the continuants. The ANOVA tables for the planned comparisons are included in Appendix C.

Latency measures of N100 peaks for all ten sentences (both presentations) for females and males are presented in Table 7. Mean N100 latency measures for both presentations of all ten sentences were somewhat shorter for females (104.48 msec) than for males (107.97 msec). Mean N100 latencies to all ten sentences for both groups of subjects were 105.09 msec for the first presentation and 107.36 msec for the second presentation.

Latency measures corresponding to N100 peaks (Table 8) were also recorded for each presentation of each of the ten sentences. Mean latencies for three of the five semantically inappropriate sentences were shorter than latencies of the semantically appropriate sentences. The peak N100 latency of the sentence with /lep/ (135.45 msec), however, was longer than the one with leg (123.22 msec) as was the peak latency of tall (112.29 msec) vs. good (83.84 msec).

Table 7. Mean N100 peak latencies (msec) at Cz for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	105.34	104.83	105.09
Presentation 2	103.61	111.11	107.36
$\bar{X}$	104.48	107.97	106.23

Table 8. Mean N100 peak latencies (msec) at Cz for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	110.21	103.36	111.64	117.00	110.55
/bʊf/	120.71	85.50	103.86	95.93	101.50
hat	106.00	113.29	136.21	118.50	118.50
/haedʒ/	79.29	89.07	89.79	107.21	91.34
leg	116.43	119.64	130.36	126.43	123.22
/lep/	133.93	142.50	135.71	129.64	135.45
good	71.79	79.29	107.14	77.14	83.84
tall	106.50	92.07	121.21	129.36	112.29
hair	132.50	118.14	115.71	114.29	120.16
teeth	76.07	93.21	96.64	95.57	90.37

Results of the repeated measures three way analysis of variance to test N100 latency effects are presented in Table 9. The main effect Sentence was determined to be significant ($F = 6.91$, $df = 9$, $p = 0.0001$).

Table 9. Analysis of variance for N100 peak latency--Cz.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	465.43	1	465.43	0.36	0.5585
Presentation x Sex	49.73	1	49.73	0.04	0.8473
Sex	5228.93	1	5228.93	1.99	0.1839
Sentence	68594.24	9	7621.58	6.91	0.0001
Sex x Sentence	8423.41	9	935.93	0.85	0.5741
Presentation x Sentence	6321.69	9	702.41	0.73	0.6857
Presentation x Sex x Sentence	7224.83	9	802.76	0.83	0.5916

Results of the orthogonal contrast testing yielded four significant contrasts. Three of the four contrasts exhibited significantly shorter latencies for the semantically inappropriate sentences. The sentence with the Key element of /hædʒ/ was determined to be significantly shorter in latency than the cognate sentence with hat ($F = 9.37$, $df = 1$, $p = 0.0028$). The sentence with teeth was determined to be significantly shorter than its cognate with hair ($F = 10.70$, $df = 1$, $p = 0.0014$), and sentences ending with /bʊf/ + /hædʒ/ were determined to be significantly shorter in latency than those ending with book + hat

($F = 8.33$, $df = 1$, $p = 0.0047$). The semantically appropriate sentence with the key word good, however, was determined to be significantly shorter than the semantically inappropriate sentence with tall ($F = 10.27$, $df = 1$, $p = 0.0018$).

P200 Amplitude and Latency Measures

Collapsed N100P200 amplitude measures for all ten sentences are presented in Table 10. Female N100P200 amplitude for both presentations of all ten sentences also remained consistently more positive (10.40 μv) than the amplitude for males (6.05 μv). N100P200 amplitude of the first presentation (8.46 μv) of all ten sentences for both sexes was also greater than the amplitude of the second presentation (7.97 μv).

Amplitude measures of N100P200 for each of the ten sentences are presented in Table 11. The mean N100P200 amplitudes for each of the semantically inappropriate sentences remained consistently more positive than the amplitudes of their semantically appropriate cognate sentences.

Table 10. Mean N100P200 amplitudes (μV) at Cz for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	11.02	5.90	8.46
Presentation 2	9.75	6.19	7.97
$\bar{X}$	10.40	6.05	8.22

Table 11. Mean N100P200 amplitudes (μV) at Cz for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	9.26	7.63	5.64	5.76	7.07
/bʊf/	8.77	8.31	6.01	7.63	7.68
hat	8.71	7.81	4.77	5.44	6.68
/hædʒ/	10.10	6.81	5.16	6.90	7.24
leg	9.91	9.49	6.00	5.97	7.84
/lep/	9.89	10.36	5.36	6.01	7.90
good	6.99	10.71	6.93	5.49	7.53
tall	12.37	13.17	7.66	6.54	9.94
hair	10.69	10.59	4.64	5.47	7.85
teeth	13.51	12.63	6.80	6.73	9.92

Results of the repeated measures three way analysis of variance (Table 12) indicated that the N100P200 amplitudes were significantly more positive for the female subjects than for the males ($F = 16.53$, $df = 1$, $p = 0.0016$). Significant differences ($F = 3.45$, $df = 9$, $p = 0.0010$) among the ten sentences were also determined. In addition the Sex x Sentence interaction approached significance ($F = 1.76$, $df = 9$, $p = 0.0831$) which indicated that N100P200 amplitude responses were significantly different for the ten different sentences. Planned comparison testing was limited to significant main effects for the purposes of this study.

Table 12. Analysis of variance for N100P200 amplitude--Cz.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	0.01	1	0.01	0.00	0.9746
Presentation x Sex	5.60	1	5.60	0.41	0.5320
Sex	1032.19	1	1032.19	16.53	0.0016
Sentence	306.80	9	34.09	3.45	0.0010
Sex x Sentence	156.93	9	17.44	1.76	0.0831
Presentation x Sentence	25.04	9	2.78	0.25	0.9999
Presentation x Sex x Sentence	112.02	9	12.45	0.88	0.7431

The significant main effect Sentence was then subjected to the same method of orthogonal contrasts. These results indicated three of the contrasts to be significant. The average of the five semantically

inappropriate sentences was judged to be significantly more positive than the average of the five semantically appropriate sentences ($F = 9.22$, $df = 1$, $p = 0.0030$). Significantly greater N100P200 components were also determined for the sentences with tall vs. its cognate sentence with good ($F = 8.20$, $df = 1$, $p = 0.0050$) and teeth vs. its cognate hair ($F = 6.08$, $df = 1$, $p = 0.0153$). Mean ERPs for these contrast pairs for both presentations for females and males are shown in Figures 6 through 9.

Peak latency measures for the P200 component are presented in Tables 13 and 14. Latency measures corresponding to P200 peaks are presented for each of the words in Table 13. Mean latencies for two of the Key elements of the five semantically inappropriate sentences were shorter than latencies of sentences with semantically appropriate Key elements. The peak P200 latency of the sentence with the Key element /hædʒ/ (209.54 msec) was shorter than the one with the Key element hat (228.11 msec) as was the peak latency of the sentence with the Key element teeth (221.61 msec) vs. hair (234.86 msec).

Latency measures (Table 14) for the first presentation (224.80 msec) of all ten sentences for females and males were slightly longer than for the second presentation (220.39 msec). Latencies of females (223.54 msec) were slightly longer than latencies for males (221.65 msec) for both presentations of all ten sentences. Significance testing with the three way analysis of variance (Table 15) indicated a significant Presentation x Sex interaction ($F = 4.85$, $df = 1$, $p = 0.0479$). However, no consistent latency differences were apparent for the females and males since latencies for the first presentation were

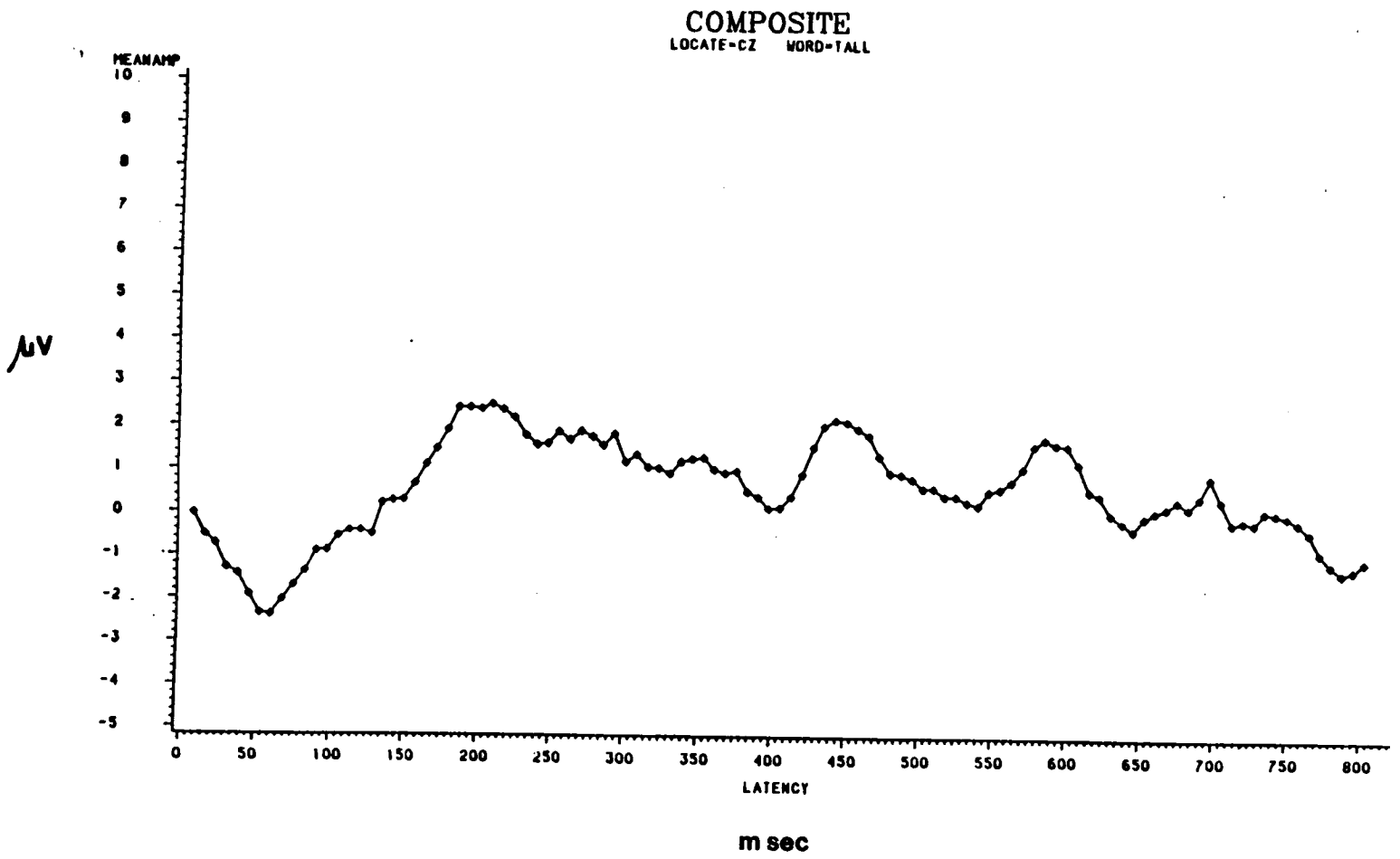

Figure 6. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "The flowers smell tall."

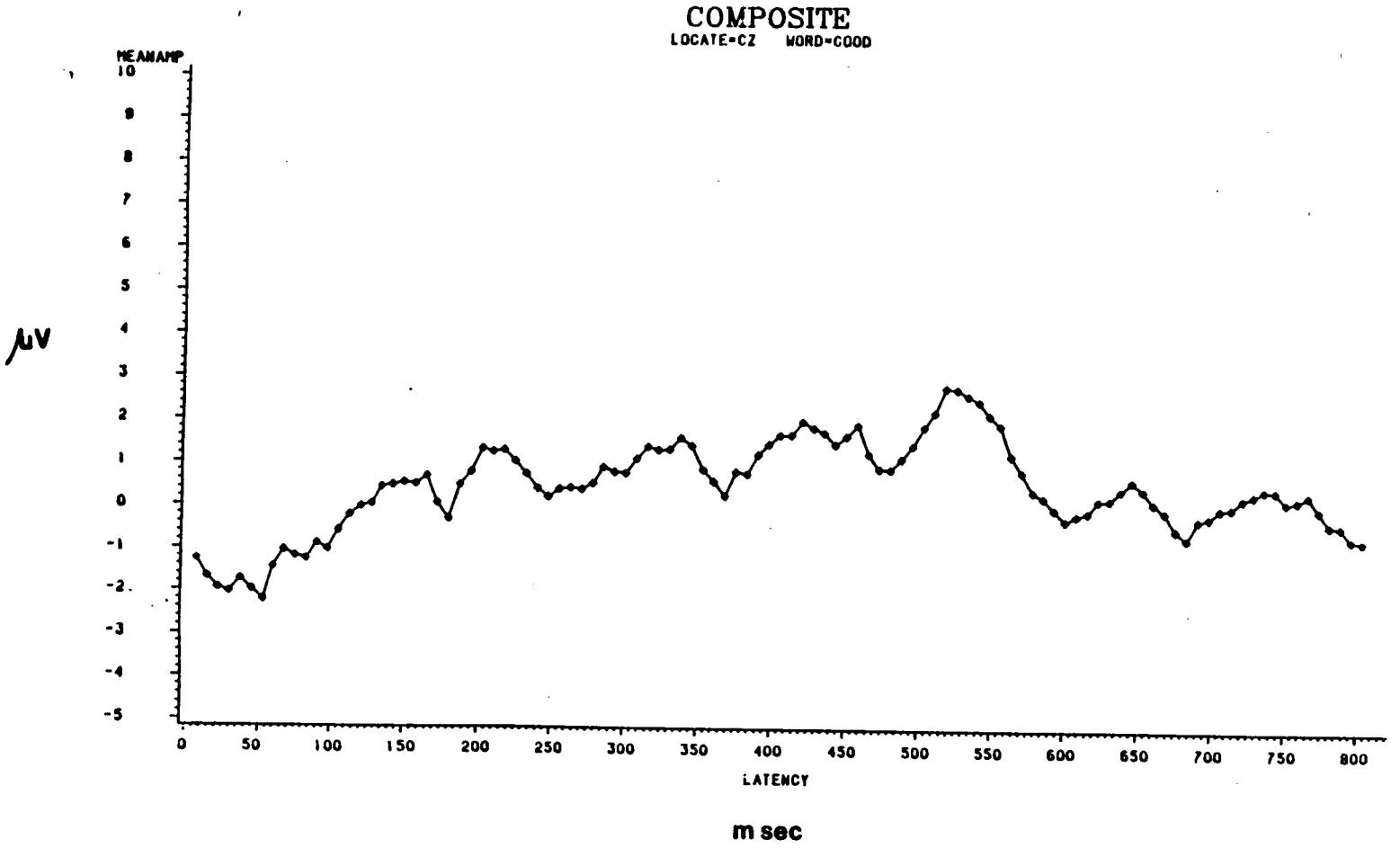

Figure 7. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "The flowers smell good."

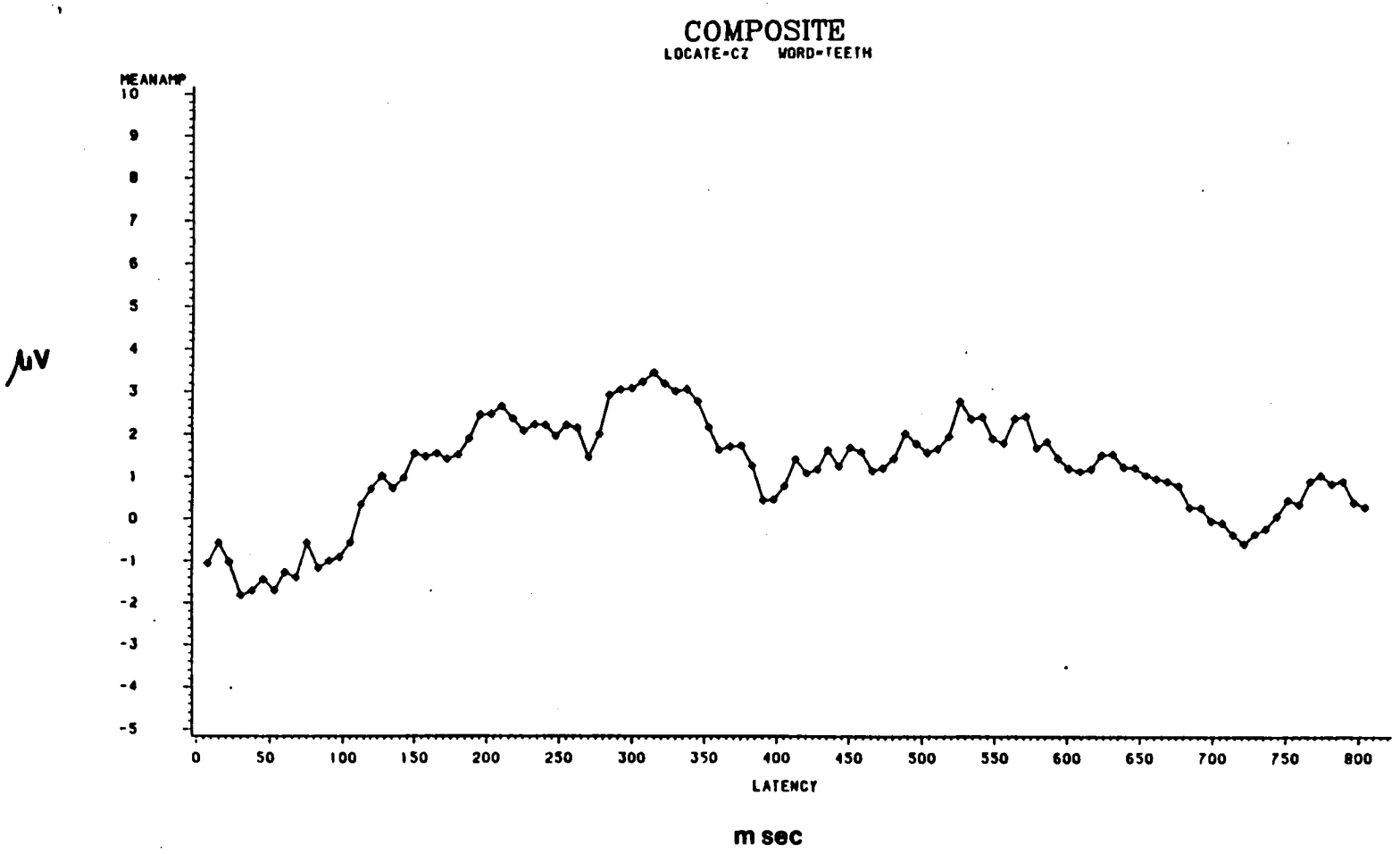

Figure 8. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "Wash your face and comb your teeth."

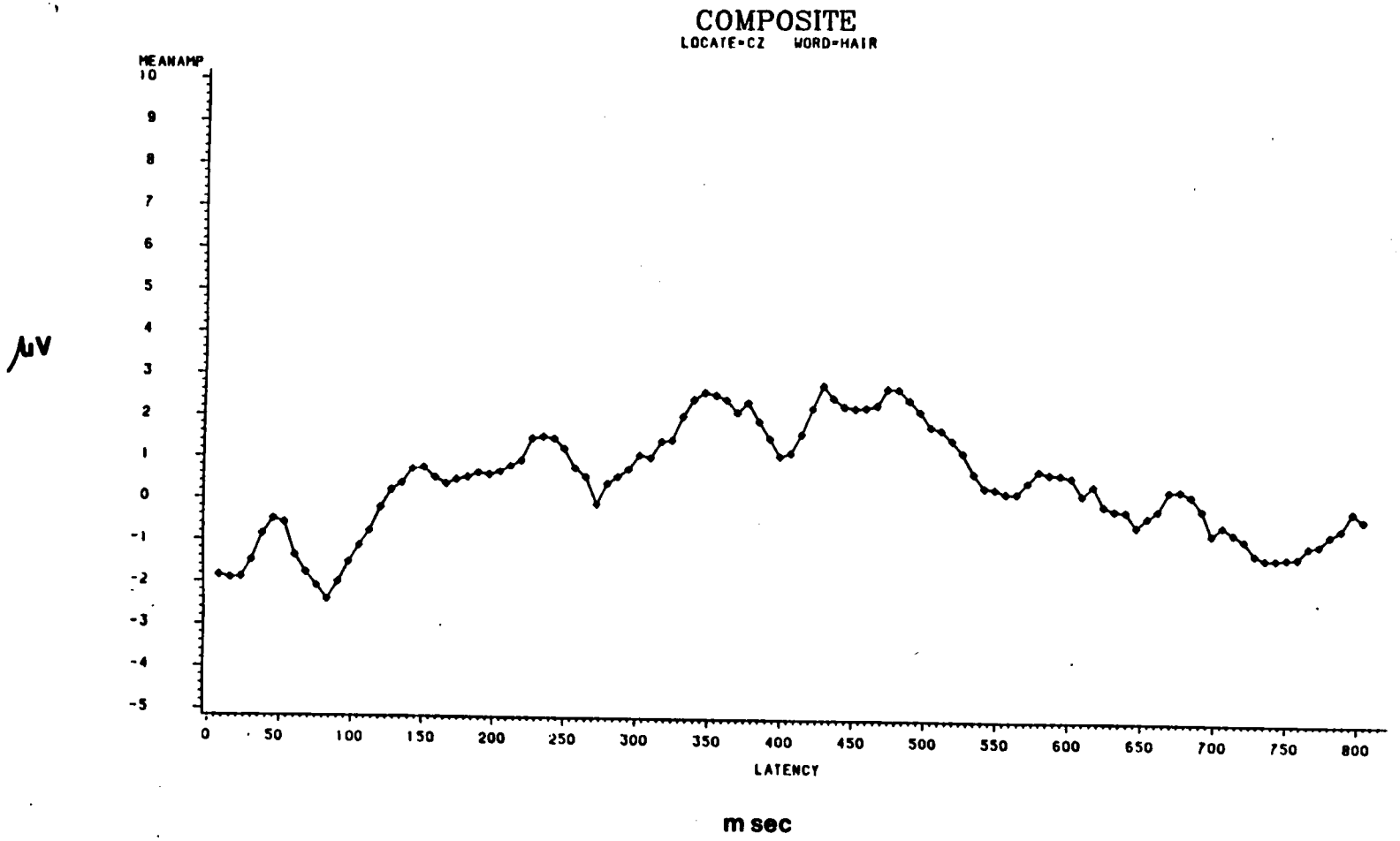

Figure 9. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "Wash your face and comb your hair."

Table 13. Mean P200 peak latencies (msec) at Cz for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	213.57	235.29	210.79	217.07	219.18
/bʊf/	224.64	242.00	205.93	216.79	222.34
hat	252.21	216.86	228.64	214.71	228.11
/hæʤ/	206.21	199.86	219.71	212.36	209.54
leg	228.93	229.29	227.14	203.57	222.23
/lep/	199.29	243.21	247.00	222.86	228.09
good	208.93	209.64	217.50	219.64	213.93
tall	230.29	219.36	238.07	216.21	225.98
hair	237.50	232.71	265.36	203.86	234.86
teeth	209.29	231.43	225.00	220.71	221.61

shorter for females but longer for females during the second presentation. No other main effects or interactions were determined to be significant.

Table 14. Mean P200 peak latencies (msec) at Cz for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	221.09	228.51	224.80
Presentation 2	225.99	214.78	220.39
$\bar{X}$	223.54	221.65	220.39

Table 15. Analysis of variance P200 peak latency--Cz.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	1342.03	1	1342.03	1.06	0.3231
Presentation x Sex	6128.93	1	6128.93	4.84	0.0479
Sex	234.06	1	234.06	0.15	0.7021
Sentence	13480.47	9	1497.83	1.29	0.2524
Sex x Sentence	9594.05	9	1066.01	0.92	0.5157
Presentation x Sentence	17838.04	9	1982.00	1.33	0.2274
Presentation x Sex x Sentence	11435.96	9	1270.66	0.86	0.5684

P300 Amplitude and Latency Measures

Amplitude measures of P300 referenced to the N100 component (N100P300) are presented in Tables 16 and 17. Amplitudes of N100P300 (Table 16) also remained consistently more positive for the female subjects (14.35 μv) vs. the male subjects (8.18 μv) for both presentations of all ten sentences. The first presentation of all ten sentences for females and males (11.69 μv) was somewhat more positive than the second presentation (10.91 μv). The amplitude differences (Table 17) between the semantically inappropriate and appropriate sentences noted at N100 and N100P200 were even more dramatic at N100P300. Amplitudes of the semantically inappropriate sentences were generally 2.00 μv's more positive than amplitudes of semantically appropriate sentences.

Table 16. Mean N100P300 amplitudes (μV) at Cz for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	14.95	8.29	11.69
Presentation 2	13.74	8.07	10.91
$\bar{X}$	14.35	8.18	

The analysis of variance (Table 18) indicated the sex differences to be significant ($F = 28.11$, $df = 1$, $p = 0.0002$). Significant differences among Sentences ($F = 5.04$, $df = 9$, $p = 0.0001$) and a significant Sex x Sentence interaction ($F = 1.91$, $df = 9$, $p = 0.0576$) were also determined.

Table 17. Mean N100P300 amplitude (μV) at Cz for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	12.79	13.21	7.28	7.31	10.15
/bʊf/	18.07	14.19	9.83	8.96	12.76
hat	15.33	12.11	7.16	5.83	10.11
/hæʤ/	18.79	15.10	9.41	10.11	13.35
leg	11.69	11.34	7.07	8.03	9.53
/lep/	17.57	18.87	8.39	8.53	13.34
good	10.10	13.14	8.03	7.54	9.70
tall	13.49	14.11	9.23	8.70	11.38
hair	14.10	11.34	7.77	7.89	10.28
teeth	17.60	13.94	8.73	7.81	12.02

Table 18. Analysis of variance for N100P300 amplitude--Cz.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	35.93	1	35.93	2.80	0.1201
Presentation x Sex	17.35	1	17.35	1.35	0.2675
Sex	2659.27	1	2659.27	28.11	0.0002
Sentence	573.79	9	67.75	5.04	0.0001
Sex x Sentence	217.64	9	24.18	1.91	0.0576
Presentation x Sentence	120.32	9	13.37	0.91	0.5232
Presentation x Sex x Sentence	95.74	9	10.64	0.72	0.6896

Further testing of N100P300 measures of the various sentences indicated the three phonemic contrast pairs to be significantly different. Significant amplitude differences were determined between the sentences with /bʊf/ vs. its cognate sentence with book ($F = 7.54$, $df = 1$, $p = 0.0071$); /hæʤ/ vs. its cognate with hat ($F = 11.66$, $df = 1$, $p = 0.0009$); and /lep/ vs. leg ($F = 16.03$, $df = 1$, $p = 0.0001$). The two contrast pairs containing real words (tall vs. good and teeth vs. hair) approached significance ($F = 3.12$, $df = 1$, $p = 0.0803$ and $F = 3.37$, $df = 1$, $p = 0.0690$, respectively). The plosive vs. continuant contrast pair was also determined to be significant ($F = 18.97$, $df = 1$, $p = 0.0001$) as were the averages of the phonemic-semantically inappropriate and appropriate sentences ($F = 34.43$, $df = 1$, $p = 0.0001$). The average of all five semantically inappropriate sentences was also determined to be significantly different from the average of

all five semantically appropriate sentences ($F = 37.90$, $df = 1$, $p = 0.0001$).

The collapsed means for P300 (Table 19) indicated that latencies for all ten sentences were somewhat shorter for the second presentation of all ten sentences for both groups of subjects (441.29 msec) than for the first presentation (457.46 msec) and were shorter for the male subjects (436.45 msec) than for the female subjects (451.32 msec). Mean ERPs for the three phonemic contrast pairs for both presentations for females and males are shown in Figures 10 through 15.

Mean latencies for P300 are presented in Table 20. With the exception of the /lep/leg contrast, the latencies of the semantically inappropriate sentences were generally shorter for both groups of subjects and both presentations.

Results of the analysis of variance testing (Table 21) on P300 latency indicated Sentence to be significant ($F = 4.43$, $df = 9$, $p = 0.0001$) as well as the interaction of Presentation x Sentence ($F = 2.19$, $df = 9$, $p = 0.0282$).

Table 19. Mean P300 peak latencies (msec) at Cz for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	457.46	435.49	446.47
Presentation 2	445.17	437.41	441.29
$\bar{X}$	451.32	436.45	443.88

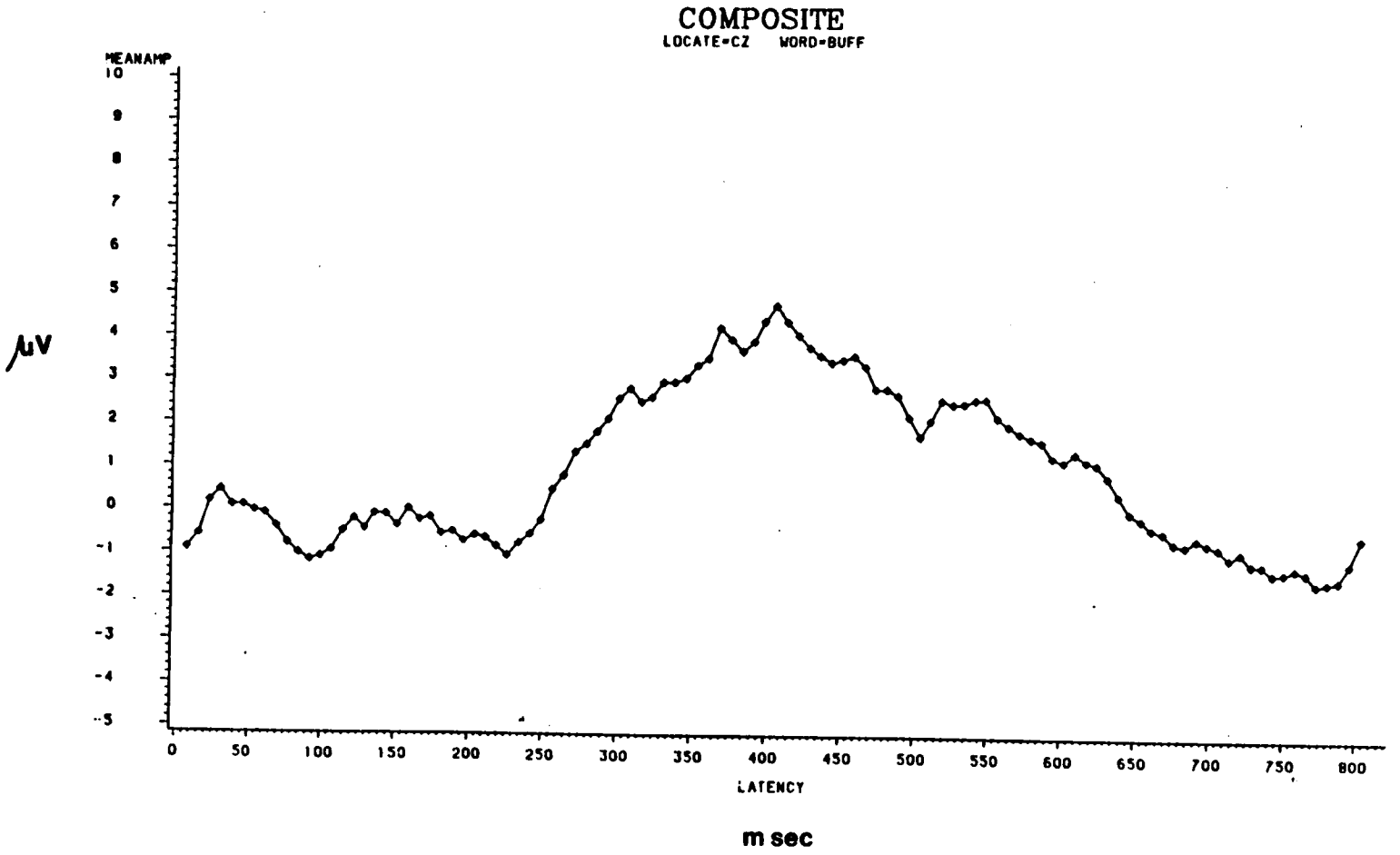

Figure 10. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "I enjoyed reading the new /bʊf/."

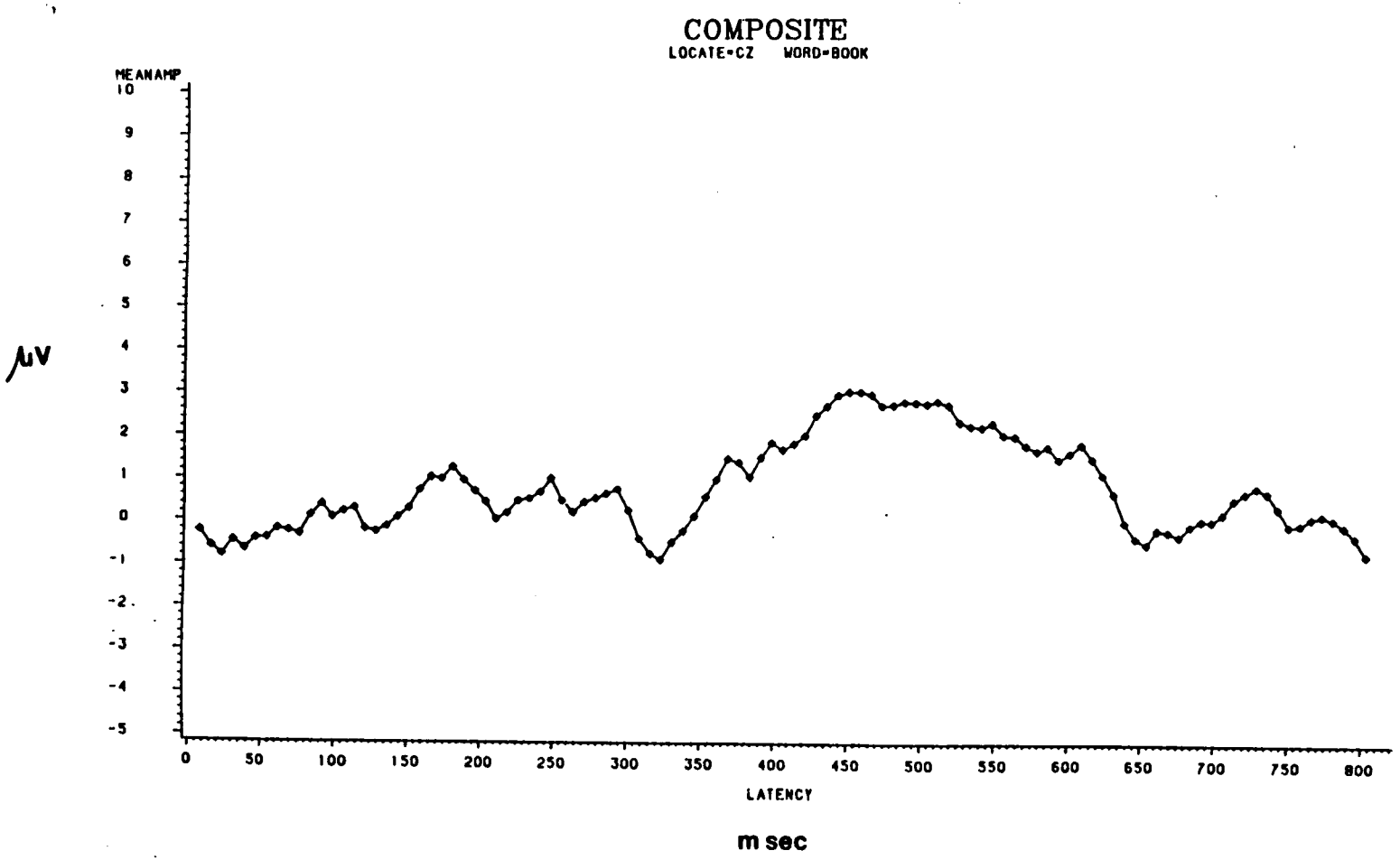

Figure 11. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "I enjoyed reading the new book."

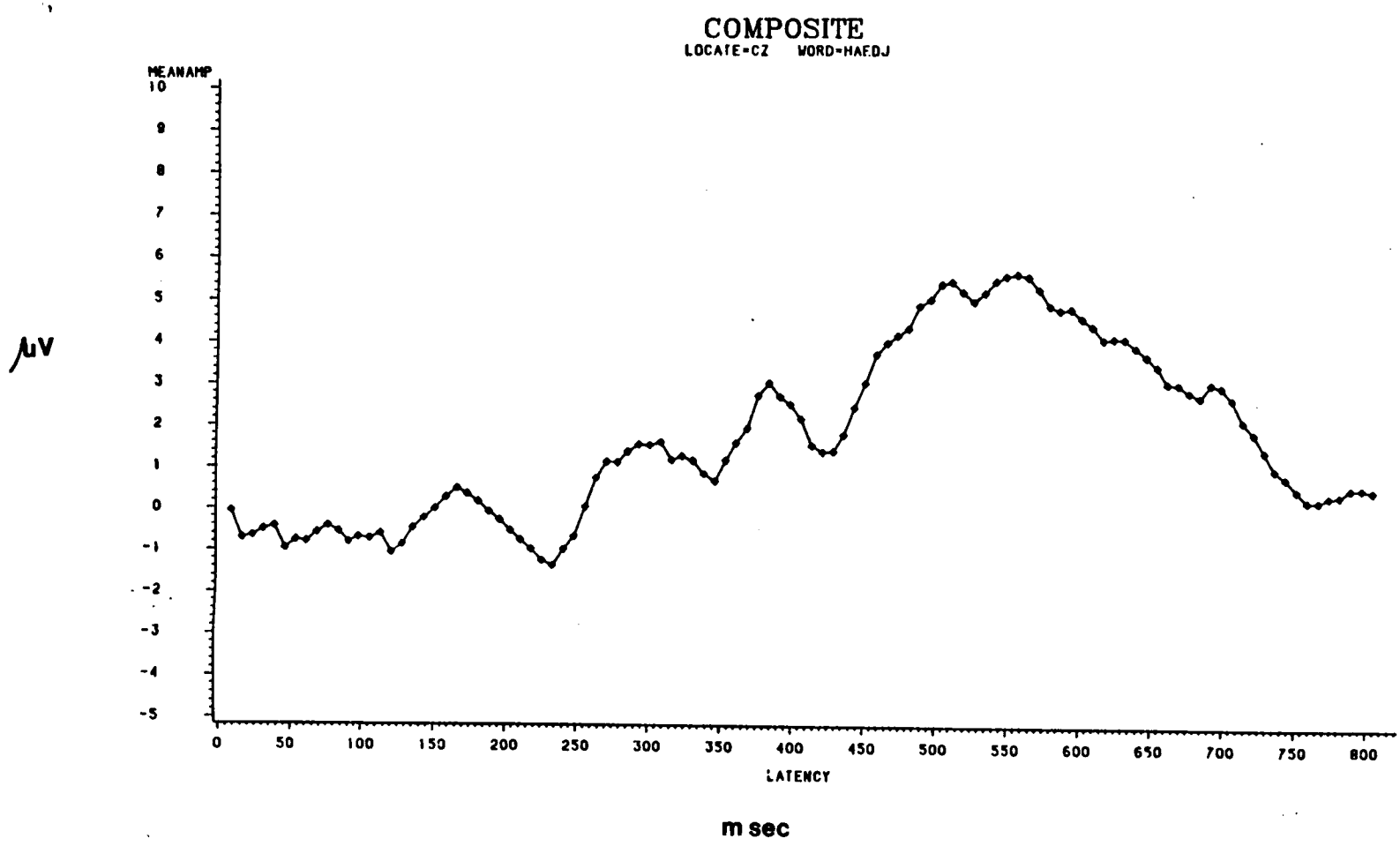

Figure 12. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "You'll catch cold if you don't wear a /hædʒ/."

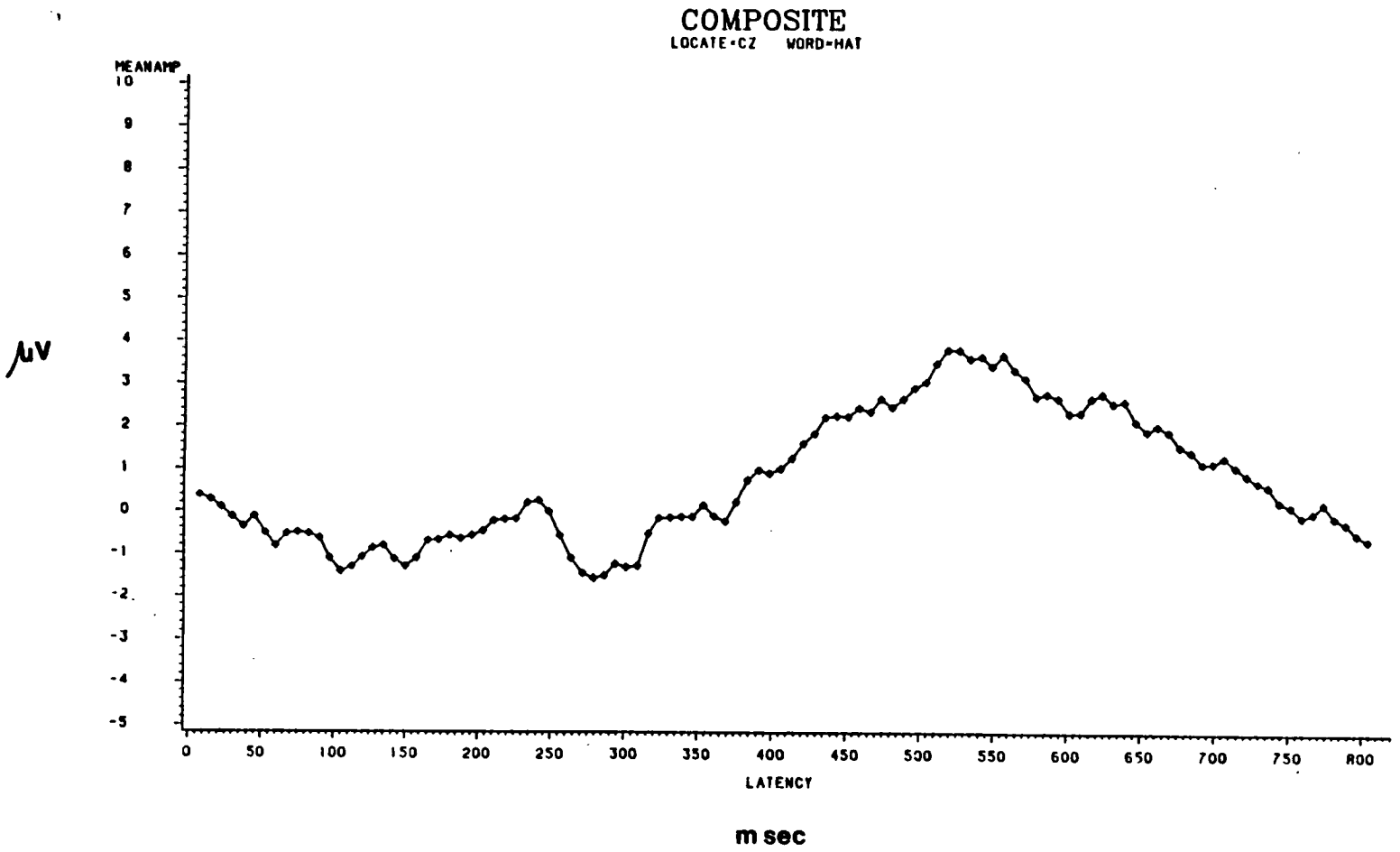

Figure 13. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "You'll catch cold if you don't wear a hat."

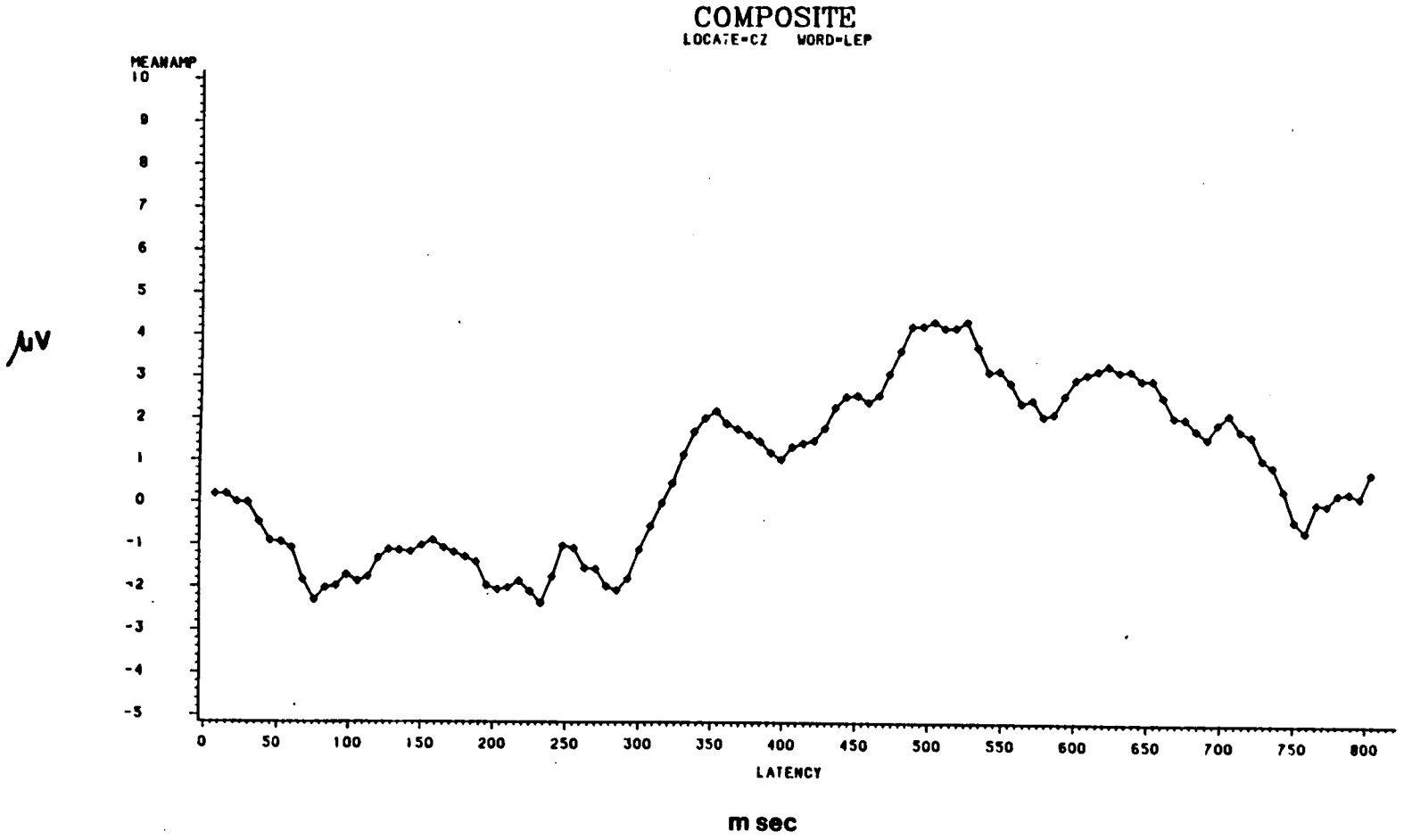

Figure 14. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "John fell down and broke his /lep/."

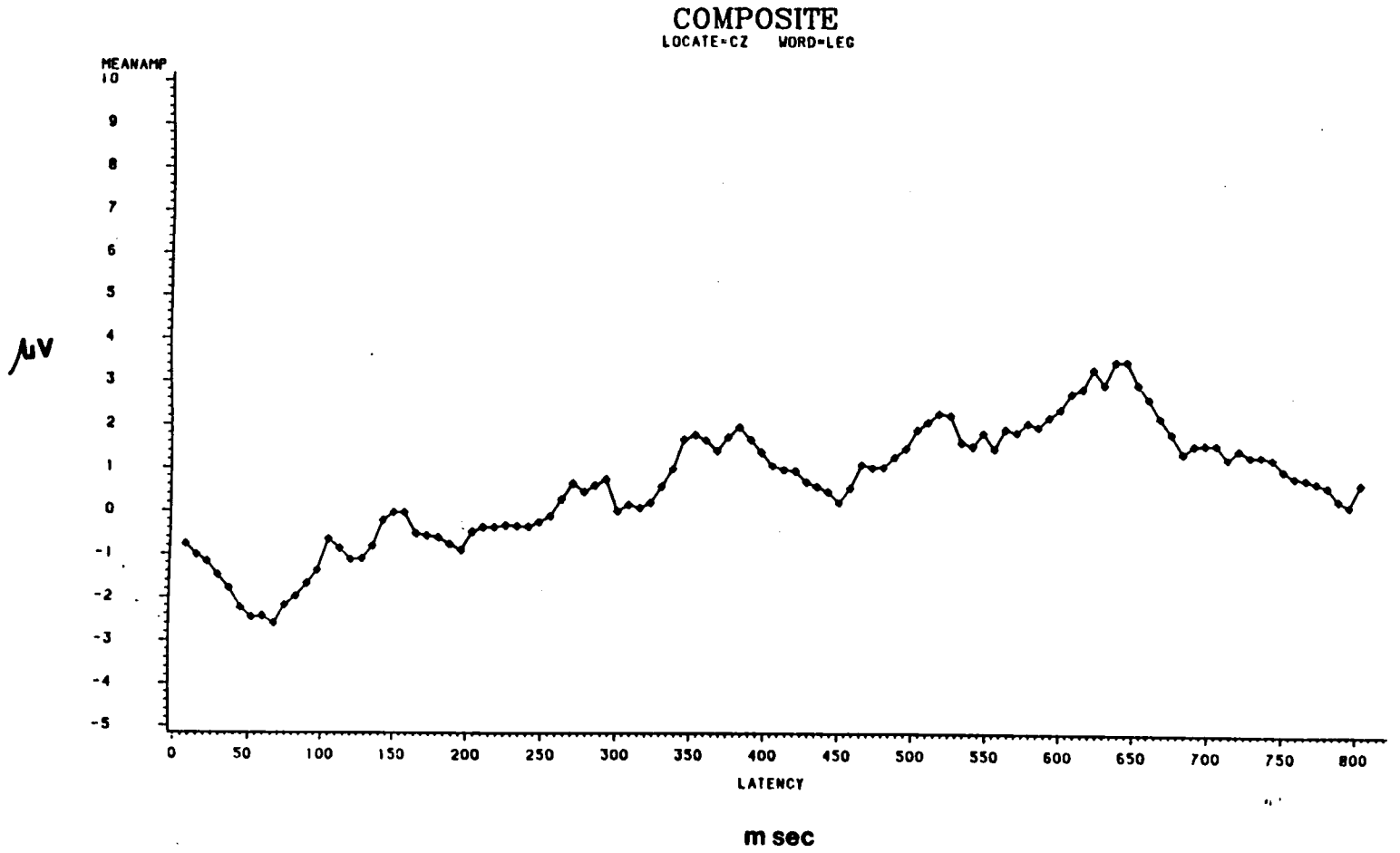

Figure 15. Mean ERP recorded from Cz and averaged across both presentations and sexes for the sentence, "John fell down and broke his leg."

Table 20. Mean P300 peak latencies (msec) at Cz for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	452.14	438.93	454.50	429.86	443.86
/bʊf/	413.50	359.36	362.64	400.21	383.93
hat	535.93	493.00	479.79	404.79	478.38
/hæʤ/	503.36	419.93	477.71	445.21	461.55
leg	456.07	443.29	393.93	430.64	430.98
/lep/	501.86	485.36	487.43	491.07	491.43
good	420.00	459.64	423.21	486.43	447.32
tall	422.57	459.86	433.14	409.79	431.34
hair	478.57	449.71	436.79	433.57	449.66
teeth	390.64	442.57	405.79	442.50	420.38

Table 21. Analysis of variance for P300 peak latency-Cz.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	1887.60	1	1887.60	0.16	0.7007
Presentation x Sex	3538.80	1	3538.80	0.29	0.5998
Sex	15466.29	1	15466.29.	0.68	0.4245
Sentence	231802.77	9	25755.86	4.43	0.0001
Sex x Sentence	41751.98	9	4639.11	0.80	0.6198
Presentation x Sentence	84653.34	9	9405.93	2.19	0.0282
Presentation x Sex x Sentence	31713.75	9	3523.75	0.82	0.6006

Planned comparison testing of the various contrasts indicated the response to /bʊf/ to be significantly shorter in latency than the response to book (F = 8.65, df = 1, p = 0.004). The response to /lep/ was significantly longer than the response to leg (F = 8.80, df = 1, p = 0.0037), and responses to /bʊf/ + /hædʒ/ were significantly shorter than responses to book + hat (F = 7.09, df = 1, p = 0.0089).

B. Parietal (P3) Measures

Amplitude and latency measures from the left parietal electrode, P3, were recorded within the same three time windows and were subjected to the same analysis procedures as previously described for Cz.

N100 Amplitude and Latency Measures

Mean N100 amplitude measures of female and male subjects for both presentations of each of the ten sentences are presented in Table 22.

Table 22. Mean N100 peak amplitudes (μV) at P3 for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	-2.44	-1.97	-2.84	-3.61	-2.72
/bʊf/	-3.57	-1.54	-4.97	-5.24	-3.83
hat	-3.16	-3.86	-3.97	-3.53	-3.63
/hædʒ/	-1.99	-2.24	-3.91	-2.99	-2.78
leg	-6.30	-4.63	-4.27	-3.24	-4.61
/lep/	-3.33	-3.11	-5.04	-4.51	-4.00
good	-1.11	-3.11	-3.37	-5.06	-3.16
tall	-3.07	-3.57	-5.21	-4.87	-4.18
hair	-3.77	-4.67	-4.17	-3.83	-4.11
teeth	-3.20	-4.26	-3.77	-4.30	-3.88

In contrast to Cz measures, N100 amplitudes for three of the semantically appropriate sentences were more negative. Semantically appropriate sentences with Key elements of hat, leg, and hair manifested more negative N100 amplitudes than their cognate semantically inappropriate sentences.

Mean amplitudes for all ten sentences presented in Table 23 indicated that the N100 for both presentations combined was more negative for male subjects (-4.14 μv) than for female subjects (-3.25 μv). This was the reverse for N100 amplitude at Cz. Mean amplitudes of the first presentation (-3.67 μv) and second presentation (-3.71 μv) for both groups of subjects were within .04 uv of each other and within .02 of the grand mean.

Table 23. Mean N100 peak amplitudes (μV) at P3 for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	-3.19	-4.15	-3.67
Presentation 2	-3.30	-4.12	-3.71
$\bar{X}$	-3.25	-4.14	-3.69

The results of the ANOVA testing, presented in Table 24, indicated no significant main effects or interactions at the 0.05 significance level. Again, a difference was apparent between Cz and P3 measures since the effects of both Sex and Sentence were determined to be significant at N100 Cz.

Table 24. Analysis of variance for N100 peak amplitude--P3.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	0.08	1	0.08	0.01	0.9400
Presentation x Sex	0.34	1	0.34	0.03	0.8766
Sex	55.54	1	55.54	1.28	0.2801
Sentence	97.15	9	10.79	1.57	0.1313
Sex x Sentence	100.18	9	11.13	1.62	0.1168
Presentation x Sentence	48.87	9	5.43	0.96	0.4757
Presentation x Sex x Sentence	21.88	9	2.43	0.43	0.9159

N100 latency measures for each of the ten sentences for both presentations and subjects, as well as means for all ten sentences, are presented in Table 25 and 26. Latency measures corresponding to N100 peaks for each presentation of each of the ten sentences (Table 25) indicated shorter latencies for three of the semantically inappropriate sentences. The sentences "John fell down and broke his /lep/," "You'll catch cold if you don't wear a /hædʒ/," and "Wash your face and comb your teeth," manifested consistently shorter latencies to their Key elements. This was consistent across both subjects and presentations and also corresponded to the N100 peak latencies obtained at Cz. Latencies for the semantically appropriate sentences, "John fell down and broke his leg," and "The flowers smell good," were shorter than the N100 peak latencies for their cognate sentences.

Table 25. Mean N100 peak latencies (msec) at P3 for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	121.64	134.57	126.00	93.00	118.95
/bʊf/	134.64	88.79	104.43	92.93	105.20
hat	121.57	120.21	108.64	106.00	114.11
/hædʒ/	108.43	99.29	113.57	109.33	107.66
leg	121.79	121.79	120.36	115.71	119.91
/lep/	128.57	142.50	130.71	128.36	132.54
good	75.00	81.43	112.50	90.00	89.73
tall	112.93	105.43	98.14	101.14	104.41
hair	120.71	123.93	121.07	118.93	121.16
teeth	104.29	95.36	93.21	93.21	96.52

Table 26. Mean N100 peak latencies (msec) at P3 for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	114.96	112.92	113.94
Presentation 2	111.33	104.86	108.10
$\bar{X}$	113.15	108.89	111.02

In contrast to the N100 latency measures at Cz, the mean N100 latency (P3) of the first presentation (113.94 msec) of all ten sentences was slightly longer than that of the second presentation (108.10 msec) for both groups of subjects. Mean latency of the female subjects (113.15 msec) was longer than that of the male subjects (108.89 msec). Results of the ANOVA are presented in Table 27. The main effect Sentence was determined to be significant ($F = 4.22$, $df = 9$, $p = 0.0001$). To further test for significant differences, the method of orthogonal contrasts was again employed. Only one contrast pair was determined to be significant. The sentence, "Wash your face and comb your teeth," was determined to have a significantly shorter N100 latency ($F = 7.87$, $df = 1$, $p = 0.0060$) than its cognate sentence, "Wash your face and comb your hair." The sentence contrast with tall vs. good also approached significance ($F = 2.79$, $df = 1$, $p = 0.0977$); however, in this instance the meaningful sentence with good was determined to be shorter in latency than the cognate sentence with tall.

Table 27. Analysis of variance for N100 peak latency--P3.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	2367.58	1	2367.58	1.51	0.2428
Presentation x Sex	334.85	1	334.85	0.21	0.6523
Sex	1282.29	1	1282.29.	0.47	0.5077
Sentence	41085.26	9	4565.03	4.22	0.0001
Sex x Sentence	9068.41	9	1007.60	0.93	0.5010
Presentation x Sentence	5337.22	9	593.02	0.61	0.7859
Presentation x Sex x Sentence	7816.34	9	868.48	0.90	0.5325

P200 Amplitude and Latency Measures

Mean N100P200 amplitudes to the ten stimuli are presented in Tables 28 and 29. Mean N100P200 amplitudes at P3 for each of the ten Key elements for both presentations and sexes are shown in Table 28. In contrast to N100P200 amplitude at Cz, only three of the semantically inappropriate sentences manifested more positive peaks to their Key elements. The semantically inappropriate sentences, "The flowers smell tall," and "Wash your face and comb your teeth," manifested more positive N100P200 amplitudes. Both of these sentences contained real words in the Key position. The semantically inappropriate sentence, "I enjoyed reading the new /buf/," also manifested a somewhat more positive N100P200 amplitude than its cognate sentence. However, the other two phonemic-semantically inappropriate sentences, "You'll catch cold if you don't wear a /hædʒ/," and "John fell down and broke his /lep/," evidenced lower amplitudes than their cognate sentences.

Table 28. Mean N100P200 amplitudes (μV) at P3 for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	7.30	4.56	4.83	5.23	5.48
/bʊf/	6.33	4.41	5.23	7.89	6.04
hat	7.79	6.01	4.06	4.87	5.68
/hædʒ/	4.21	5.89	4.63	4.99	4.93
leg	7.70	6.93	4.79	4.69	6.03
/lep/	6.19	4.64	4.63	6.19	5.41
good	2.76	6.11	6.49	6.73	5.52
tall	6.39	7.99	7.61	6.83	7.20
hair	6.47	6.23	5.47	4.96	5.78
teeth	8.45	8.60	6.94	6.79	7.70

Table 29. Mean N100P200 amplitudes (μV) at P3 for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	6.36	5.47	5.92
Presentation 2	5.94	5.91	5.93
$\bar{X}$	6.15	5.69	5.92

Although the mean N100P200 amplitude of the female subjects (6.15 μv) was slightly higher than the mean amplitude of the males (5.69 μv) for both presentations of all ten sentences, the dramatic sex differences evident at the Cz location were not apparent. Amplitude differences between presentations were also not evident since mean amplitudes of the first (5.92 μv) and second presentation (5.93 μv) were within .01 of each other for both sexes.

ANOVA results were also similar to the N100P200 findings for Cz; however, the main effect of Sex was not significant. The ANOVA is presented in Table 30. Significant differences were determined among the ten sentences ($F = 2.34$, $df = 9$, $p = 0.0187$). A significant Sex x Sentence interaction was also determined ($F = 1.91$, $df = 9$, $p = 0.0578$) which indicated that significant amplitude differences existed between the females' and males' responses to the different sentences.

Planned comparison testing for differences between sentence pairs and groups of sentences indicated significant differences in N100P200 amplitudes for the sentences with real Key words. The semantically

inappropriate sentences with Key words of tall and teeth manifested significantly more positive amplitudes than their cognate sentences with good and hair ($F = 4.61$, $df = 1$, $p = 0.0340$, $F = 5.97$, $df = 1$, $p = 0.0161$, respectively). The same two contrast pairs were also determined to be significant at N100P200 at Cz. Mean ERPs for these contrast pairs for both presentations for females and males are presented in Figures 16 through 19.

Table 30. Analysis of variance for N100P200 amplitude--P3.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	0.67	1	0.67	0.08	0.7767
Presentation x Sex	7.14	1	7.14	0.90	0.3625
Sex	20.57	1	20.57	0.26	0.6175
Sentence	181.10	9	20.12	2.34	0.0187
Sex x Sentence	147.50	9	16.39	1.91	0.0578
Presentation x Sentence	44.26	9	4.92	0.49	0.8774
Presentation x Sex x Sentence	101.63	9	11.29	1.13	0.3475

Latency measures for P200 (Tables 31 and 32) underwent the same analysis procedure. No consistent latency differences (Table 31) between the sentence pairs were evident. Means of females (224.75 msec), males (225.15), first presentation (224.51 msec) and second presentation (225.39 msec) did not vary greatly from the grand mean of 224.95 msec.

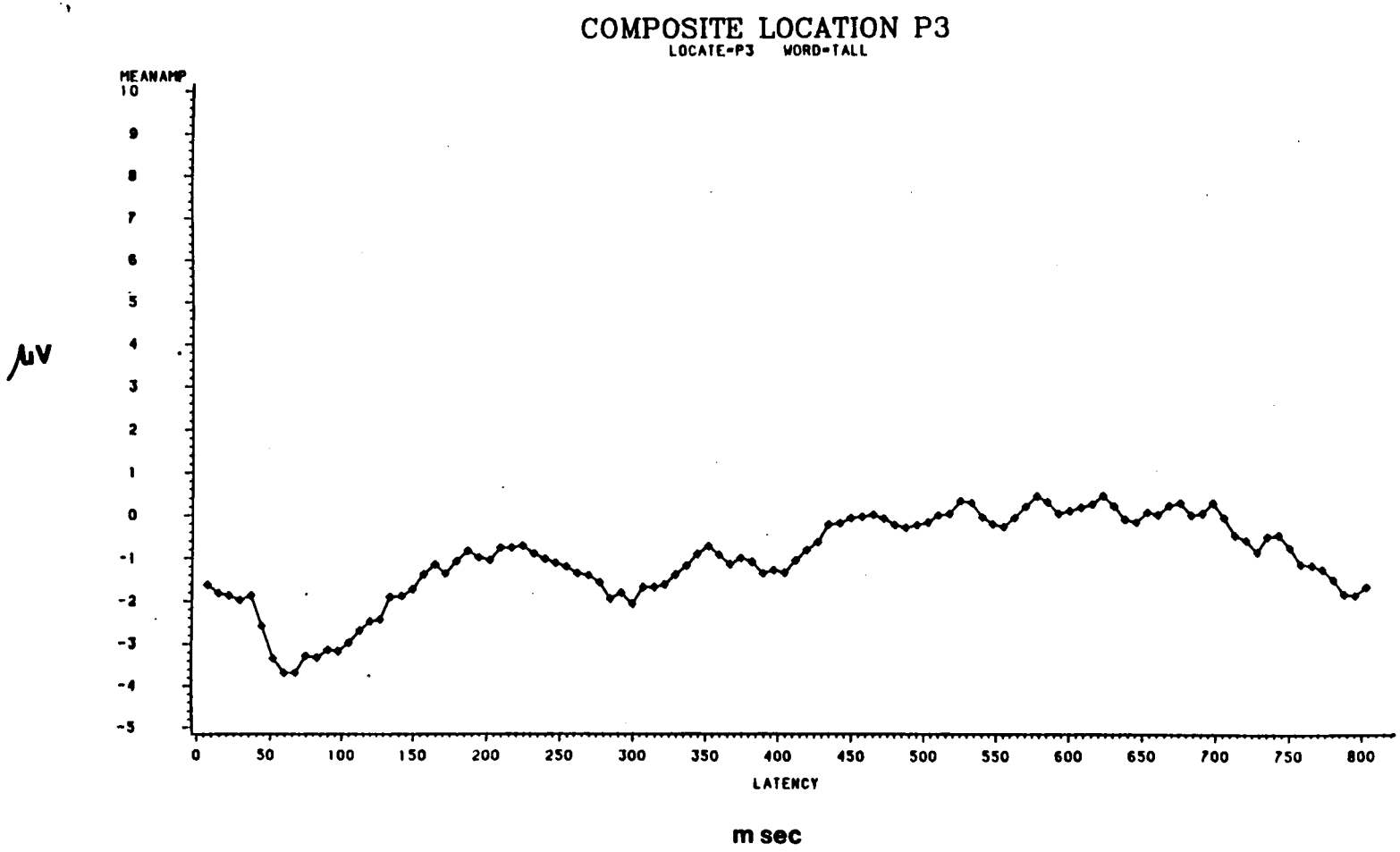

Figure 16. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "The flowers smell tall."

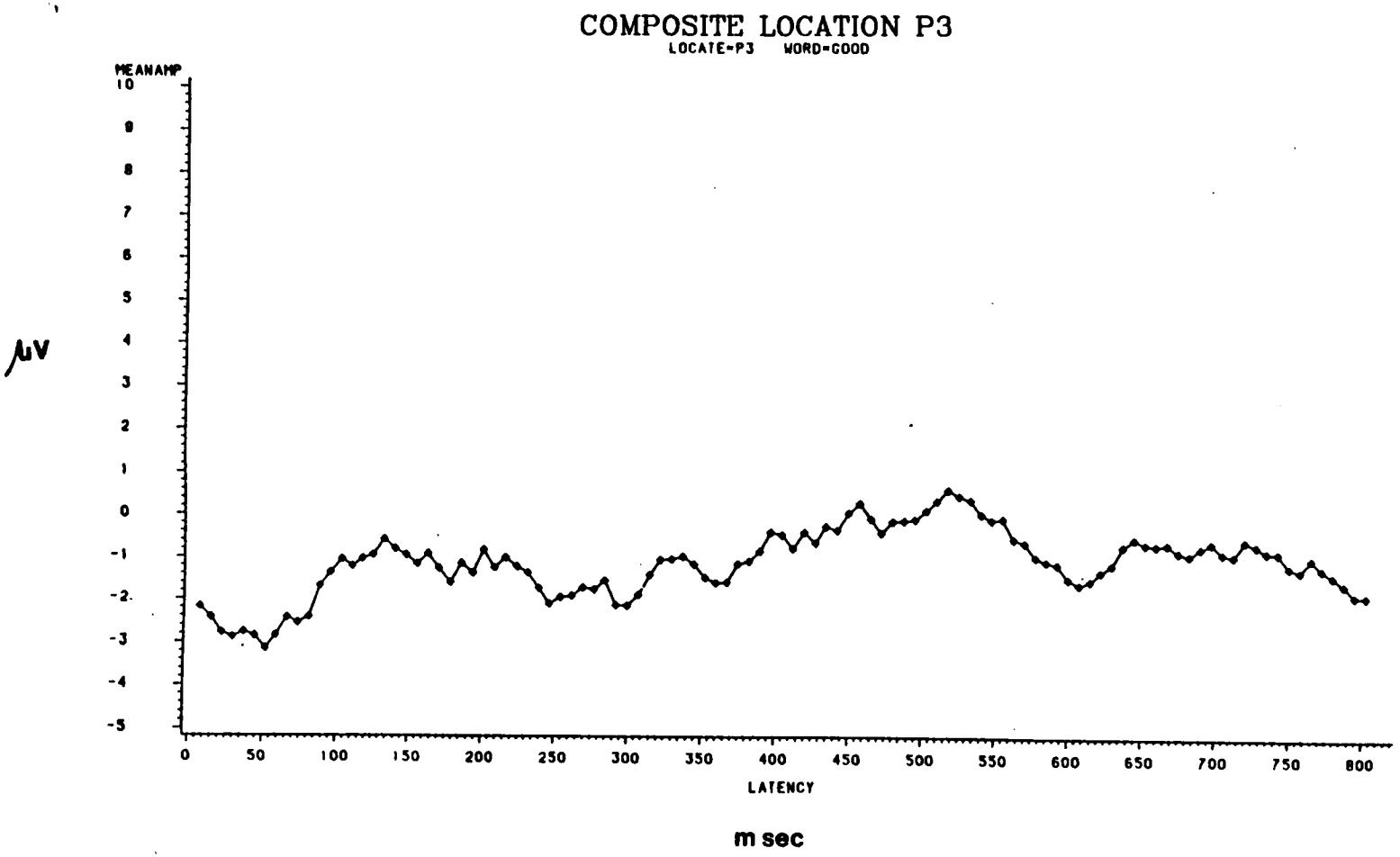

Figure 17. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "The flowers smell good."

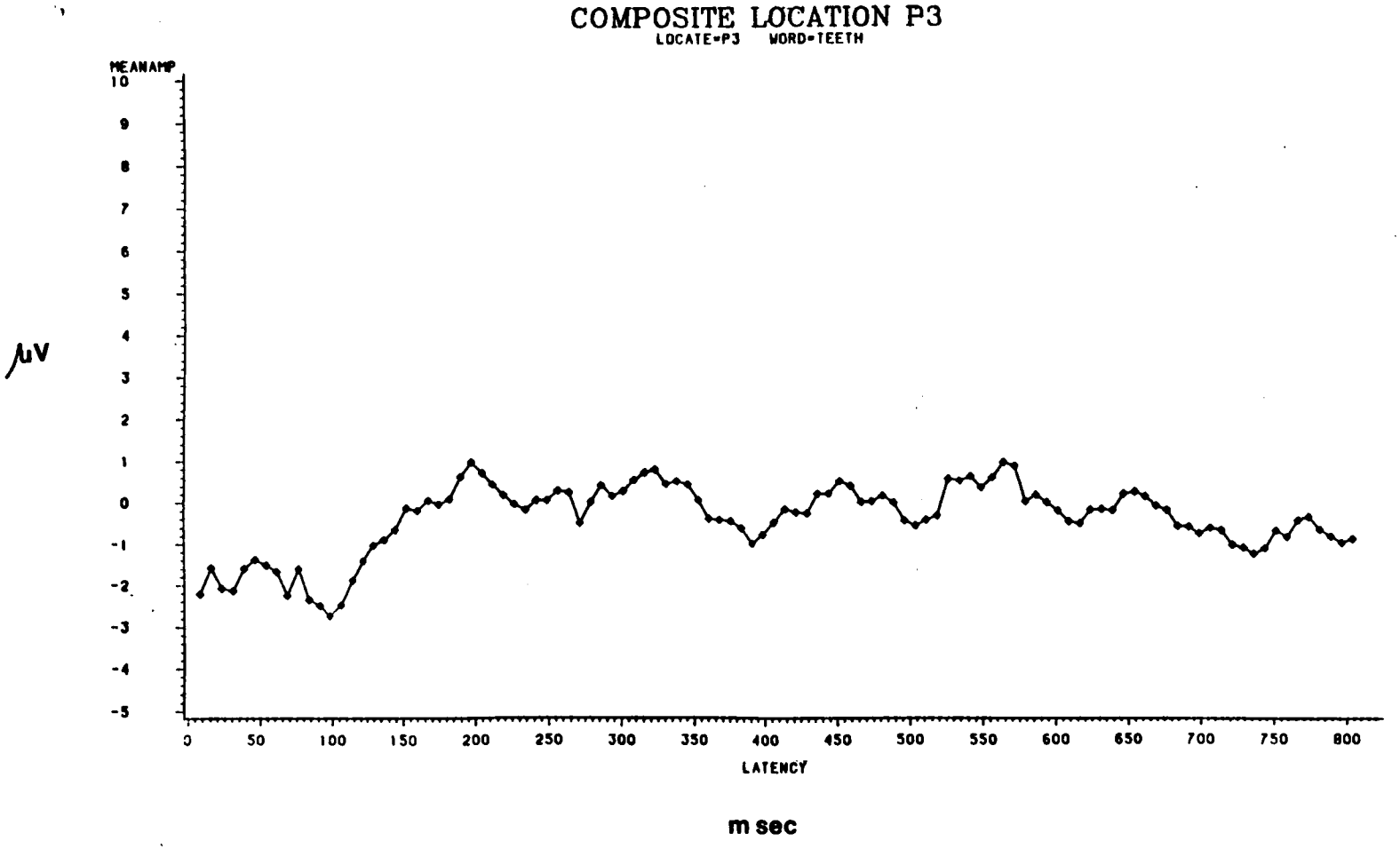

Figure 18. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "Wash your face and comb your teeth."

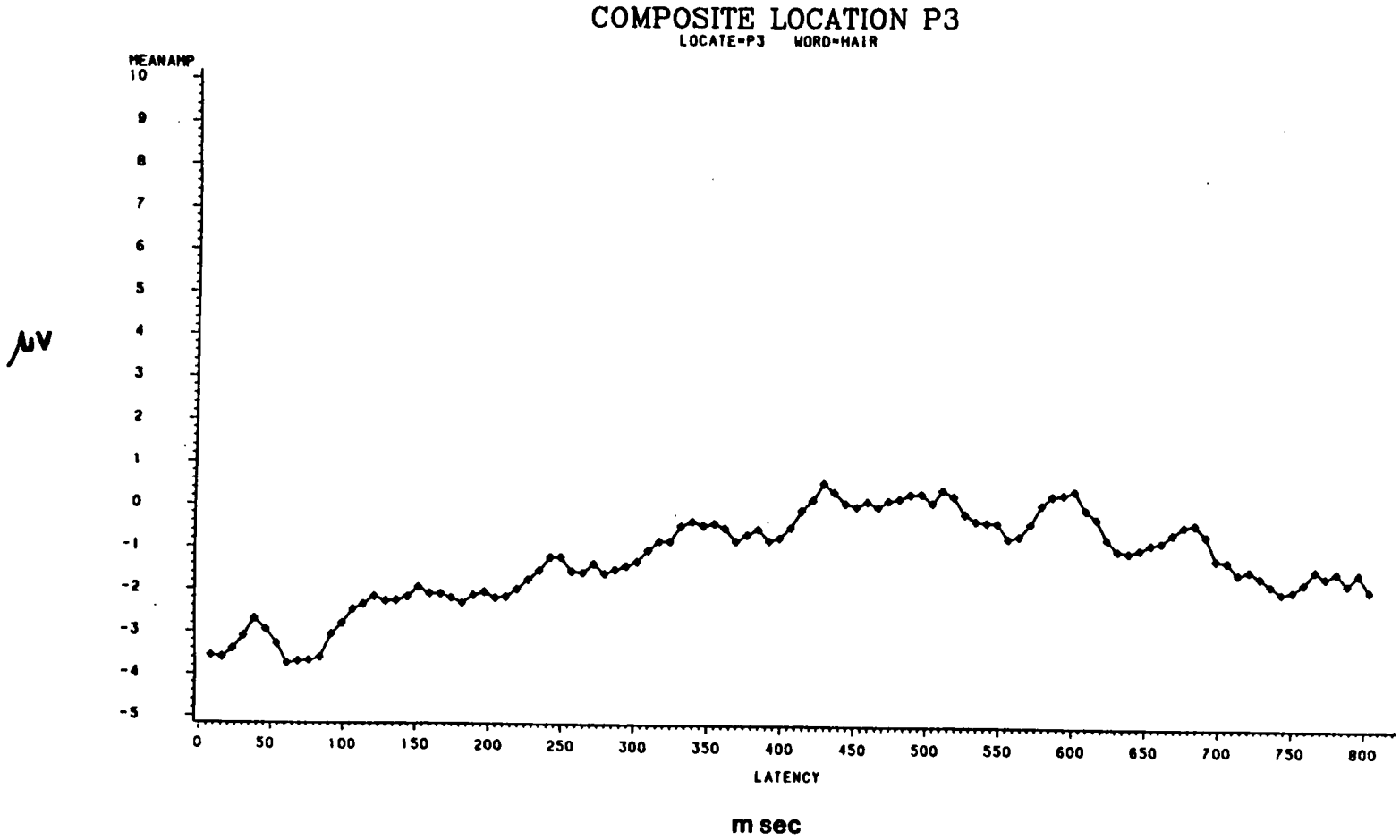

Figure 19. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "Wash your face and comb your hair."

Table 31. Mean P200 peak latencies (msec) at P3 for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	225.81	223.20	224.51
Presentation 2	223.68	227.09	225.39
$\bar{X}$	224.75	225.15	224.95

The ANOVA procedure (Table 33) indicated that significant differences existed among the latencies of the ten different sentences ($F = 1.93$, $df = 9$, $p = 0.0543$). The orthogonal contrast testing revealed a significantly shorter latency for the Key element of the sentence, "You'll catch cold if you don't wear a /hædʒ/," vs. the Key element of the cognate sentence, "You'll catch cold if you don't wear a hat," ($F = 7.41$, $df = 1$, $p = 0.0076$) and for the average of the three phonemic inappropriate sentences vs. the three phonemic appropriate sentences ($F = 3.81$, $df = 1$, $p = 0.0535$). Furthermore, the plosive vs. continuant contrast and the hair vs. teeth contrast also approached the significance level ($F = 3.54$, $df = 1$, $p = 0.0627$, $F = 3.29$, $df = 1$, $p = 0.0725$, respectively). In both cases nonmeaningful elements had shorter latencies than the meaningful elements. These results contrast with those of the Cz location for P200 peak latencies which yielded a significant Presentation x Sex interaction but no significant differences among the sentences.

Table 32. Mean P200 peak latency (msec) at P3 for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	212.36	224.14	238.86	235.21	227.64
/bʊf/	238.50	238.36	194.79	241.07	228.18
hat	225.43	237.93	233.71	218.64	236.43
/hædʒ/	223.79	193.00	203.57	232.07	213.11
leg	236.43	215.79	228.93	238.86	230.00
/lep/	214.29	239.64	218.86	222.50	223.82
good	203.21	221.79	228.21	228.21	220.36
tall	224.50	240.43	239.36	231.79	234.02
hair	234.29	216.07	237.86	214.64	225.71
teeth	215.36	209.64	207.86	207.86	210.18

Table 33. Analysis of variance for P200 peak latency--P3.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	53.59	1	53.59	0.05	0.8340
Presentation x Sex	634.51	1	634.51	0.54	0.4754
Sex	11.00	1	11.00	0.01	0.9153
Sentence	17879.72	9	1986.64	1.93	0.0543
Sex x Sentence	11621.08	9	1291.23	1.26	0.2684
Presentation x Sentence	11113.34	9	1234.82	1.17	0.3215
Presentation x Sex x Sentence	110959.33	9	12328.81	0.97	0.5561

P300 Amplitude and Latency Measures

The N100P300 measures presented in Tables 34 and 35 were consistent with those measures from the same component at Cz. Amplitudes of the semantically inappropriate sentences were approximately 1.58 μv's greater than their semantically appropriate cognate sentences.

Table 34. Mean N100P300 amplitudes (μV) at P3 for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	11.44	7.83	9.64
Presentation 2	10.32	7.35	8.84
$\bar{X}$	10.88	7.59	9.24

Table 35. Mean N100P300 amplitudes (μV) at P3 for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	9.64	9.34	6.94	6.30	8.06
/bʊf/	14.36	9.49	9.79	8.84	10.62
hat	12.00	10.41	6.01	6.26	8.67
/hædʒ/	13.83	11.11	9.27	8.24	10.61
leg	13.20	8.19	7.37	6.14	8.73
/lep/	10.37	12.74	8.40	7.96	9.87
good	6.81	10.44	6.50	7.20	7.74
tall	10.96	10.57	8.79	8.13	9.61
hair	10.56	10.57	7.59	7.41	9.03
teeth	12.67	10.36	7.64	6.99	9.41

Strong sex differences between females (10.88 μv) and males (7.59 μv) were again evident. A slight increase in N100P300 amplitude was evident on the first presentation (9.64 μv) compared to the second presentation (8.84 μv). The analysis of variance (Table 36) indicated that the amplitude differences between female and male subjects were significant (F = 9.72, df = 1, p = 0.0089). Although the critical value for Sentences (F = 1.80, df = 9, p = 0.0750) exceeded the 0.05 significance level, it was considered for posttesting since it was within a 0.10 level of significance.

Table 36. Analysis of variance for N100P300 amplitude--P3.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	44.80	1	44.80	2.30	0.1552
Presentation x Sex	7.04	1	7.04	0.36	0.5588
Sex	759.00	1	759.00	9.72	0.0089
Sentence	241.69	9	26.85	1.80	0.0750
Sex x Sentence	59.84	9	6.65	0.45	0.9065
Presentation x Sentence	168.49	9	18.72	1.59	0.1279
Presentation x Sex x Sentence	89.94	9	9.99	0.85	0.5761

Planned comparison testing indicated the following sentence contrasts to be significant: /bʊf/ vs. book (F = 6.17, df = 1, p = 0.0145); /bʊf/ + /hædʒ/ vs. book + hat (F = 9.54, df = 1, p = 0.0026); the average of the three phonemic-semantically inappropriate

sentences vs. the average of the three phonemic-semantically appropriate sentences ($F = 10.00$, $df = 1$, $p = 0.0020$); and all five semantically inappropriate vs. all five semantically appropriate sentences ($F = 11.74$, $df = 1$, $p = 0.0009$). Two sentence contrast pairs, with Key elements of tall vs. good and /hædʒ/ vs. hat approached the .05 significance level ($F = 3.30$, $df = 1$, $p = 0.0723$ and $F = 3.55$, $df = 1$, $p = 0.0622$, respectively). The ERPs for the three phonemic-semantically inappropriate sentences with Key elements of (/bʊf/, /hædʒ/, and /lep/) and their three phonemic-semantically appropriate cognate sentences (Key elements of book, hat, leg) are presented in Figures 20 through 25.

Latency measures for P300 presented in Tables 37 and 38 were subjected to the same analysis and followed trends similar to the P300 latencies for Cz. With the exception of the /lep/ / leg and tall/good contrasts, the latencies of the other three semantically inappropriate sentences were generally shorter for both groups of subjects and both presentations. In general, mean latency for the second presentation of all ten sentences was slightly shorter (448.58 msec) than mean latency for the first presentation (459.26 msec) for both groups of subjects. Mean latency of the female subjects for both presentations of all ten sentences (459.47 msec) was longer than that of the males (442.08 msec) and was 8.69 msec longer than the mean latency. Analysis of variance testing (Table 39) indicated significance for the same factor and interaction identified as significant at the Cz P300 latency: Sentence ($F = 3.55$ $df = 9$, $p = 0.0007$) and Presentation x Sentence ($F = 2.36$, $df = 9$, $p = 0.0180$).

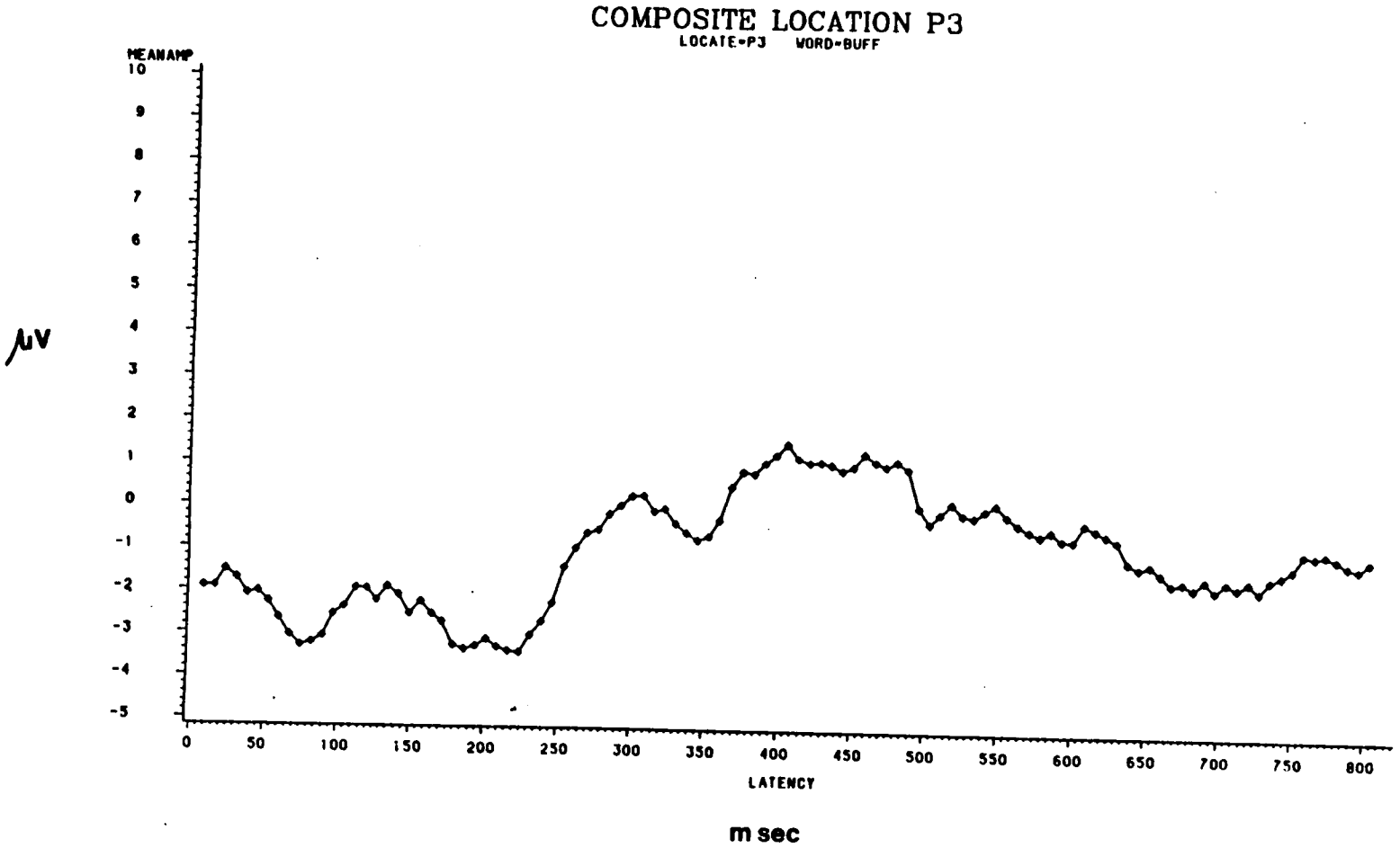

Figure 20. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "I enjoyed reading the new /bʊf/."

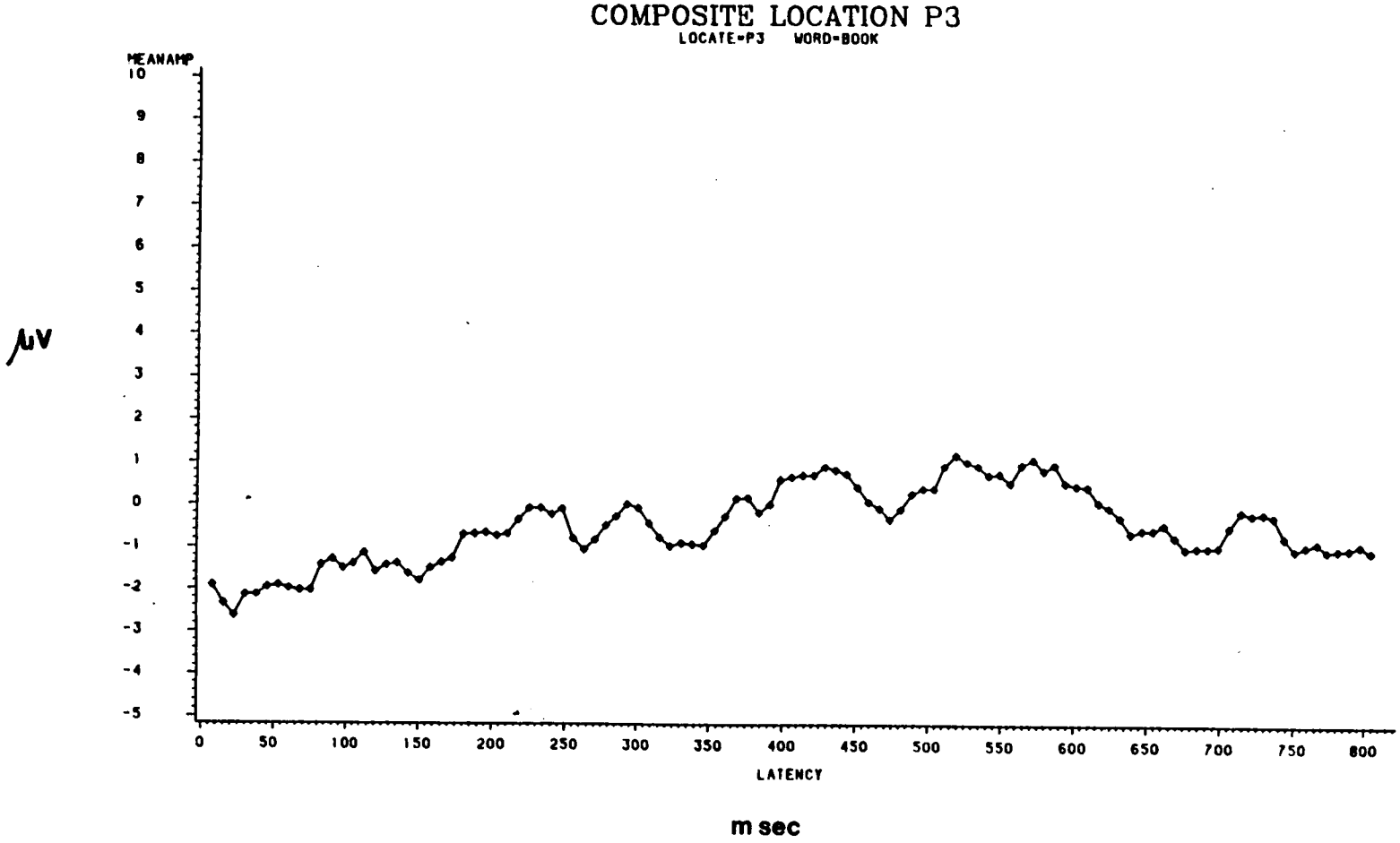

Figure 21. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "I enjoyed reading the new book."

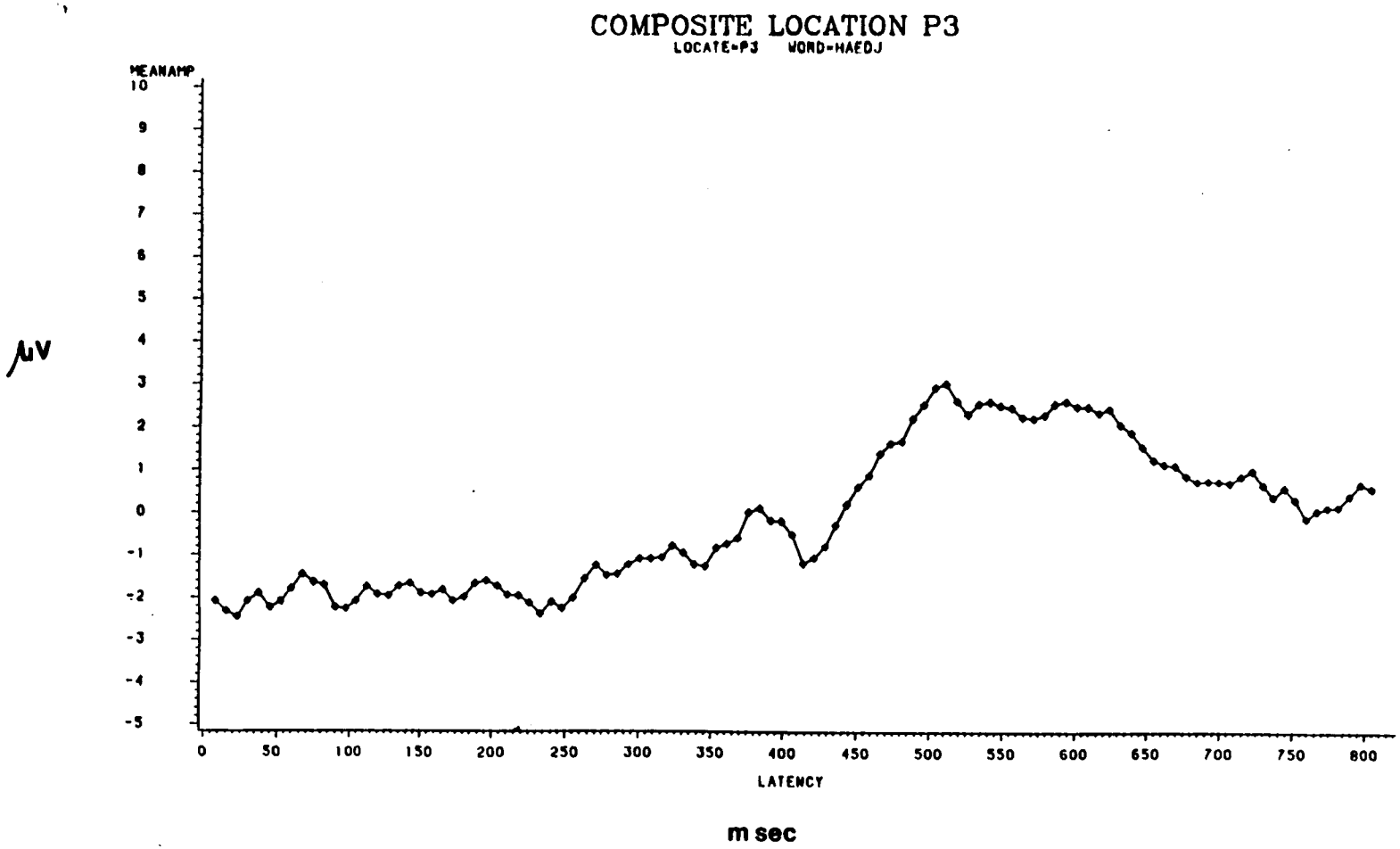

Figure 22. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "You'll catch cold if you don't wear a /hædʒ/."

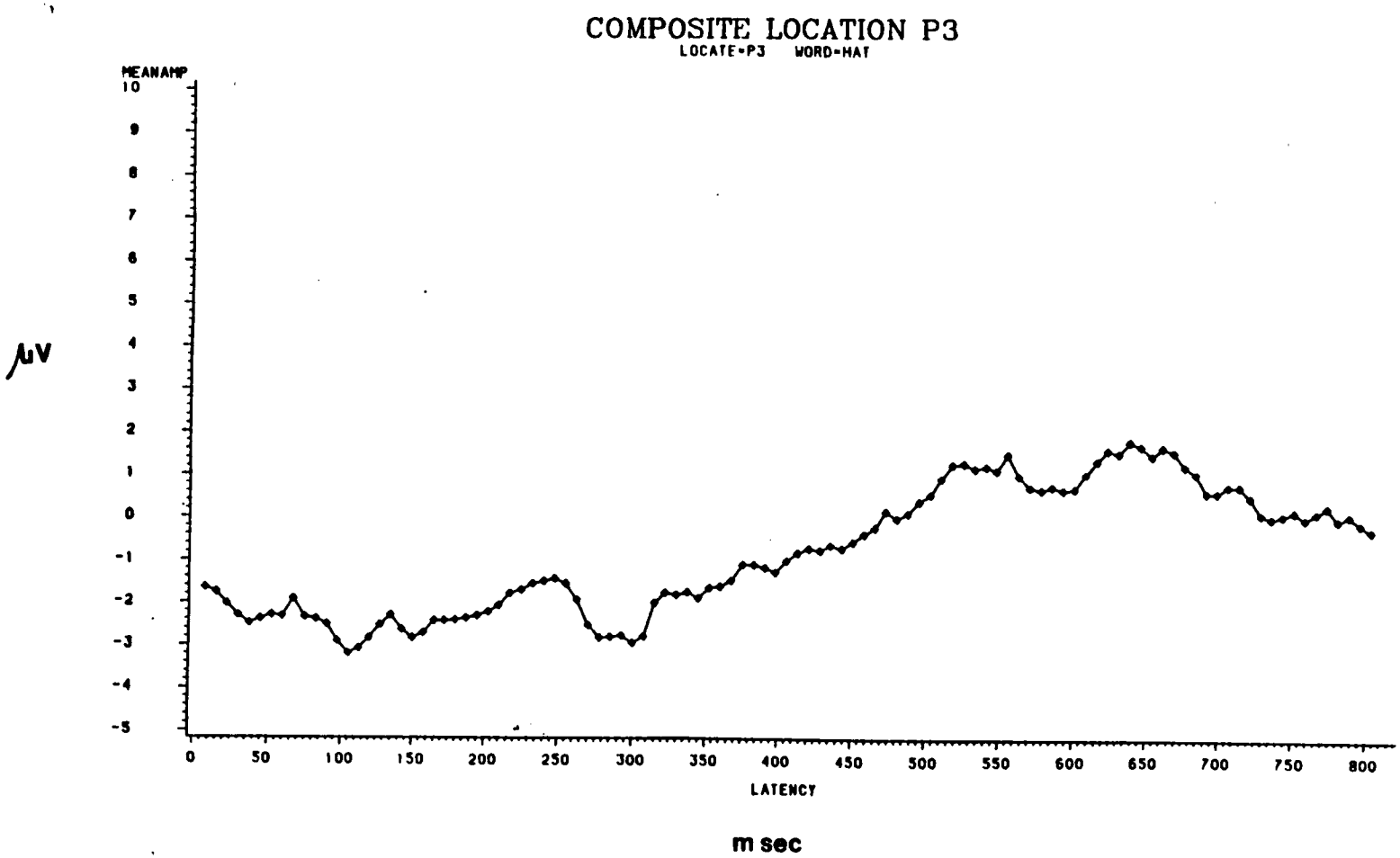

Figure 23. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "You'll catch cold if you don't wear a hat."

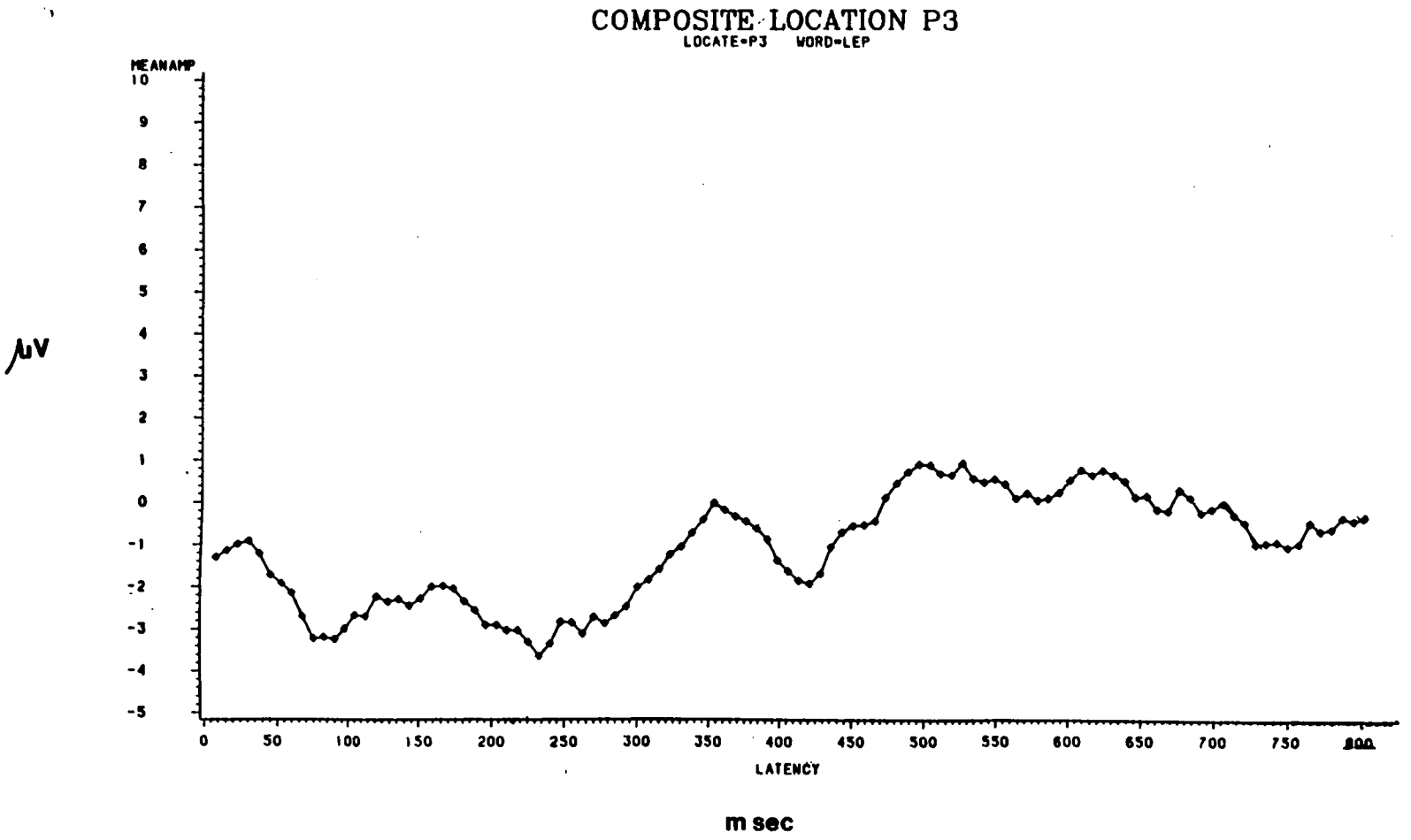

Figure 24. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "John fell down and broke his /lep/."

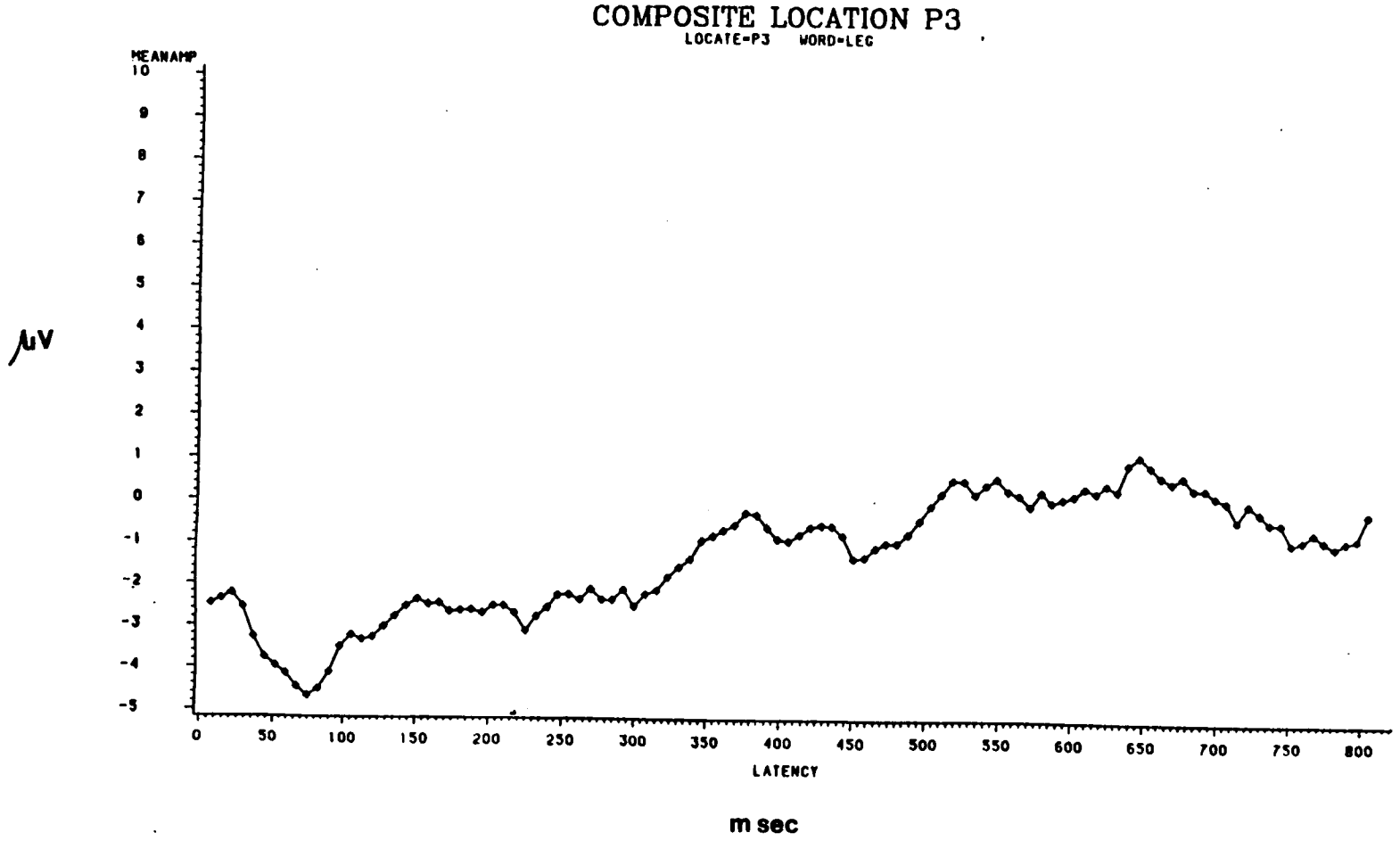

Figure 25. Mean ERP recorded from P3 and averaged across both presentations and sexes for the sentence, "John fell down and broke his leg."

Table 37. Mean P300 peak latency (msec) at P3 for each of the ten Key elements of the sentences for both presentations and sexes and also averaged across Presentation and Sex.

Sentence key word or CVC	Females Presentation 1	Females Presentation 2	Males Presentation 1	Males Presentation 2	$\bar{X}$
book	473.64	388.00	485.79	430.21	444.41
/bʊf/	403.71	387.29	359.86	408.00	389.71
hat	521.07	493.29	476.64	404.29	473.82
/hæʤ/	490.50	441.00	481.14	463.57	469.05
leg	503.57	423.93	429.93	446.79	451.05
/lep/	497.14	514.21	445.07	462.57	479.75
good	463.93	471.36	471.43	433.93	460.16
tall	458.79	515.36	400.71	467.36	460.55
hair	467.86	468.93	440.86	443.00	455.16
teeth	368.57	437.14	418.93	471.43	424.02

Table 38. Mean P300 peak latencies (msec) at P3 for all ten Key elements of the sentences for both presentations and sexes.

	Females	Males	$\bar{X}$
Presentation 1	464.88	441.04	459.26
Presentation 2	454.05	443.11	448.58
$\bar{X}$	459.47	442.08	453.92

Table 39. Analysis of variance for P300 peak latency--P3.

Source	Sum of Squares	df	Mean Square	F	P>F
Presentation	1339.84	1	1339.84	0.18	0.6823
Presentation x Sex	2915.40	1	2915.40	0.38	0.5477
Sex	21167.11	1	21167.11	1.87	0.1964
Sentence	178994.99	9	19888.33	3.55	0.0007
Sex x Sentence	78437.03	9	8715.23	1.56	0.1373
Presentation x Sentence	123551.25	9	13729.92	2.36	0.0180
Presentation x Sex x Sentence	31685.05	9	3520.56	0.60	0.7916

The method of planned comparisons used to test for significance between the various contrasts indicated that the response to the sentence with /bʊf/ was significantly shorter in latency than the one with book and that the stops /bʊf/ + /hæʤ/ were significantly shorter in latency than the continuants book + hat. These two contrasts were also significant for the same component at Cz.

C. Summary of Results

The major results of this study for the Cz location were as follows:

1. N100 amplitude was significantly more negative for females than for males for both presentations of all ten sentences.

2. Average N100 amplitude of all five semantically inappropriate sentences was significantly more negative than the average N100 amplitude of all five semantically appropriate sentences for both presentations and both groups of subjects.

3. N100 latency was significantly shorter for the sentences with Key elements of /hædʒ/ vs. hat; teeth vs. hair; /bʊf/ + /hædʒ/ vs. book + hat; and good vs. tall for both presentations and both groups of subjects.

4. N100P200 amplitude was significantly more positive for females than for males for both presentations of all ten sentences.

5. N100P200 amplitude was significantly more positive for the semantically inappropriate sentences with Key words of tall vs. good and teeth vs. hair for both presentations and both groups of subjects. N100P200 amplitude of the average of all five semantically inappropriate sentences was significantly more positive than the average of all five semantically appropriate sentences for both presentations and both groups of subjects.

6. Latency of P200 responses of female and male subjects was significantly different for the first vs. the second presentation of all ten sentences.

7. N100P300 amplitude was significantly more positive for females than for males for both presentations of all ten sentences.

8. N100P300 amplitude was significantly more positive for the phonemic-semantically inappropriate sentences with Key elements of /bʊf/ vs. book; /hædʒ/ vs. hat; and /lep/ vs. leg for both presentations and both groups of subjects. N100P300 amplitude of the average of all five semantically inappropriate sentences was significantly more positive than the average of all five semantically appropriate sentences for both presentations and both groups of subjects. N100P300 amplitude of the average of the three phonemic-semantically inappropriate sentences was significantly more positive than the average of the three phonemic-semantically appropriate sentences. The sentences ending with continuants (/bʊf/ + /hædʒ/) were also determined to be significantly more positive than the sentences ending with plosives (book + hat).

9. N100P300 amplitude responses of females and males were significantly different for the ten different sentences.

10. P300 latency was significantly shorter for the sentences with Key elements of /bʊf/ vs. book; leg vs. /lep/; and /bʊf/ + /hædʒ/ vs. book + hat for both presentations by both groups of subjects.

11. The P300 latencies of the ten different sentences were significantly different for the two different presentations for both females and males.

The major results for the P3 location were as follows:

1. There were no significant main effects or interactions for the N100 amplitude.

2. N100 peak latency was significantly shorter for the semantically inappropriate sentence with the Key word teeth vs. hair for both presentations by both groups of subjects.

3. N100P200 amplitude was significantly more positive for the semantically inappropriate sentences with Key words of tall vs. good and teeth vs. hair for both presentations and both groups of subjects.

4. N100P200 amplitude responses of females and males were significantly different for the ten different sentences.

5. P200 peak latency was significantly shorter for the sentence with a Key element of /hæʤ/ vs. hat and for the average of the three phonemic-semantically inappropriate sentences vs. the three phonemic-semantically appropriate sentences for both presentations and by both groups of subjects.

6. N100P300 amplitude was significantly more positive for females than for males for both presentations of all ten sentences.

7. N100P300 amplitude was significantly more positive for the sentences with Key elements of /bʊʃ/ vs. book, /bʊʃ/ + /hæʤ/ vs. book + hat; the average of three phonemic-semantically inappropriate vs. the average of the three phonemic-semantically appropriate sentences; and the average of all five semantically inappropriate vs. the average of all five semantically appropriate sentences for both presentations by both groups of subjects.

8. P300 latency was significantly shorter for the sentences with Key elements of /bʊʃ/ vs. book and /bʊʃ/ + /hæʤ/ vs. book + hat for both presentations by both groups of subjects.

9. P300 latencies of the ten different sentences were significantly different for the two different presentations for both females and males.

CHAPTER V

DISCUSSION

The relationship between language meaning and the linguistic structures by which meaning is expressed implies systematic and well defined processing strategies. Unfortunately, formal documentation of these operations is not yet possible and they remain largely theoretical. One of the strategies, however, which has been recognized to be crucial to the processing of speech and language is redundancy. The English language is especially redundant and easily permits only partially perceived patterns to be integrated into meaningful wholes. Generally, highly predictable words expected within a given context are recognized, remembered, and verbalized more accurately than the same word presented alone or in a semantically incongruous context (Schuberth and Eimas, 1977). Kutas and Hillyard (1980c) characterized language comprehension as the continual testing and updating of hypotheses about words that are likely to occur next in a text or conversation. Several ERP studies have reported neurophysiological responses to semantically incongruous sentences which violate this basic principle of redundancy. Certain ERP components recorded from the scalp appear to be sensitive to a subject's expectations and reflect particular responses to unexpected or surprising stimuli. Documentation of these reactions may be the first step in deciphering the elaborate coding system engaged in linguistic processing. With this in mind, the present study was undertaken in order to further expand

present knowledge of cognitive/linguistic functions. The amplitude and latency differences reported here indicated that certain components can serve as indices of information processing activities.

The greater peak amplitudes, especially at P300, which were manifested by the semantically inappropriate sentences were congruent with results from similar studies and could not be attributed solely to physical differences between the two groups of sentences. Several researchers (Squires et al., 1976; Duncan-Johnson and Donchin, 1977) have suggested that P300 amplitude varies with the expectancy of a stimulus and that expectancy is determined by the fine structure of events immediately preceding that stimulus. The semantically inappropriate sentences generally disconfirmed subjects' expectancies, apparently even with several repetitions, and produced the enhanced late positive components. Sutton et al. (1965), who first identified P300, related it to time and the amount of uncertainty reduction. He observed a large P300 component following the presentation of low probability stimuli compared with a smaller P300 elicited by higher probability stimuli. Disconfirming events also tended to produce larger P300 waves than confirming events even when the probabilities of these outcomes were equal, as in the case of the two types of sentences used in the present study.

A. Visual Differences Among ERPs

The ERPs to each sentence are included in Appendix D. These waveforms represented responses of the females and males to the two presentations of the ten repetitions of each of the ten sentences.

Visual inspection indicated that the ERPs did not necessarily manifest the dramatic well-defined components often reported in the literature. Although P300 was usually discernible, it was not necessarily as prominent as might be expected. The other two components, N100 and P200, were even less well-defined and manifested even more variation. Three different factors most likely influenced these results. First, endogenous components, by definition, have been reported to reflect intrinsic processes. These processes, under the subject's control rather than the experimentor's, most likely caused changes in the components from trial-to-trial. These fluctuations, in turn, affected the amplitudes and latencies of the components, especially P300. For this reason, several investigators (Donchin, 1979; Squires and Donchin, 1976) have cautioned against indiscriminate signal averaging since significant variations in P300 can easily be obscured. Donchin (1979) reported that it was not always possible to distinguish amplitude changes from latency variability since the latency of endogenous components depends on the time at which events internal to the subject occur. Since these times could easily vary relative to the external synchronizing stimulus, the amplitude of a signal could artifactually be reduced (Brazier, 1964). For these reasons, alternatives such as light averaging or single-trial measurements have been suggested.

Light averaging was the method adopted in the present study and may have been the second cause for the less clear waveforms. Since these ERPs were obtained from averaging only ten stimuli, the ratio of the power in the ERP to the power of the ongoing EEG may not have been favorable enough to sustain such a limited number of averages. Nevertheless, peaks were generally discernible within the specified time

windows and peak measurements were obtained with relatively little difficulty. Averaging of more repetitions may have enhanced the peaks or may have actually reduced the amplitude because of intrinsic subject variability or because of fatigue.

Subject fatigue and habituation to the stimuli may have been the third factor contributing to the reduced waveforms. Although Presentation was not a significant effect in the present study, peak measurements to the average of the second ten presentations of the stimuli were generally less than peak amplitudes from the average of the first ten. Since the ten different sentences were each repeated ten times within a presentation, the subjects may have fatigued after several presentations. Many of the subjects reported having difficulty attending to the listening tasks after several repetitions of the stimuli.

Visual inspection of the ERPs to the ten Key sentence elements also revealed several other trends. Several of the Key elements manifested more easily discernible ERP components. Sentences with the Key elements book, /bʊf/, /hædʒ/, hat, and /lep/ manifested waveforms with sharper, more clearly defined P300 components. Sentences with the Key elements tall and teeth evoked waveforms with clearer, more positive P200 components. These differences may have been related, in part, to the phonemic composition of the words or CVCs. The responses to book, hat, /lep/, tall, and teeth, in particular, may have been enhanced by the voiceless stop plosive consonants which appeared in either the initial or final position of the word or CVC. Differences in ERP components related to phonetic or acoustic cues have been reported, and isolated ERP components of phonological cues such as

voicing and place of articulation contrasts have been determined. Lawson and Gaillard (1981a) determined that N100 latencies distinguished a set of stimuli composed of a tone and the voiceless plosive CVs /pe, te, ke/ from a second set of stimuli composed of the CVs/ we, je, me, ne, ve, and fe/. N100P200 peak amplitude distinguished the tone and /pe, te, ke, we/ from /fe/ and /se/. Molfese (1979) recorded ERPs from scalp locations over the left and right temporal regions in response to CVC words and nonsense syllables. Various components of the ERP were found to vary systematically with changes in meaning and changes in voicing and place of articulation. Molfese and Molfese (1979a, b) reported bilateral changes in the N100P200 complex when place of articulation cues were manipulated. The voiceless plosives /k, t, p/ which appeared in the final positions of book, hat, and /lep/ may have contributed to the enhanced N100P300 complex in sentences with those elements. The appearance of /t/ in the initial positions of tall and teeth may also have contributed to the enhanced N100P200 complex in sentences with these elements since the evoked response to an initial phoneme would naturally have occurred earlier.

Regardless of these acoustic features, however, semantically inappropriate sentences consistently manifested more positive N100P200 and N100P300 components although the voiceless plosives /k/ and /t/ appeared in the final positions of two words (book and hat) in the semantically appropriate sentences. Voiced plosives which also have been shown to produce more discrete ERPs (Molfese, 1979) were included in the semantically appropriate sentence with good. However, the ERP to this sentence was essentially unremarkable and was significantly

lower in N100P200 amplitude than its cognate sentence with tall at both Cz and P3. The two semantically inappropriate cognate sentences (Key elements = /bʊf/ and /hædʒ/) which did not contain voiceless plosives were significantly more positive at N100P300 for both the Cz and P3 locations. The enhanced N100P200 complexes of sentences with tall and teeth may have been influenced by a combination of acoustic and linguistic factors. The initial plosive /t/ may have contributed to the enhanced component; however, subjects were also able to make the linguistic decisions earlier in the two sentence pairs with these real-word contrasts.

B. Differences in N100 Amplitude and Latency

Although no significant N100 amplitude effects were determined at the P3 location, N100 amplitude of the average of all five semantically inappropriate sentences was significantly more negative than N100 amplitude of the average of the five semantically appropriate sentences at the Cz location. Significantly shorter N100 latencies for the sentences with Key elements of /hædʒ/ vs. hat; teeth vs. hair; /bʊf/ + /hædʒ/ vs. book + hat; and good vs. tall were determined at Cz. Significantly shorter N100 latency for the sentence with teeth vs. hair was determined at the P3 location.

The amplitude and latency differences reflected by N100 at Cz may have been related to selective attention effects. Several researchers have identified mid-latency (80-200 msec) aspects of the ERP with attention. Hillyard (1978) defined a selective attention experiment as one involving a situation in which there were at least two stimulus

categories. Selectivity was demonstrated when a subject processed one of these stimulus categories more efficiently than the other. Processing was indicated by a behavioral measure such as faster reaction time, more accurate discriminations, etc. Schwent and Hillyard (1975) and Schwent et al. (1976a, b) determined that N100 amplitude of the ERP component was greatly enhanced as a subject's attention was directed toward the relevant stimulus. Hillyard (1978) also determined that in a dichotic listening task, the amplitude of N100 was larger for relevant stimuli possessing easily identifiable characteristics toward which the subject's attention had been directed. The increased N100 amplitude of the semantically inappropriate sentences may have reflected a subject's decision to label them as the relevant stimuli. Although subjects were instructed to listen to each sentence and categorize it as meaningful or nonmeaningful, the novel, semantically inappropriate sentences may have "commanded" more attention than the semantically appropriate sentences, thereby becoming the relevant stimuli.

The N100 component of the ERP may have served as an index of a continual process related to the initial selection of information for further processing. However, whether the selective filtering was limited to basic stimulus attributes or extended to linguistic distinctions could not be determined. Wilkinson and Lee (1972) proposed that N100 and possibly N100P200 of the auditory evoked response reflects selective filtering only for basic stimulus attributes such as modality and location in space and time but not for other attributes such as pitch and linguistic distinctions. However, in the present

study N100 appeared to reflect linguistic distinctions at the central vertex location but not at the parietal location. Selective attention has been more readily documented from the N100 vertex location. Arezzo et al. (1975) proposed that an N100 component has a fronto-central distribution and is elicited by stimuli in all three modalities--auditory, visual, or somatosensory. It was unclear, however, whether the auditory N100 had a frontal source, temporal source, or both frontal and temporal source. The parietal, P3, location used in the present study was apparently too far removed from the distribution area of N100 and failed to reflect any of the differences noted at the Cz location.

The linguistic distinctions reflected by differences in N100 amplitude and latency were consistent with results of other studies. Molfese (1979) recorded ERPs from four CVC words and four CVC nonsense syllables and determined that various components of the ERP reflected changes in stimulus meaning and changes in voicing and place of articulation. Molfese reported a later component, Factor 10, with a latency between 240-280 msec which was sensitive to the word-nonword distinction. An early factor (65-140 msec), Factor 3, distinguished between meaningful and nonsense stimuli which contained an initial voiceless consonant or began with a back consonant. Molfese concluded that isolated portions of the ERP were sensitive to semantic and phonemic distinctions. Molfese also suggested that the early components reflected parallel processing of coarticulated speech cues (Liberman et al., 1967). In other words some aspect of the initial consonant burst apparently contained information regarding the later

sounds. The existence of a subcortical region which utilized co-articulated cues to identify later speech sounds and process those materials semantically was also suggested.

Coarticulatory effects may have contributed somewhat to the fact that semantic effects were identified at N100 and N100P200 amplitudes and latencies. Although listeners based their decisions on the final consonant in three of the five sentence pairs, the N100 and P200 latencies were considerably shorter than the duration of the Key elements.

C. Differences in N100P200 Amplitude and P200 Latency

Significantly more positive N100P200 amplitudes were determined for sentences with Key elements of tall vs. good and teeth vs. hair for both the Cz and P3 locations. In addition N100P200 amplitude of the average of all five semantically inappropriate sentences was significantly more positive than N100P200 amplitude of the average of the five semantically appropriate sentences at the Cz location. Significantly shorter P200 latencies for the sentence with the Key element /hædʒ/ vs. hat as well as a significantly shorter P200 latency for the average of the three phonemic-semantically inappropriate sentences vs. the three phonemic-semantically appropriate sentences were also determined at the P3 location.

Manipulation of phonological variables appeared to effect changes in the N100P200 complex at both electrode locations. While sentences with words and CVCs which differed only in the final phoneme were more distinguishable at P300, the two sentence pairs with real word contrasts, tall vs. good and teeth vs. hair, were more distinguishable at

N100P200. Lower order sensory effects related to physical or acoustic features of the stimuli may have been responsible, in part, for these differences. Unlike the phonemic contrast pairs, variations in both initial and final consonants and vowels existed within the two contrast sentence pairs with tall vs. good and teeth vs. hair.

Variations in the N100P200 complex have been reported by researchers who have manipulated phonological variables of the stimuli. Megela and Teyler (1978) determined that ERPs were more similar between words of different meanings but similar physical characteristics (homonyms) than between words of similar meanings but different physical characteristics (synonyms) at both N100P200 and P300. Megela and Teyler attributed these findings to the greater importance of lower order sensory effects than semantic effects in influencing ERP waveforms. The fact that P300 did not distinguish semantic effects in the Megela and Teyler study may have been due to the passive state of their subjects who were not required to make linguistic decisions.

The phonemic-linguistic distinctions reflected by N100P200 at the Cz and P3 location were consistent with results of other studies. Matsumiya et al. (1972) determined larger P60N180 amplitude components to meaningful stimuli. Molfese (1979) reported four components, P60, N250, P300, and N370, which reflected whether a CVC was a meaningful word or a nonsense syllable. Molfese speculated that coarticulatory effects were reflected by P60 since meaningfulness/nonmeaningfulness of the stimuli could only be determined by the final phoneme. Begleiter and Platz (1969) recorded VEPs to taboo words, neutral words, and blank visual fields in a study of connotative meaning. Larger

N100P160 amplitudes were elicited by the taboo words. Larger N100P160 amplitude was also recorded over all stimuli when the subject was required to attend and respond to the stimuli. Begleiter and Platz concluded that amplitude of a component was affected by both connotative meaning of the stimulus and the demand for a response. Brown et al. (1976) reported a larger N150 component to nouns than verbs. Galambos et al. (1975) reported that N100 and P300 latencies differed for speech and tone stimuli. They suggested that the shift in latency may have resulted from the engagement of different processing mechanisms in the identification of speech and nonspeech stimuli.

Other researchers (Dorman, 1974; Molfese, 1978a, 1979; Molfese and Hess, 1978; and Molfese and Molfese, 1979a) have determined that N100P200 reflects phoneme category differences when VOT is manipulated. Bilateral changes in all age groups from infants (Molfese and Molfese, 1979a, 1980) to adults (Molfese, 1978b, 1980b) were reported when place of articulation features were manipulated.

Semantic variables may also have influenced these results since listeners were able to make the linguistic decision earlier in the two contrast pairs. That is, listeners were able to determine after the first presentation whether the sentence was meaningful or nonmeaningful after hearing the initial /t/ in tall or teeth or the initial /g/ in good and /h/ in hair. Listeners could not determine meaningfulness or nonmeaningfulness of the other three contrast pairs until hearing the final phoneme, since the first two phonemes of each of these contrast pairs were identical.

The significantly shorter P200 latency for the average of the three phonemic-semantically inappropriate sentences may have reflected some aspect of the decision process (meaningful vs. nonmeaningful sentence). Initially subjects were able to determine the inappropriateness of the sentence with the onset of the final phoneme. In the case of the three phonemic-semantically appropriate sentences, subjects had to listen to the entire word to determine its appropriateness. Of course, after the initial presentations of the ten sentences, subjects learned that the sentences would be repeated, and they were able to make their determination on the basis of the onset of the final phoneme. The earlier latency which was also determined for some of the contrasts at P300 may have reflected the subjects' enhanced awareness of the inappropriate sentences and their designation of these as the relevant stimuli.

The significantly shorter latency for the average of the three phonemic-semantically inappropriate sentences determined at P3 may have also reflected processing of coarticulated speech cues occurring during the initial two phonemes from the final consonant position.

D. Differences in N100P300 Amplitude and P300 Latency

The P300 complex appeared to be the primary differentiator between the semantically inappropriate and semantically appropriate sentences in the present study. At the Cz location N100P300 amplitude was significantly more positive for the sentences with /bʊf/ vs. book; /hædʒ/ vs. hat; /lep/ vs. leg; and /bʊf/ + /hædʒ/ vs. book + hat.

Significantly more positive N100P300s were also determined for the average of the three phonemic-semantically inappropriate sentences and the average of all five semantically inappropriate sentences. At the P3 location significantly more positive N100P300s were determined for sentences with /bʊf/ vs. book and /bʊf/ + /hædʒ/ vs. book + hat. The average of the three phonemic-semantically inappropriate sentences and the average of all five semantically inappropriate sentences were also determined to have significantly more positive N100P300s than the averages of the three phonemic-semantically appropriate and all five semantically appropriate sentences. Significantly shorter P300 latencies were determined at Cz and P3 for the sentences with /bʊf/ vs. book and /bʊf/ + /hædʒ/ vs. book + hat. Significantly shorter latency for the semantically appropriate sentence with leg vs. /lep/ was also determined at the Cz location.

In contrast to the N100P200 complex which differentiated the two real-word contrasts, the N100P300 component, especially at Cz, distinguished the three phonemic-semantically inappropriate and three phonemic-semantically appropriate sentences. These three contrast pairs which differed only in their final consonants were more controlled in terms of their acoustic-phonemic features. The sentence pair with /lep/ vs. leg contrasted the voiceless plosive /p/ with the voiced plosive /g/. The other two sentence pairs with Key elements of /hædʒ/ vs. hat and /bʊf/ vs. book contrasted the voiced continuant /dʒ/ with the voiceless plosive /t/ and the voiceless continuant /f/ with the voiceless plosive /k/.

An additive effect was demonstrated by the significant difference between the average amplitudes of all five semantically inappropriate sentences vs. all five semantically appropriate sentences for N100, N100P200, and N100P300 at Cz. These significant differences, especially at the early components, suggested a coarticulatory-semantic interaction since meaningfulness/nonmeaningfulness was the one feature distinguishing these two groups of sentences.

Latencies of the words or key elements of the semantically inappropriate sentences were generally determined to be shorter than the latencies of the words or elements of the semantically appropriate sentences. A consistent exception was the semantically appropriate sentence with the Key word leg which was determined to be significantly shorter than the semantically inappropriate sentence with /lep/. This result should not have been due to the duration difference since /lep/ was approximately 49 msec shorter than leg. Molfese (1979) reported shorter latencies for voiced stops /b/ and /g/ which are also marked by shorter voice onset time values than the voiceless stops /p/ and /k/. He speculated that the shorter latencies for voiced stops coincided with the VOT cue. Since leg contained the voiced plosive /g/ and /lep/ contained the voiceless plosive /p/, the shorter latency of leg may have been related to this phonemic difference. However, since the other four sentence pairs did not involve this voiced-voiceless plosive contrast, such interpretation could only be speculative.

The voiceless stop plosives /k, t/ in the final positions of book and hat were contrasted with the voiceless continuant /f/ in /bvf/ and

the voiced continuant /dʒ/ in /hædʒ/. At both Cz and P3, P300 latency for /bʊf/ + /hædʒ/ was significantly shorter than that for book + hat. N100 latency of the voiceless stop plosives was also significantly shorter at Cz. The N100P300 amplitude of the voiceless stop plosives was also significantly higher at P3. The significantly higher amplitude was most likely due to the fact that these two elements comprised semantically inappropriate sentences. The latency differences may have also been related to the semantic inappropriateness of the sentences; however, phonemic differences may have also been responsible. Due to the timing differences in triggering, however, conclusions based on latency differences could only be speculative.

In a study somewhat similar to the present one but employing visual stimuli, Kutas and Hillyard (1980 a, b, c) demonstrated differential ERP effects when the final word in a sentence either confirmed or disconfirmed the information contained in that sentence. Subjects were presented with 160 different seven-word sentences. One hundred of the sentences ended with a semantically appropriate final word; 20 sentences ended with a semantically inappropriate final word; 20 sentences with a semantically appropriate final word with larger type size; and 20 sentences with an inappropriate final word in large type size. Kutas and Hillyard identified a negative peak with a latency of 400-500 msec which occurred independent of type size for the inappropriate seventh word. This effect was identified at the central sites only. The N400 wave elicited by the semantically inappropriate words was surprising since previous studies with disconfirming stimuli resulted in enhanced late positive components.

Kutas and Hillyard speculated that the semantic deviations activated a different neurophysiological operation than the physical deviations. They concluded that ERP measures are sensitive to differences in sentences with expected and unexpected endings and also suggested that the different modes of cognitive reactions to surprising events need further delineation.

Several differences between the present study and Kutas and Hillyard's may have accounted for the polarity discrepancy. The most obvious was the mode of presentation. Kutas and Hillyard's visual presentation may have engaged a different area in the processing mechanism. Another point of confusion stemmed from the fact that Kutas and Hillyard displayed N400 as a positive wave although it was reported as negative. This confusion regarding polarity rendered any comparisons even more difficult. The latency range, however, was similar to the P300 component reported in the present study. Perhaps the only valid commonalities between the two studies were the differentiation of the semantic deviations from the semantically appropriate sentences by means of ERP components and the sensitivity of the central locations.

Contectual effects appeared to be crucial for the engagement of the processing index for the semantically deviant stimuli. Studies involving only words and nonwords (visual and auditory modes) have failed to produce such dramatic differences. Kutas and Hillyard (1980b) suggested that repeated presentations of simple, isolated syllables or even words are unlikely to engage normal language processes as consistently as would more natural contexts such as

conversation or reading. Shelburne (1972, 1973) presented visual stimuli in the form of consonant-vowel-consonant word and nonsense syllable trigrams. Subjects were normal and learning disabled children whose task it was to decide whether the CVC formed a word or nonsense syllable. Visual evoked potentials (VEPs) were recorded to each letter; the last letter determined whether the syllable was a word or nonsense syllable. The normal children who were able to distinguish between words and nonsense syllables (behaviorally) manifested larger late positive components to the third position stimuli than to the first or second letters. These effects were greatest at the Cz lead. Learning disabled children who generally could not make this distinction did not manifest any differences between first and third position stimuli. Although no VEP differences between words and nonsense syllables were noted for any letter position, Shelburne speculated that his data reflected a decision process (word versus nonword). The VEP differences may have reflected the subject's ability to perform the task and resolve the uncertainty. The lack of specific differences in the two types of stimuli may have resulted from the lack of a syntactic structure or semantic framework.

The engagement of a specific neurophysiological mechanism during semantic processing was also alluded to by Friedman et al. (1975b). Normal subjects were presented visually with a series of words comprising a sentence. A key word delivered information either late in the sentence (Condition 1) or early in the sentence (Condition 2). Although all words in the sentences produced P300s, the P300 to the last word in both conditions was significantly larger than the P300 to all the other words. Friedman et al. attributed the P300 components

to all words to the engagement of the P300 system whenever task-related language stimuli were used. The enhanced P300 to the last word of a sentence regardless of meaning and point of task information delivery suggested that P300 was a correlate of "syntactic closure." The experimenters speculated that the brain processed language stimuli in terms of their meaning and syntactic structures simultaneously. Therefore, when a syntactic structure such as a sentence ended, the brain presumably recognized it as a language unit and reacted with a neurophysiological response. Friedman et al. also reported longer P300 latencies to the words which delivered information in the sentence. According to the experimenters, the major effect of information delivery was on P300 latency while "syntactic closure" had its major effect on P300 amplitude. Although Friedman et al.'s study involved visual stimuli as well as a different experimental paradigm, several similarities were evident. Although ERPs were recorded to the final word only (in the present study), the P300s may have been a manifestation of Friedman et al.'s "syntactic closure" phenomenon. The enhanced P300s to the semantically inappropriate sentences may have resulted from a neurological "double take" to the ending of the syntactic structure with a semantically deviant word. Since all ten sentences in the present study were syntactically correct, the "syntactic closure" effect would be expected as well as a reaction to the semantic deviance within the correct syntactic structure.

Syntactic/grammatic aspects of language processing have been further delineated by ERP studies depicting clearer differences to nouns and verbs than to synonyms and antonyms. Since noun-verb distinctions

are grammatical properties of language and synonym-antonym distinctions are not, perhaps the ERP distinctions reflected information concerning the way the brain processed linguistic meaning. Brown et al. (1973), for example, found that ERPs to the word "fire" differed if the word appeared in phrases "sit by the fire" versus "ready, aim, fire." As a control, the word appeared in the initial position of a phrase ("fire is hot" or "fire the gun"). ERPs to the word "fire" in the initial position were not significantly different. The experimenters suggested that contextual effects which evoked differences in the meaning of the word produced the significant ERP differences. Brown et al. (1976) next attempted to control for physical differences in the stimuli preceeding the key word. Physically identical stimuli within an ambiguous context were presented to subjects who were instructed prior to each presentation to interpret the final word as a noun or a verb. Differences in ERP waveforms were elicited when the word was differently interpreted. Thatcher (1978), however, questioned whether the ERP differences were due to different meanings or to the different syntactic contexts implied by the different interpretations.

Teyler et al. (1973) and Roemer and Teyler (1977) reported that responses to clicks preceeding words were dissimilar depending on whether the words were interpreted as nouns or verbs. The Brown et al. (1973) and Teyler et al. (1973) studies employed verbal information to provide a disambiguating context for subsequent ambiguous information; however, both studies suffered from the confounding of syntactic function and word meaning. In the present study, syntactic

structure was controlled within each of the five sentence pairs. The three phonemic contrast pairs provided further control since only the final phoneme differed between pairs. The significant differences between sentence pairs provided additional evidence that ERP components to language stimuli could change as a function of context. Pragmatics, the use of context to determine an individual's interpretation of linguistic events (Bates, 1976) may therefore provide the mechanism for indexing cognitive/linguistic functioning using ERPs.

E. ERP Differences Between Females and Males

Differences between females and males were more evident at the Cz location. Significantly more negative N100 and significantly more positive N100P200 and N100P300 amplitudes were determined for the female subjects at Cz. Additionally, the P200 latencies of the females and males were significantly different for the first and second presentations of all ten sentences at Cz. N100P300 amplitudes of the females and males were also significantly different for the ten different sentences at Cz. Significant N100P300 amplitude differences were determined between females and males at P3. The N100P200 amplitudes of the females and males were also significantly different for the ten different sentences at P3.

These results were in general agreement with other studies that have indicated sex differences in ERP amplitudes and latencies. Previous researchers have suggested either anatomically or genetically based female-male differences as the basis for these results. Halliday et al. (1982) determined shorter latencies for females than males to a

checkerboard reversal response and also reported higher P100 amplitudes for females. These differences were attributed to the smaller average head size and skull thickness in women as well as a higher deep body temperature in women. The smaller physical size of females and concomitant neuroanatomical distance between various brainstem nuclei have also been cited as the principal reasons for female-male latency differences in BSER studies. Beagley and Sheldrake (1978) reported significant female-male BSER latency differences in normal hearing subjects, ages 14-79 years. Jerger and Hall (1980) determined consistently shorter Wave V latencies and larger amplitudes in both normal and hearing impaired females.

Some researchers have theorized that females, being smaller, have shorter neurological pathways. Central conduction time between the various sites such as the cochlear nuclei (Wave I) and the olivary complex (Wave III) would therefore be shorter for females. Several researchers have questioned the anatomical theories, however, since females should therefore manifest faster late (N100P200, P300) responses than males. However, no data have supported the existence of faster late components in females. In the present study significant female-male amplitude differences were primarily determined. The only exception was a significant presentation X sex interaction determined for P200 latency at Cz. Stockard et al. (1978) found no differences in external skull dimensions for subjects in their study where they found significant female-male differences in interpeak latencies (IPLs). Seitz et al. (1980) suggested that the ERP differences between females and males may have been a further manifestation of the

significant auditory processing skills advantage found in females. Several non ERP studies (Ferry et al., 1979) have documented female advantages related to auditory processing and linguistic skills. Females, for example, have been determined to acquire language earlier than males, and morphologic asymmetry between the left and right temporal lobes has been shown to occur earlier in females than in males (Sherman, 1978). Males, on the other hand, have been shown to have definite advantages in certain visual-spatial activities (Macoby and Jacklin, 1974). Molfese and Molfese (1979a, b) reported significant Factor I responses for female infants in response to both speech and nonspeech.

Gur et al. (1982) used the Xe inhalation technique and measured cerebral blood flow in 62 healthy right and left-handed females and males during periods of resting, solving verbal analogues, and solving a spatial line orientation task. Females manifested a higher rate of blood flow per unit weight of brain. Right-handed females showed a stronger lateralization of cerebral blood flow than right-handed males. Greater increases in the left hemisphere during the performance of verbal tasks and greater increases in the right hemisphere during the performance of spatial tasks were reported for all subjects.

The explanation of these sex differences as purely anatomical has therefore been questioned, and support for a genetic difference in auditory processing has been strengthened. However, although the sex differences in auditory processing have been documented, the anatomical or genetic basis for these differences have not been determined at this time.

F. ERP Differences Between Presentations

Although the main effect Presentation was not determined to be significant in the present study, significant interactions were determined at P200 and P300 latencies. A significant Presentation x Sentence interaction was determined at P300 for both the Cz and P3 locations. Apparently significant differences in P300 latencies existed among the ten different sentences for the two presentations. However, these differences were not determined to be crucial to the questions of this study and post hoc testing was therefore not performed on any of the significant interactions. A significant Presentation x Sex interaction was also determined for the P200 latency at Cz. In other words females and males manifested significantly different P200 latencies between the two presentations of the ten sentences.

Visual inspection of the various ERP tracings of the stimuli indicated that peaks were generally reduced somewhat for the second presentation of the stimuli. However, these differences were generally not enough to be significant. The fact that the ten different sentences were presented in a random order may have helped to maintain the attention of the subjects, thereby reducing fatigue and habituation. Subjects were also given short rest periods after each presentation of 25 stimuli which may also have lessened fatigue. The interstimulus interval was also varied between seven and nine seconds as still another means of maintaining interest in the listening task. Shucard and Callaway (1974) examined auditory ERP habituation using tones in two experimental sessions separated by seven days. Stimuli presented in a random series generally produced larger evoked

responses than stimuli in an ordered series. Tones that were part of a discrimination task produced larger evoked responses than did tones presented while the subject read. ERPs for the first half of the experimental session were also determined to be greater in amplitude than those for the second half.

The lack of significance between the two different presentations may have been due to a combination of the above factors. A secondary purpose of the two presentations was to determine if valid results could be obtained with only ten presentations of a stimulus. Since light averaging has been proposed as one alternative to the inherent limitations of signal averaging, this factor was incorporated into the present design. The fact that significant results were determined on the basis of ten averages supported the validity of this technique in evoked response studies of cognitive/linguistic processing.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate event-related potentials to semantically inappropriate and semantically appropriate sentences. Female and male subjects listened to two separate recordings of the ten randomized presentations of each sentence. Peak-to-peak amplitude and peak latency measures were obtained from Cz and P3 within the following time windows: 52.5 to 170.0 msec (N100), 172.5 to 285.0 msec (P200), and 290.0 to 580.0 msec (P300). The P200 and P300 amplitude measures were referenced to N100.

The ten different sentences consisted of five matched pairs with each semantically inappropriate sentence differing from its cognate sentence in the final (Key) word or element. Two of the semantically inappropriate sentences contained real words inappropriately placed in the final position. The other three (phonemic) semantically inappropriate sentences contained a nonsense CVC which differed only in its final phoneme from its cognate sentence.

Seven adult females and seven adult males served as subjects. All subjects met the following criteria: right handedness; normal hearing; negative history of neurological disorders or sumptoms; and no history of speech or language disorders.

Subsequent analyses of variance yielded the following major results:

1. N100 amplitude was significantly more negative for females than for males for both presentations of all ten sentences at Cz. This effect was not significant at P3.

2. Average N100 amplitude of all five semantically inappropriate sentences was significantly more negative than the average N100 amplitude of all five semantically appropriate sentences for both presentations and both groups of subjects at Cz. This effect was not significant at P3.

3. N100 latency was significantly shorter for the semantically inappropriate sentence with the Key word teeth vs. hair for both presentations and both groups of subjects at Cz and P3. N100 latency was significantly shorter for sentences with Key elements of /hædʒ/ vs. hat; /bʊf/ + /hædʒ/ vs. book + hat; and good vs. tall for both presentations and groups of subjects at Cz.

4. N100P200 amplitude was significantly more positive for females than for males for both presentations of all ten sentences at Cz. N100P200 amplitude responses of females and males were significantly different for the ten different sentences at P3.

5. N100P200 amplitude was significantly more positive for the semantically inappropriate sentences with Key words tall vs. good and teeth vs. hair for both presentations and groups of subjects at Cz and P3. The N100P200 average of all five semantically inappropriate sentences was significantly more positive than the average of the five semantically appropriate sentences for both presentations and both groups of subjects at Cz.

6. P200 latency at P3 was significantly shorter for the sentence with the Key element /hæʤ/ vs. hat and for the average of the three phonemic-semantically inappropriate sentences for both presentations and groups of subjects. P200 latency responses of females and males were significantly different for the first vs. the second presentation of all ten sentences at Cz.

7. N100P300 amplitude was significantly more positive for females than for males for both presentations of all ten sentences at Cz and P3.

8. N100P300 amplitude of the sentence with /bʊf/ vs. book was significantly more positive for both presentations and groups of subjects at Cz and P3. N100P300 amplitudes of the averages of all five semantically inappropriate sentences and the three phonemic-semantically inappropriate sentences were significantly more positive for both presentations and groups of subjects at Cz and P3. Sentences with Key elements /bʊf/ vs. book and /lep/ vs. leg were significantly more positive at Cz. The sentences with /bʊf/ + /hæʤ/ vs. book + hat were significantly more positive at P3.

9. N100P300 amplitude responses of females and males were significantly different for the ten different sentences at Cz.

10. P300 latency was significantly shorter for sentences with /bʊf/ vs. book and /bʊf/ + /hæʤ/ vs. book + hat for both presentations and groups of subjects at Cz and P3. P300 latency was significantly shorter for the semantically appropriate sentence with leg vs. /lep/ at Cz.

11. P300 latencies of the ten different sentences were significantly different for the two different presentations for both females and males at Cz and P3.

This study attempted to offer further insights into the electrophysiological correlates of language processing. ERPs recorded from the two electrode locations appeared to be sensitive to the language relevant stimulus manipulations of nonmeaningful vs. meaningful sentence processing. While Cz appeared to be a more sensitive indicator of sentence and sex differences, both locations differentiated semantic and phonemic distinctions within the various sentence pairs.

Although a relatively new technique, ERPs have demonstrated utility in the study of cognitive/linguistic processing. ERP techniques have the potential to become powerful research and clinical tools. Because of the immediacy of the neurophysiological responses, ERPs might actually provide a more sensitive metric of the substraits of speech perception and linguistic processing than behavioral measures. ERPs also offer the possibility of providing new information concerning the nature, sequence and timing of processing tasks since recordings can be made from several different sites. The relationship between particular aspects of language functioning and brain activity might also be more clearly specified by studying patients with specific cognitive or linguistic deficits caused by localized brain damage. Thus it may be possible to study damage to a particular area and consequent alterations to particular features of the waveforms. Currently, such a study is being undertaken with aphasics. Neurological recovery and/or reorganization will be followed by recording

ERPs from aphasics during the period of spontaneous recovery when most of the improvement in language functioning generally occurs.

However, with any technique, ERP methodology is not without its limitations. The sensitivity to features such as stimulus attributes and task involvements, and the need to average several repetitions of a stimulus are only a few factors to be considered. Although stimulus influences such as loudness level and rise/decay time were controlled in the present study, phonemic/phonetic controls were minimal. Although linguistic differences generally overrode phonemic/phonetic factors, their influence was still obviously apparent. ERP responses appeared to be influenced, especially in amplitude, by the interaction of acoustic and linguistic factors. The use of synthesized speech and key elements differing by only one distinctive feature would provide a stricter phonemic control and should be considered in future research designs. Stricter control of the duration of the sentences and their key elements, as well as a more accurate triggering mechanism, would also have improved the controls in the present study and should be incorporated into future research.

However, with any new experimental technique, methodological mistakes are inevitable, and refinements in experimental design, signal extraction, and measurement techniques are certain to follow. Considerable progress in the area of electrophysiological neurolinguistics has already been accomplished, and the evidence is strong that the ERP is a manifestation of "real" brain activity. Future research will hopefully clarify these components, diminish the uncertainty which currently pervades them, and provide an index into the intricacies of cognitive/linguistic processing events.

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APPENDIXES

APPENDIX A

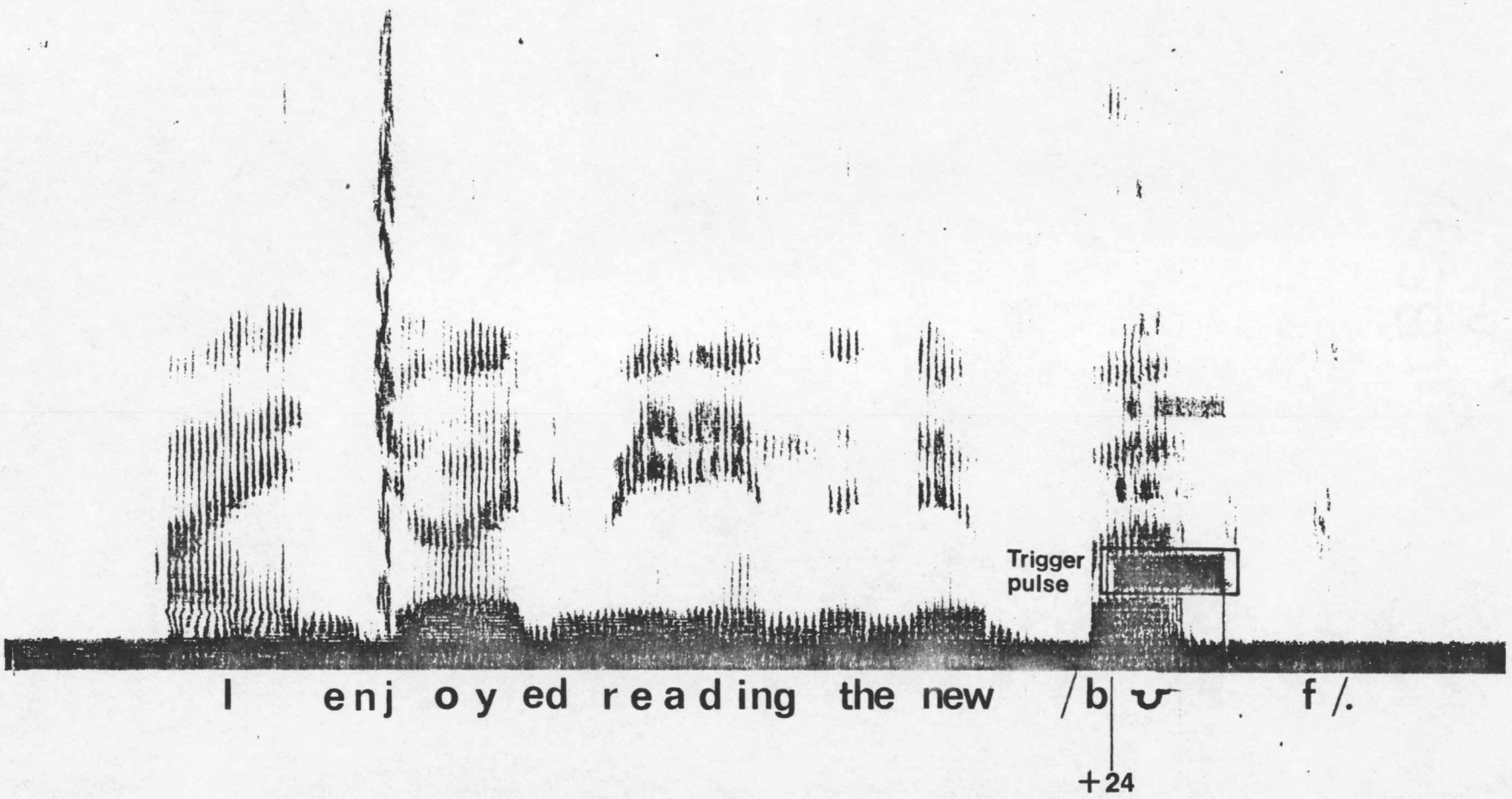

Figure A-1. Spectrographic recording of the sentence, "I enjoyed reading the new /bʊf/," indicating the trigger pulse.

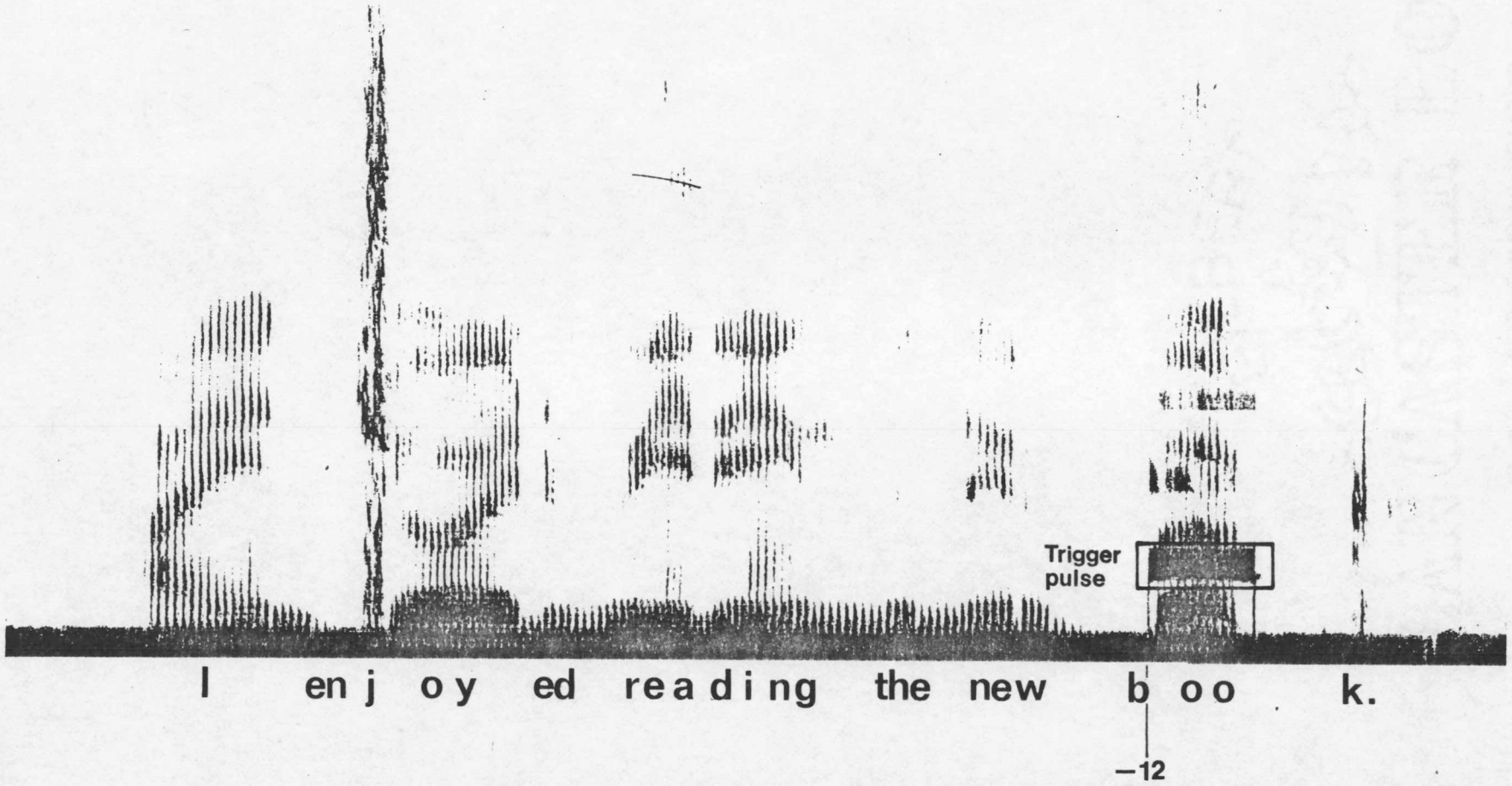

Figure A-2. Spectrographic recording of the sentence, "I enjoyed reading the new book," indicating the trigger pulse.

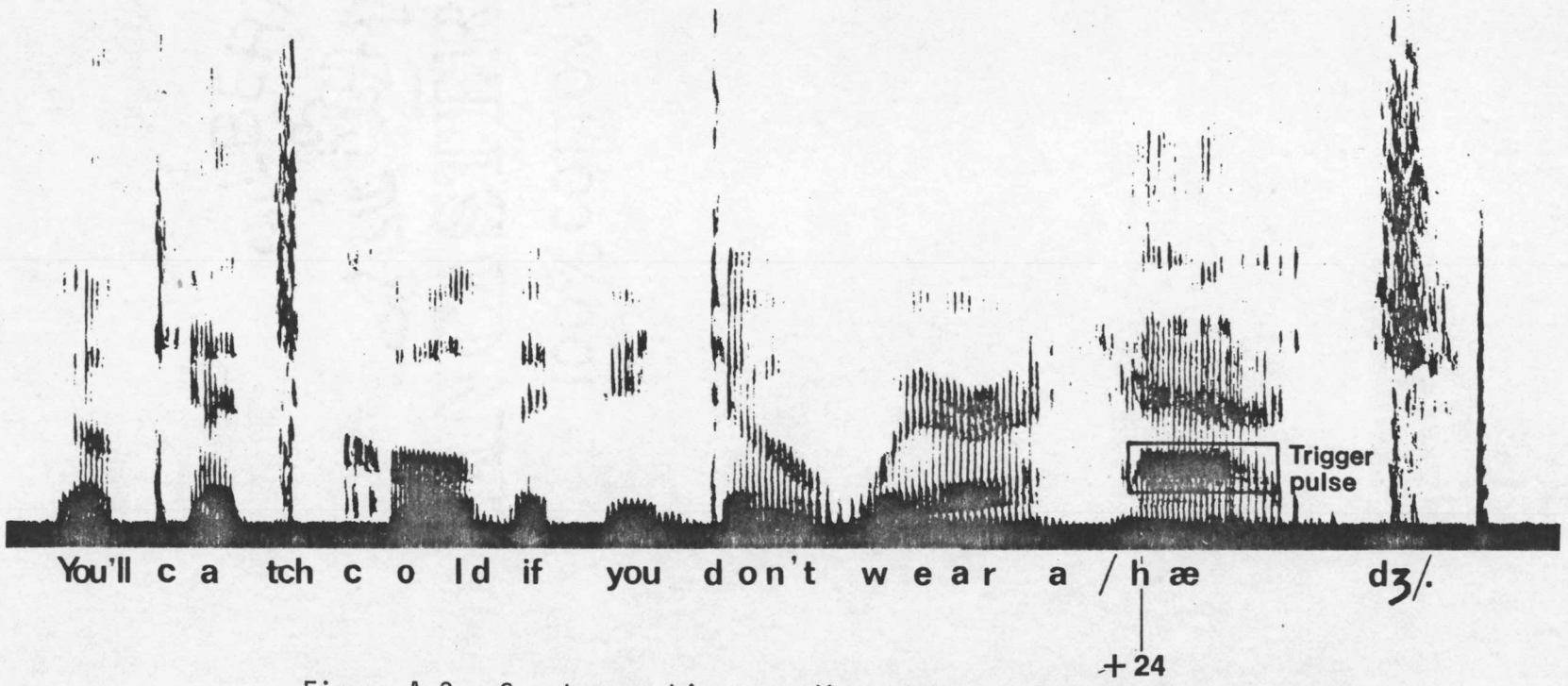

Figure A-3. Spectrographic recording of the sentence, "You'll catch cold if you don't wear a /hædʒ/," indicating the trigger pulse.

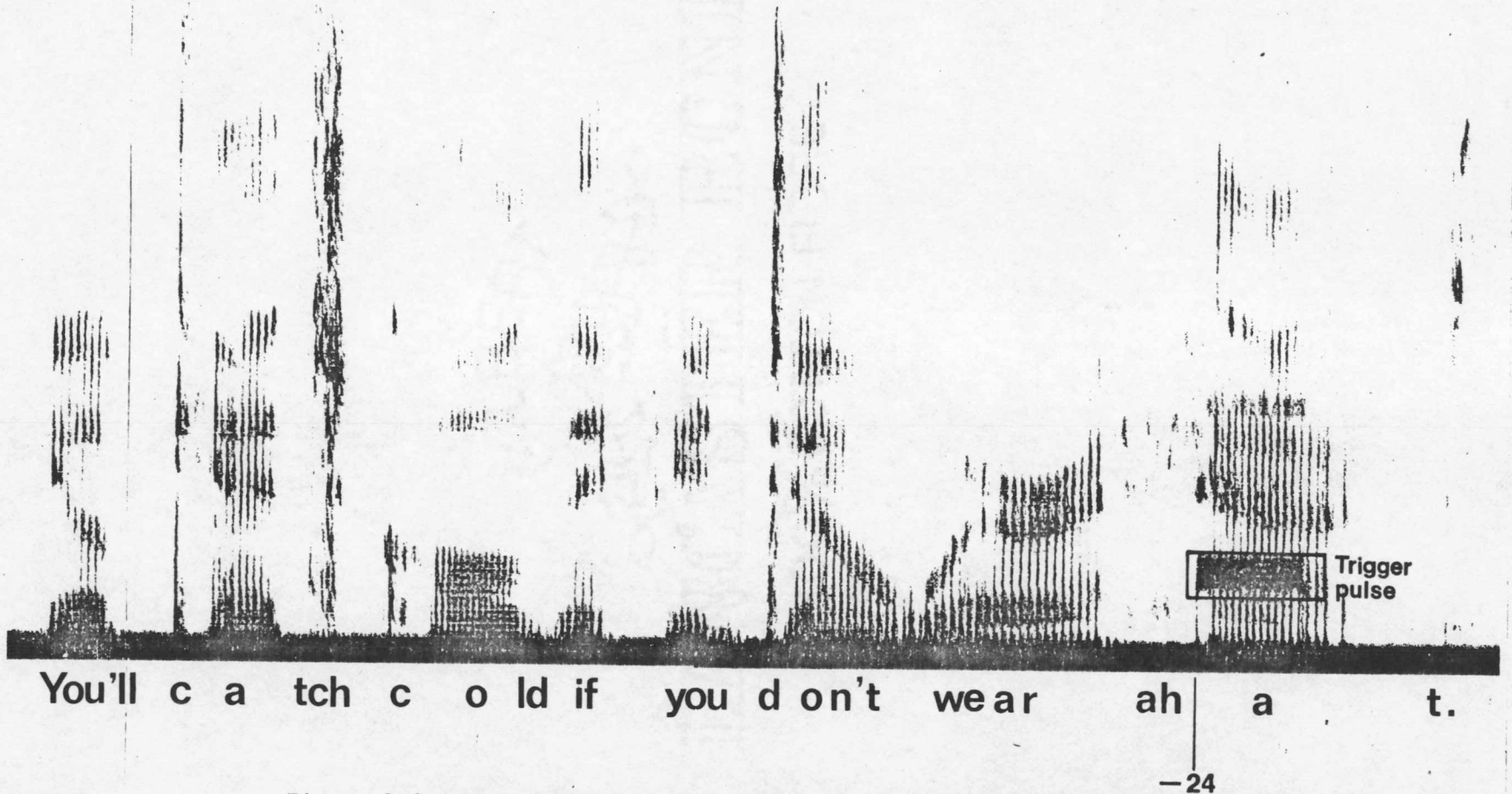

Figure A-4. Spectrographic recording of the sentence, "You'll catch cold if you don't wear a hat," indicating the trigger pulse.

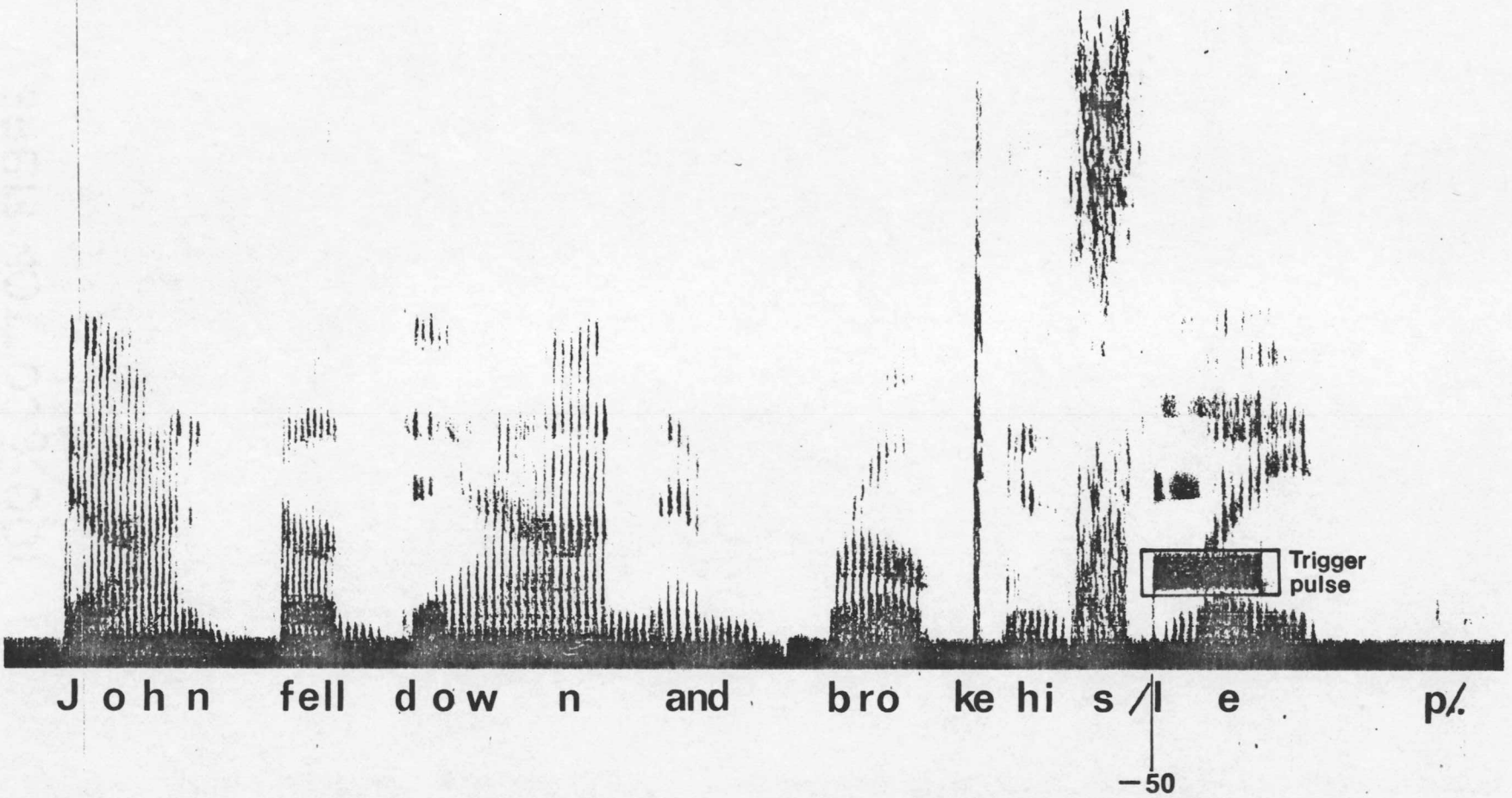

Figure A-5. Spectrographic recording of the sentence, "John fell down and broke his /lep/," indicating the trigger pulse.

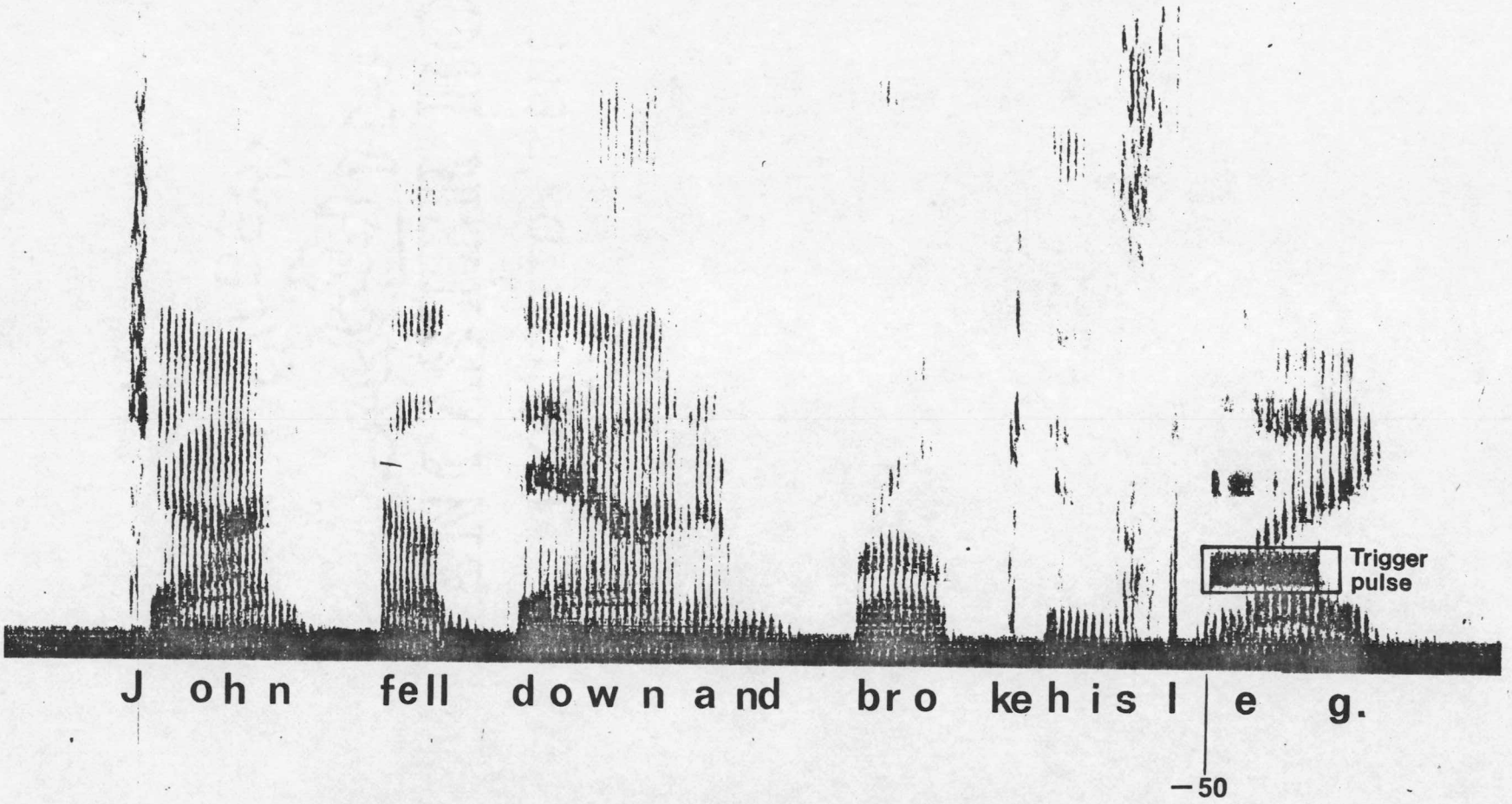

Figure A-6. Spectrographic recording of the sentence, "John fell down and broke his leg," indicating the trigger pulse.

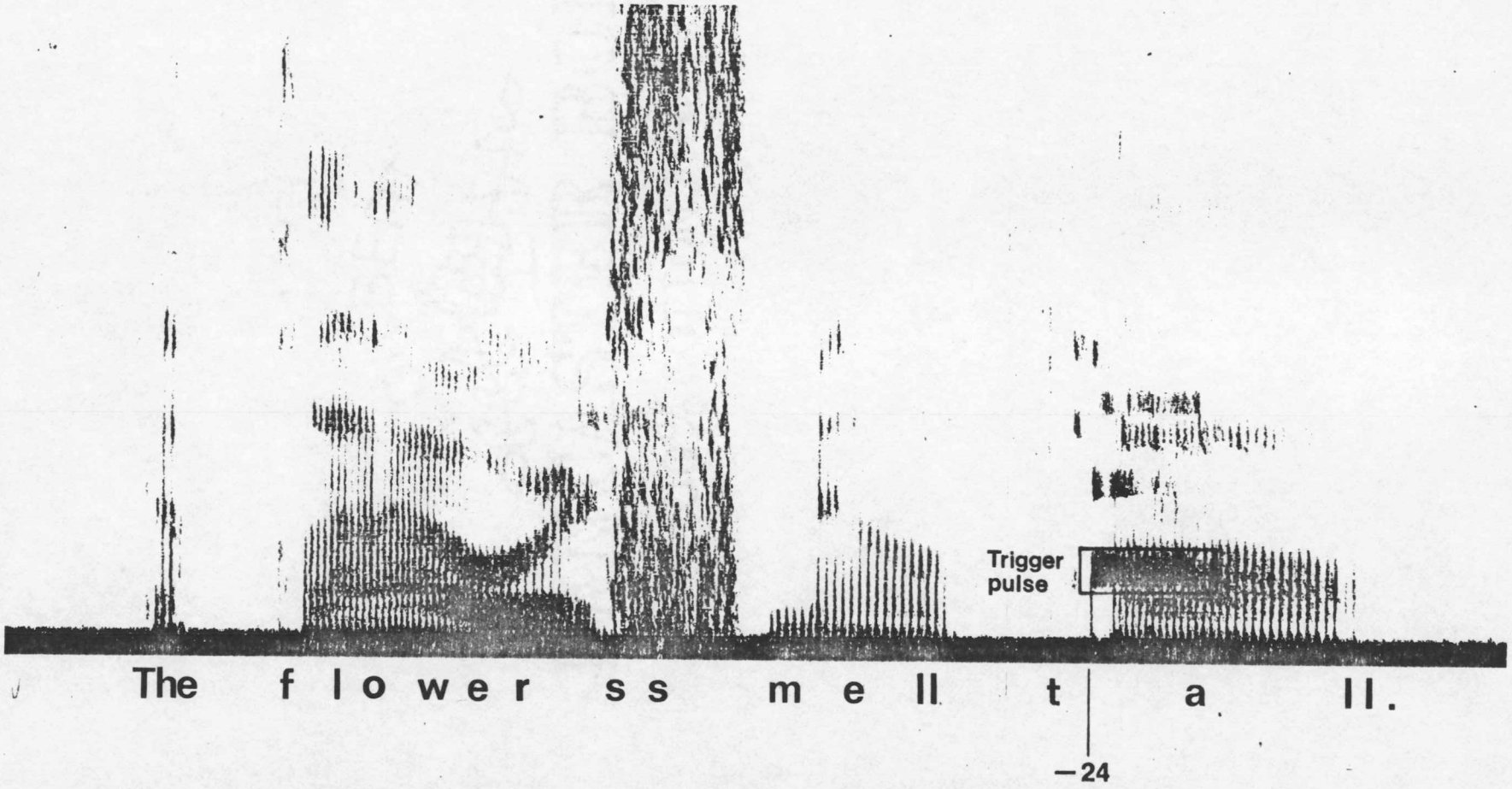

Figure A-7. Spectrographic recording of the sentence, "The flowers smell tall," indicating the trigger pulse.

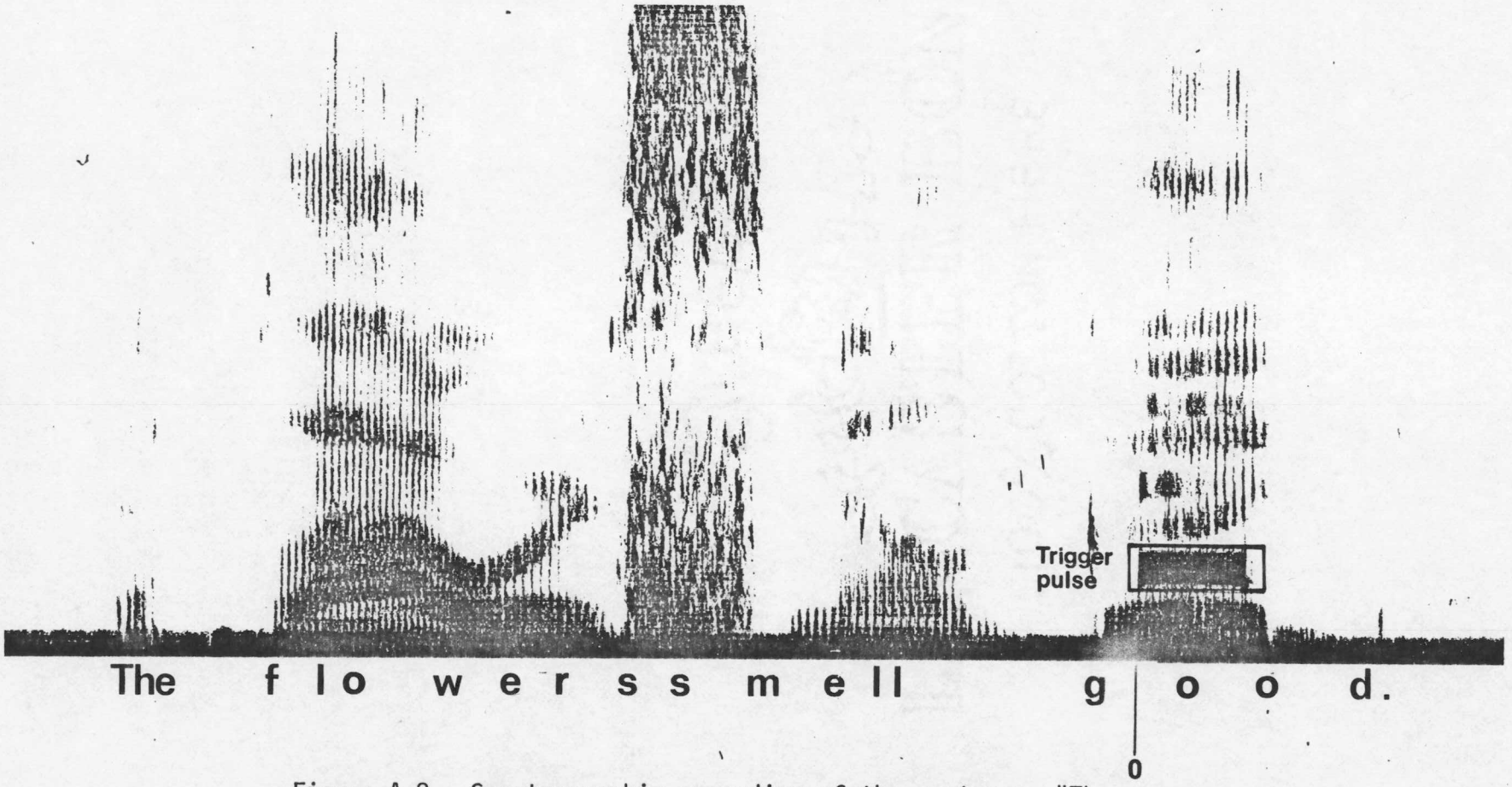

Figure A-8. Spectrographic recording of the sentence, "The flowers smell good," indicating the trigger pulse.

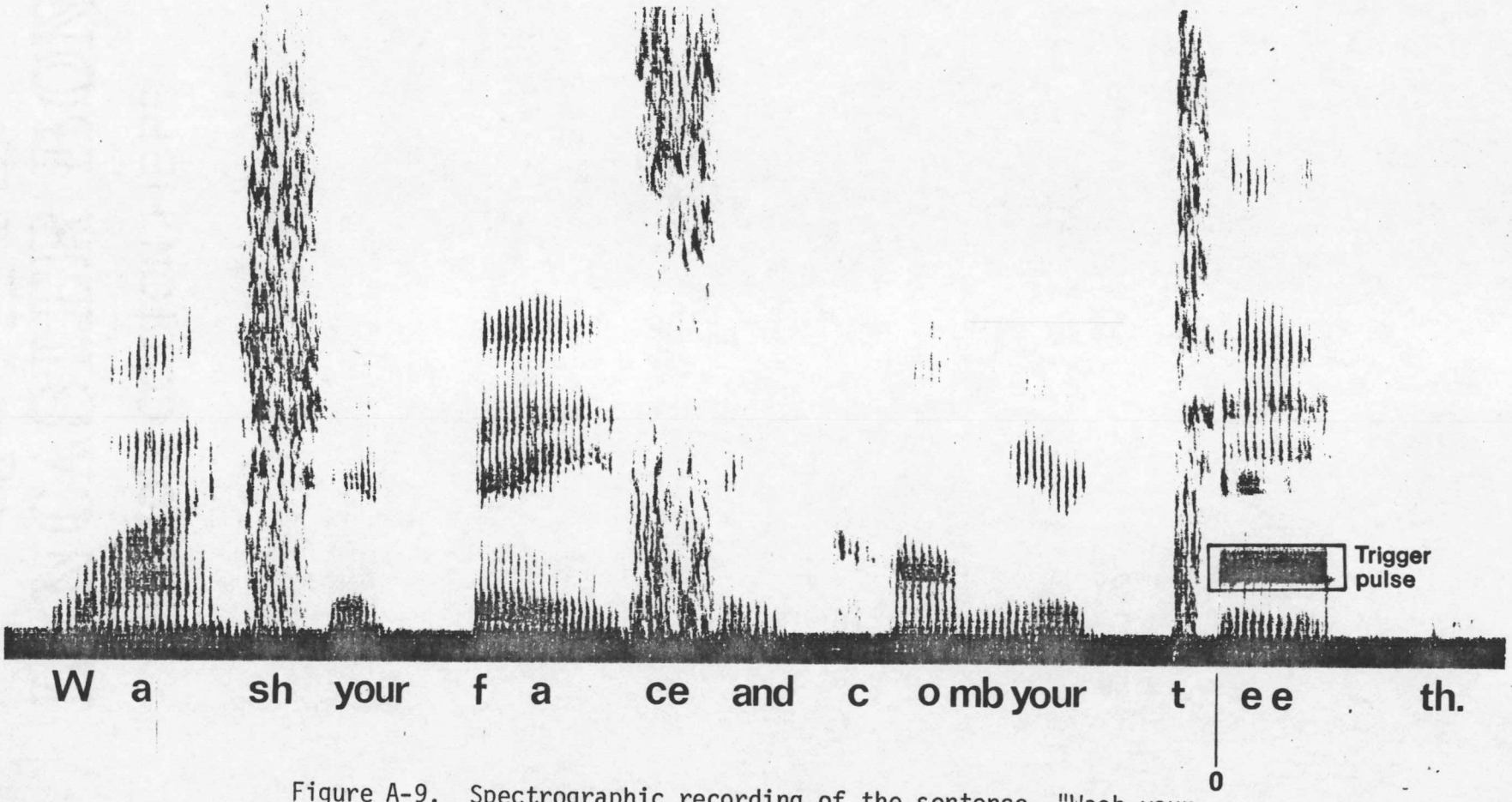

Figure A-9. Spectrographic recording of the sentence, "Wash your face and comb your teeth," indicating the trigger pulse.

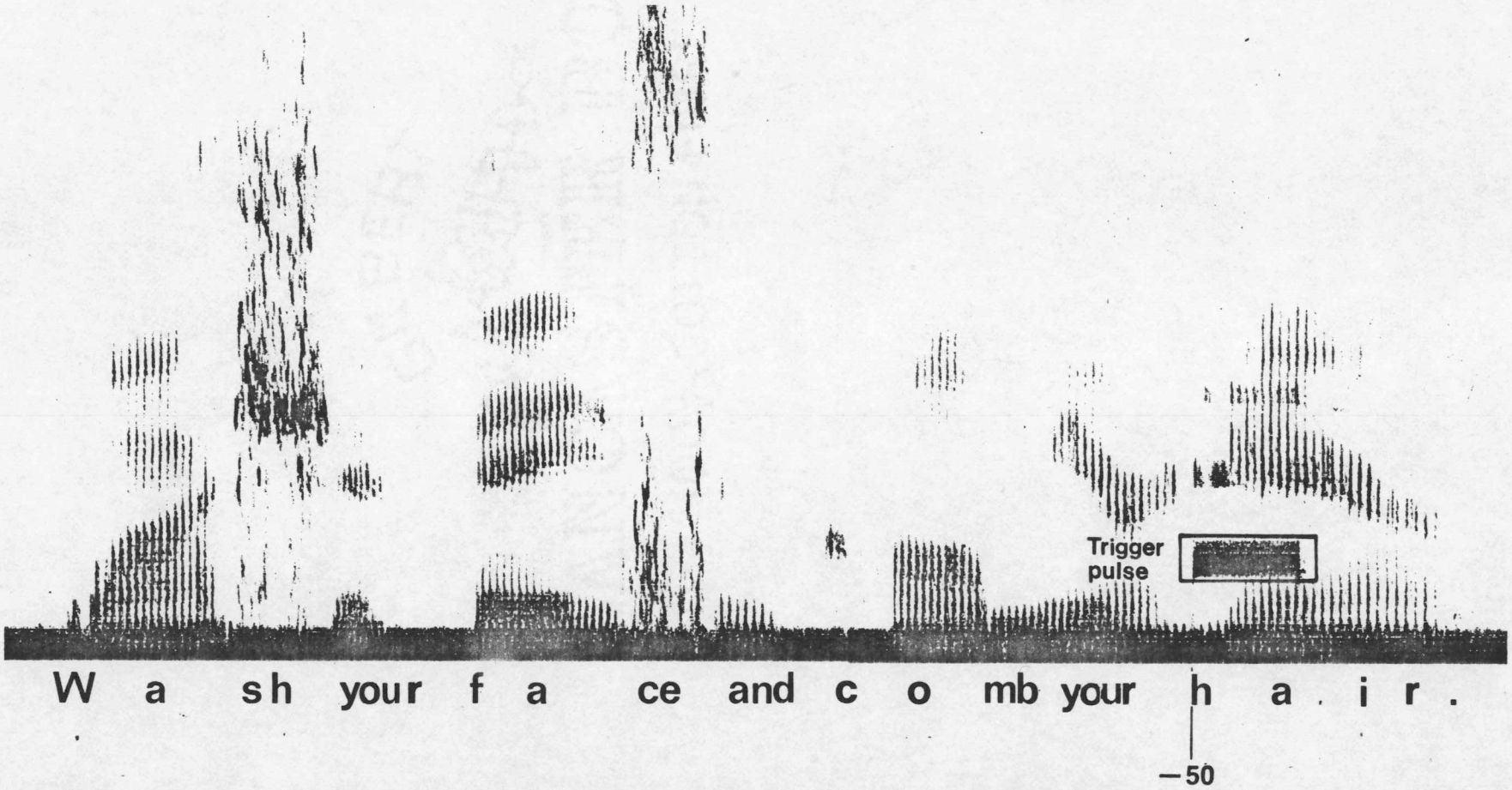

Figure A-10. Spectrographic recording of the sentence, "Wash your face and comb your hair," indicating the trigger pulse.

APPENDIX B

INSTRUCTIONS TO THE SUBJECT

As a subject in this study, you will be listening to a series of sentences. Some of the sentences will make sense to you, and some of them will not. Before each sentence is presented, a light will come on. It will remain on while your evoked responses are being recorded. It is extremely important that you are relaxed but also that you remain very still while the light is on. Please refrain from any annecessary body movements during this time. Please try not to cough, blink, squirm, frown, etc. while the light is on. If you need to shift position, clear your throat, or cough, you may do that in between presentations while the light is off. You will also be given a short break after several presentations.

Your task is to listen to each sentence and decide whether or not it makes sense. You will indicate your decision by raising your right index finger if it makes sense and your left index finger if it doesn't make sense. You will raise your finger only after the light has gone off.

You will be asked to practice this task first. After you have had sufficient practice, the actual testing situation will begin. Do you have any questions?

APPENDIX C

Table C-1. Tests of hypotheses of N100 amplitude (Cz) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	5.16	1	1.12	0.2913
/hædʒ/ vs. hat	0.06	1	0.01	0.9108
/lep/ vs. leg	6.45	1	1.40	0.2385
tall vs. good	13.80	1	3.01	0.0857
teeth vs. hair	4.07	1	0.89	0.3483
/bʊf/ + /hædʒ/ vs. book + hat	3.16	1	0.69	0.4088
/bʊf/ + /hædʒ/ + /lep/ vs. book + hat + leg	8.51	1	1.85	0.1762
/bʊf/ + /hædʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	23.16	1	5.07	0.0264

Table C-2. Tests of hypotheses of N100 latency (Cz) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	1,147.54	1	1.04	0.3099
/hædʒ/ vs. hat	10,327.86	1	9.37	0.0028
/lep/ vs. leg	2,094.75	1	1.90	0.1710
tall vs. good	11,328.79	1	10.27	0.0018
teeth vs. hair	11,803.02	1	10.70	0.0014
/bʊf/ + /hædʒ/ vs. book + hat	9,180.32	1	8.33	0.0047
/bʊf/ + /hædʒ/ + /lep/ vs. book + hat + leg	2,684.00	1	2.43	0.1217
/bʊf/ + /hædʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	1,690.51	1	1.53	0.2183

Table C-3. Tests of hypotheses of N100P200 amplitude (Cz) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	5.22	1	0.53	0.4690
/hædʒ/ vs. hat	4.35	1	0.44	0.5088
/lep/ vs. leg	0.05	1	0.01	0.9425
tall vs. good	81.12	1	8.20	0.0050
teeth vs. hair	60.07	1	6.08	0.0153
/bʊf/ + /hædʒ/ vs. book + hat	9.55	1	0.97	0.3280
/bʊf/ + /hædʒ/ + /lep/ vs. book + hat + leg	7.04	1	0.71	0.4005
/bʊf/ + /hædʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	91.20	1	9.22	0.0030

Table C-4. Tests of hypotheses of N100P300 amplitude (Cz) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	95.42	1	7.54	0.0071
/hæedʒ/ vs. hat	147.55	1	11.66	0.0009
/lep/ vs. leg	202.92	1	16.03	0.0001
tall vs. good	39.45	1	3.12	0.0803
teeth vs. hair	42.70	1	3.37	0.0690
/bʊf/ + /hæedʒ/ vs. book + hat	240.14	1	18.97	0.0001
/bʊf/ + /hæedʒ/ + /lep/ vs. book + hat + leg	435.86	1	34.43	0.0001
/bʊf/ + /hæedʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	479.72	1	37.90	0.0001

Table C-5. Tests of hypotheses of P300 latency (Cz) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	50,280.07	1	8.65	0.0040
/hædʒ/ vs. hat	3,961.45	1	0.68	0.4108
/lep/ vs. leg	51,152.79	1	8.80	0.0037
tall vs. good	3,576.00	1	0.62	0.4345
teeth vs. hair	12,007.14	1	2.07	0.1535
/bʊf/ + /hædʒ/ vs. book + hat	41,233.94	1	7.09	0.0089
/bʊf/ + /hædʒ/ + /lep/ vs. book + hat + leg	1,240.43	1	0.21	0.6450
/bʊf/ + /hædʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	10,614.91	1	1.83	0.1794

Table C-6. Tests of hypotheses of N100 latency (P3) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	2,592.16	1	2.40	0.1244
/hæedʒ/ vs. hat	583.08	1	0.54	0.4642
/lep/ vs. leg	2,231.47	1	2.06	0.1536
tall vs. good	3,016.45	1	2.79	0.0977
teeth vs. hair	8,501.79	1	7.87	0.0060
/bʊf/ + /hæedʒ/ vs. book + hat	2,817.03	1	2.61	0.1093
/bʊf/ + /hæedʒ/ + /lep/ vs. book + hat + leg	258.02	1	0.24	0.6261
/bʊf/ + /hæedʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	847.73	1	0.78	0.3778

Table C-7. Tests of hypotheses of N100P200 amplitude (P3) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	4.40	1	0.51	0.4756
/hædʒ/ vs. hat	7.95	1	0.93	0.3381
/lep/ vs. leg	5.28	1	0.62	0.4345
tall vs. good	39.61	1	4.61	0.0340
teeth vs. hair	51.30	1	5.97	0.0161
/bʊf/ + /hædʒ/ vs. book + hat	0.26	1	0.03	0.8621
/bʊf/ + /hædʒ/ + /lep/ vs. book + hat + leg	3.04	1	0.35	0.5531
/bʊf/ + /hædʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	21.78	1	2.54	0.1141

Table C-8. Tests of hypotheses of P200 latency (P3) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	4.02	1	0.00	0.9503
/hæedʒ/ vs. hat	7,614.45	1	7.41	0.0076
/lep/ vs. leg	534.45	1	0.52	0.4723
tall vs. good	2,612.61	1	2.54	0.1137
teeth vs. hair	3,379.02	1	3.29	0.0725
/bʊf/ + /hæedʒ/ vs. book + hat	3,634.32	1	3.54	0.0627
/bʊf/ + /hæedʒ/ + /lep/ vs. book + hat + leg	3,915.01	1	3.81	0.0535
/bʊf/ + /hæedʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	2,662.97	1	2.59	0.1103

Table C-9. Tests of hypotheses of N100P300 amplitude (P3) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	91.80	1	6.17	0.0145
/hædʒ/ vs. hat	52.85	1	3.55	0.0622
/lep/ vs. leg	18.29	1	1.23	0.2701
tall vs. good	49.03	1	3.30	0.0723
teeth vs. hair	2.04	1	0.14	0.7116
/bʊf/ + /hædʒ/ vs. book + hat	141.98	1	9.54	0.0026
/bʊf/ + /hædʒ/ + /lep/ vs. book + hat + leg	148.78	1	10.00	0.0020
/bʊf/ + /hædʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	174.75	1	11.74	0.0009

Table C-10. Tests of hypotheses of P300 latency (P3) using the Type III MS for Subject x Sentence (Sex) as an error term.

Contrast	Sum of Squares	df	F	P>F
/bʊf/ vs. book	41,883.79	1	7.48	0.0073
/hædʒ/ vs. hat	318.25	1	0.06	0.8121
/lep/ vs. leg	11,528.79	1	2.06	0.1543
tall vs. good	2.16	1	0.00	0.9844
teeth vs. hair	13,578.29	1	2.42	0.1224
/bʊf/ + /hædʒ/ vs. book + hat	24,752.01	1	4.42	0.0379
/bʊf/ + /hædʒ/ + /lep/ vs. book + hat + leg	4,417.75	1	0.79	0.3765
/bʊf/ + /hædʒ/ + /lep/ + tall + teeth vs. book + hat + leg + good + hair	10,596.45	1	1.89	0.1719

APPENDIX D

Figure D-1. Average ERP of the female subjects to the first presentation of, "I enjoyed reading the new /buf/" at Cz.

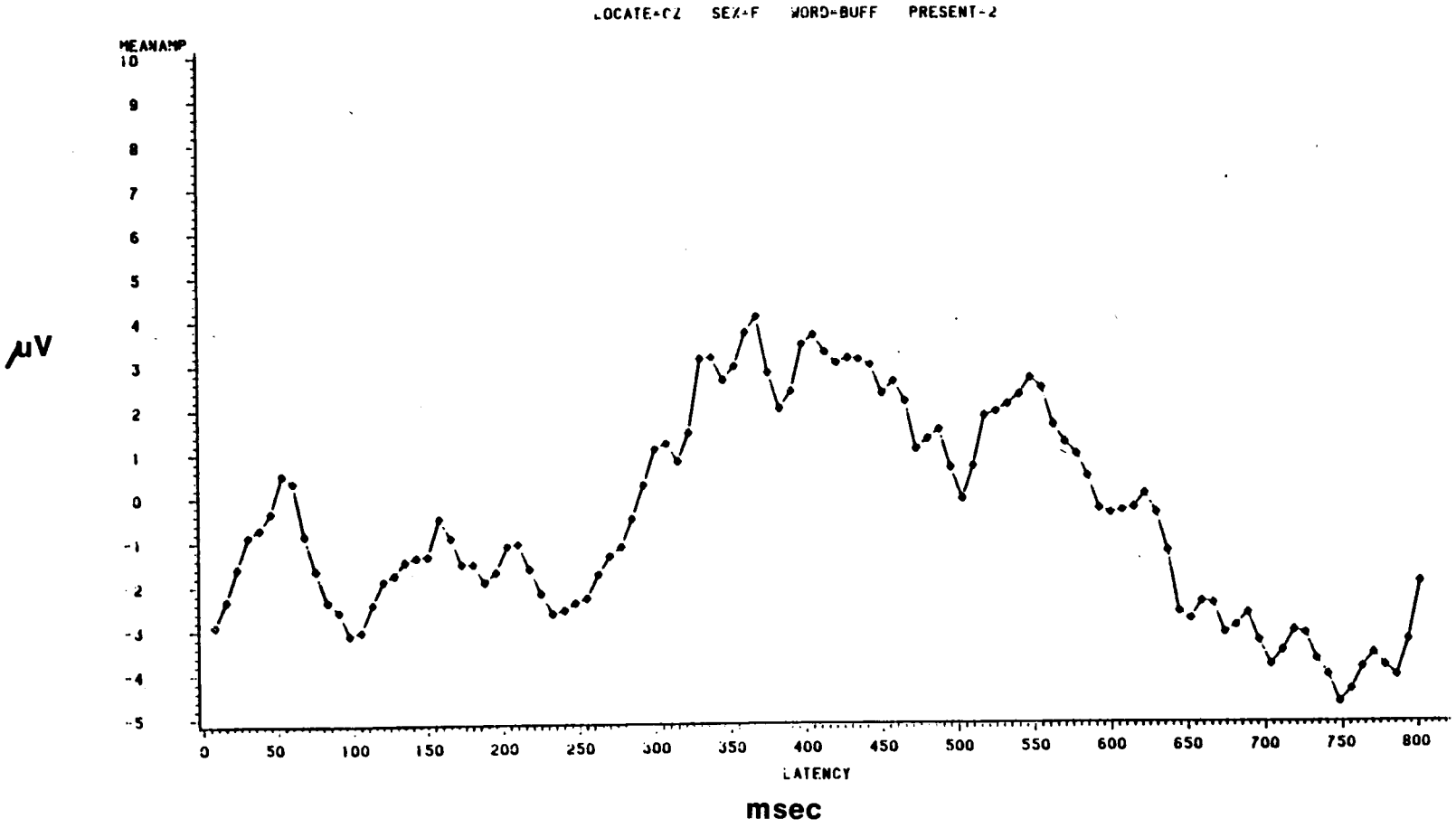

Figure D-2. Average ERP of the female subjects to the second presentation of," I enjoyed reading the new /buf/," at Cz.

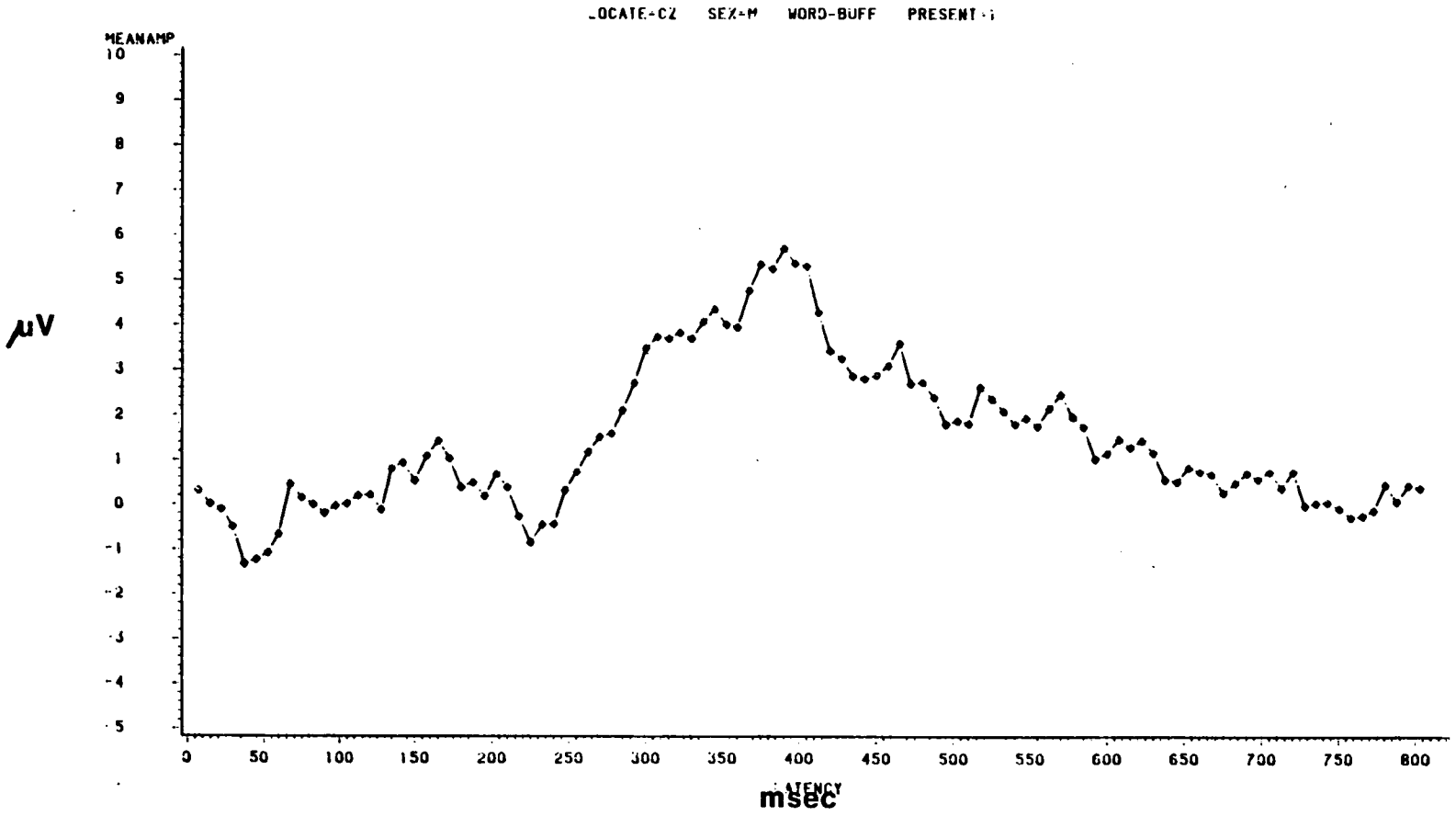

Figure D-3. Average ERP of the male subjects to the first presentation of, "I enjoyed reading the new /buf/," at Cz.

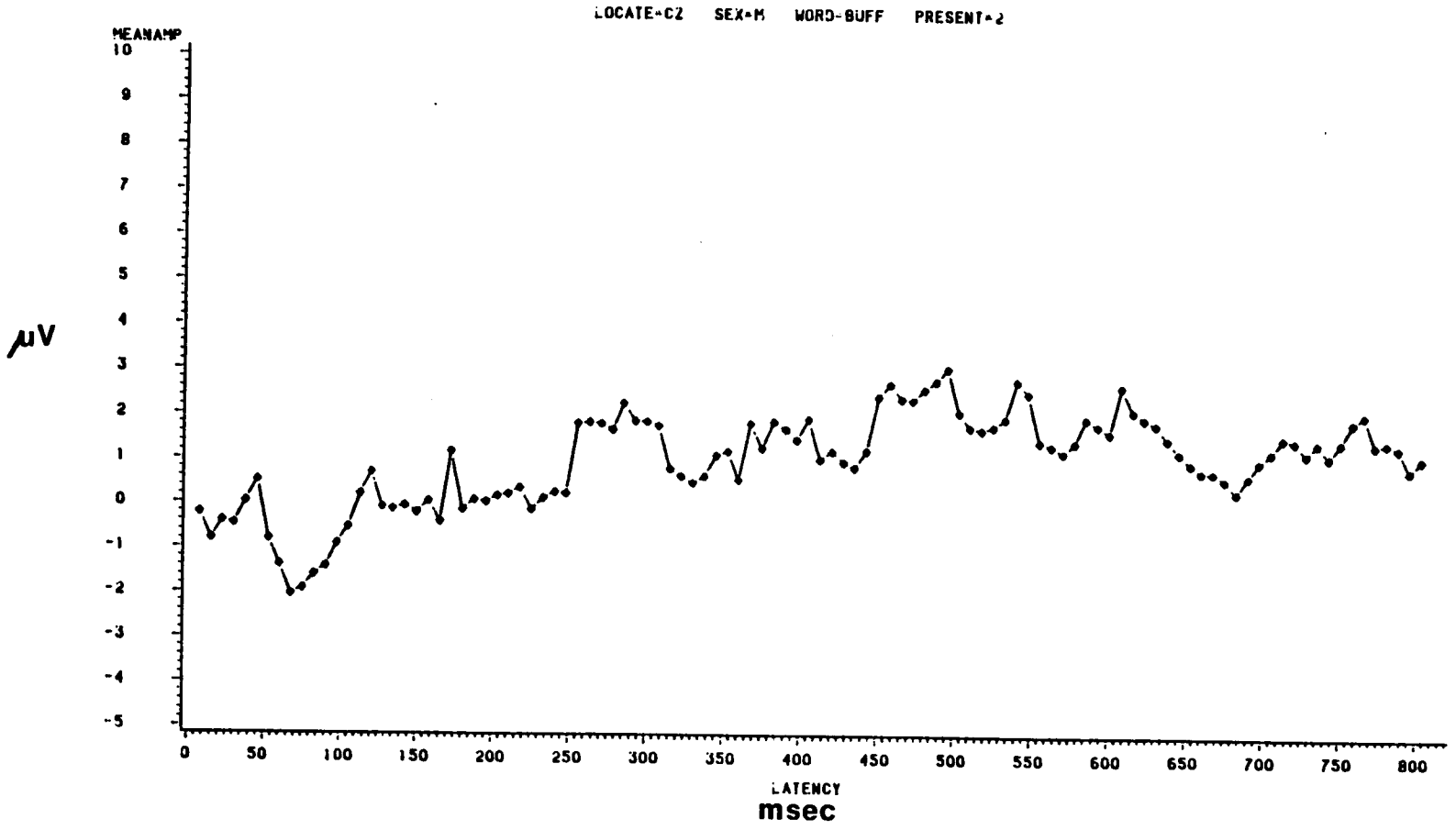

Figure D-4. Average ERP of the male subjects to the second presentation of, "I enjoyed reading the new /buf/," at Cz.

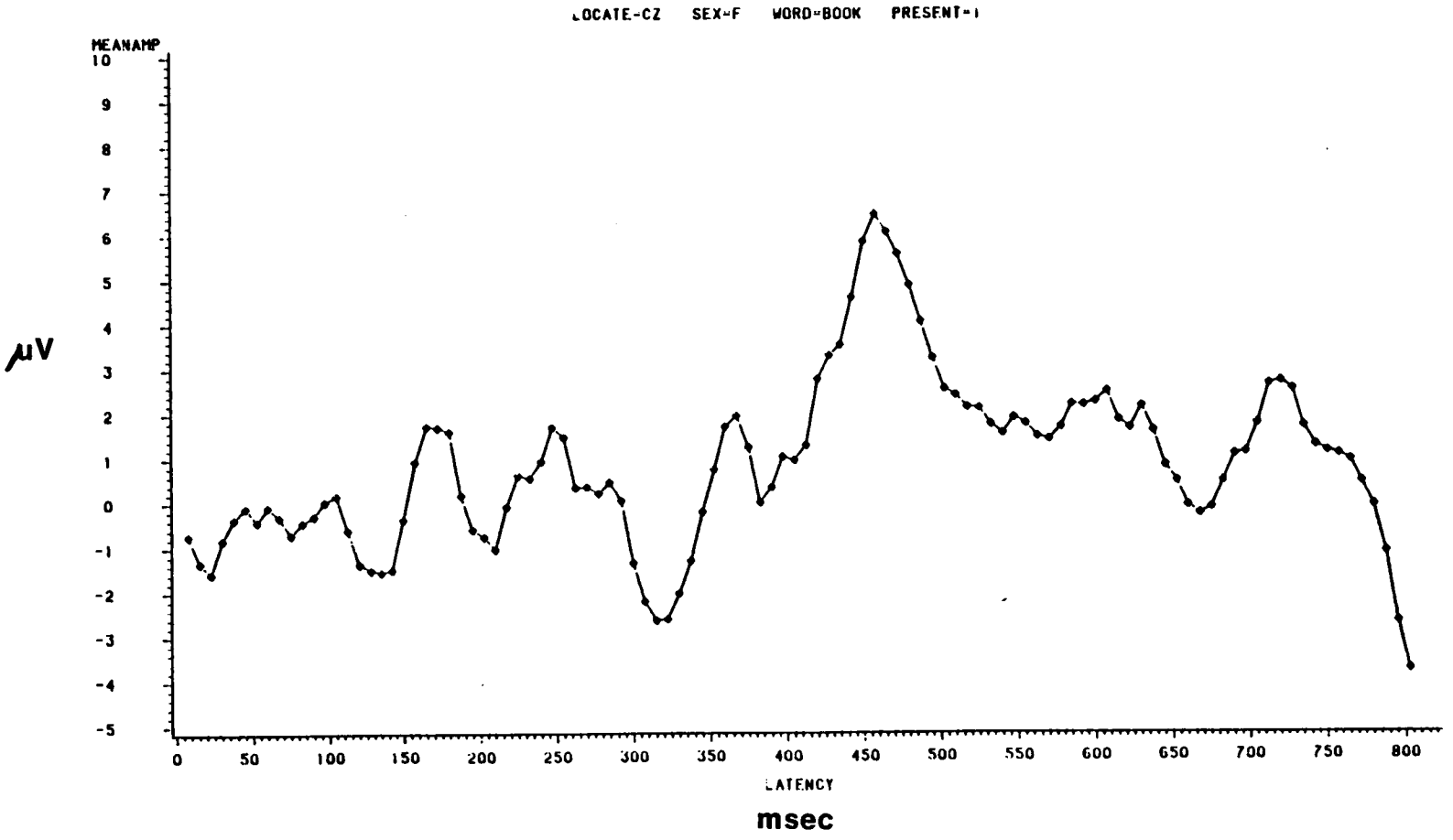

Figure D-5. Average ERP of the female subjects to the first presentation of, "I enjoyed reading the new book," at Cz.

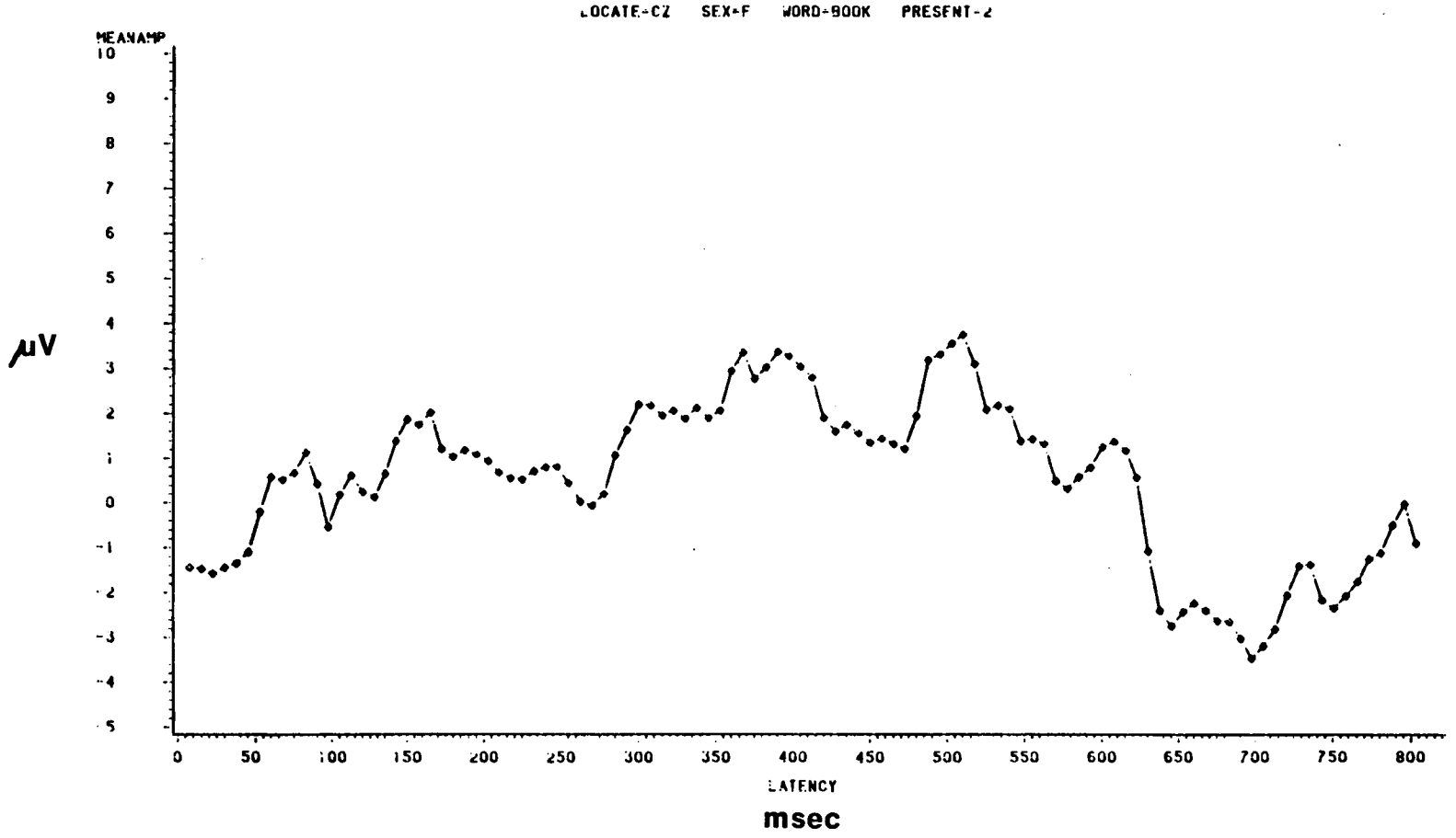

Figure D-6. Average ERP of the female subjects to the second presentation of, "I enjoyed reading the new book," at Cz.

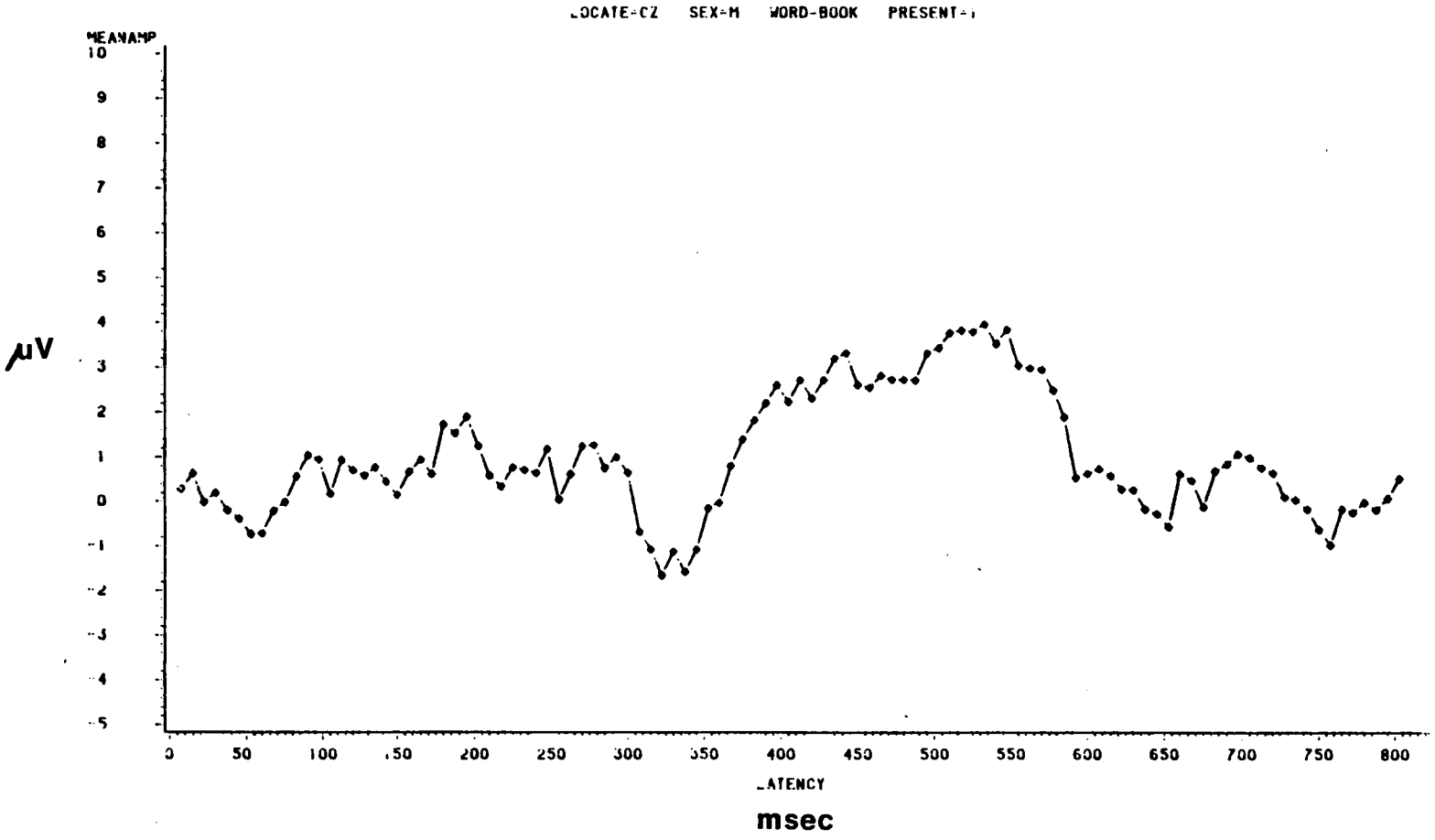

Figure D-7. Average ERP of the male subjects to the first presentation of, "I enjoyed reading the new book," at Cz.

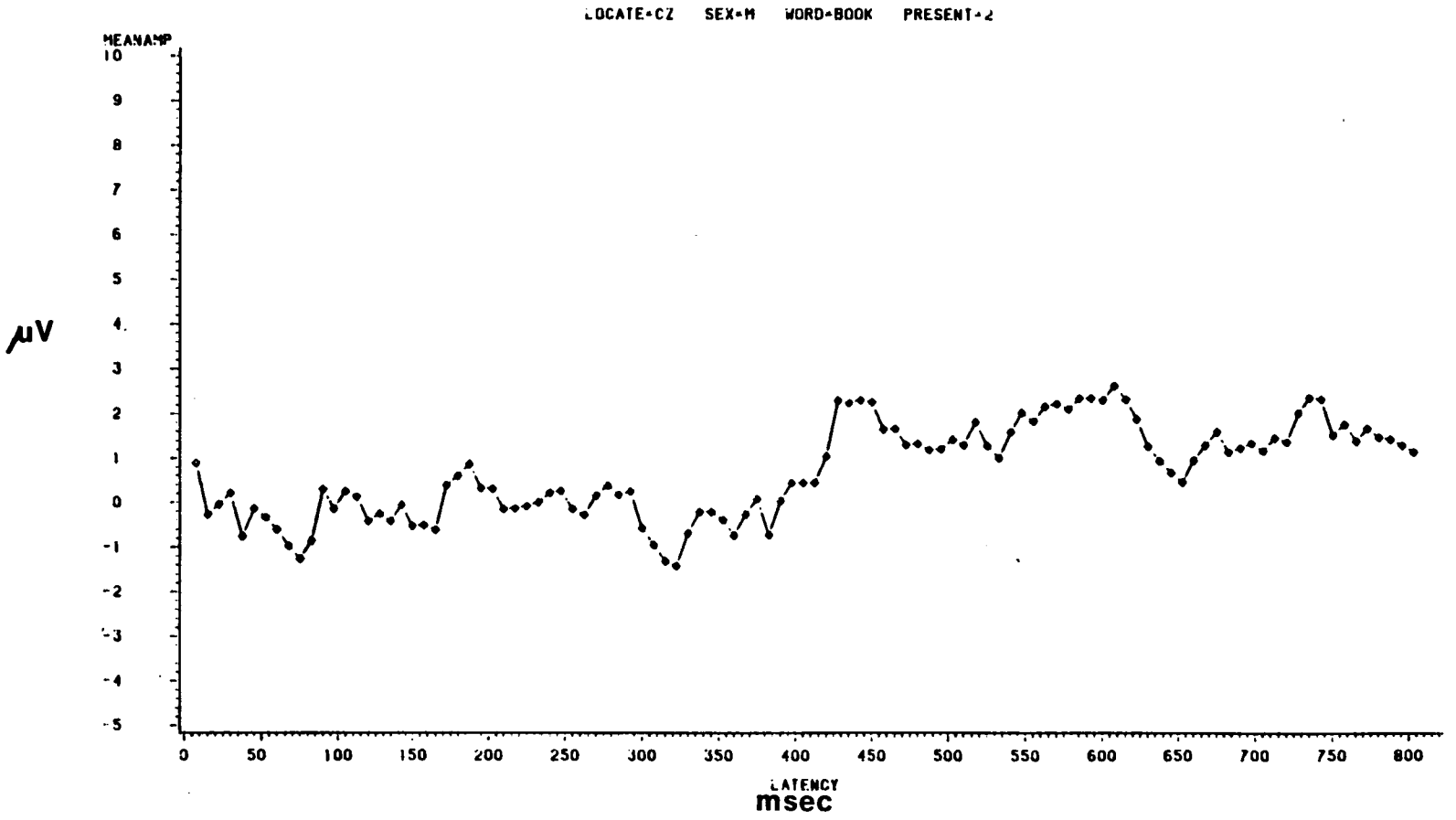

Figure D-8. Average ERP of the male subjects to the second presentation of, "I enjoyed reading the new book," at Cz.

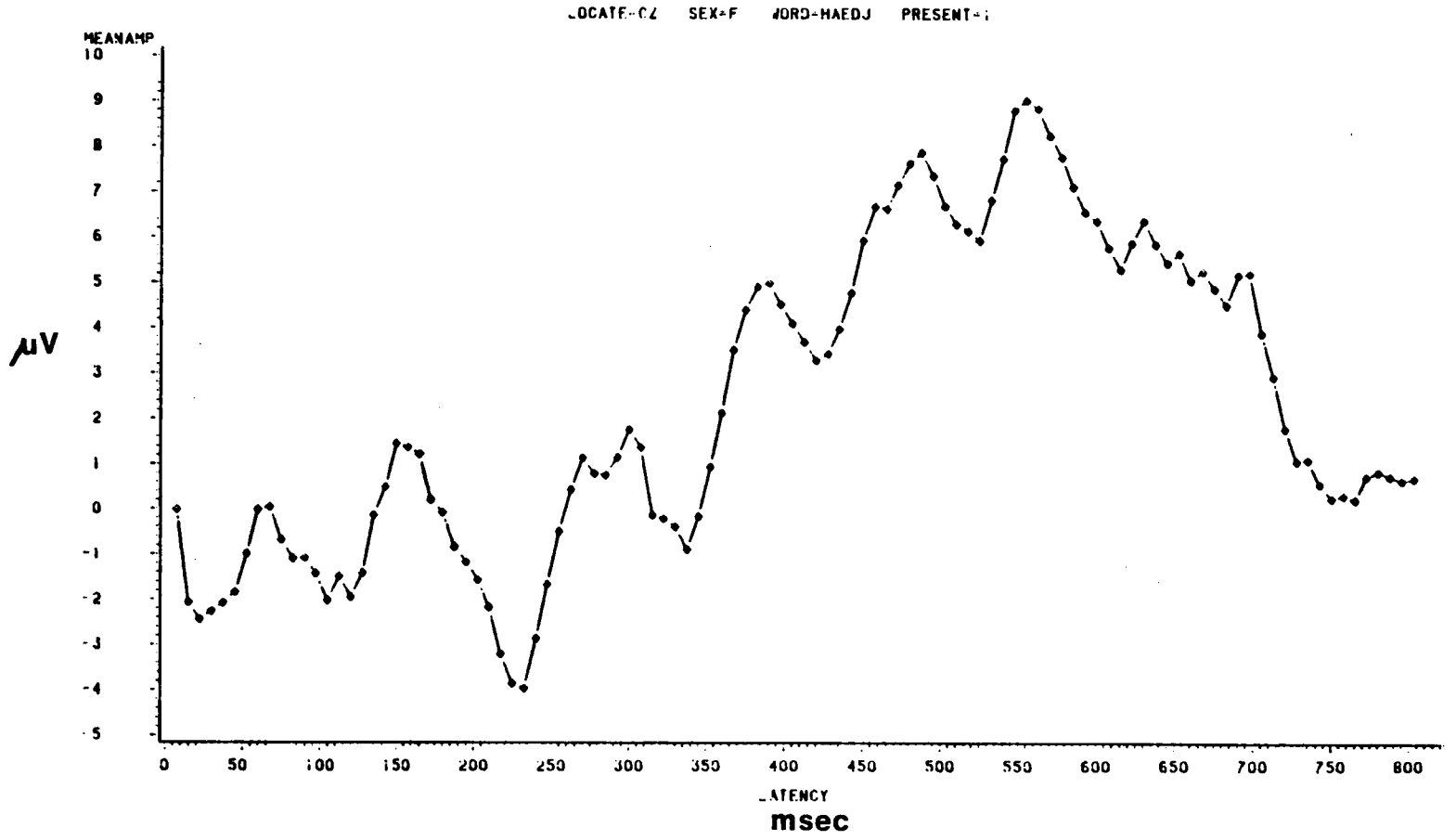

Figure D-9. Average ERP of the female subjects to the first presentation of, "You'll catch cold if you don't wear a /hædʒ/," at Cz.

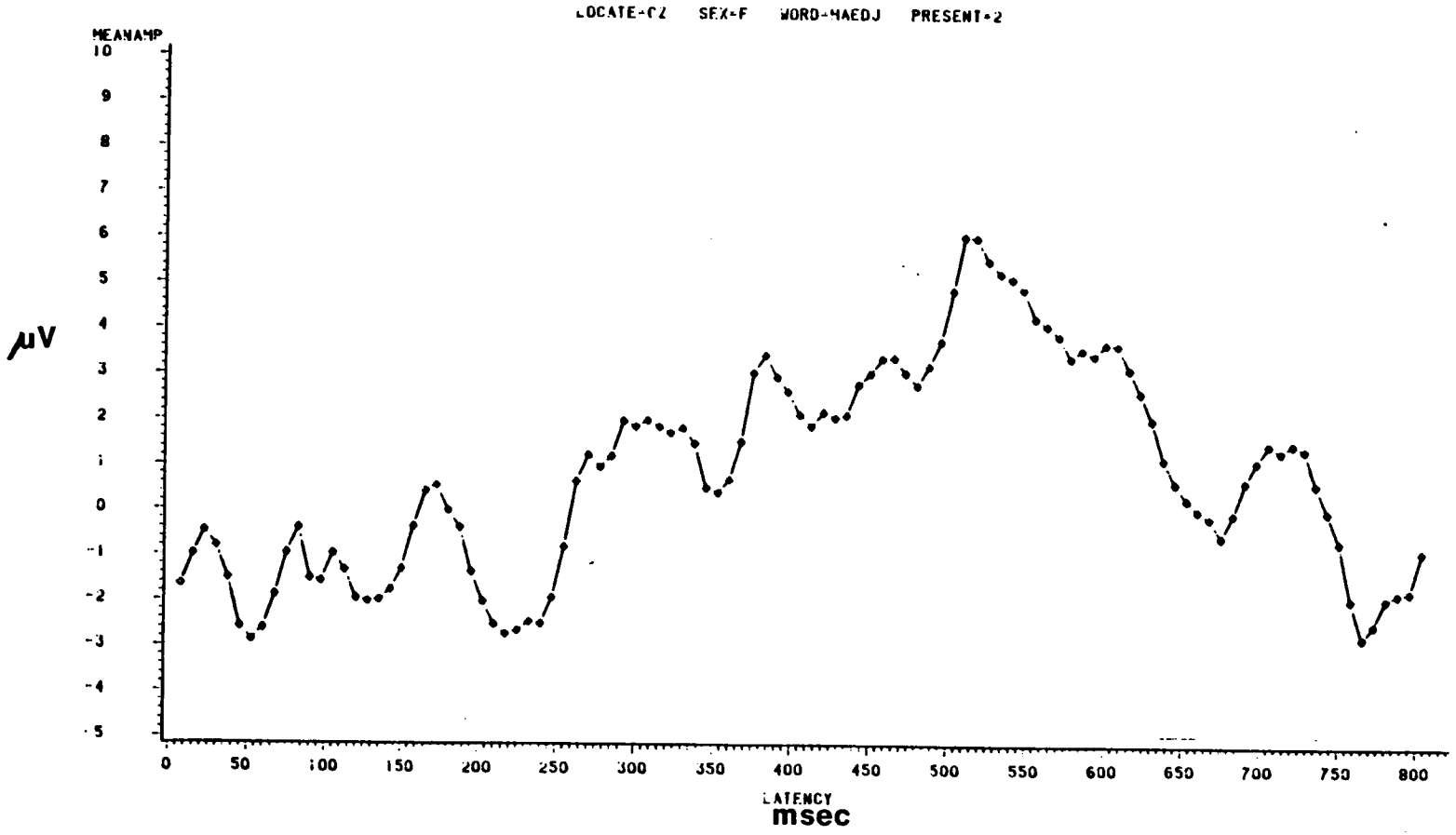

Figure D-10. Average ERP of the female subjects to the second presentation of, "You'll catch cold if you don't wear a /hædʒ/," at Cz.

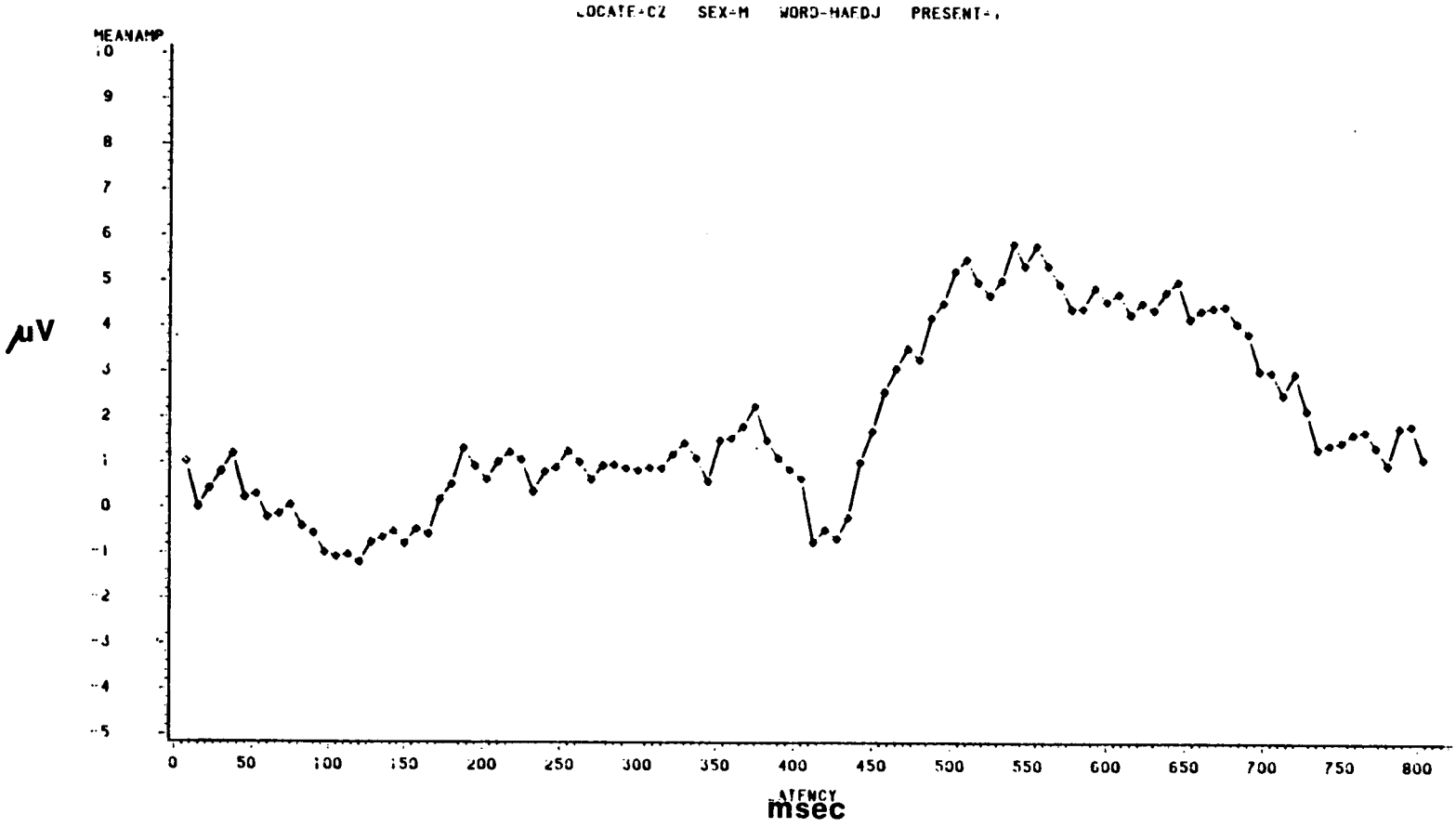

Figure D-11. Average ERP of the male subjects to the first presentation of, "You'll catch cold if you don't wear a /hædʒ/," at Cz.

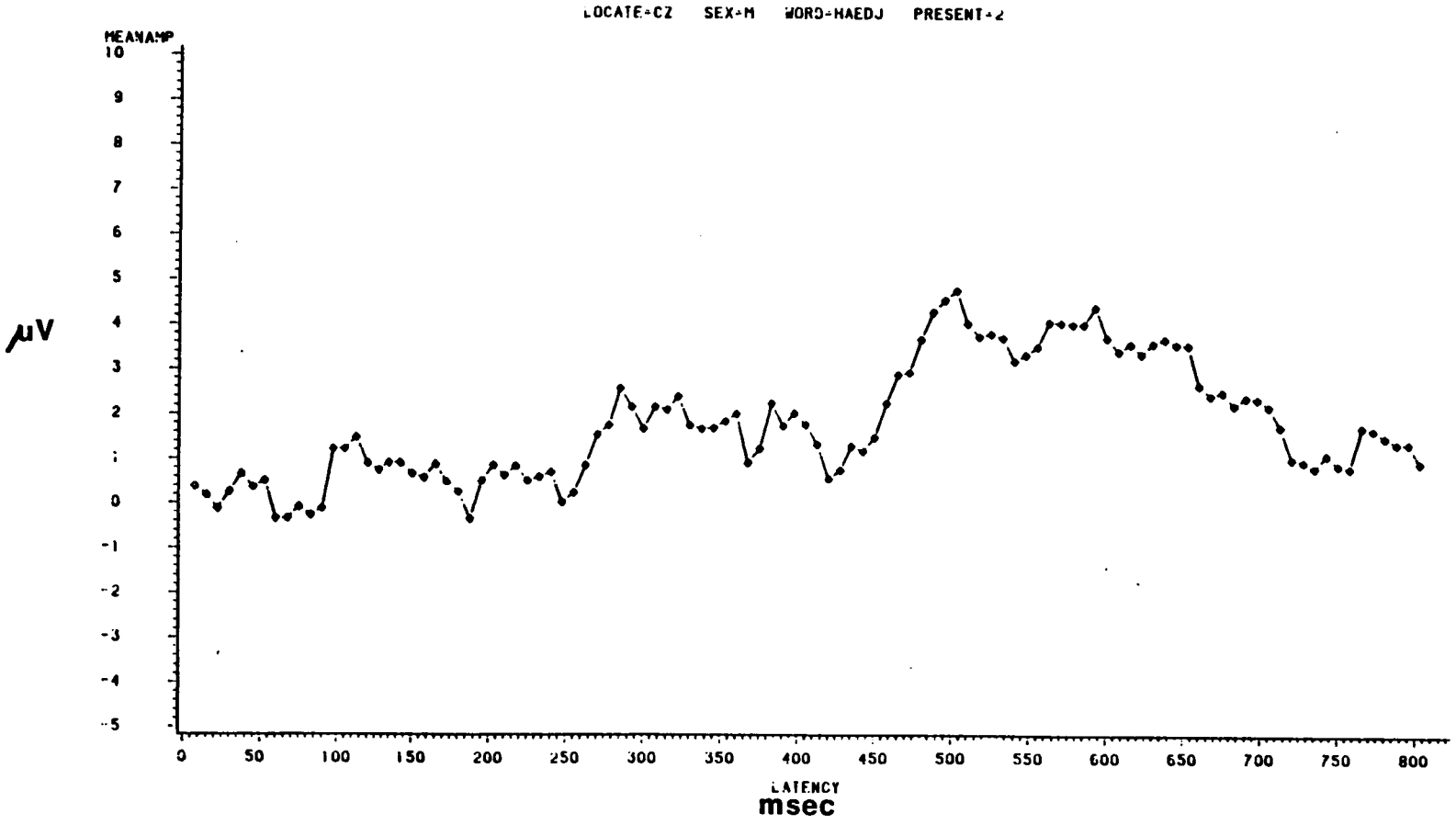

Figure D-12. Average ERP of the male subjects to the second presentation of, "You'll catch cold if you don't wear a /hædʒ/," at Cz.

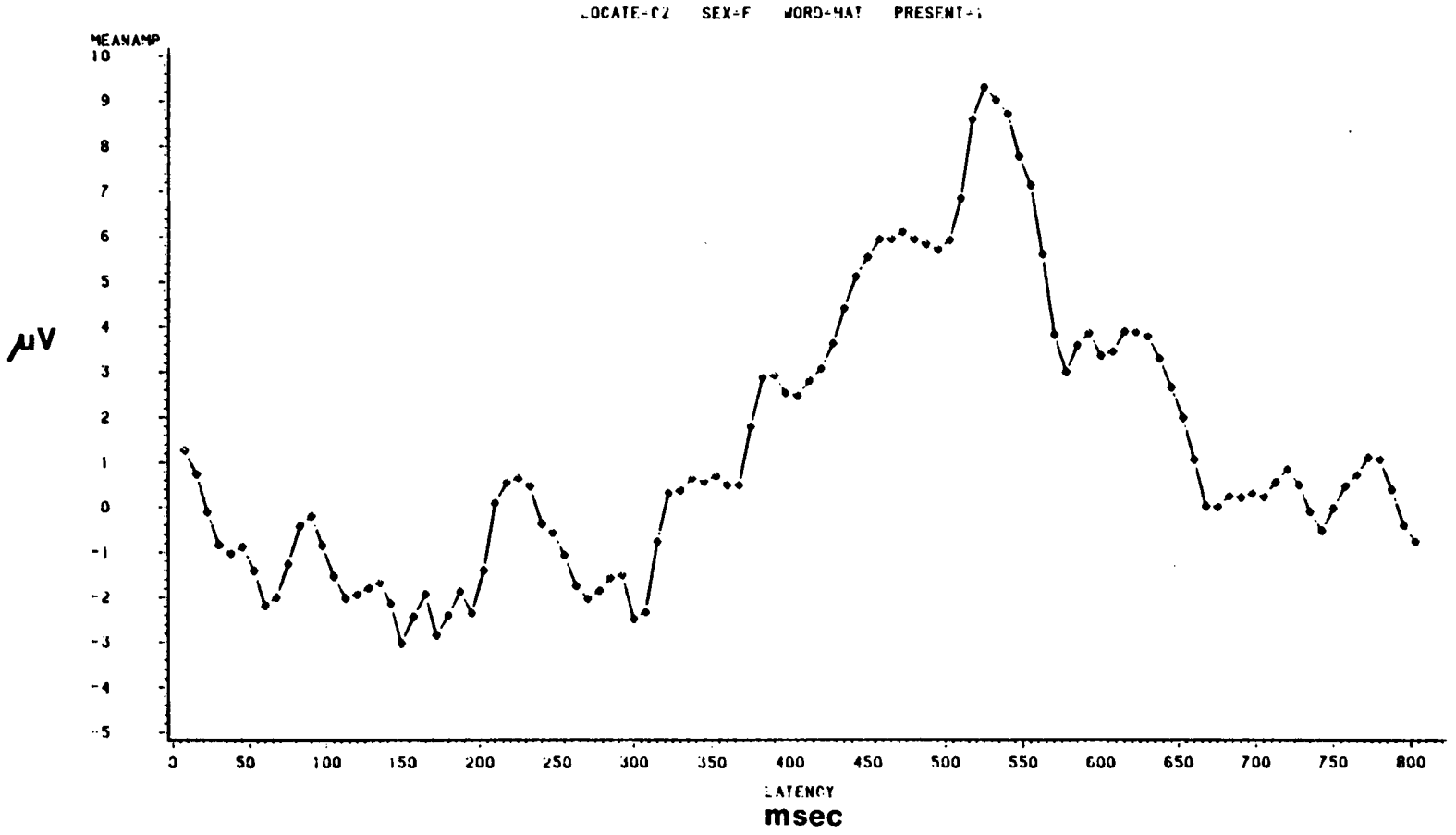

Figure D-13. Average ERP of the female subjects to the first presentation of, "You'll catch cold if you don't wear a hat," at Cz.

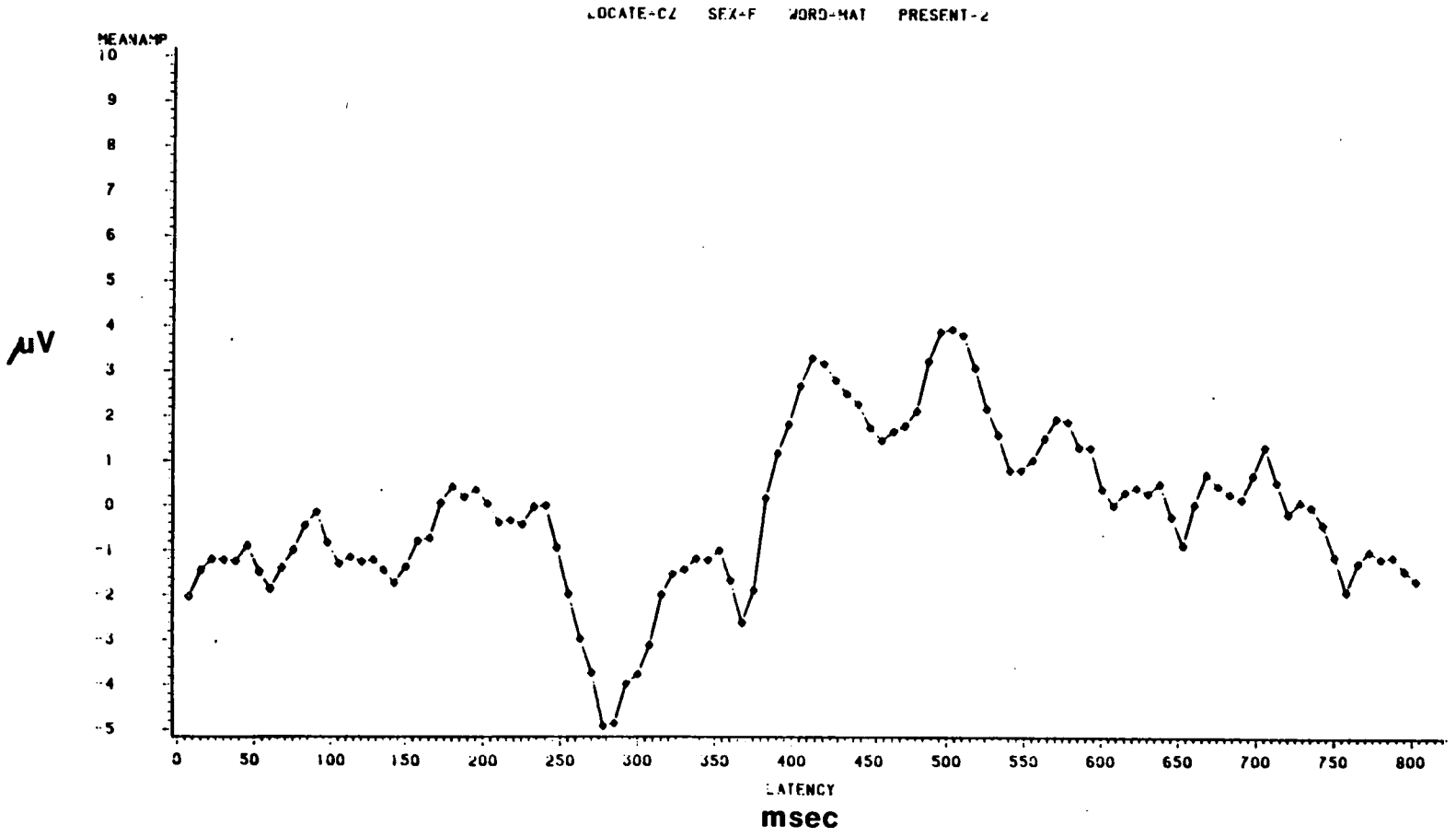

Figure D-14. Average ERP of the female subjects to the second presentation of, "You'll catch cold if you don't wear a hat," at Cz.

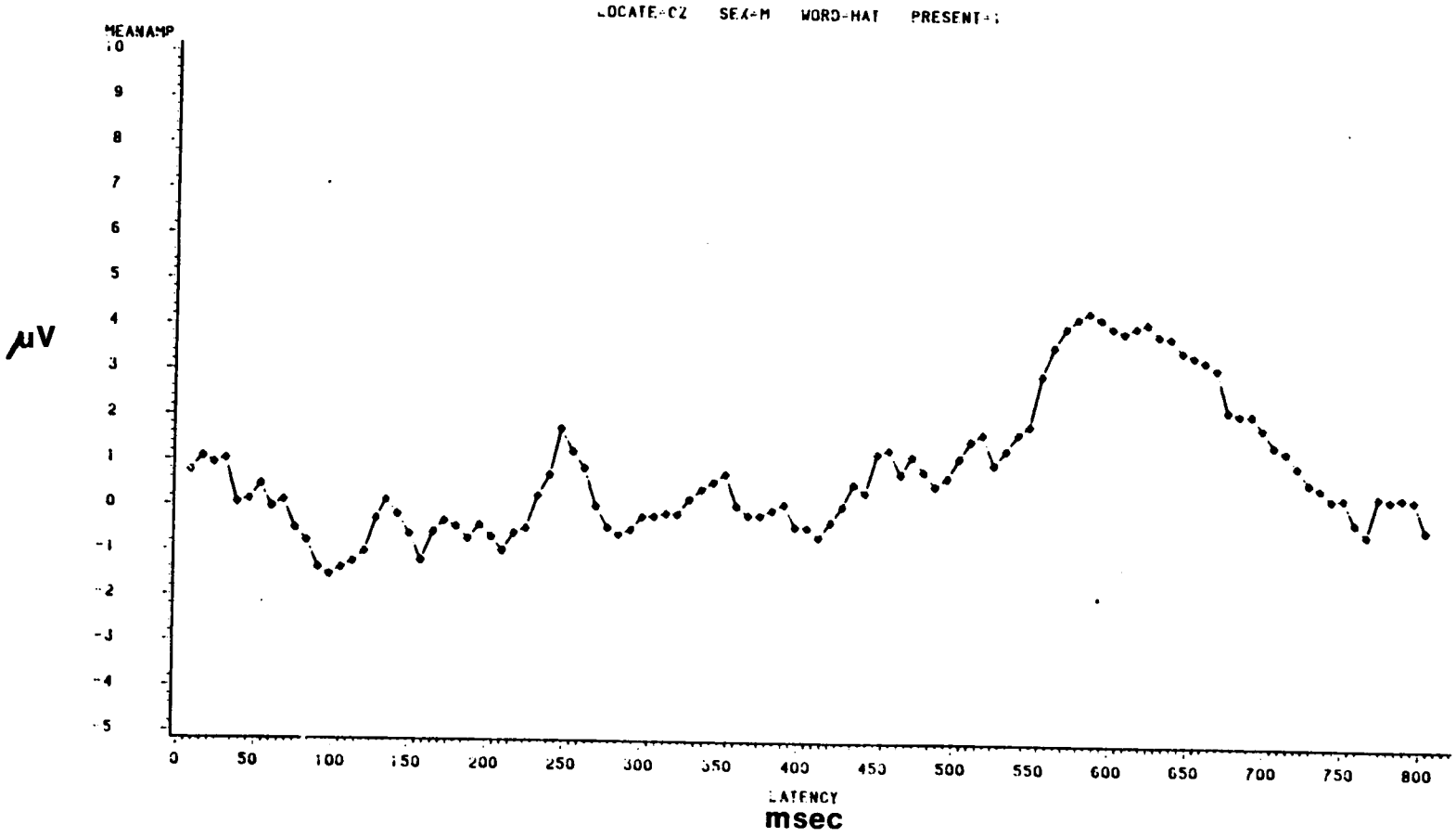

Figure D-15. Average ERP of the male subjects to the first presentation of, "You'll catch cold if you don't wear a hat," at Cz.

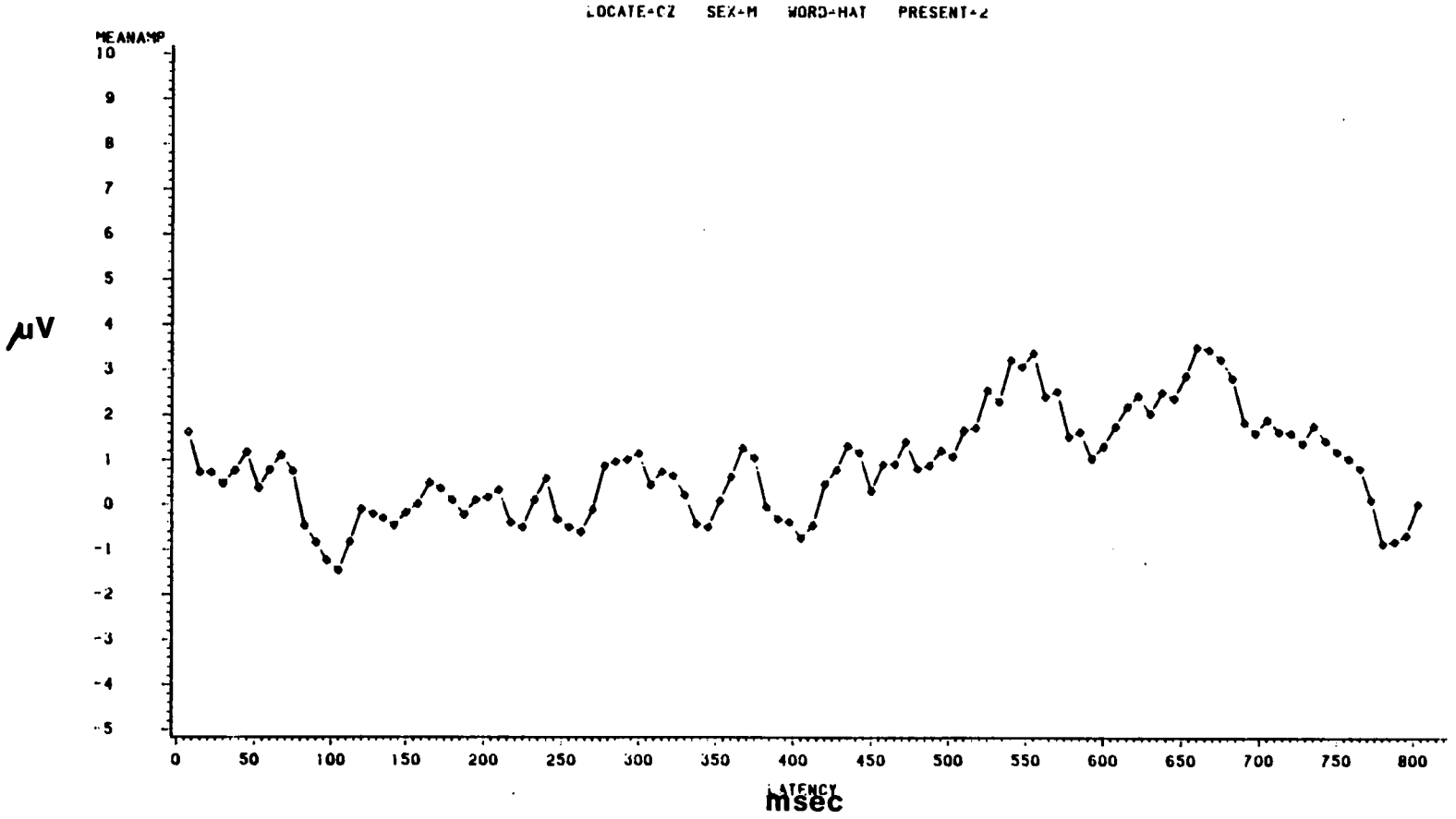

Figure D-16. Average ERP of the male subjects to the second presentation of, "You'll catch cold if you don't wear a hat," at Cz.

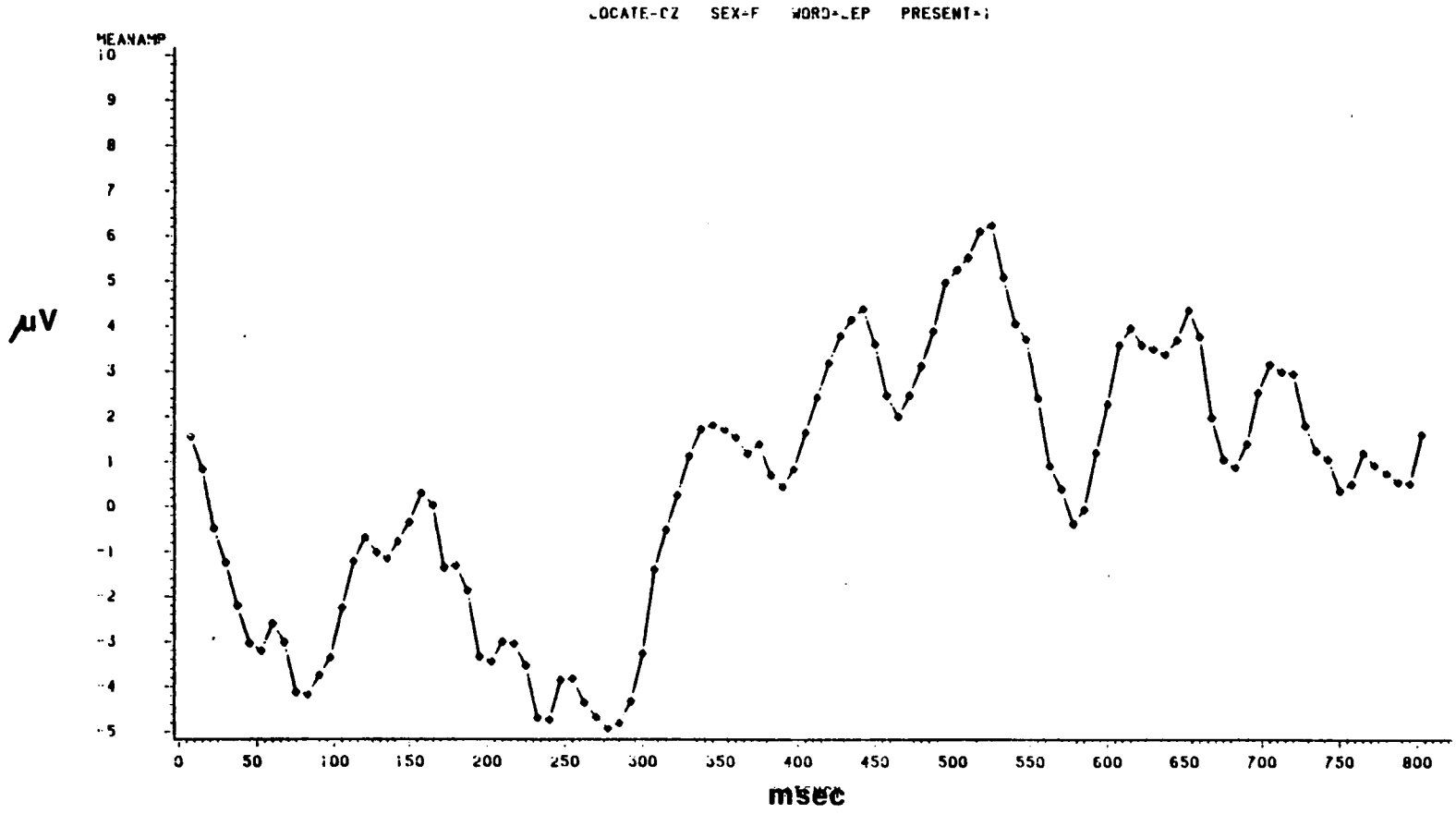

Figure D-17. Average ERP of the female subjects to the first presentation of, "John fell down and broke his /lep/," at Cz.

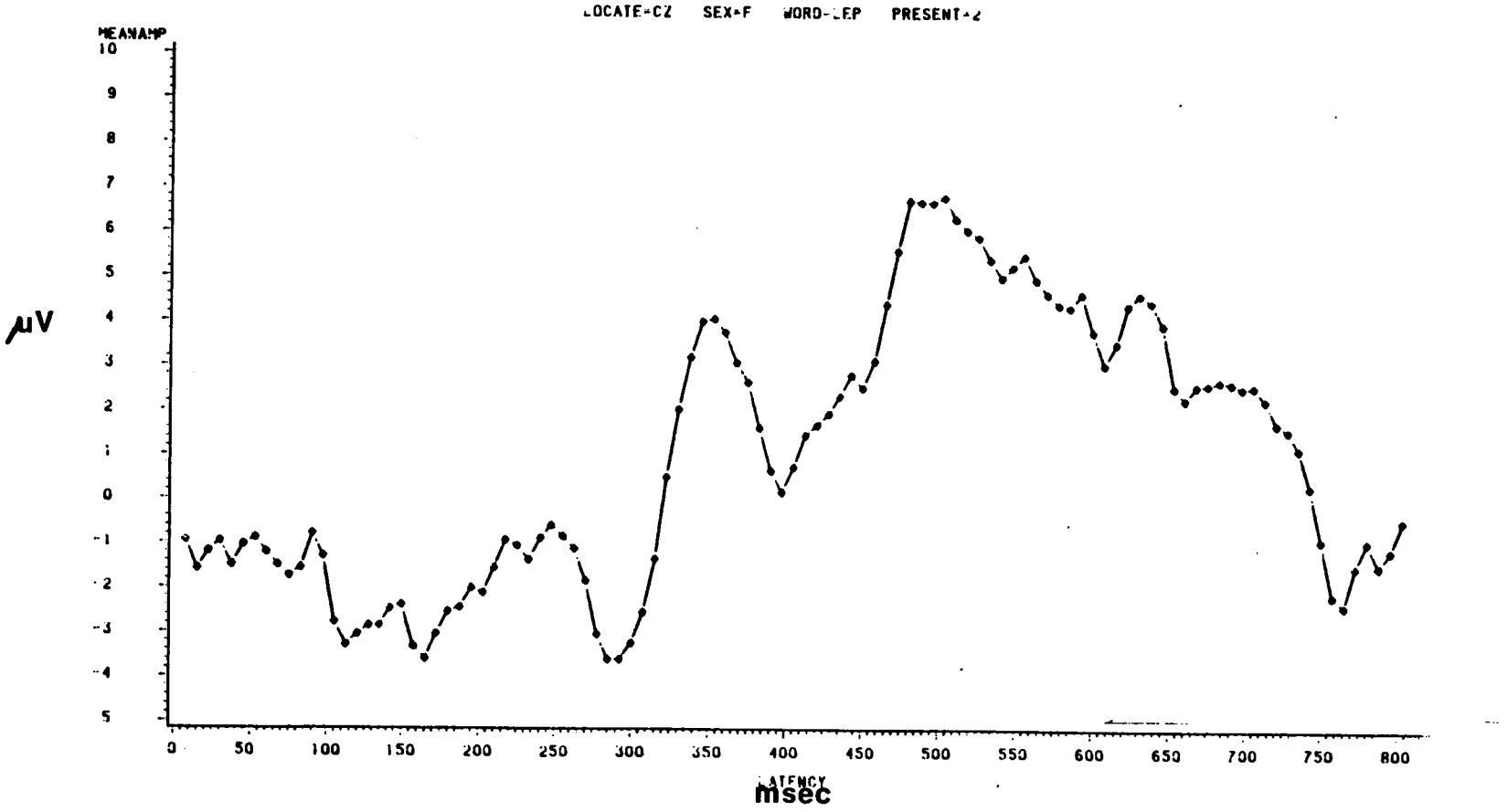

Figure D-18. Average ERP of the female subjects to the second presentation of, "John fell down and broke his /lep/," at Cz.

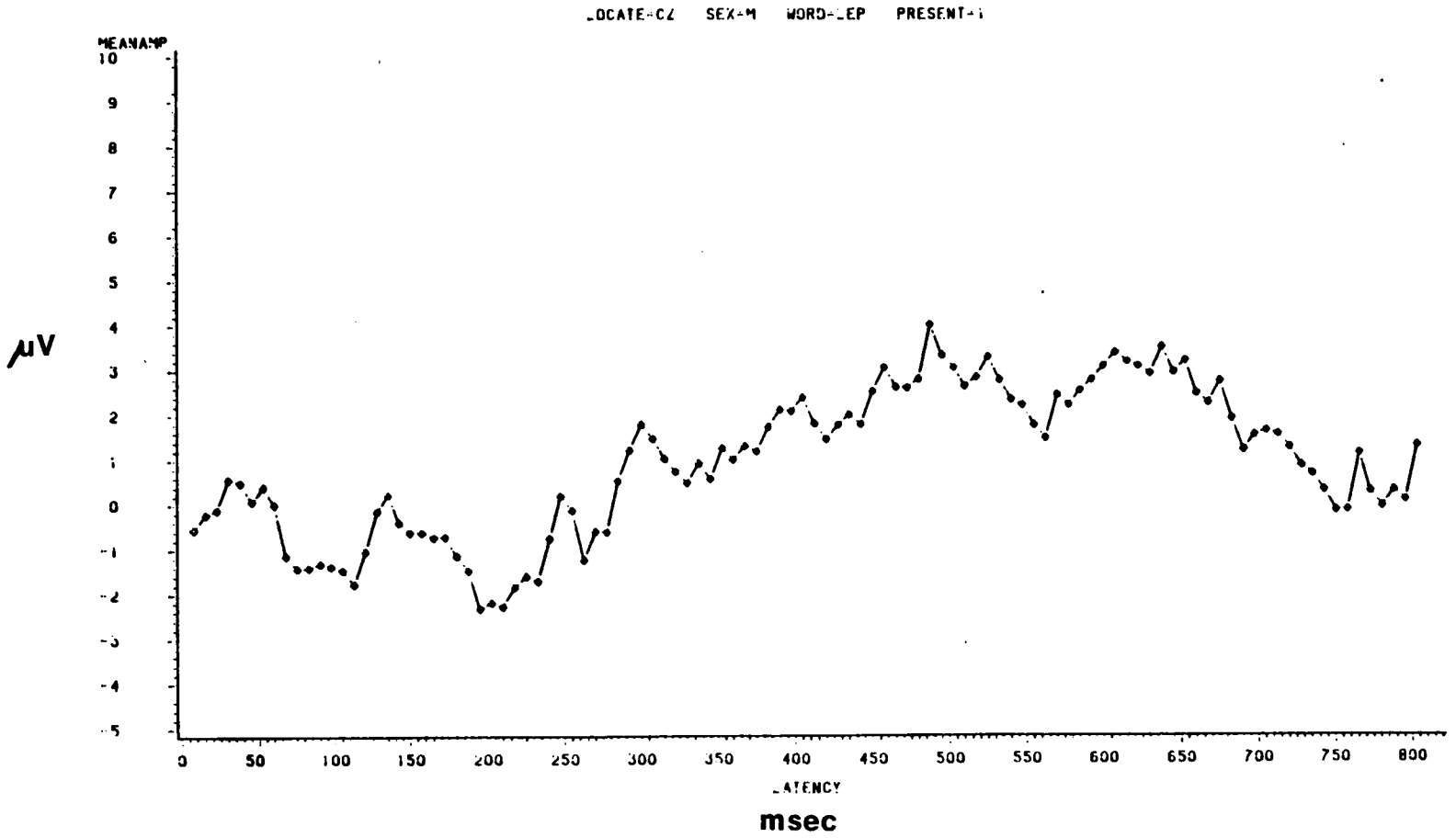

Figure D-19. Average ERP of the male subjects to the first presentation of, "John fell down and broke his /lep/," at Cz.

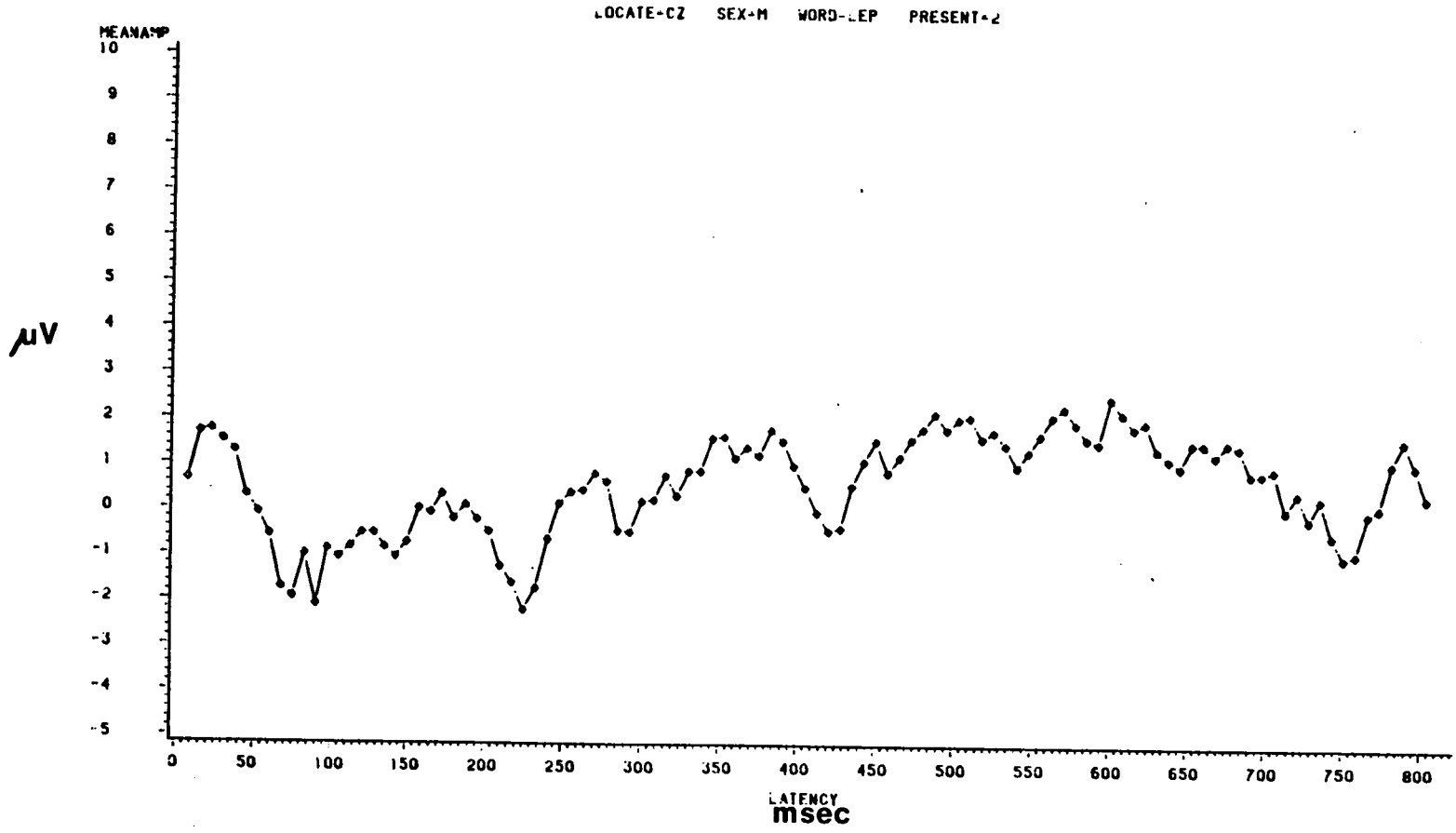

Figure D-20. Average ERP of the male subjects to the second presentation of, "John fell down and broke his /lep/," at Cz.

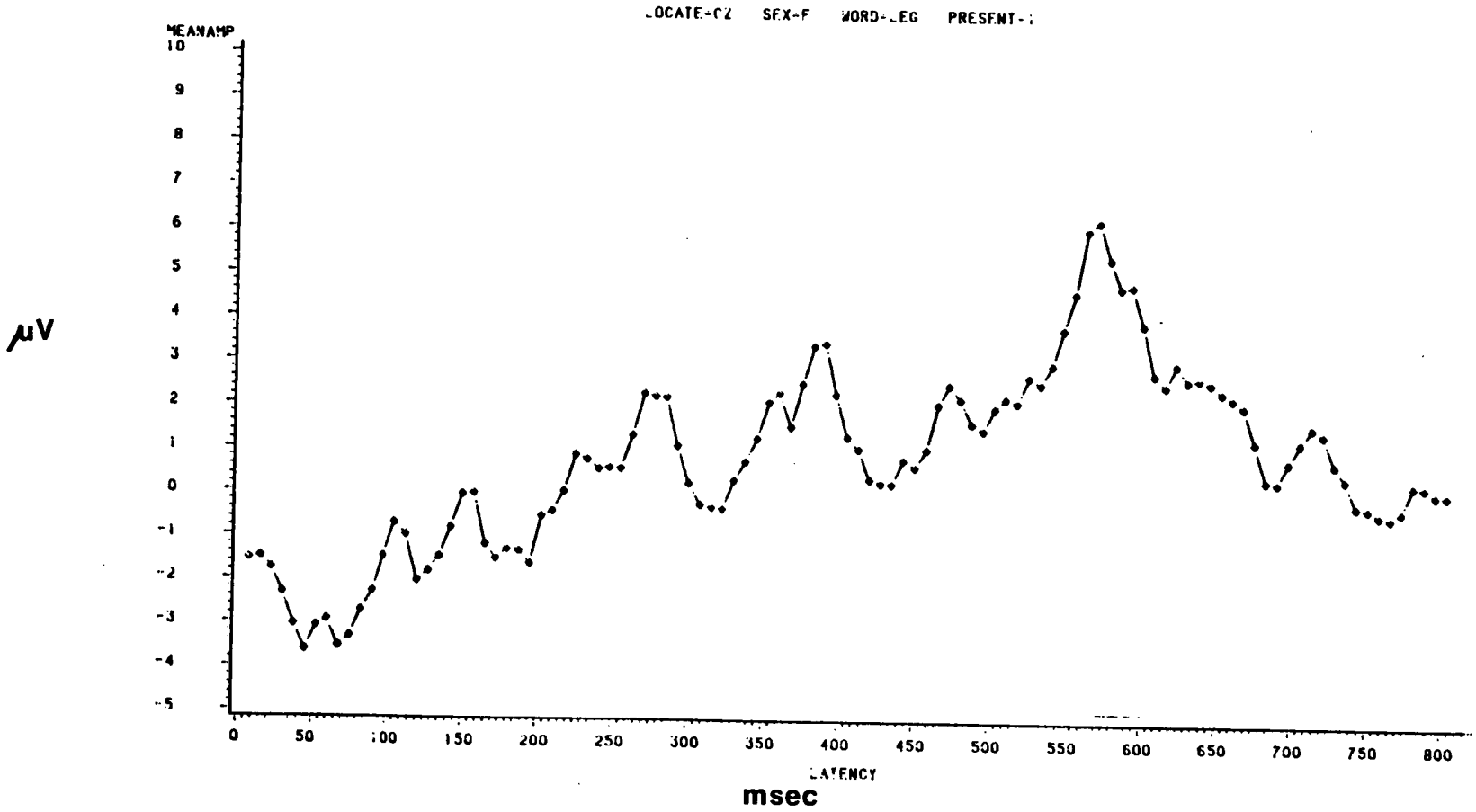

Figure D-21. Average ERP of the female subjects to the first presentation of, "John fell down and broke his leg," at Cz.

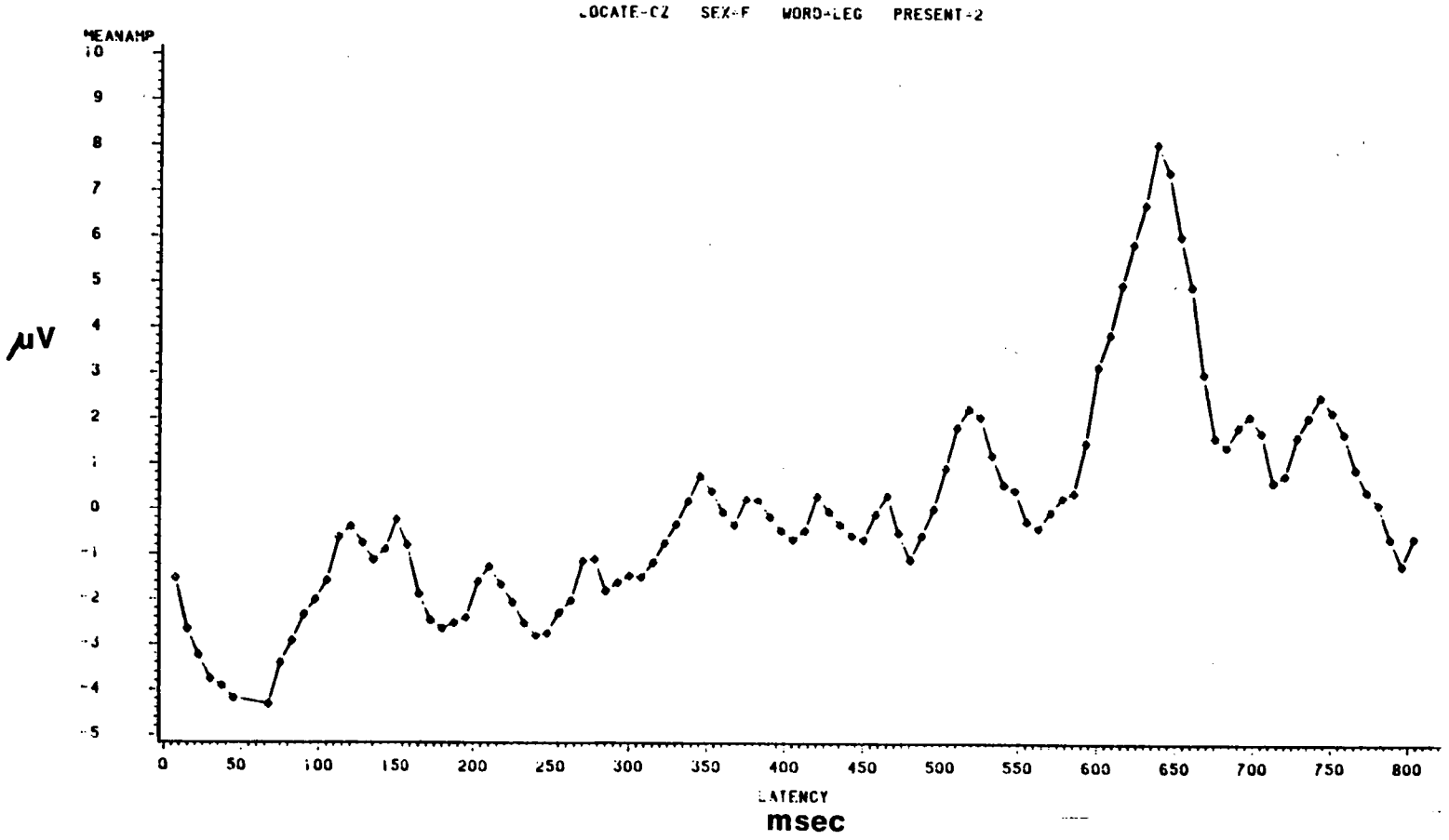

Figure D-22. Average ERP of the female subjects to the second presentation of, "John fell down and broke his leg," at Cz.

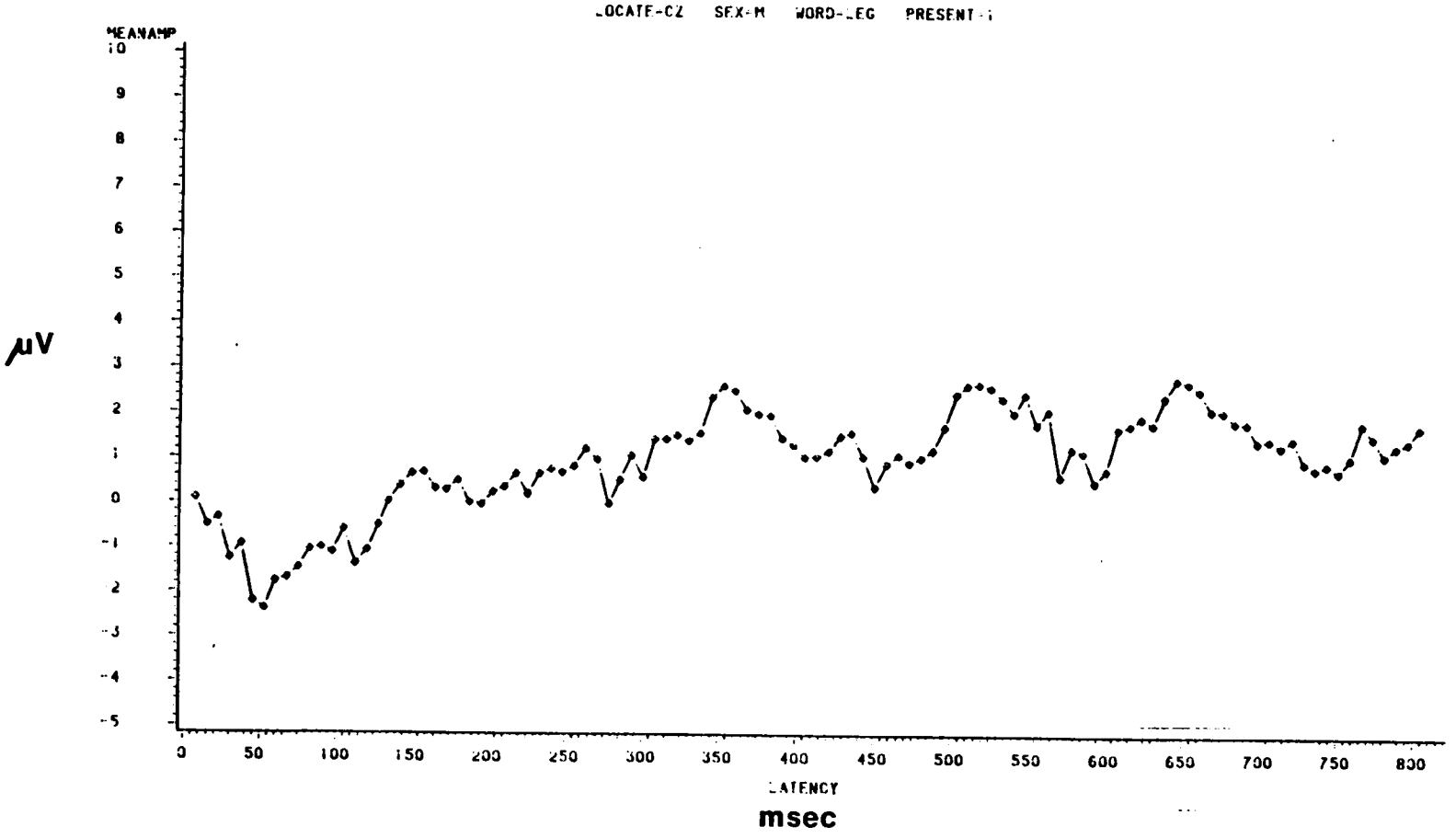

Figure D-23. Average ERP of the male subjects to the first presentation of, "John fell down and broke his leg," at Cz.

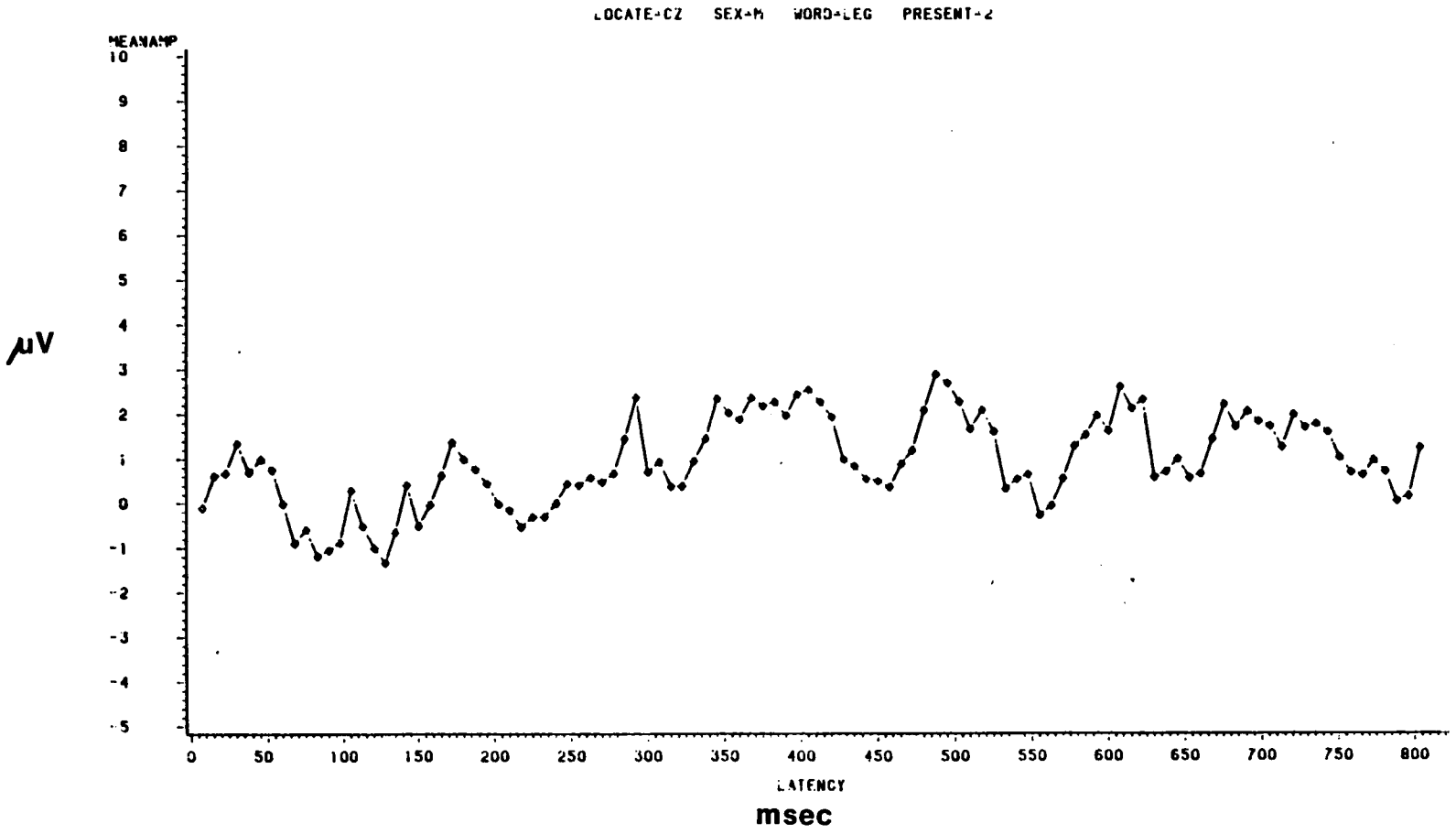

Figure D-24. Average ERP of the male subjects to the second presentation of, "John fell down and broke his leg," at Cz.

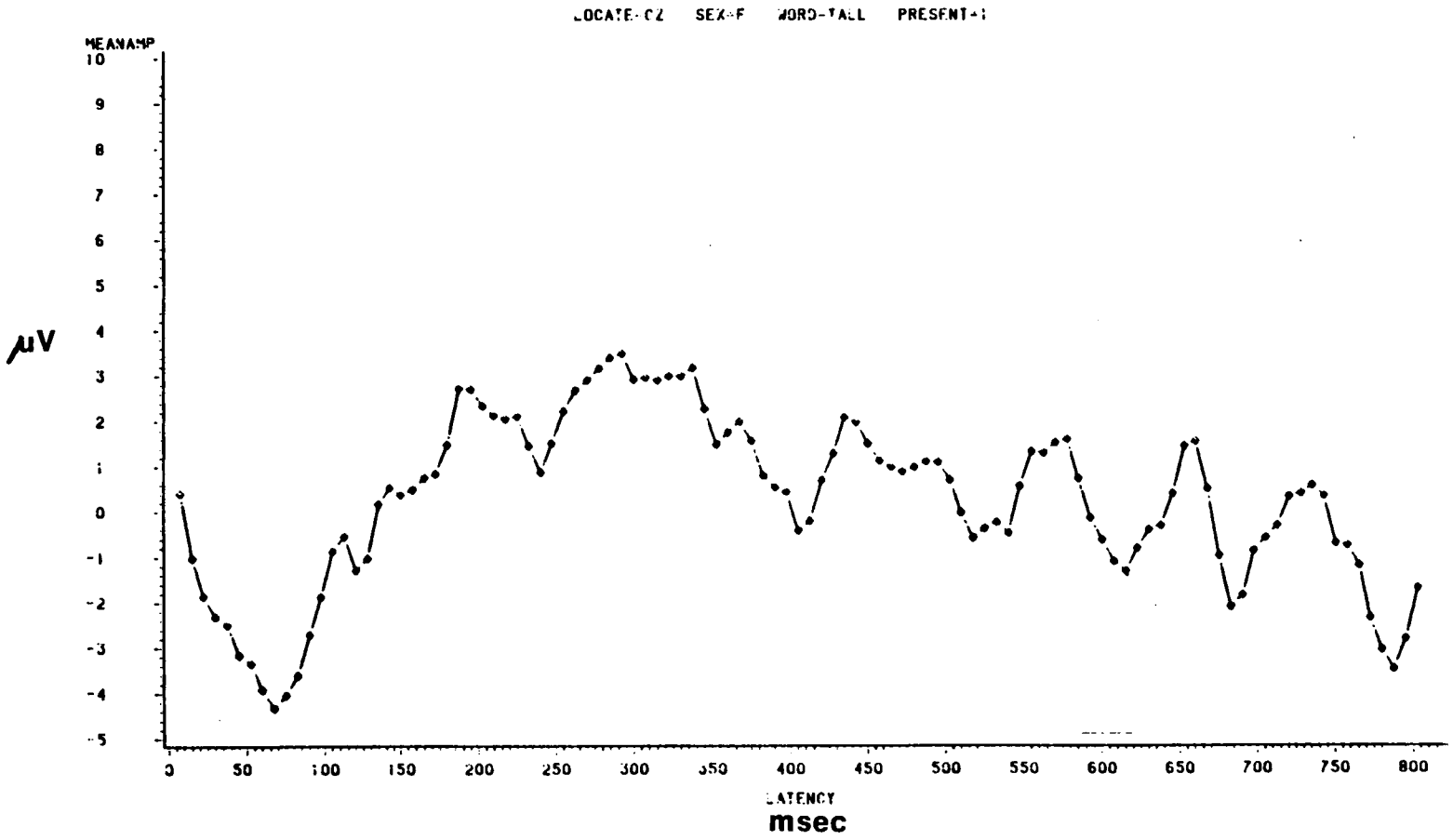

Figure D-25. Average ERP of the female subjects to the first presentation of, "The flowers smell tall," at Cz.

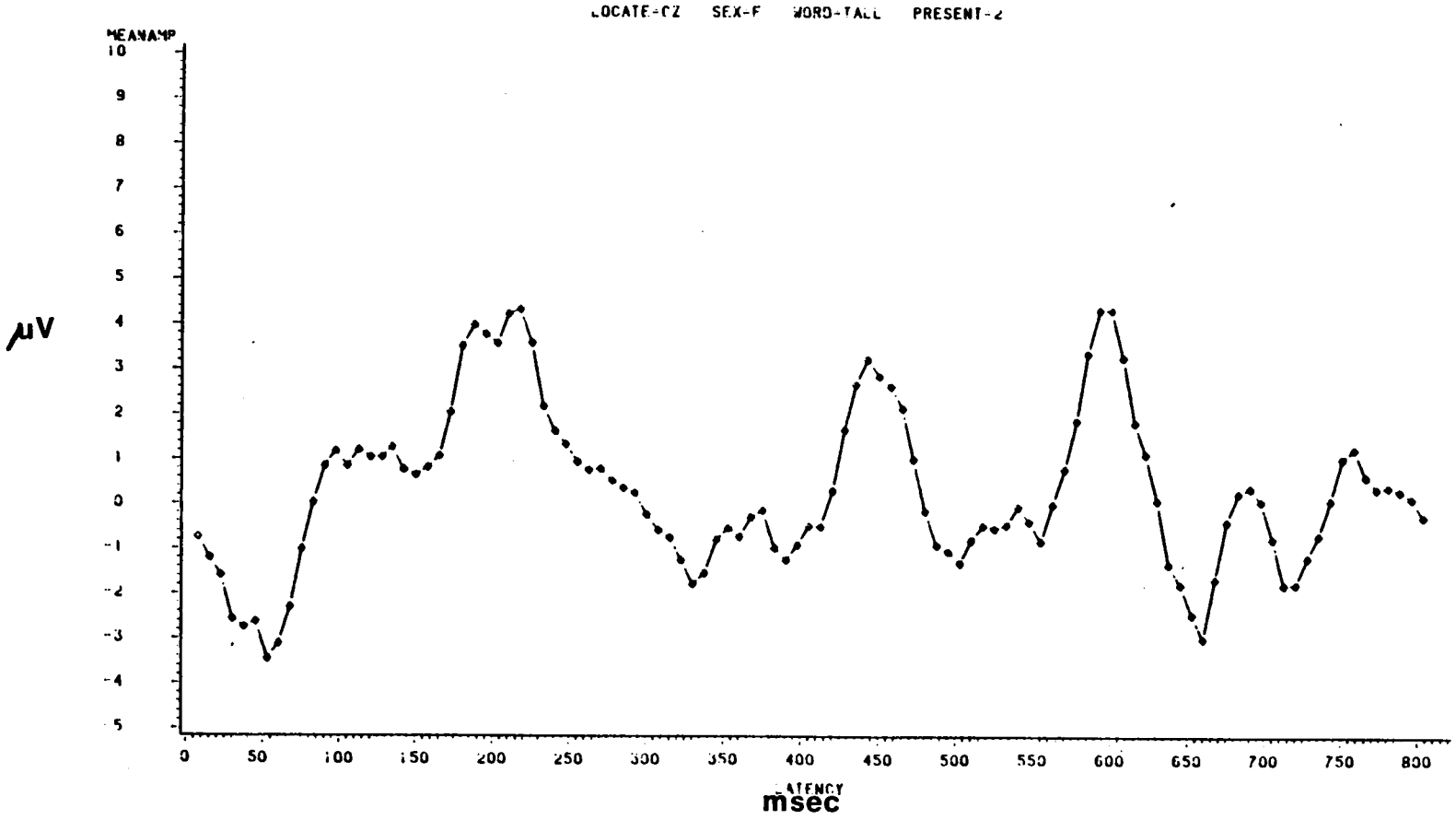

Figure D-26. Average ERP of the female subjects to the second presentation of, "The flowers smell tall," at Cz.

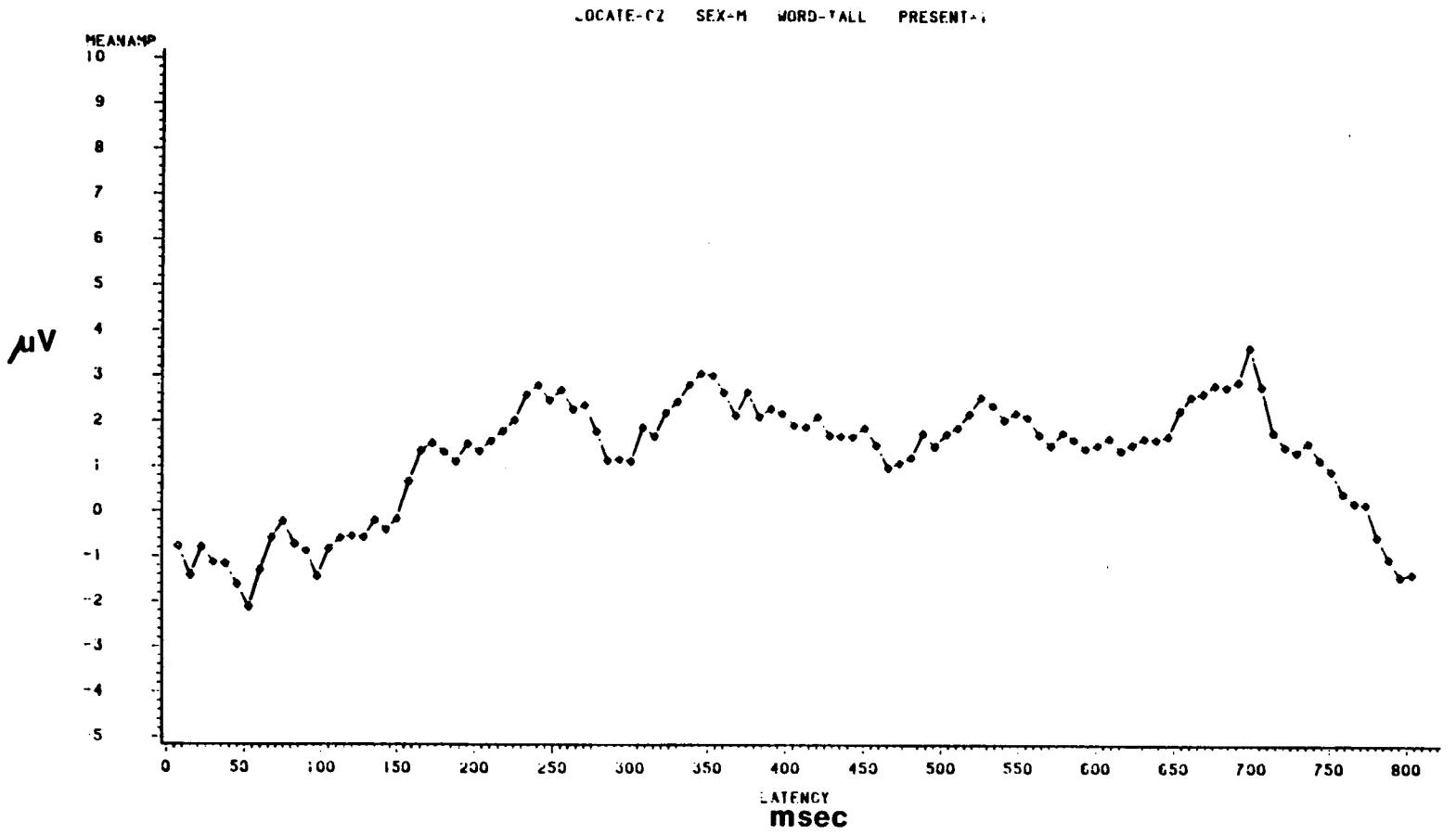

Figure D-27. Average ERP of the male subjects to the first presentation of, "The flowers smell tall," at Cz.

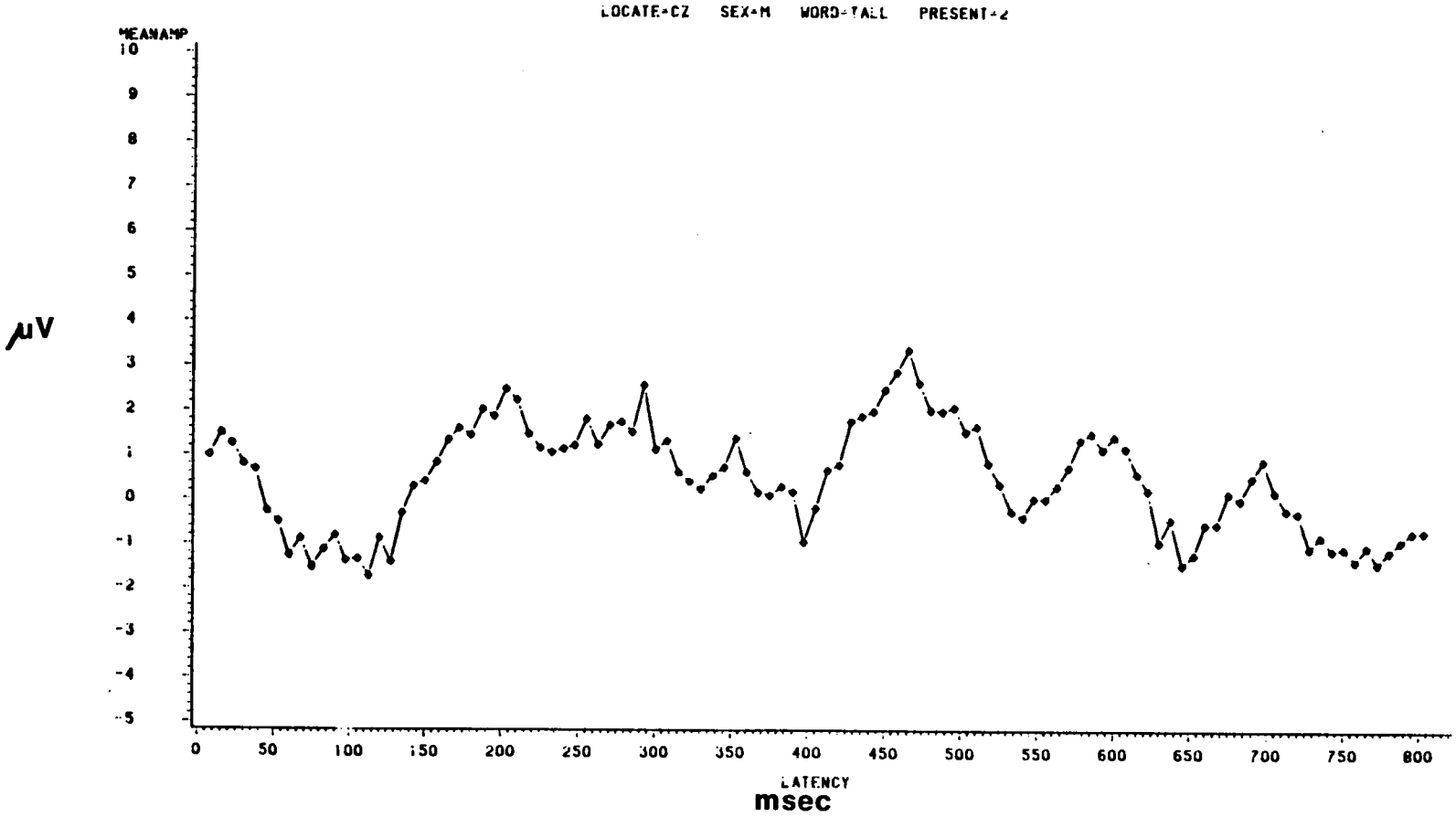

Figure D-28. Average ERP of the male subjects to the second presentation of, "The flowers smell tall," at Cz.

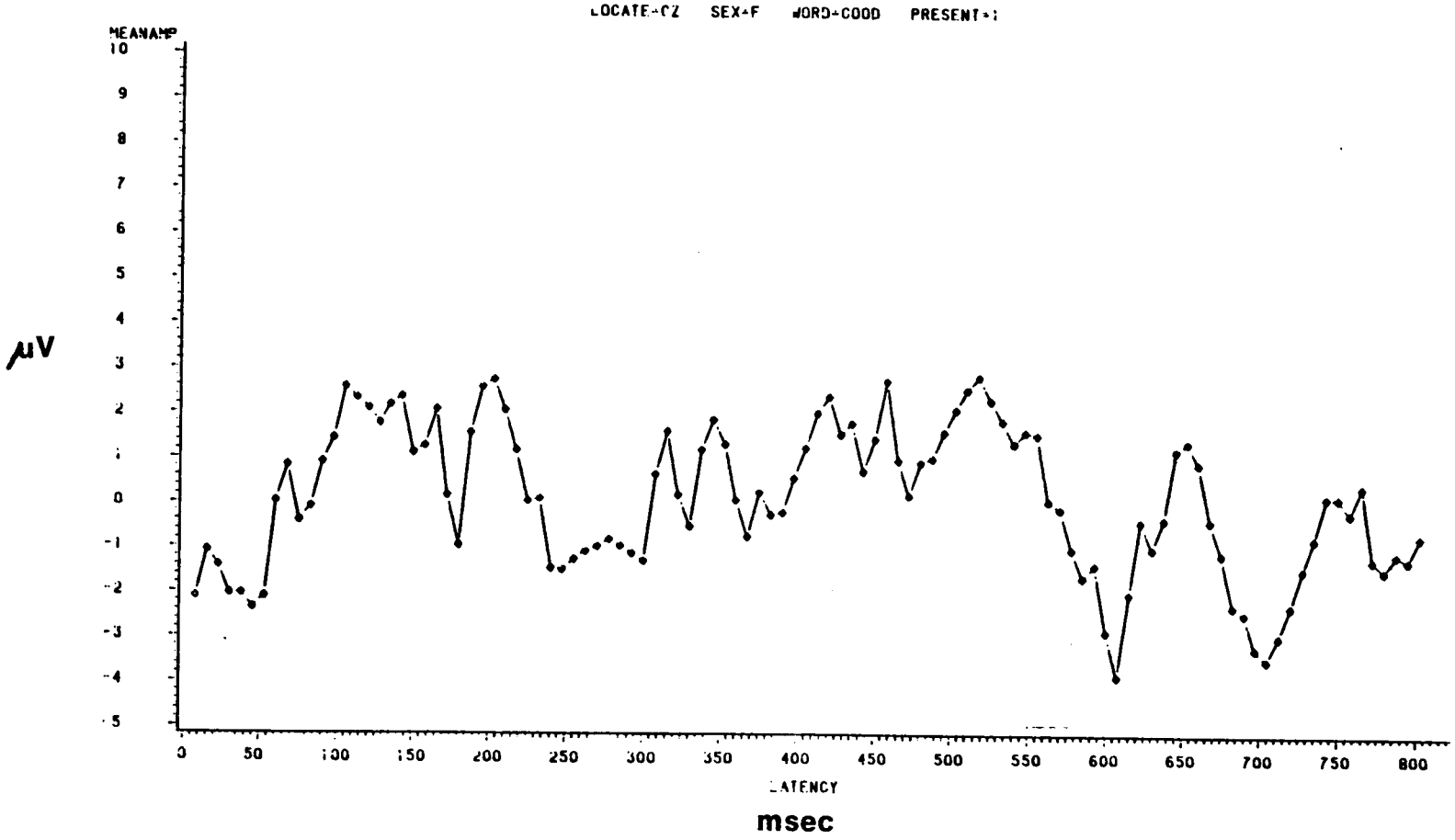

Figure D-29. Average ERP of the female subjects to the first presentation of, "The flowers smell good," at Cz.

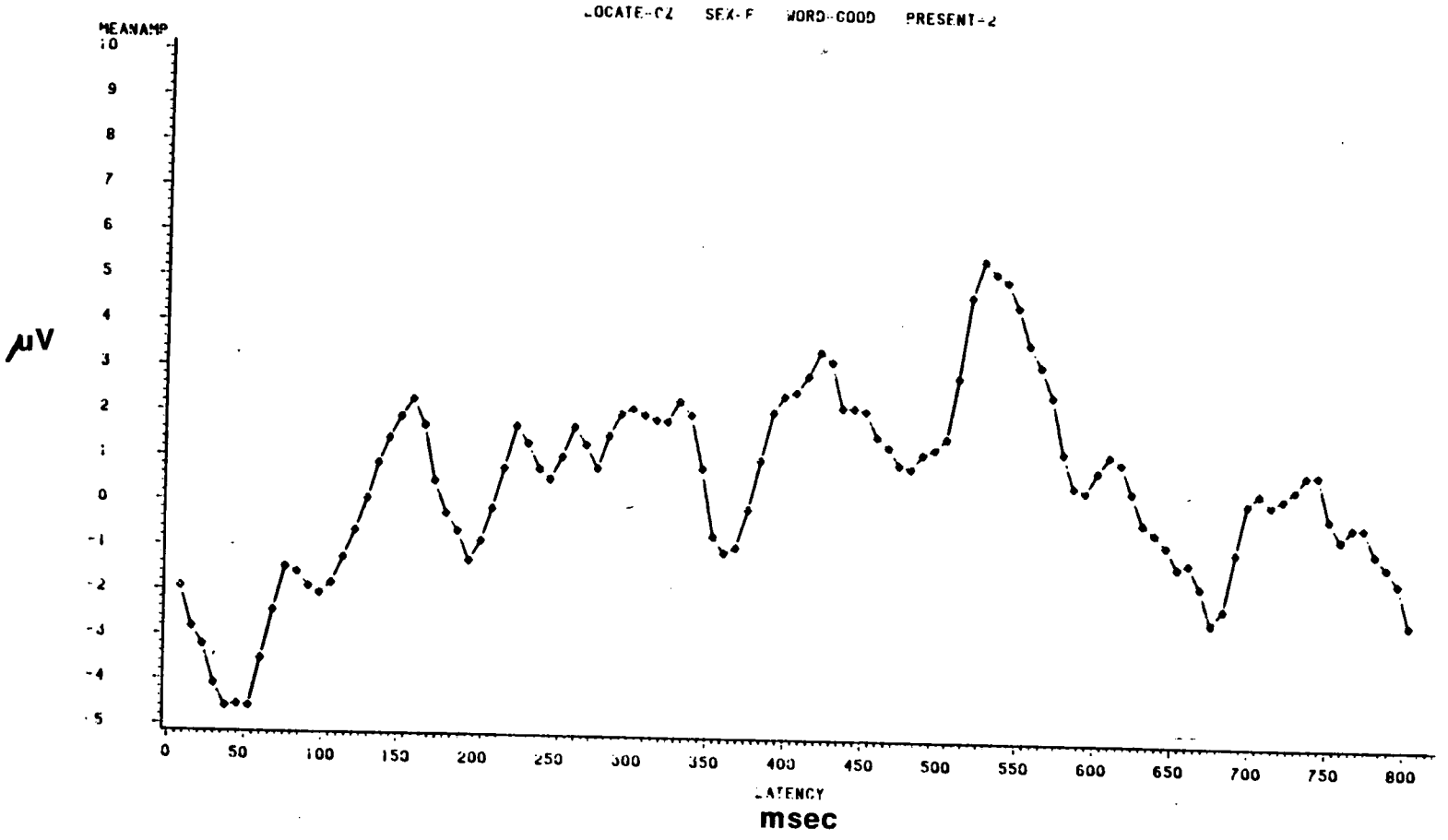

Figure D-30. Average ERP of the female subjects to the second presentation of, "The flowers smell good," at Cz.

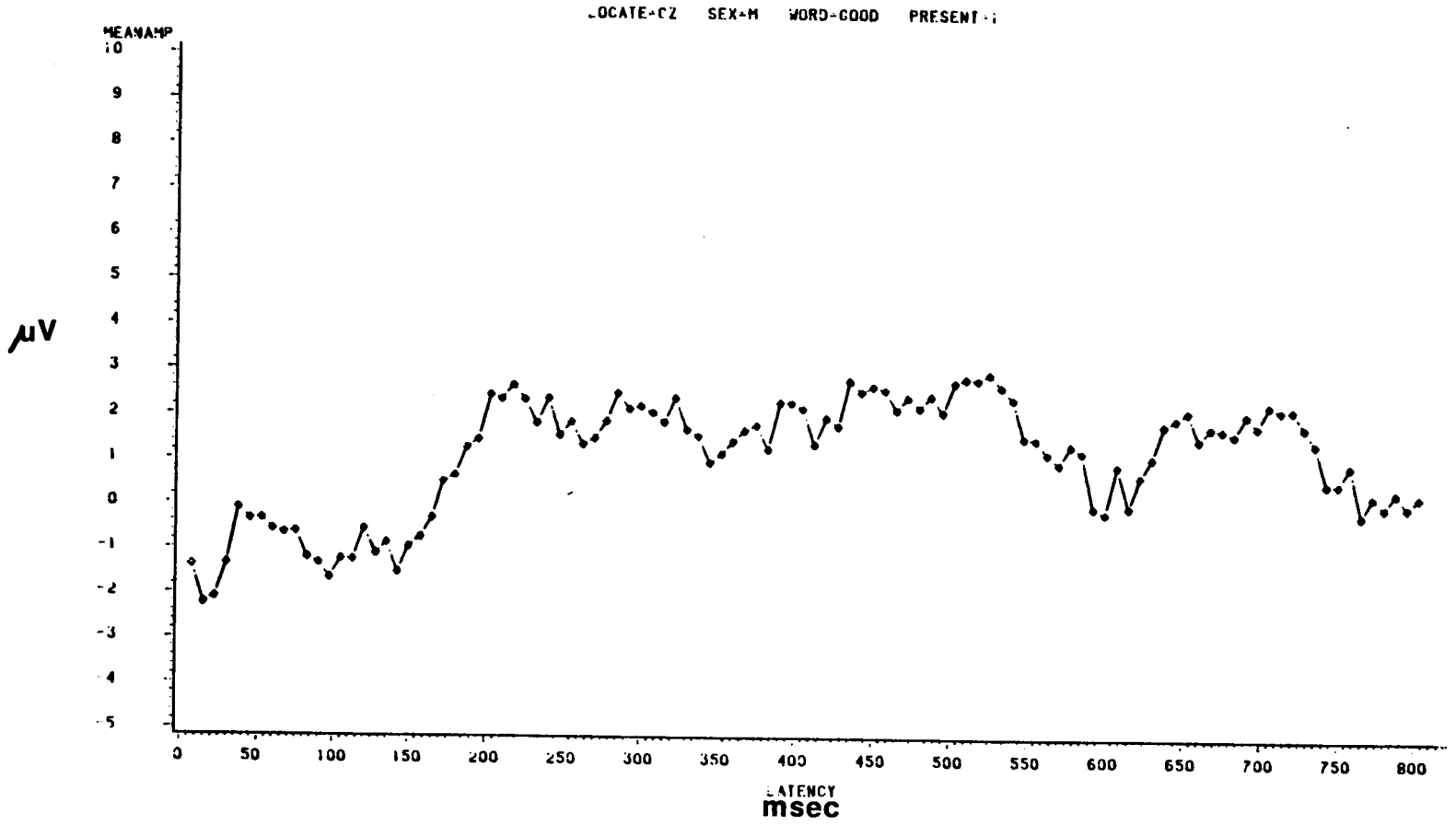

Figure D-31. Average ERP of the male subjects to the first presentation of, "The flowers smell good," at Cz.

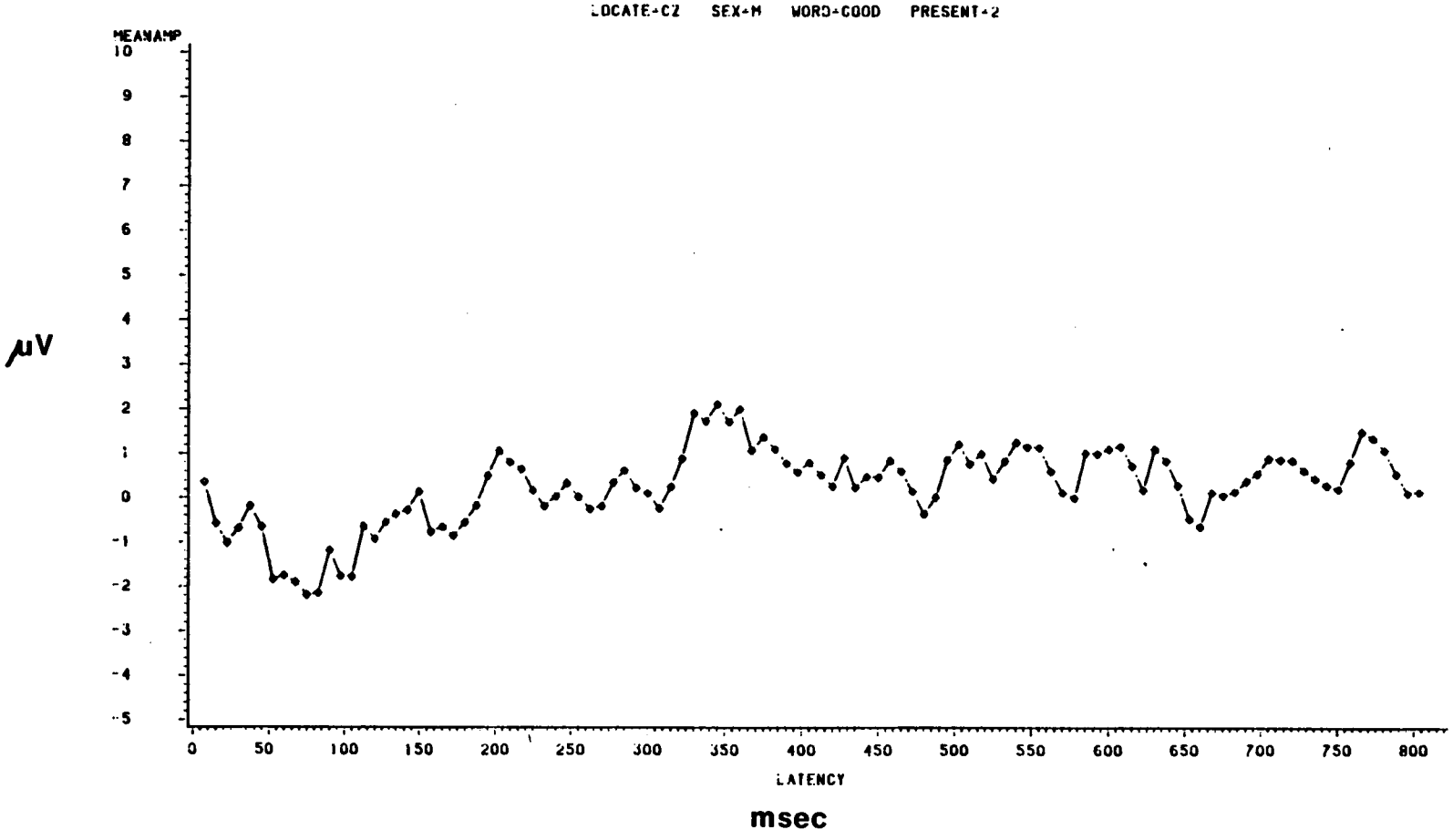

Figure D-32. Average ERP of the male subjects to the second presentation of, "The flowers smell good," at Cz.

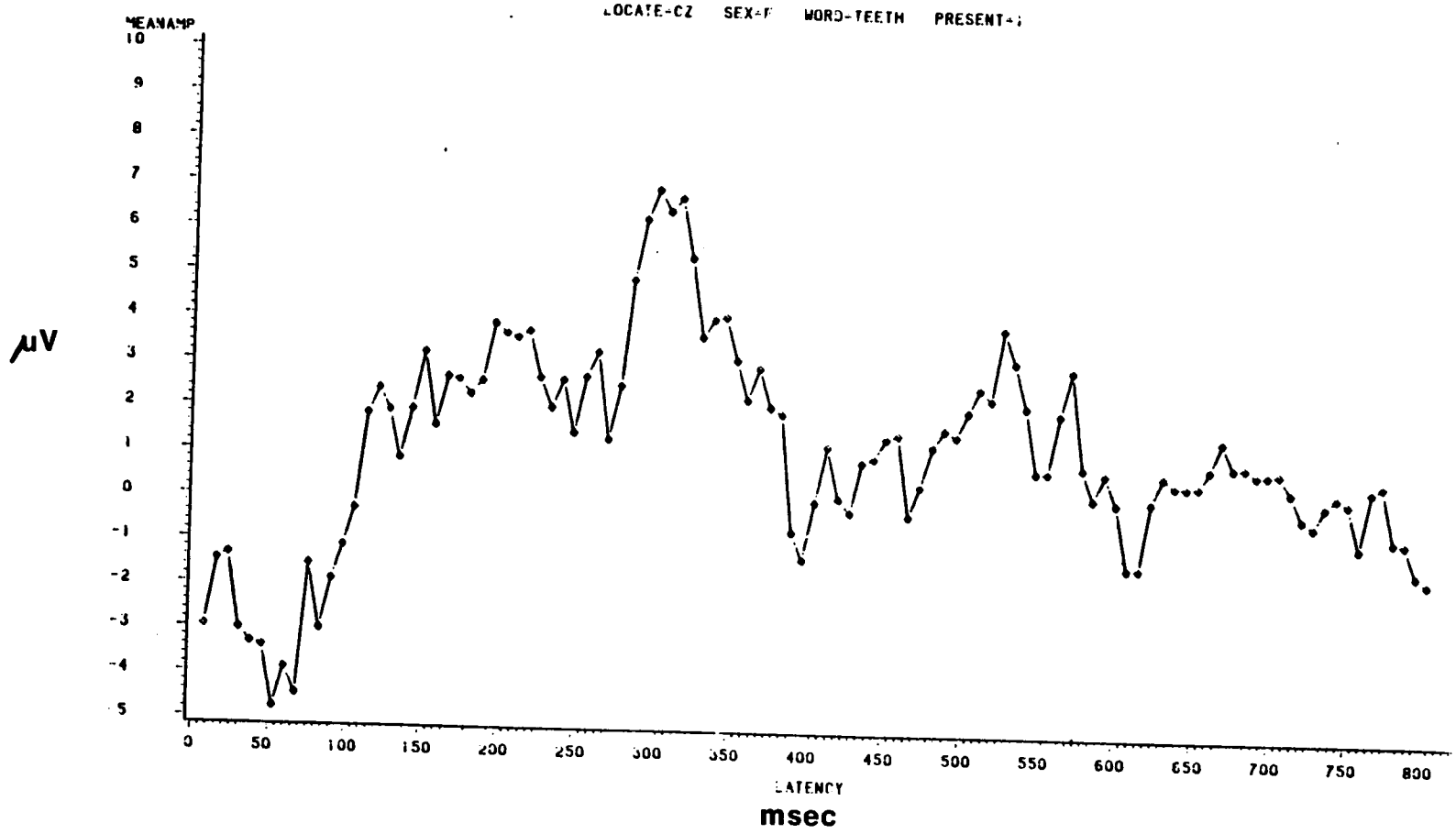

Figure D-33. Average ERP of the female subjects to the first presentation of, "Wash your face and comb your teeth," at Cz.

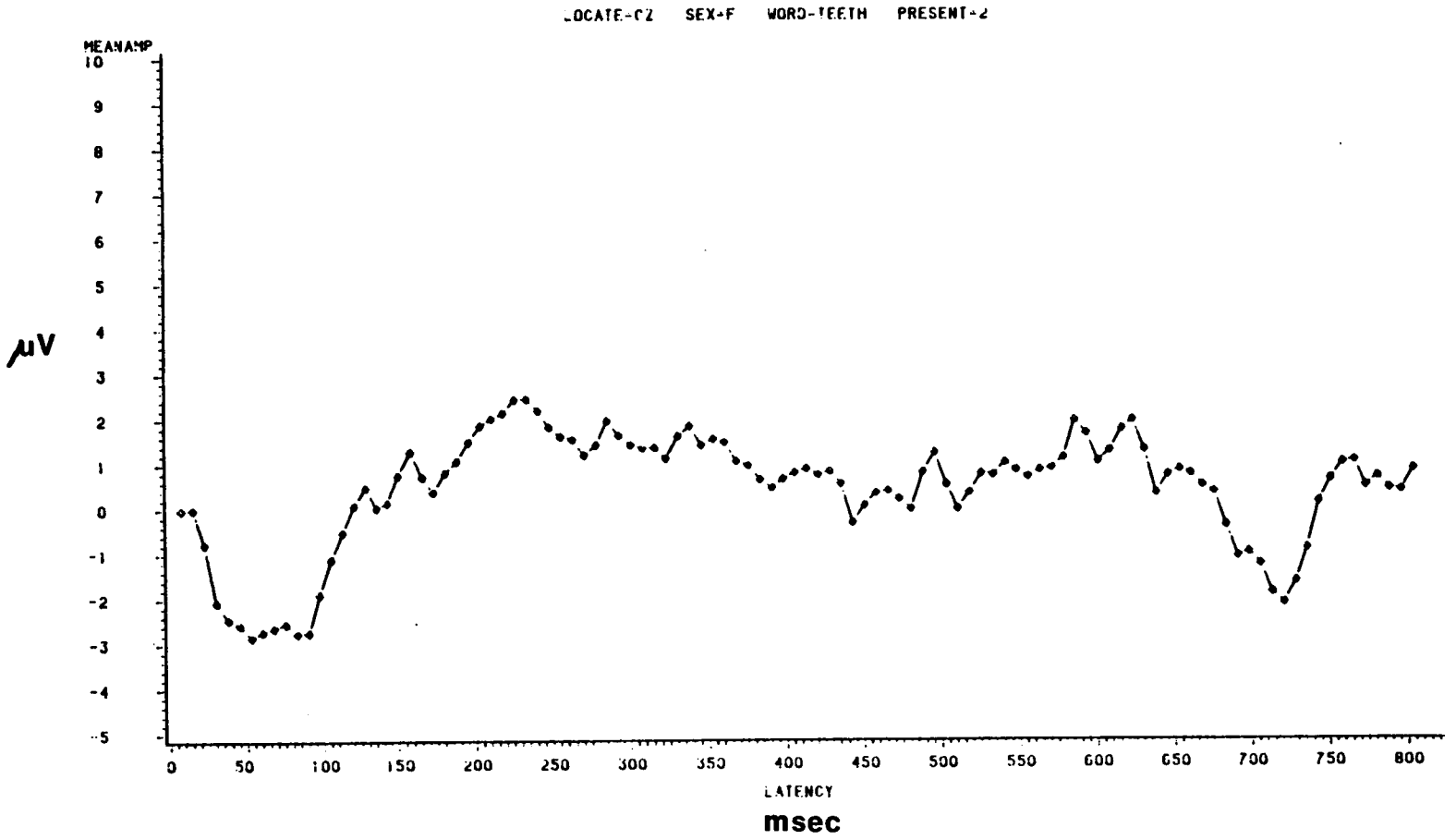

Figure D-34. Average ERP of the female subjects to the second presentation of, "Wash your face and comb your teeth," at Cz.

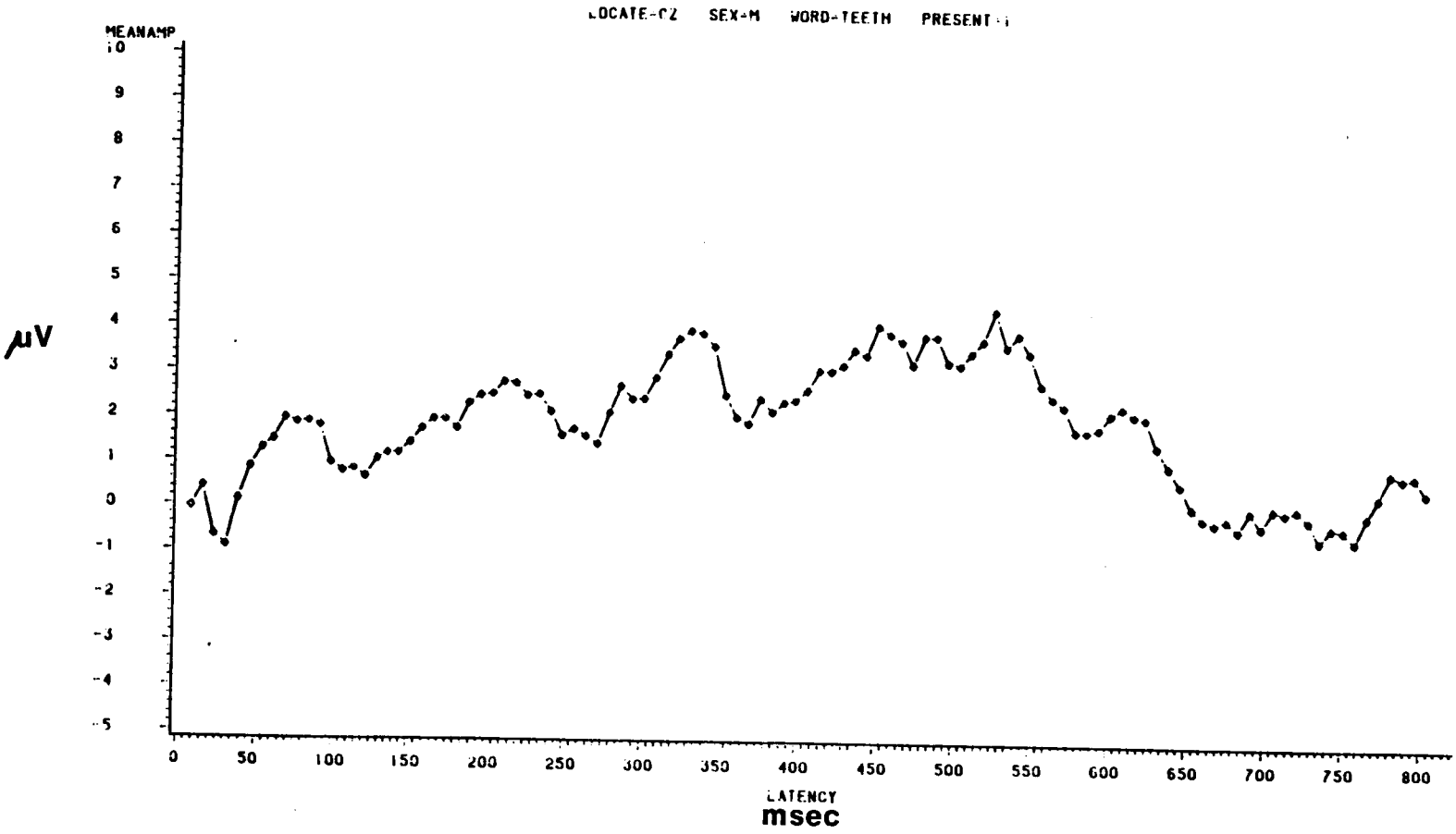

Figure D-35. Average ERP of the male subjects to the first presentation of, "Wash your face and comb your teeth," at Cz.

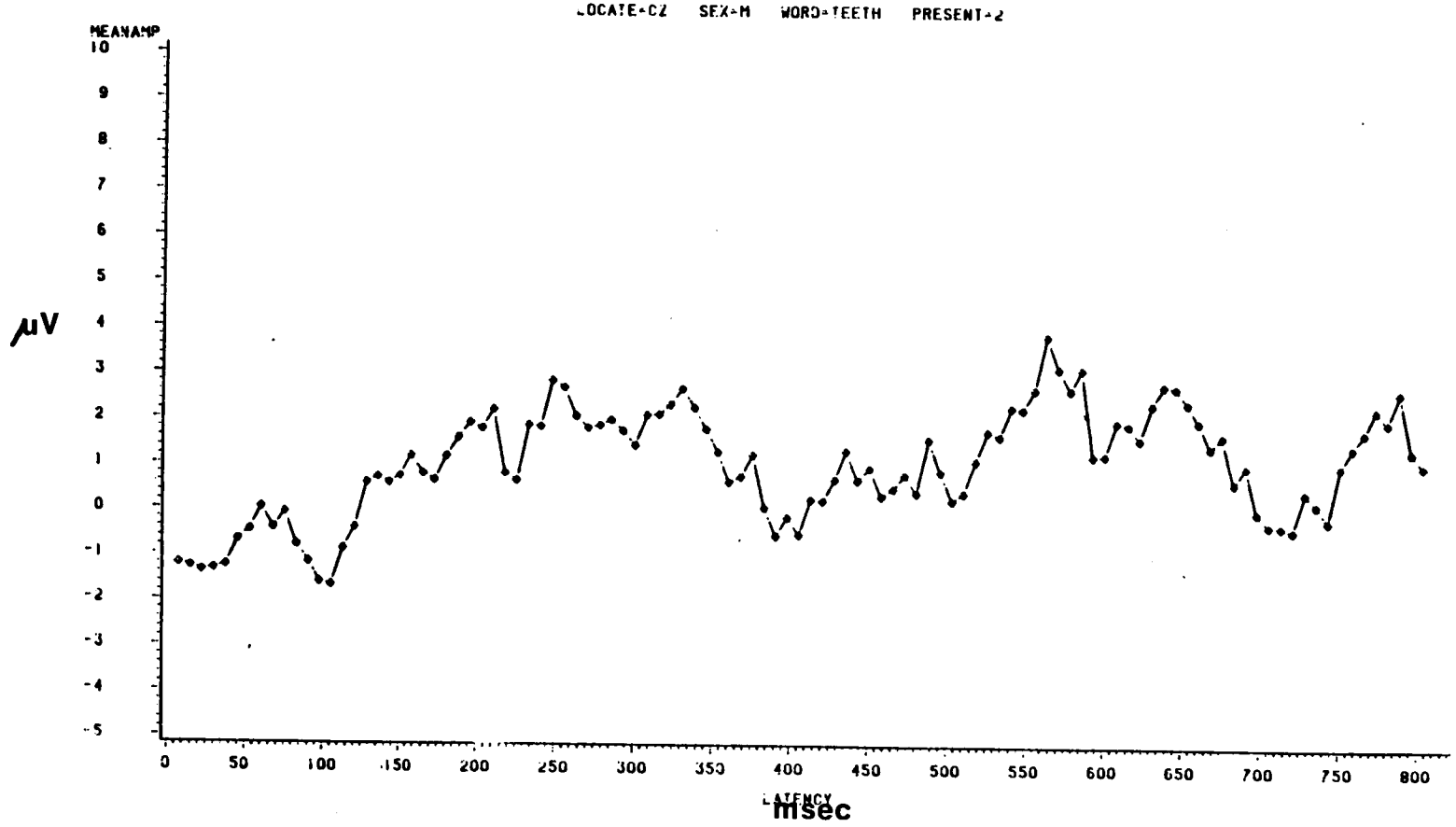

Figure D-36. Average ERP of the male subjects to the second presentation of, "Wash your face and comb your teeth," at Cz.

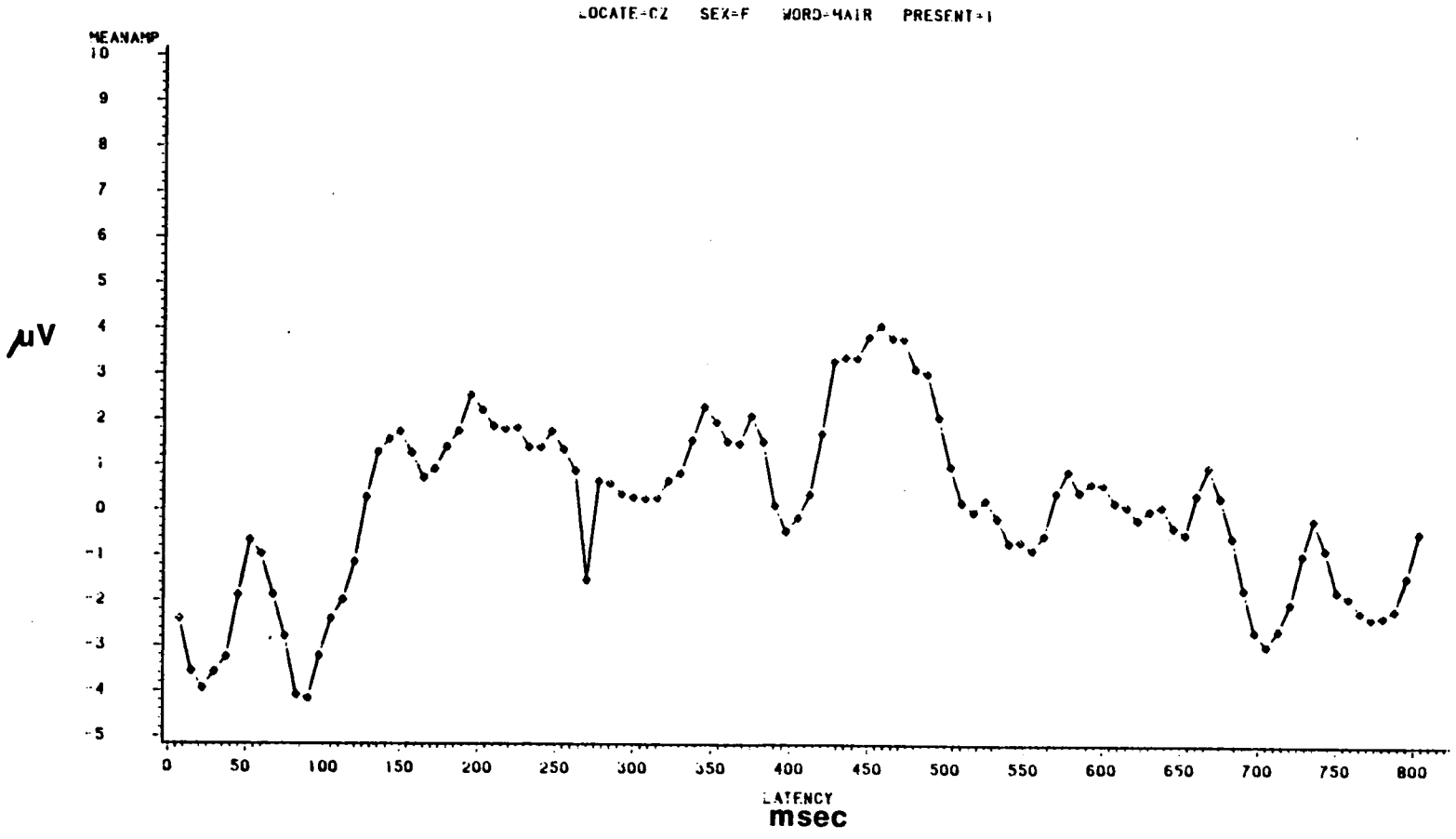

Figure D-37. Average ERP of the female subjects to the first presentation of, "Wash your face and comb your hair," at Cz.

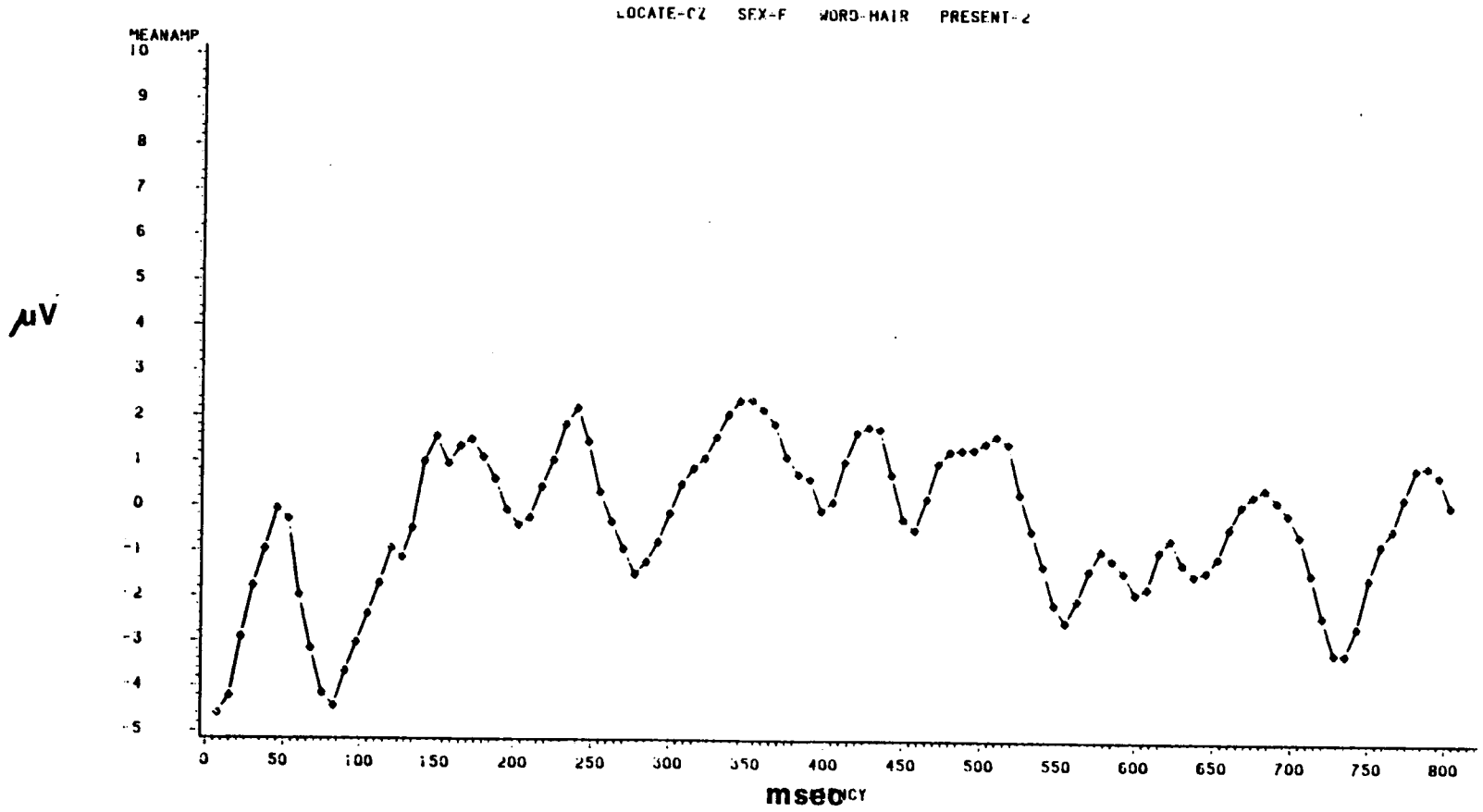

Figure D-38. Average ERP of the female subjects to the second presentation of, "Wash your face and comb your hair," at Cz.

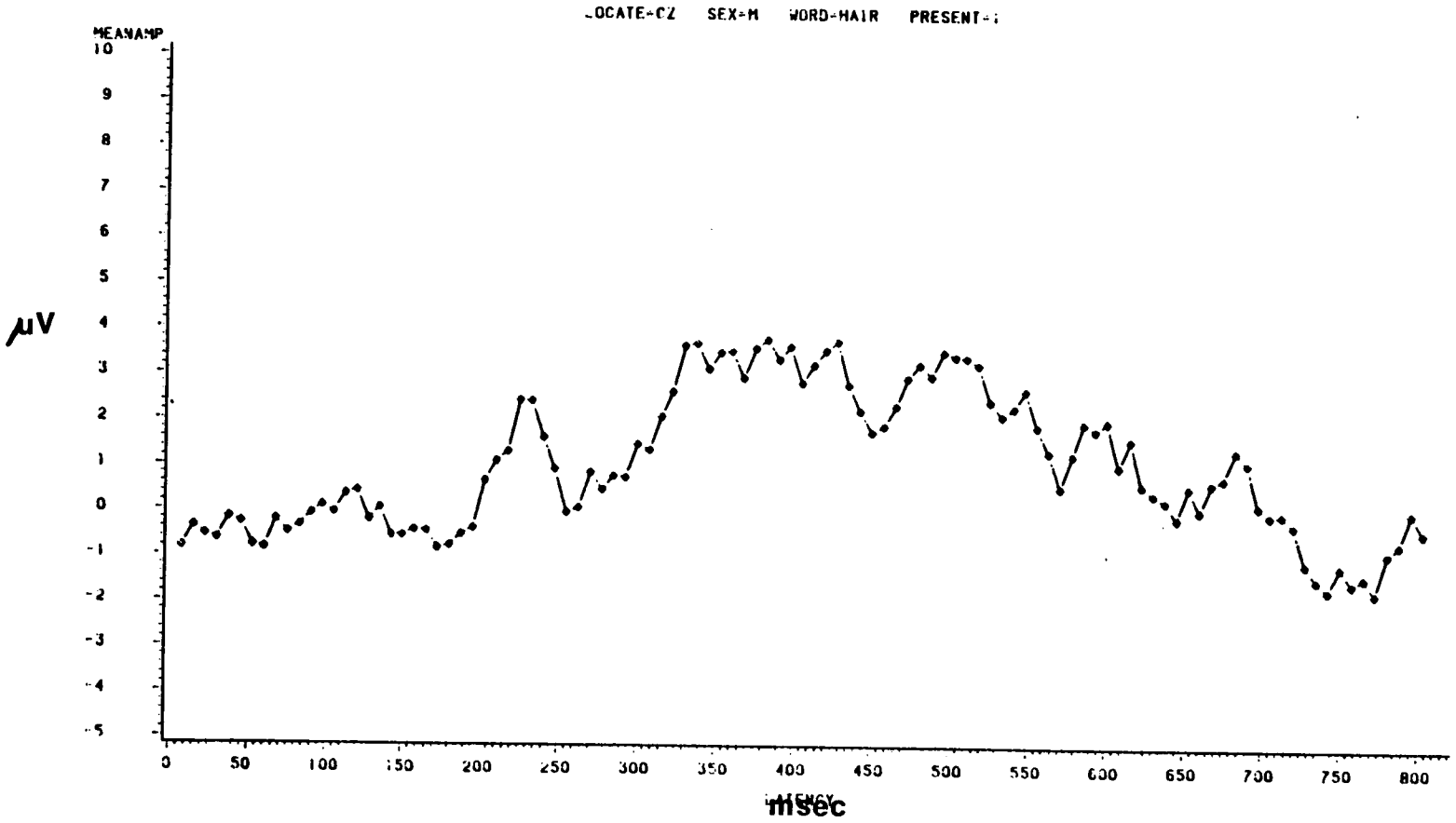

Figure D-39. Average ERP of the male subjects to the first presentation of, "Wash your face and comb your hair," at Cz.

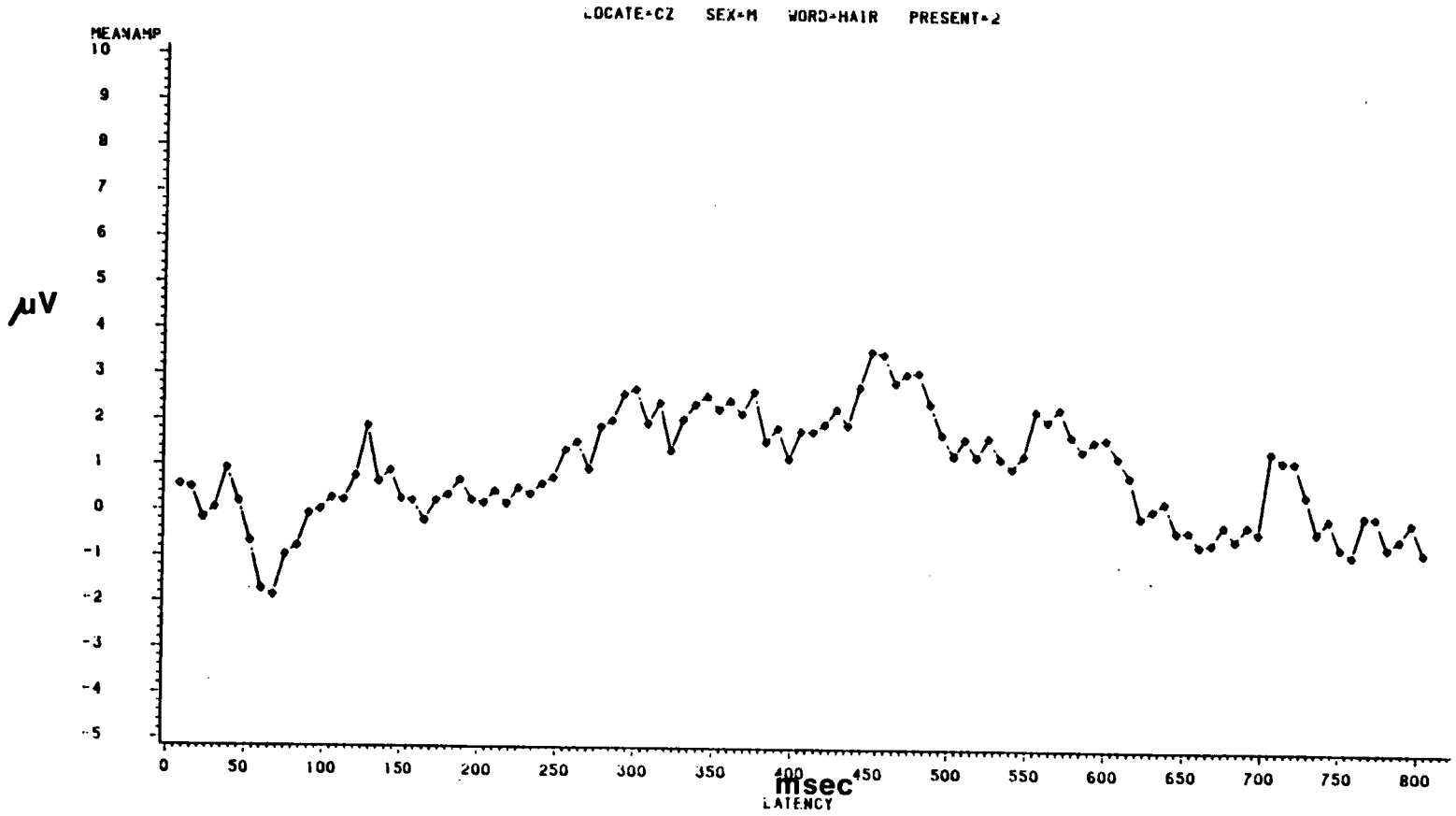

Figure D-40. Average ERP of the male subjects to the second presentation of, "Wash your face and comb your hair," at Cz.

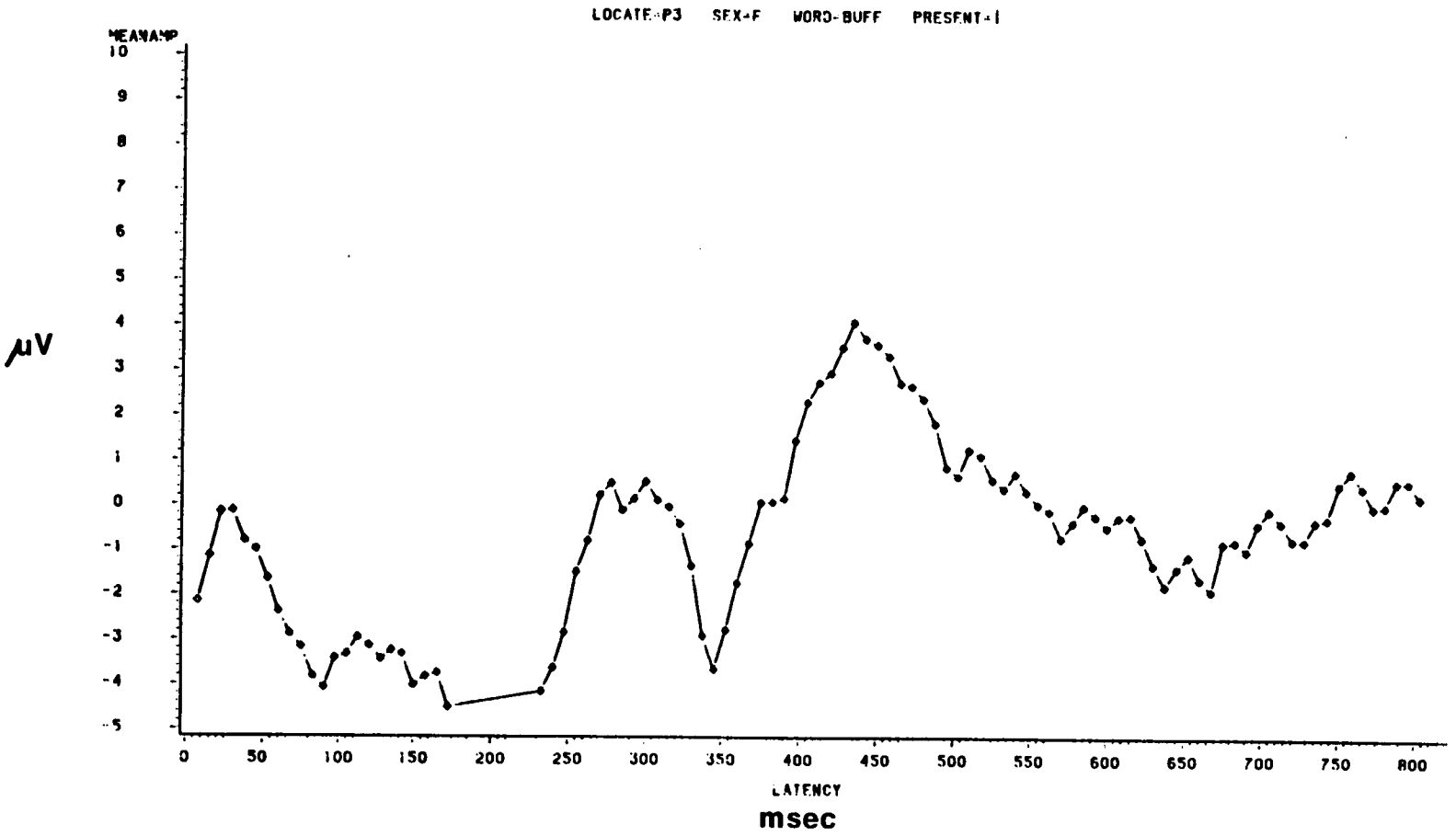

Figure D-41. Average ERP of the female subjects to the first presentation of, "I enjoyed reading the new /<u>buf</u>/" at P3.

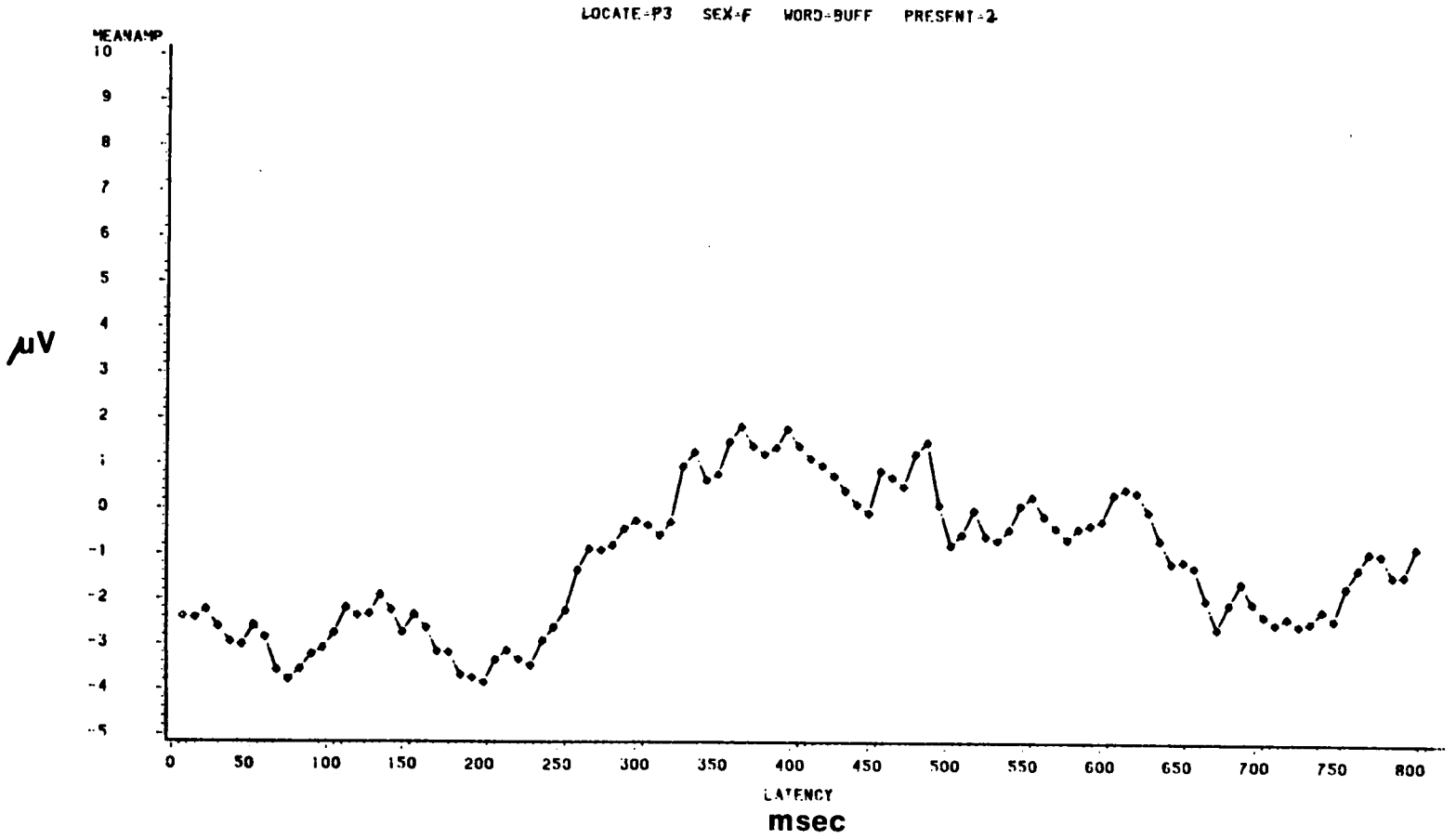

Figure D-42. Average ERP of the female subjects to the second presentation of," I enjoyed reading the new /<u>buf</u>/," at P3.

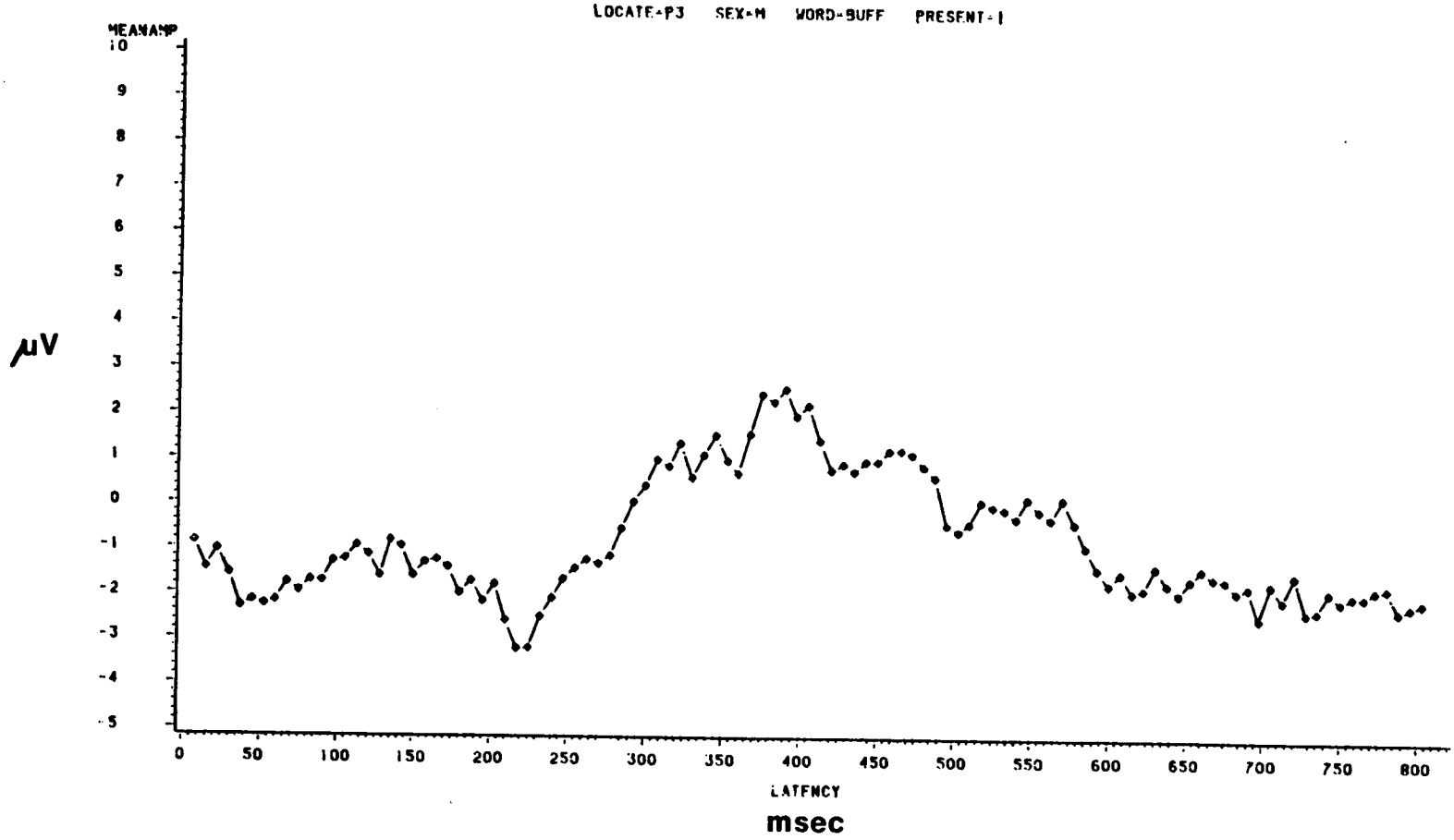

Figure D-43. Average ERP of the male subjects to the first presentation of, "I enjoyed reading the new /bʊf/," at P3.

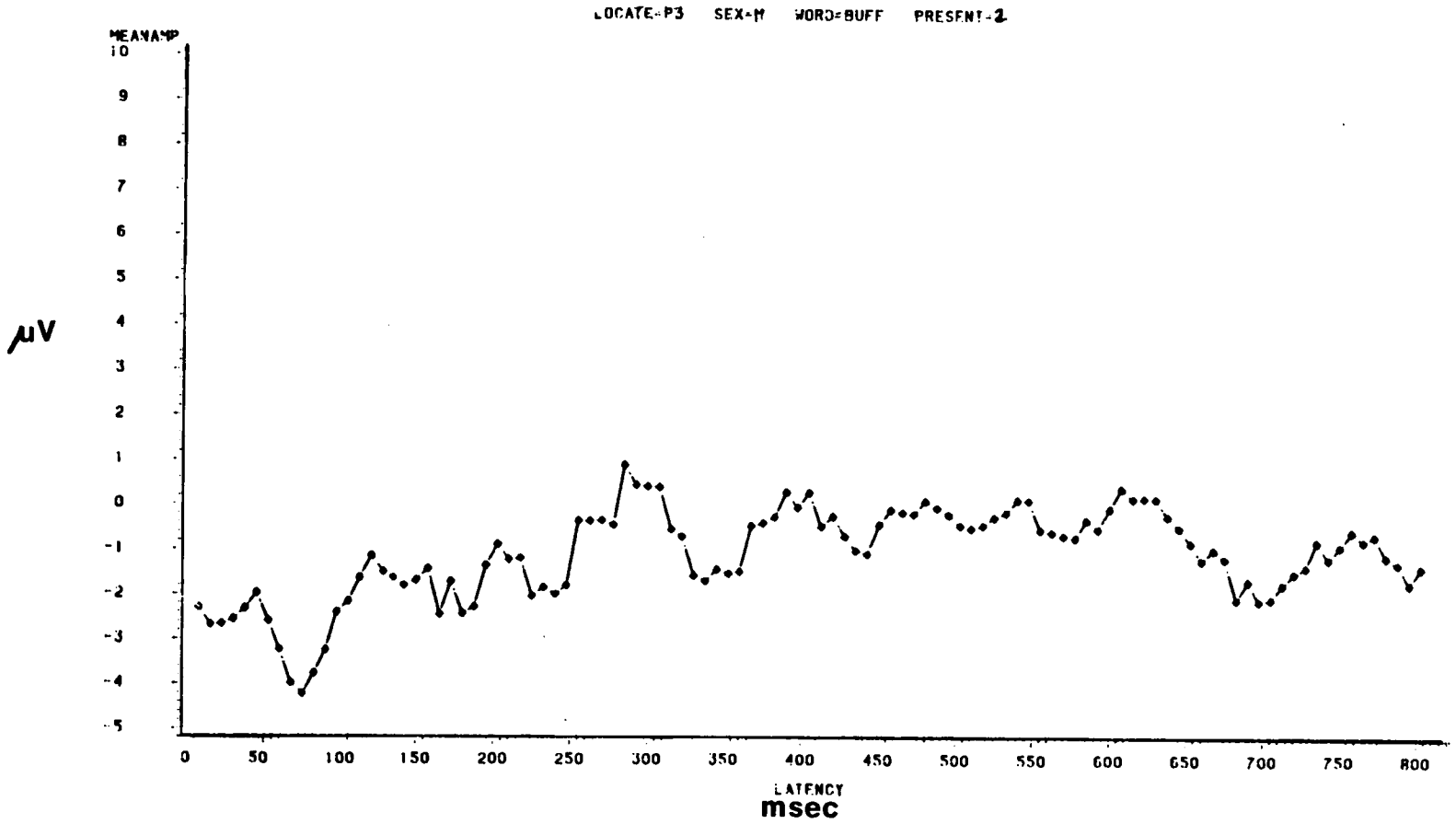

Figure D-44. Average ERP of the male subjects to the second presentation of, "I enjoyed reading the new /buf/," at P3.

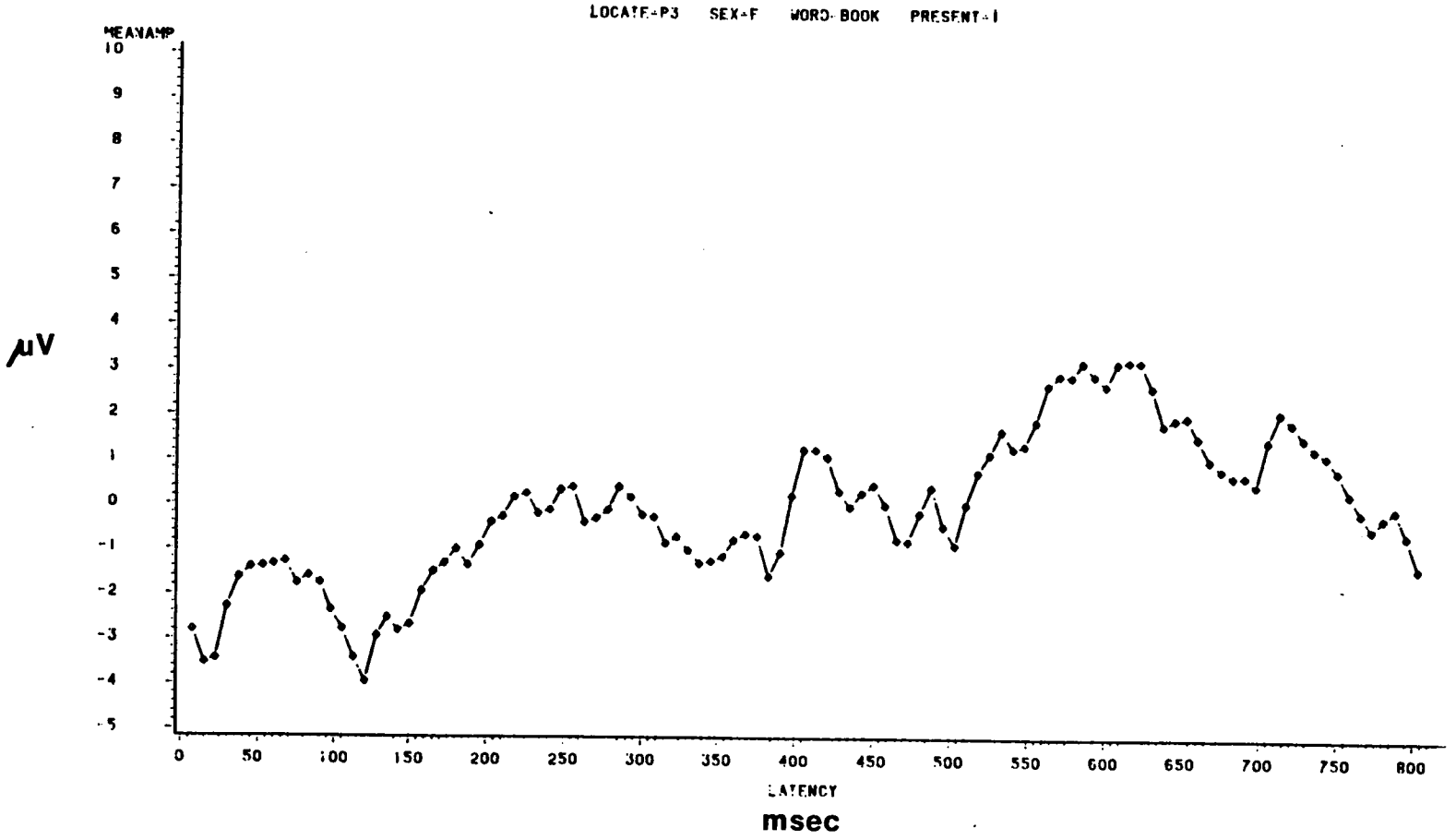

Figure D-45. Average ERP of the female subjects to the first presentation of, "I enjoyed reading the new book," at P3.

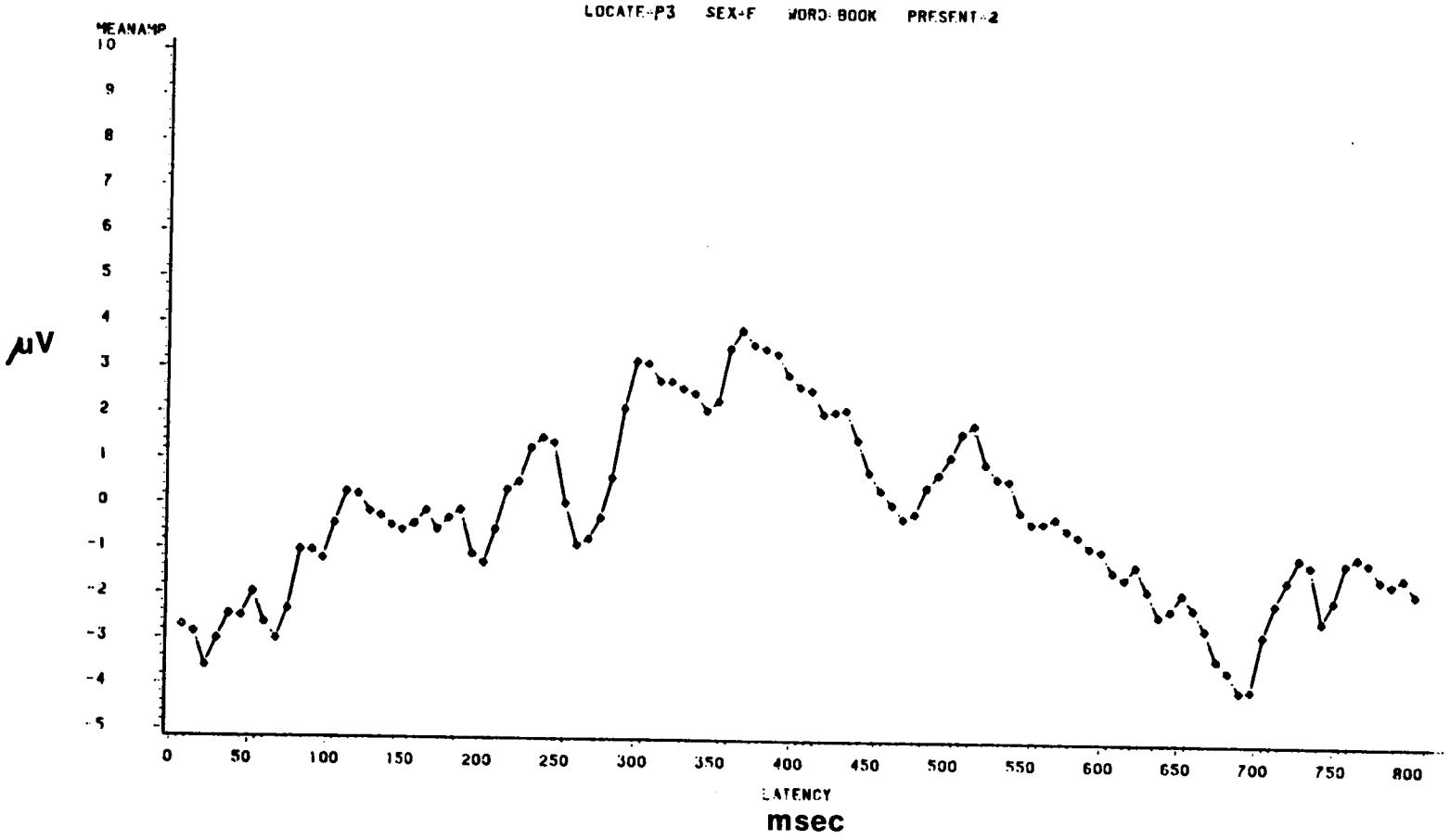

Figure D-46. Average ERP of the female subjects to the second presentation of, "I enjoyed reading the new book," at P3.

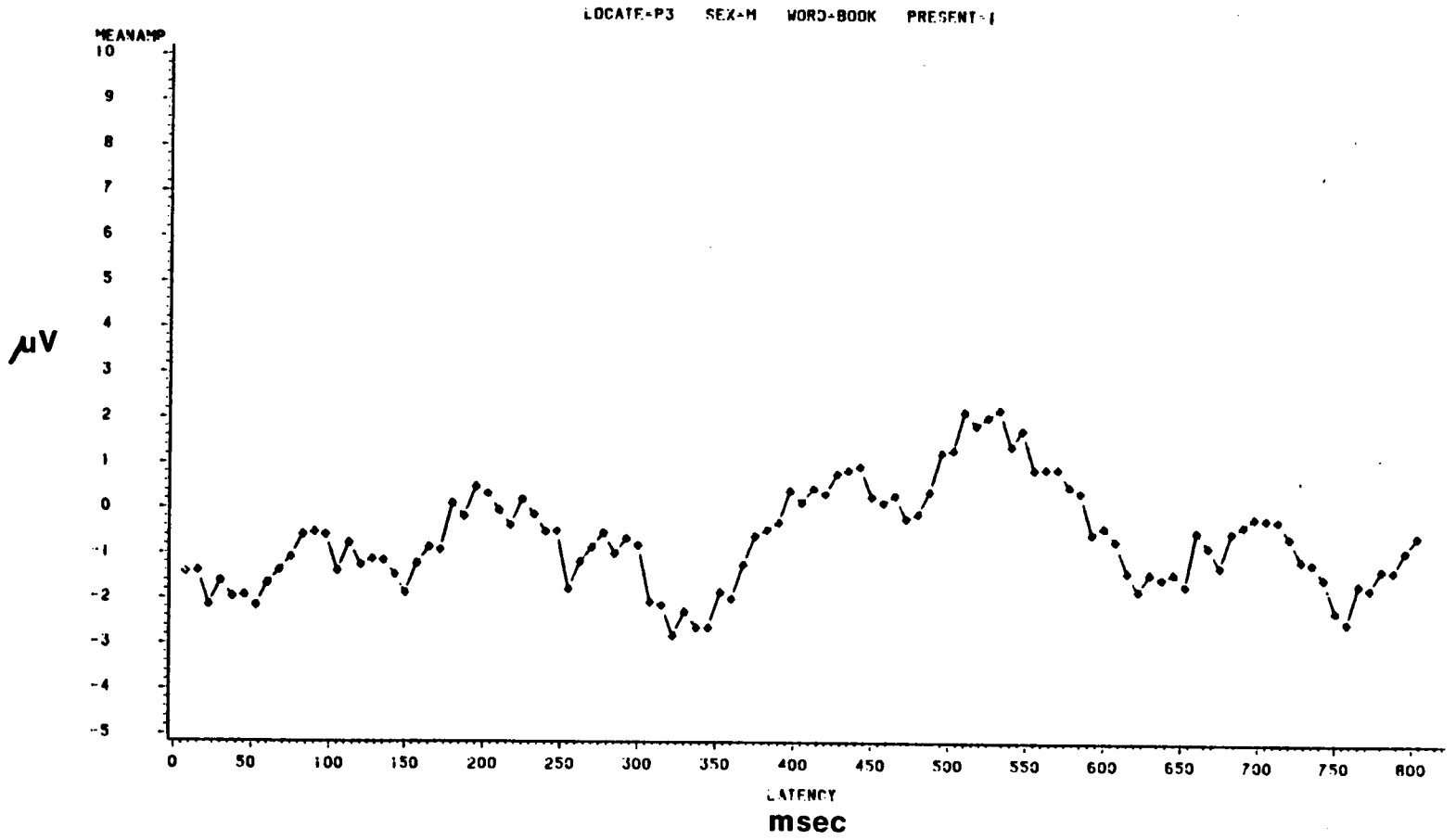

Figure D-47. Average ERP of the male subjects to the first presentation of, "I enjoyed reading the new book," at P3.

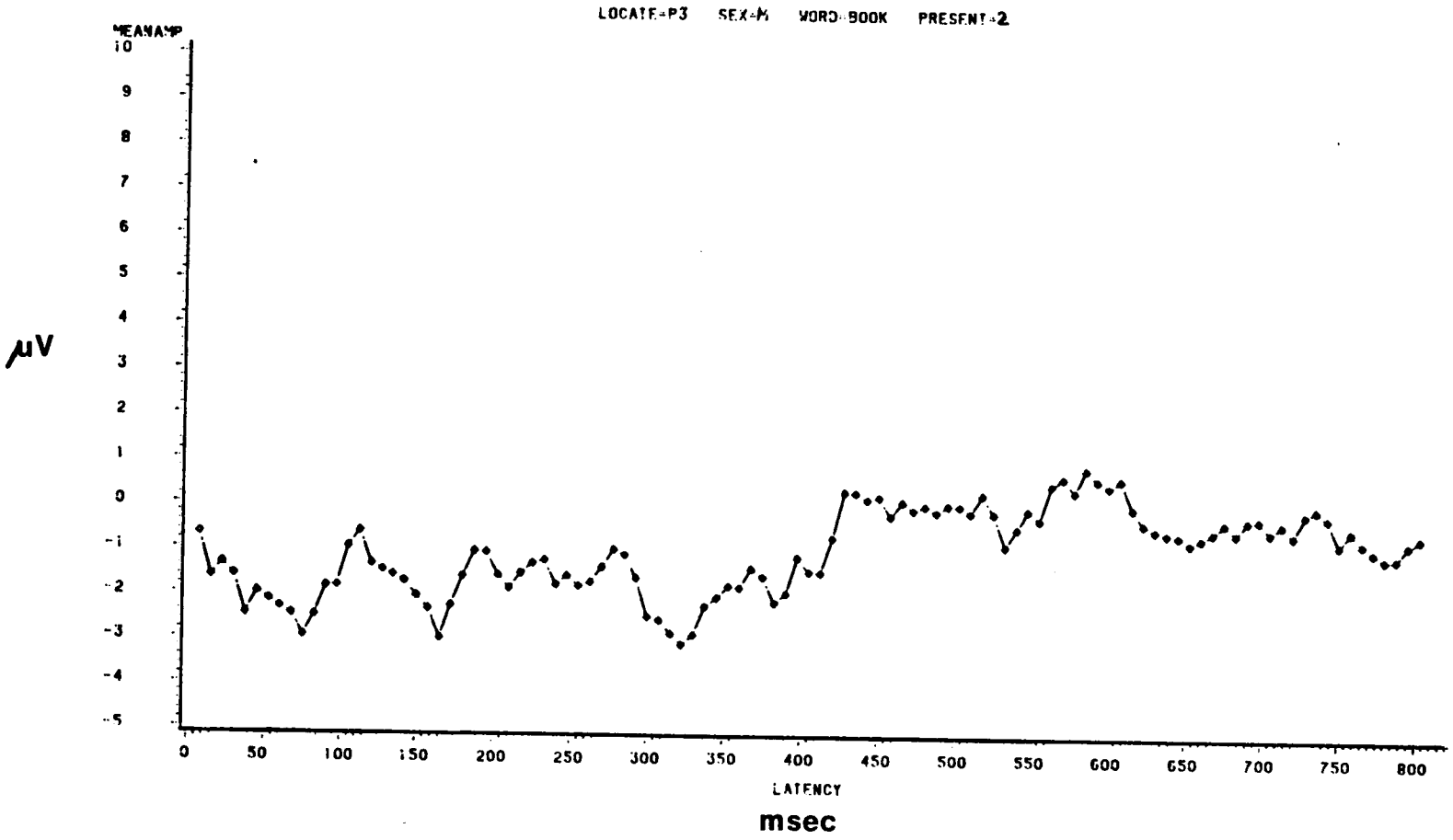

Figure D-48. Average ERP of the male subjects to the second presentation of, "I enjoyed reading the new book," at P3.

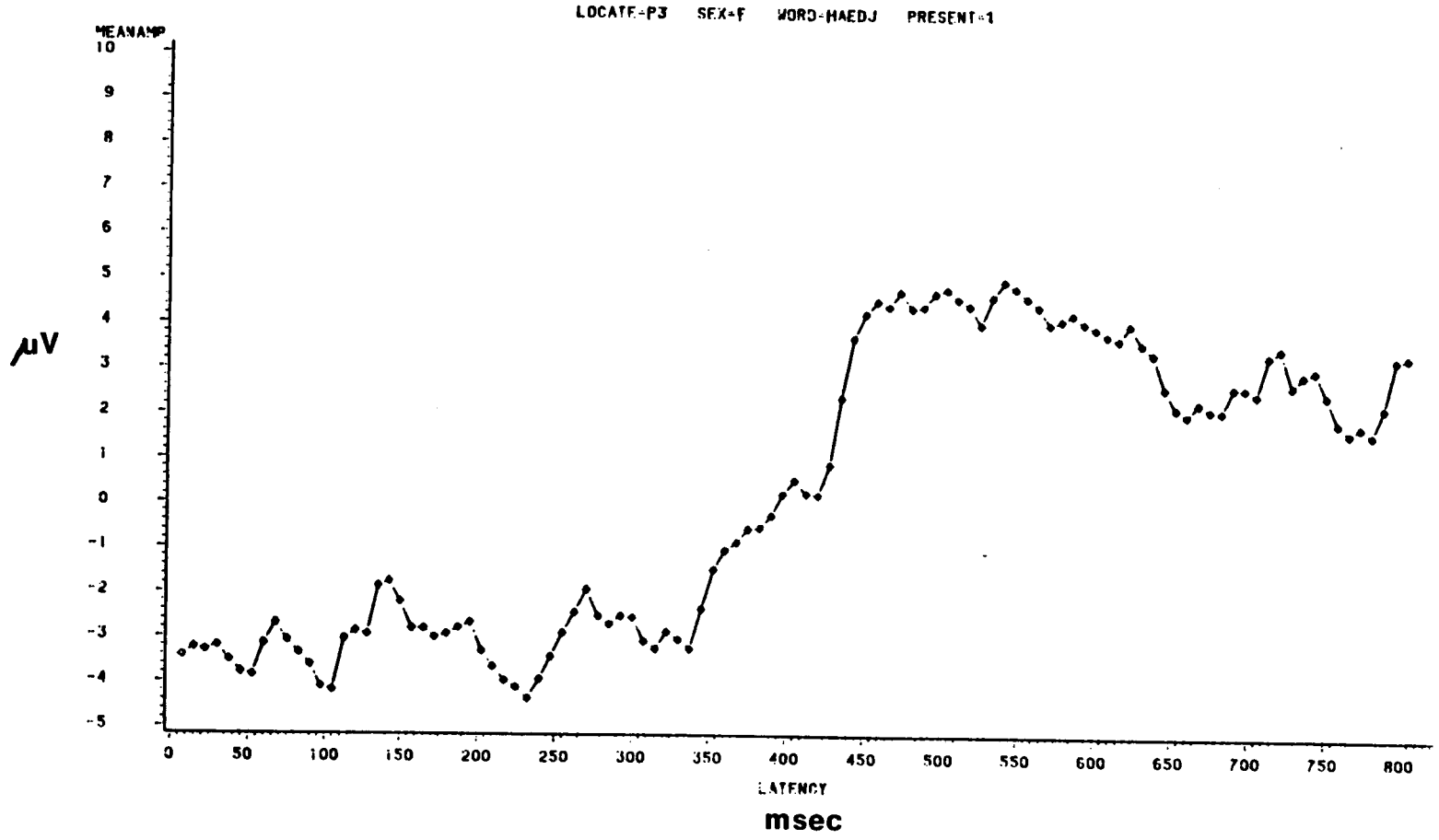

Figure D-49. Average ERP of the female subjects to the first presentation of, "You'll catch cold if you don't wear a /hædʒ/," at P3.

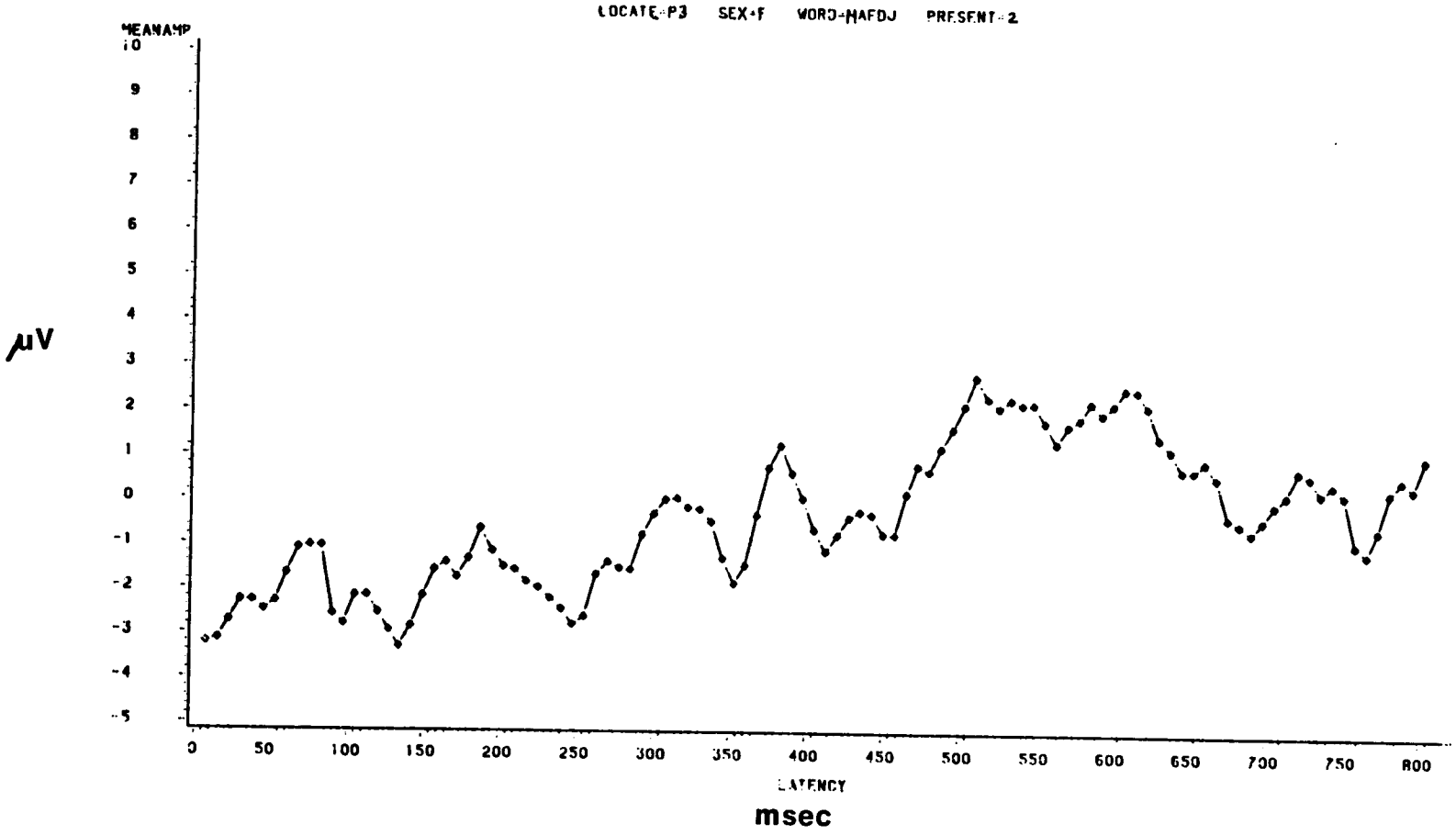

Figure D-50. Average ERP of the female subjects to the second presentation of, "You'll catch cold if you don't wear a /hædʒ/," at P3.

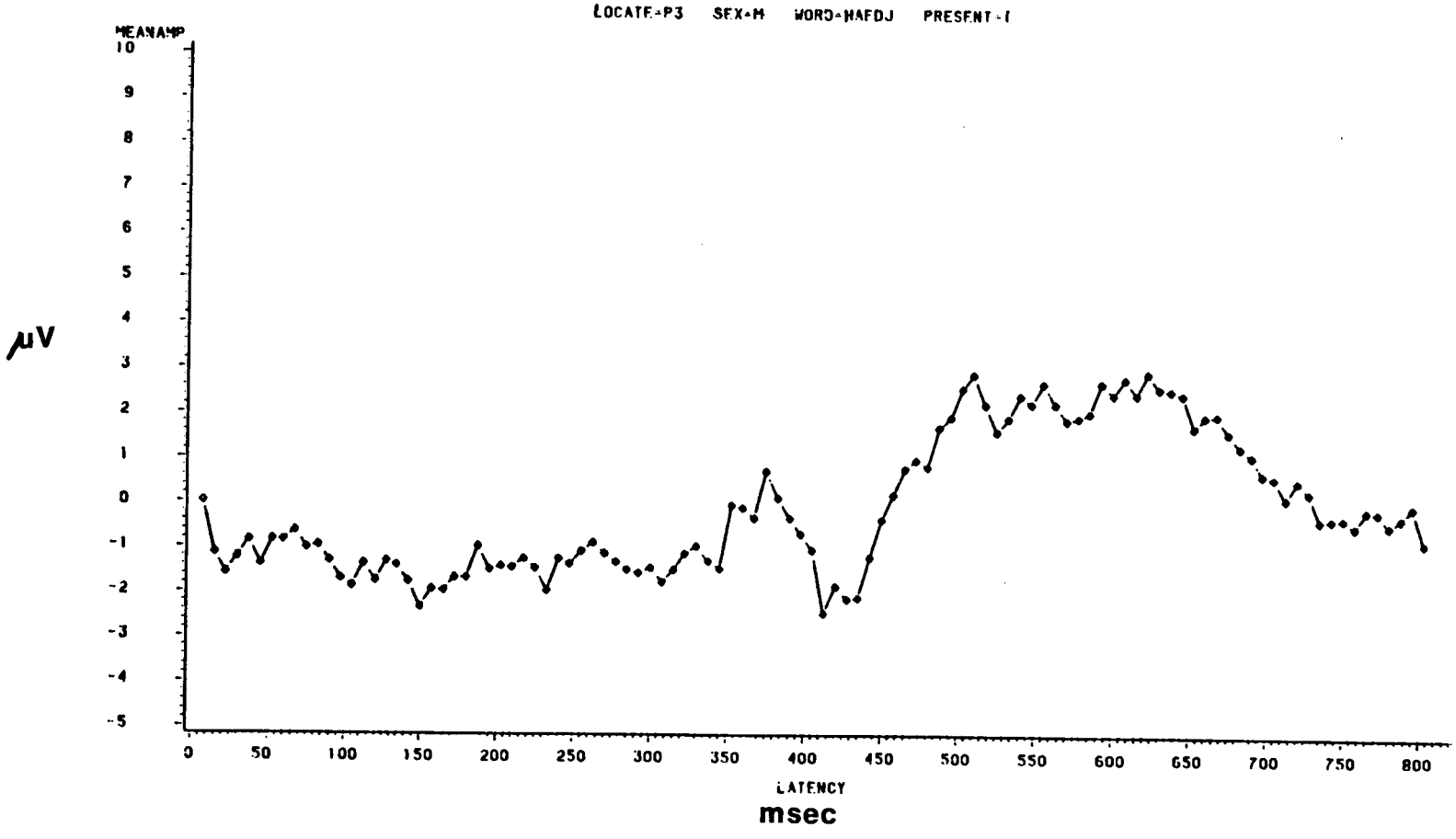

Figure D-51. Average ERP of the male subjects to the first presentation of, "You'll catch cold if you don't wear a /hædʒ/," at P3.

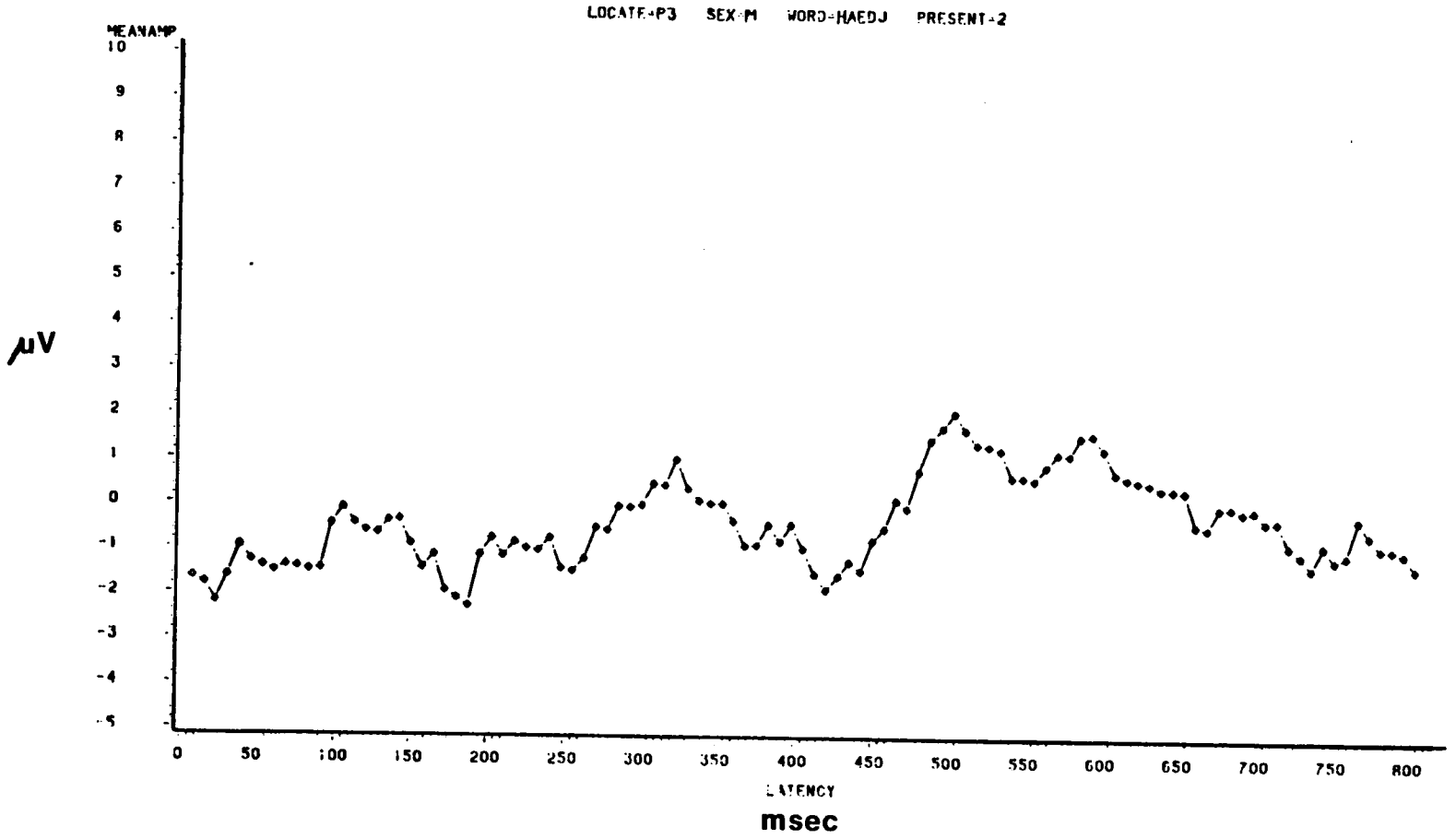

Figure D-52. Average ERP of the male subjects to the second presentation of, "You'll catch cold if you don't wear a /hædʒ/," at P3.

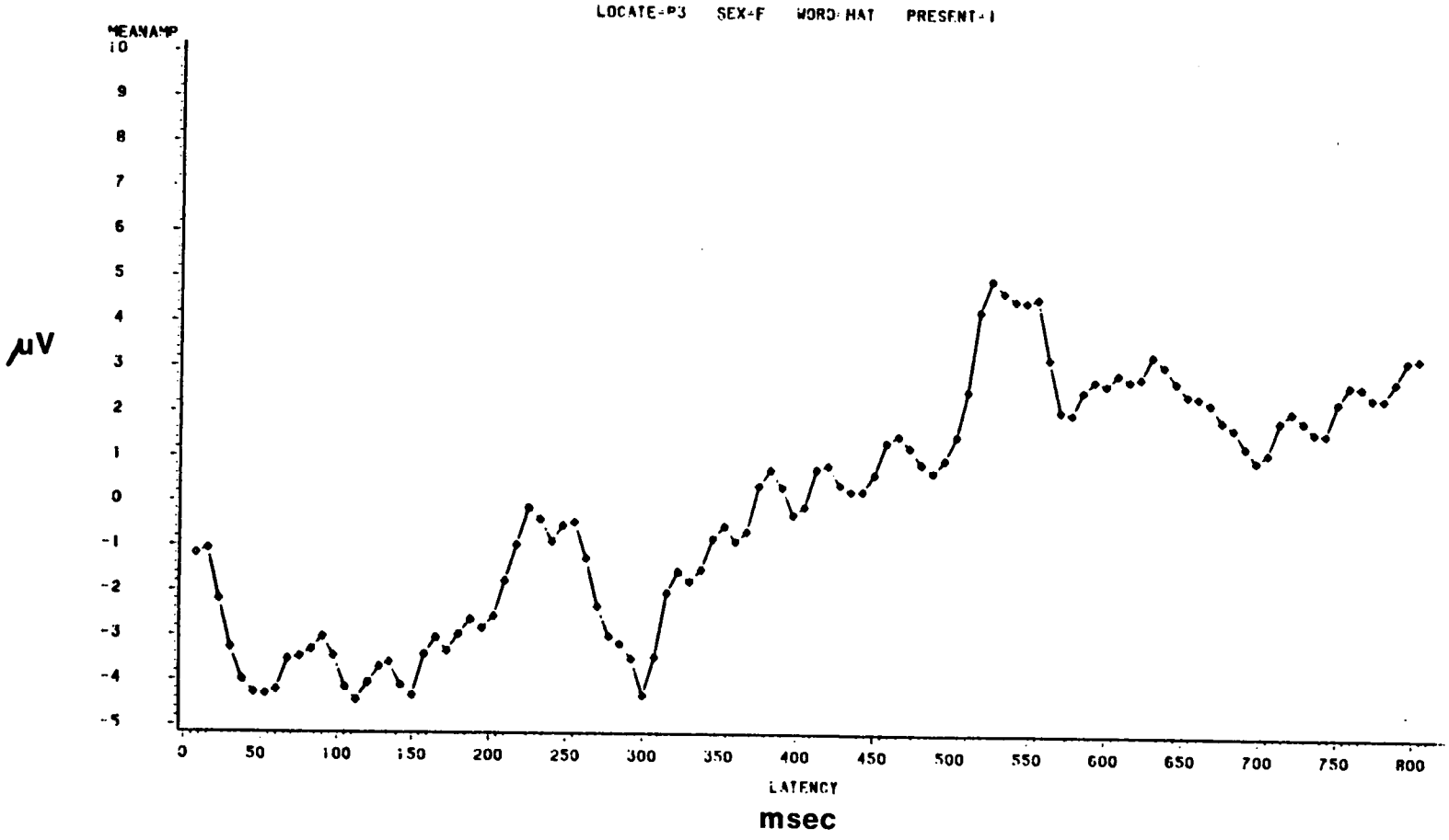

Figure D-53. Average ERP of the female subjects to the first presentation of, "You'll catch cold if you don't wear a hat," at P3.

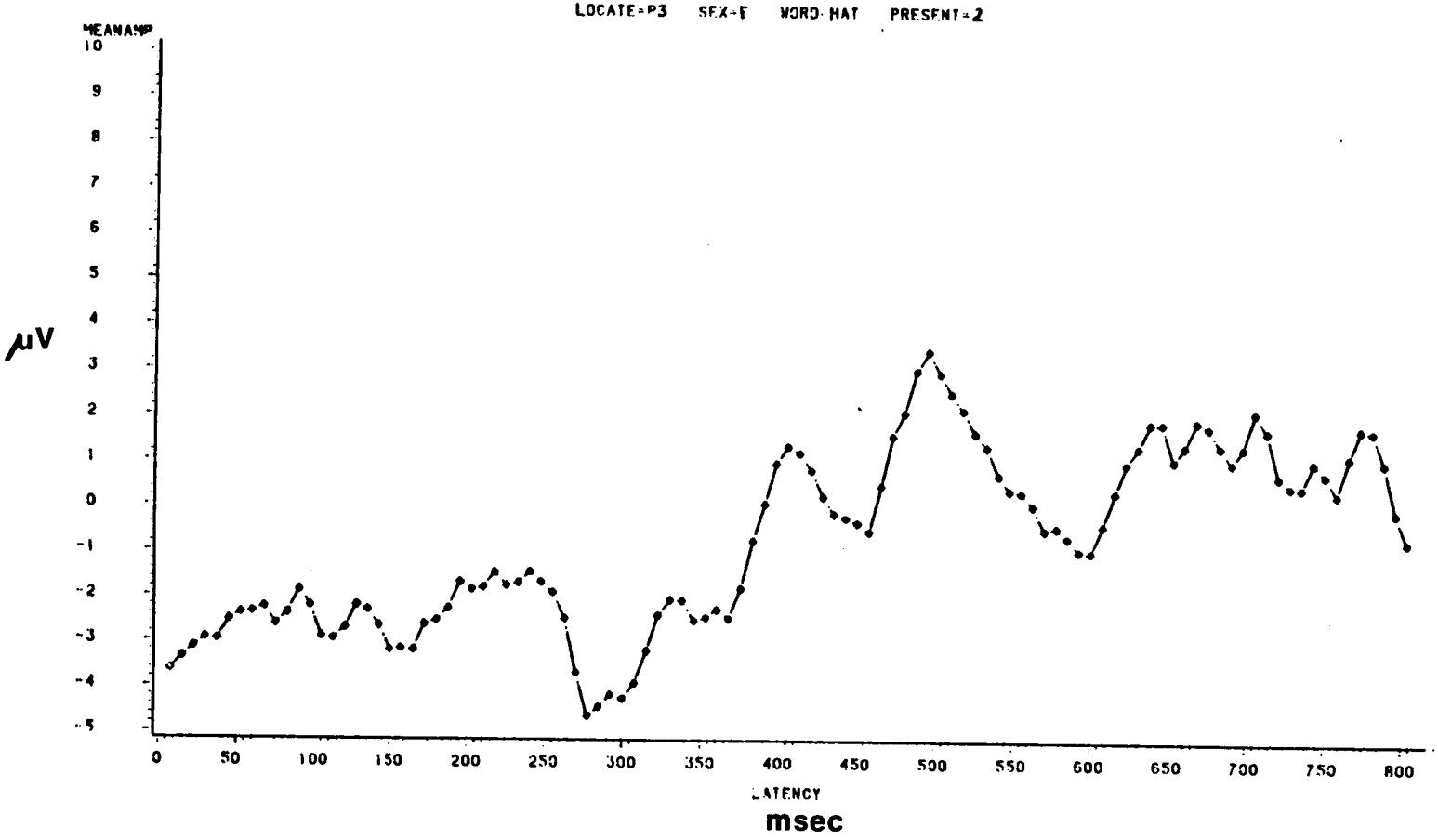

Figure D-54. Average ERP of the female subjects to the second presentation of, "You'll catch cold if you don't wear a hat," at P3.

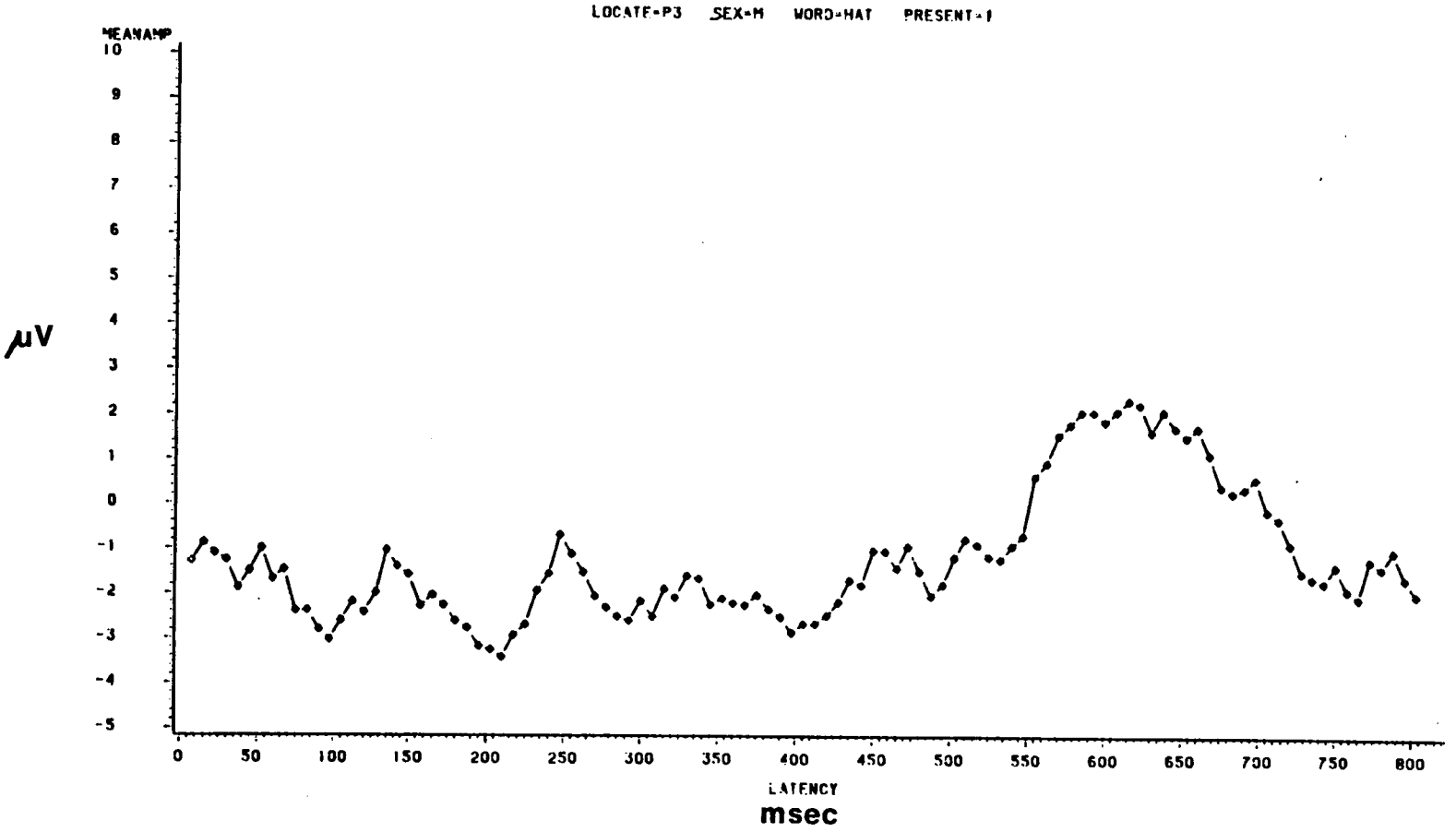

Figure D-55. Average ERP of the male subjects to the first presentation of, "You'll catch cold if you don't wear a hat," at P3.

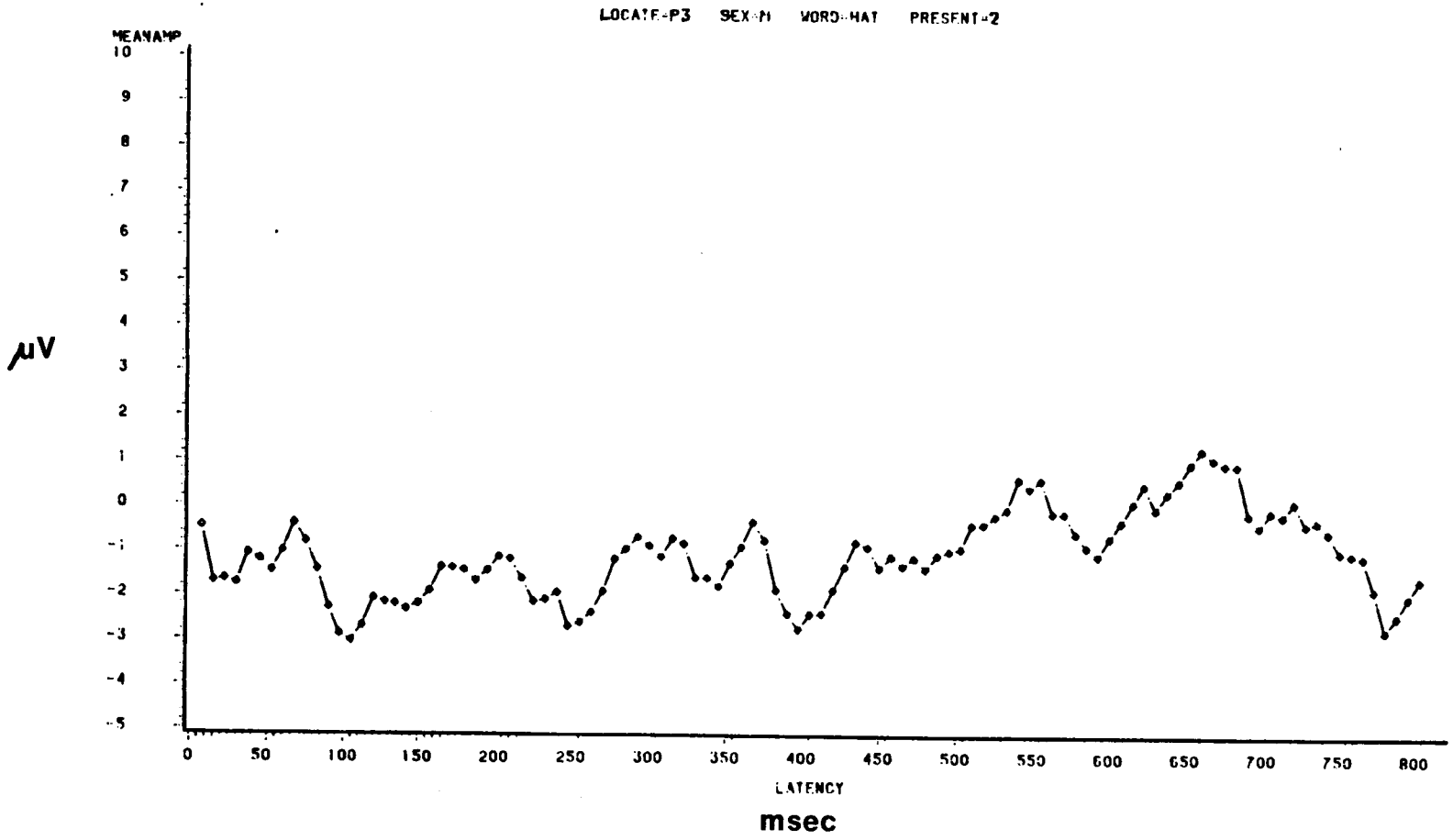

Figure D-56. Average ERP of the male subjects to the second presentation of, "You'll catch cold if you don't wear a hat," at P3.

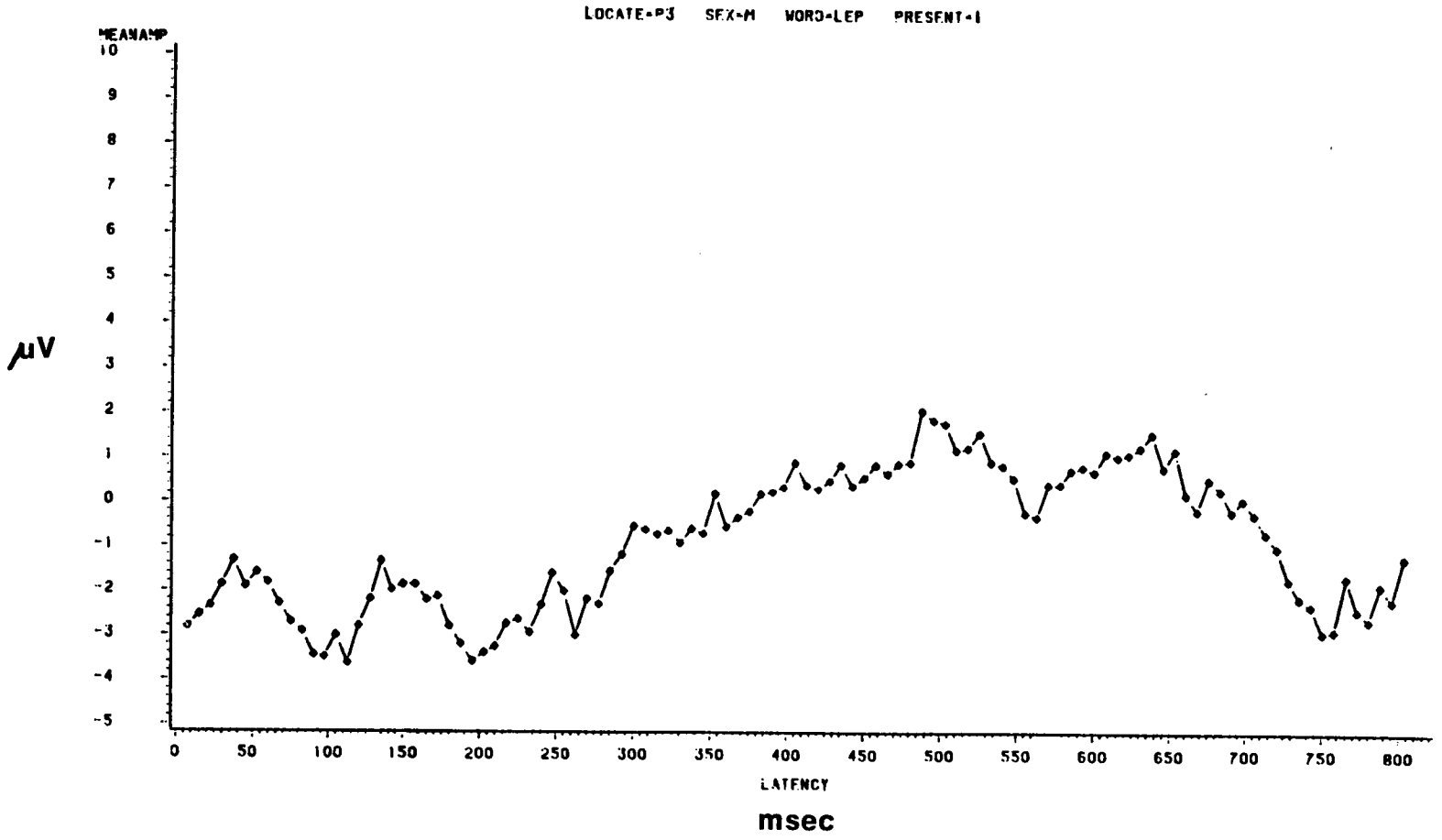

Figure D-57. Average ERP of the female subjects to the first presentation of, "John fell down and broke his /lep/," at P3.

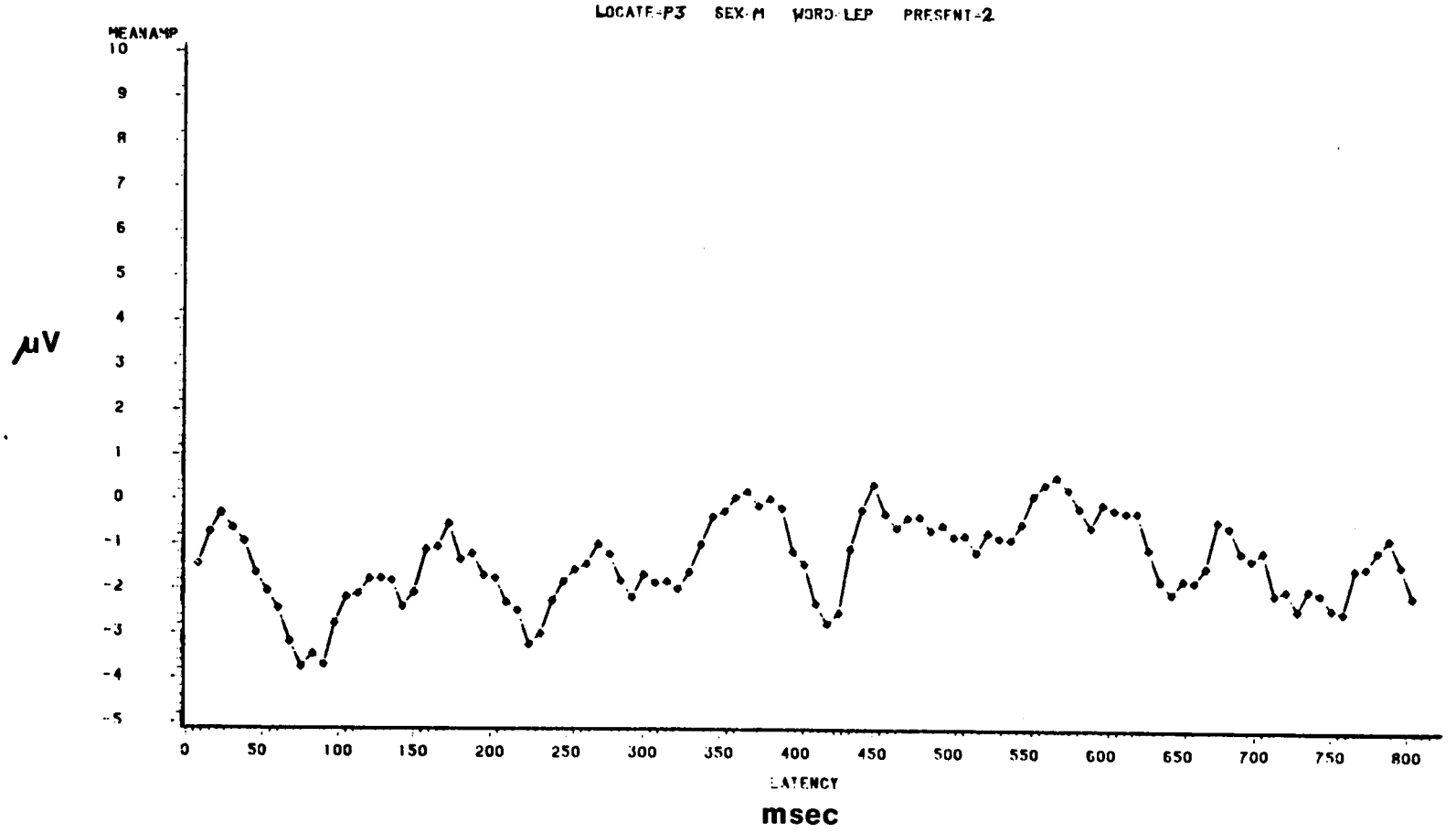

Figure D-58. Average ERP of the female subjects to the second presentation of, "John fell down and broke his /lep/," at P3.

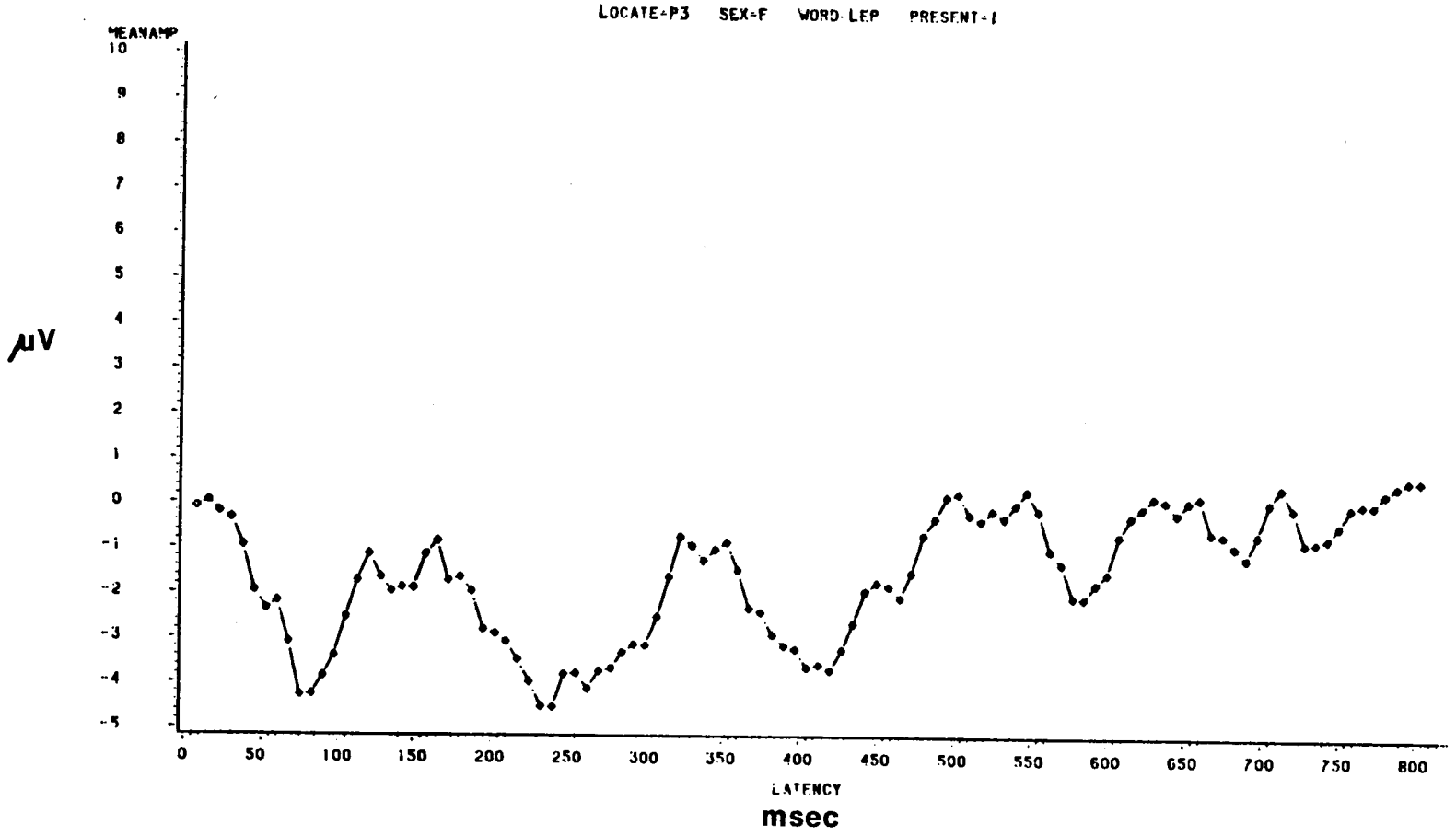

Figure D-59. Average ERP of the male subjects to the first presentation of, "John fell down and broke his /lep/," at P3.

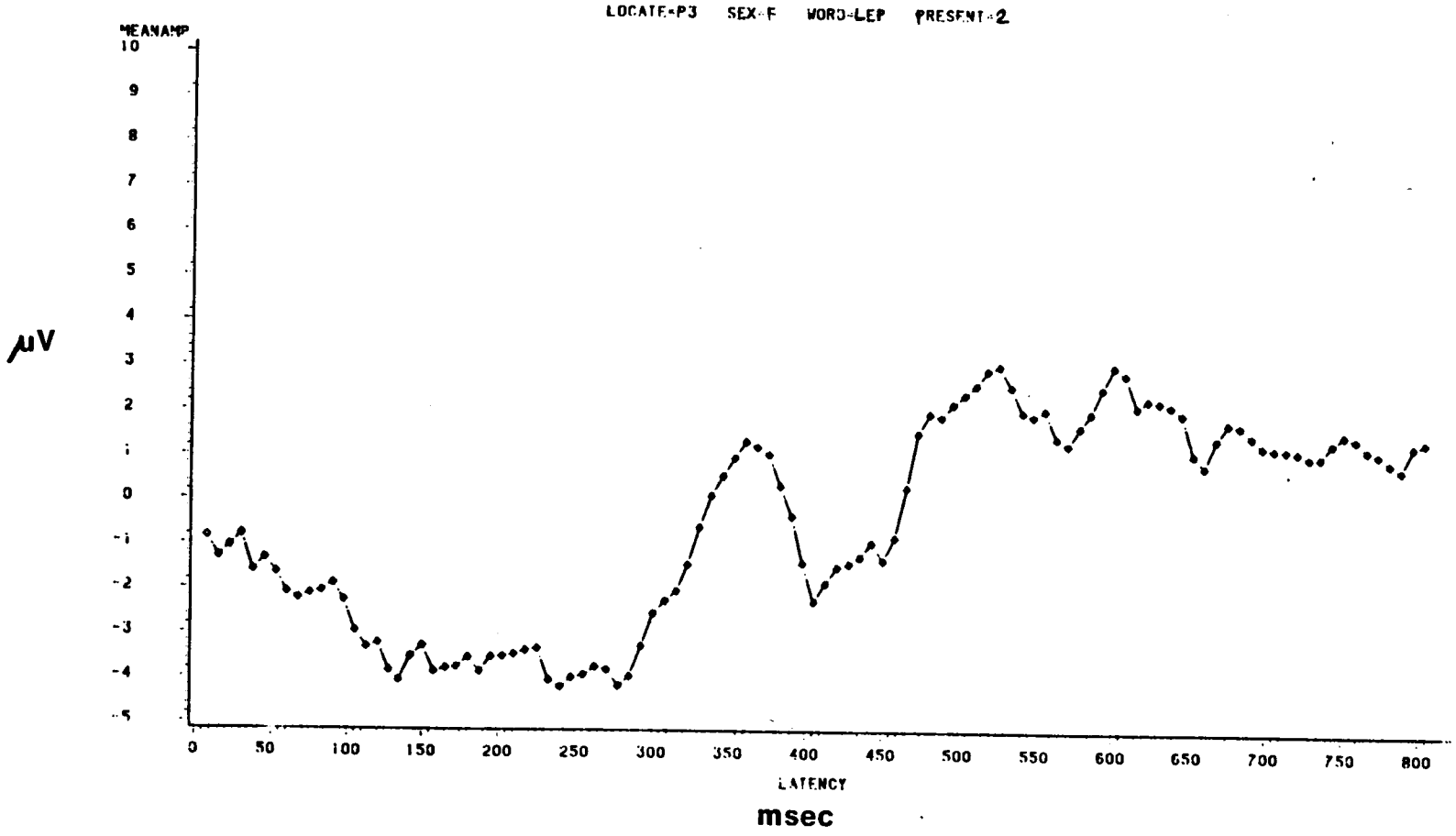

Figure D-60. Average ERP of the male subjects to the second presentation of, "John fell down and broke his /lep/," at P3.

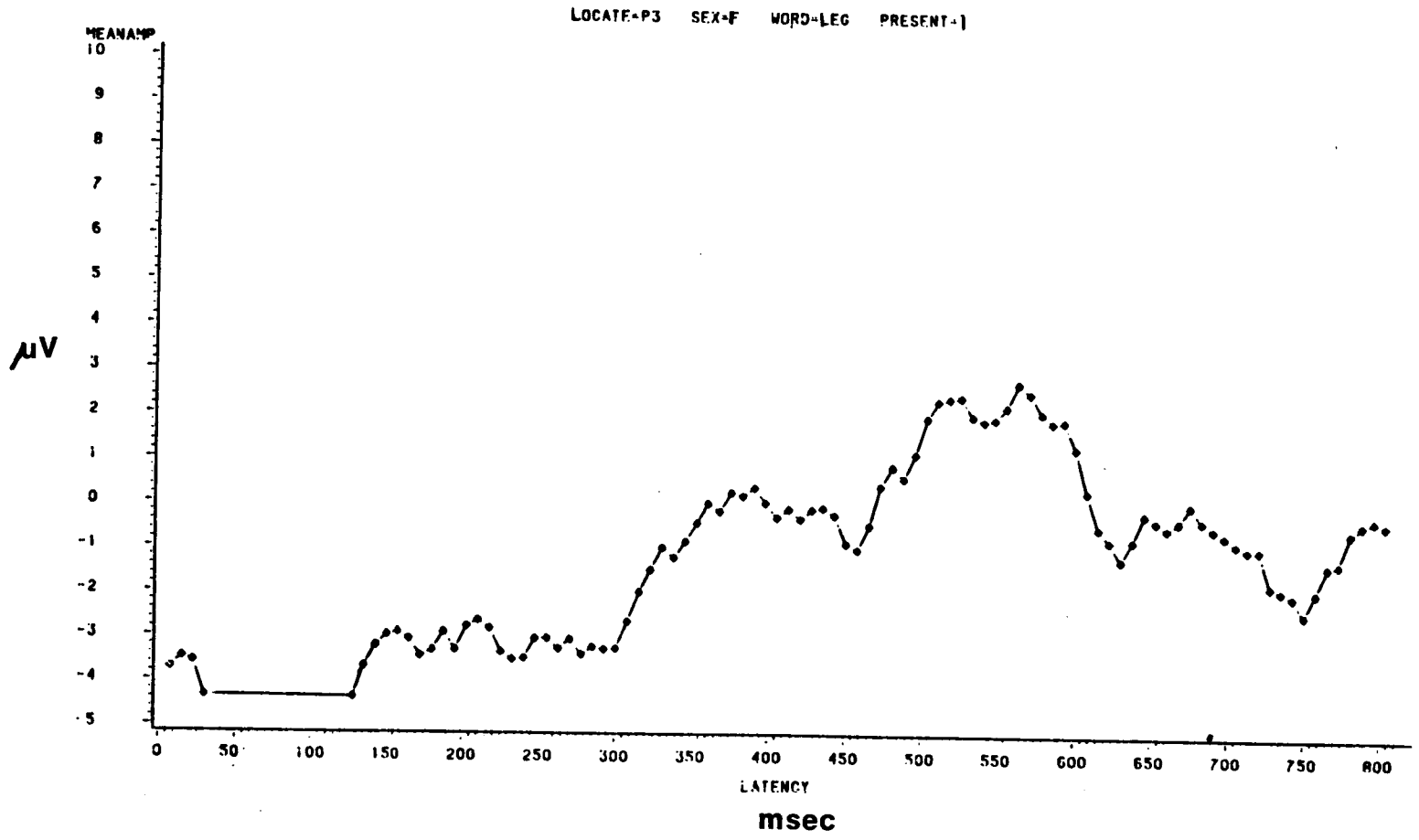

Figure D-61. Average ERP of the female subjects to the first presentation of, "John fell down and broke his leg," at P3.

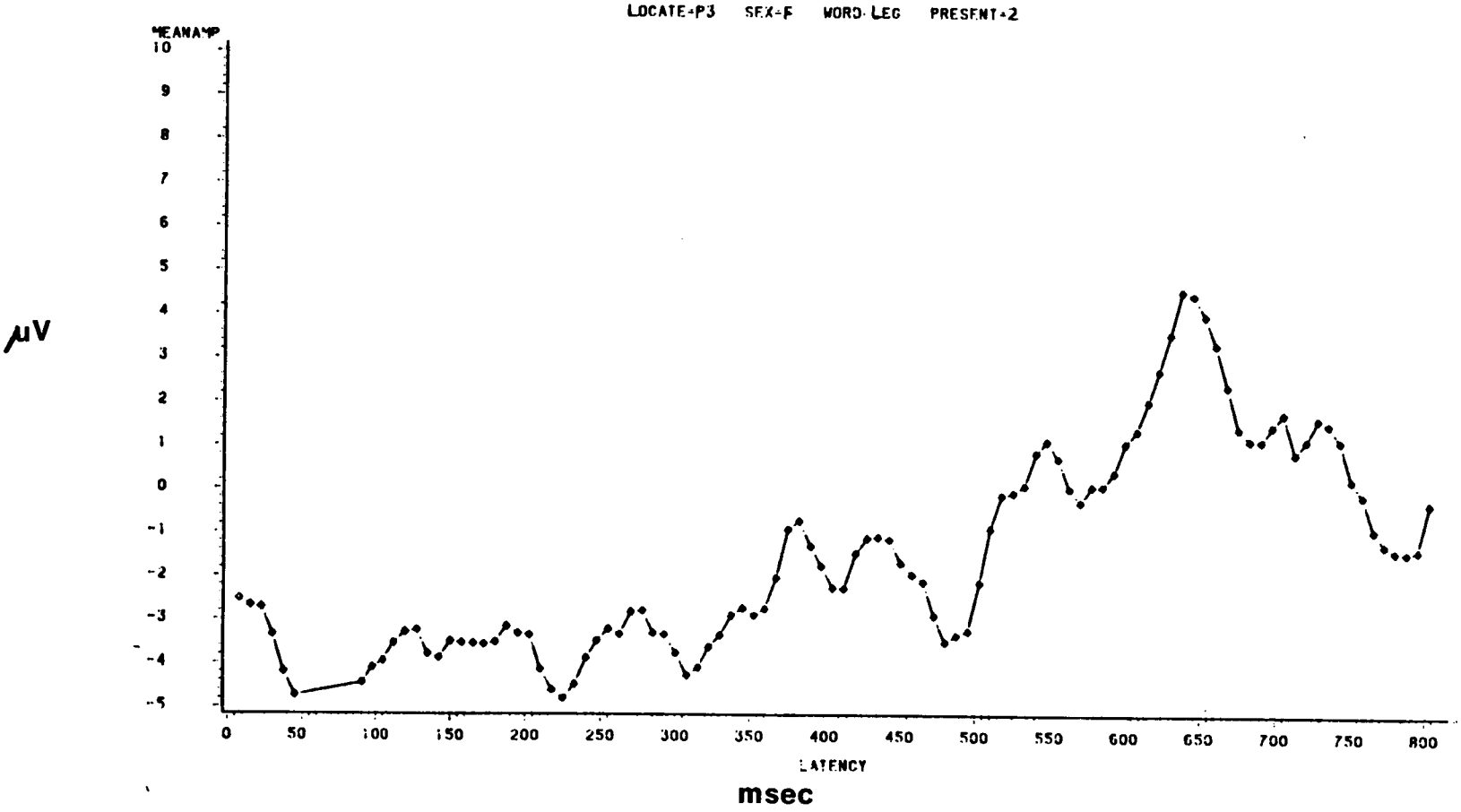

Figure D-62. Average ERP of the female subjects to the second presentation of, "John fell down and broke his leg," at P3.

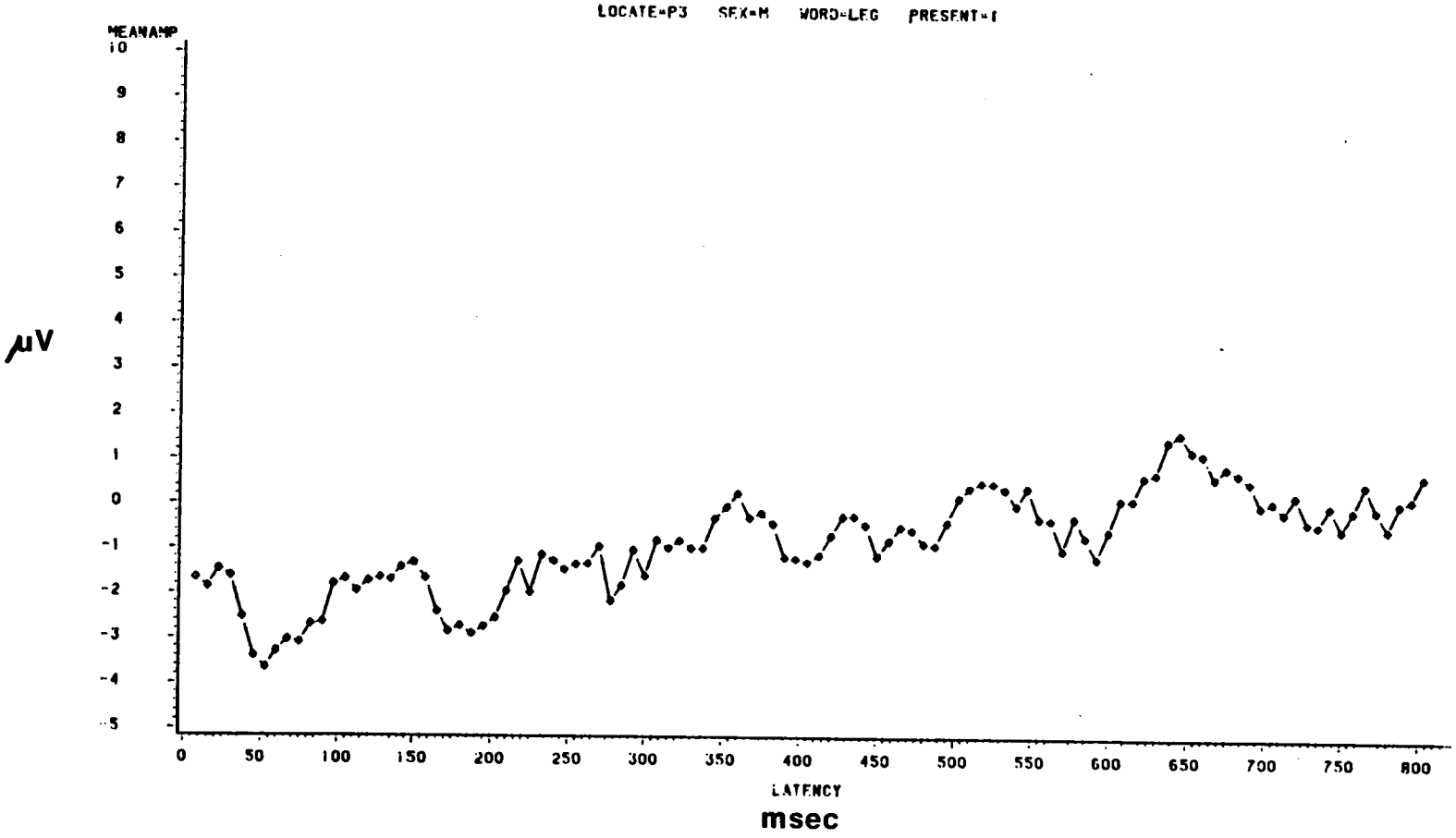

Figure D-63. Average ERP of the male subjects to the first presentation of, "John fell down and broke his leg," at P3.

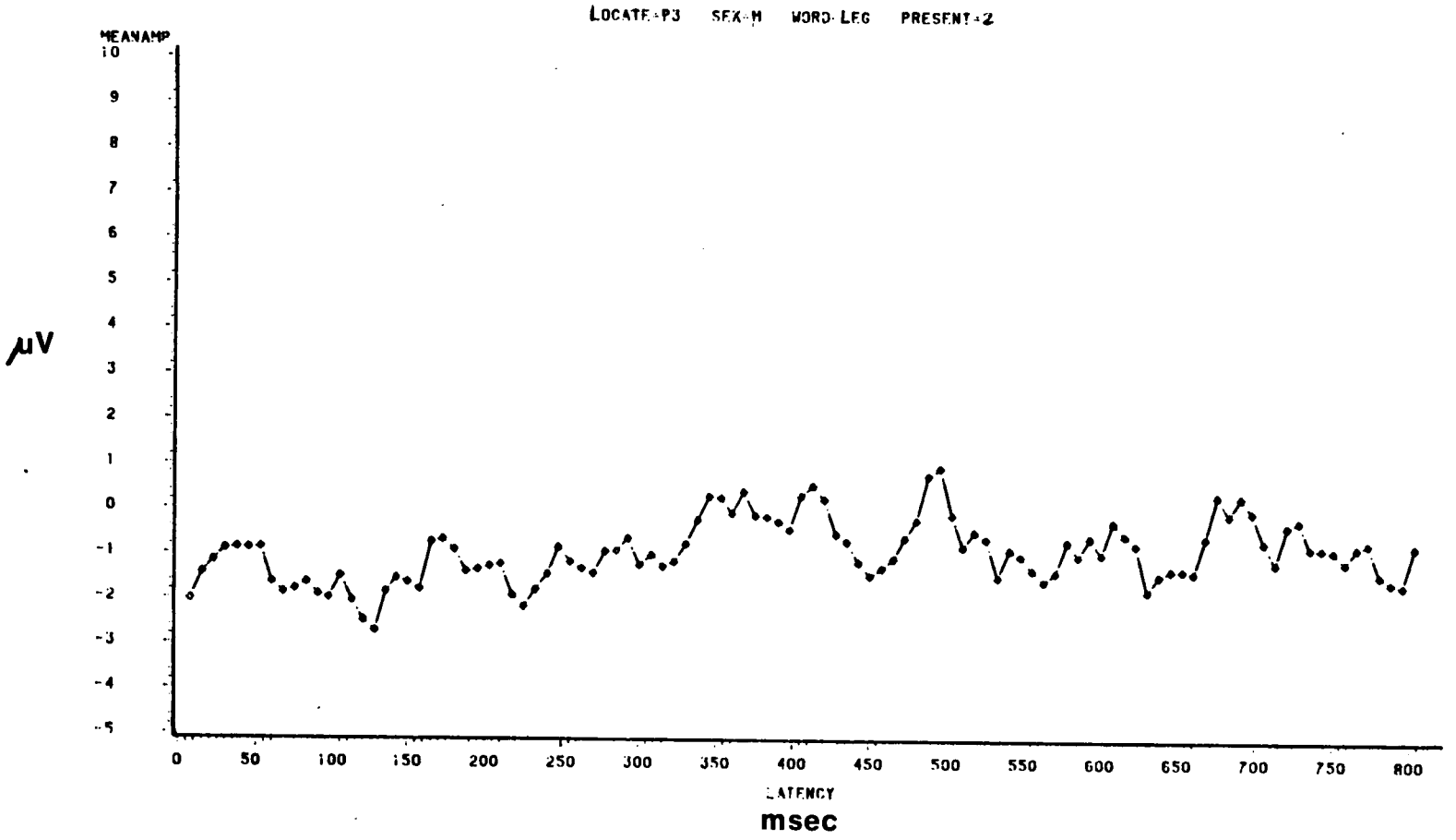

Figure D-64. Average ERP of the male subjects to the second presentation of, "John fell down and broke his leg," at P3.

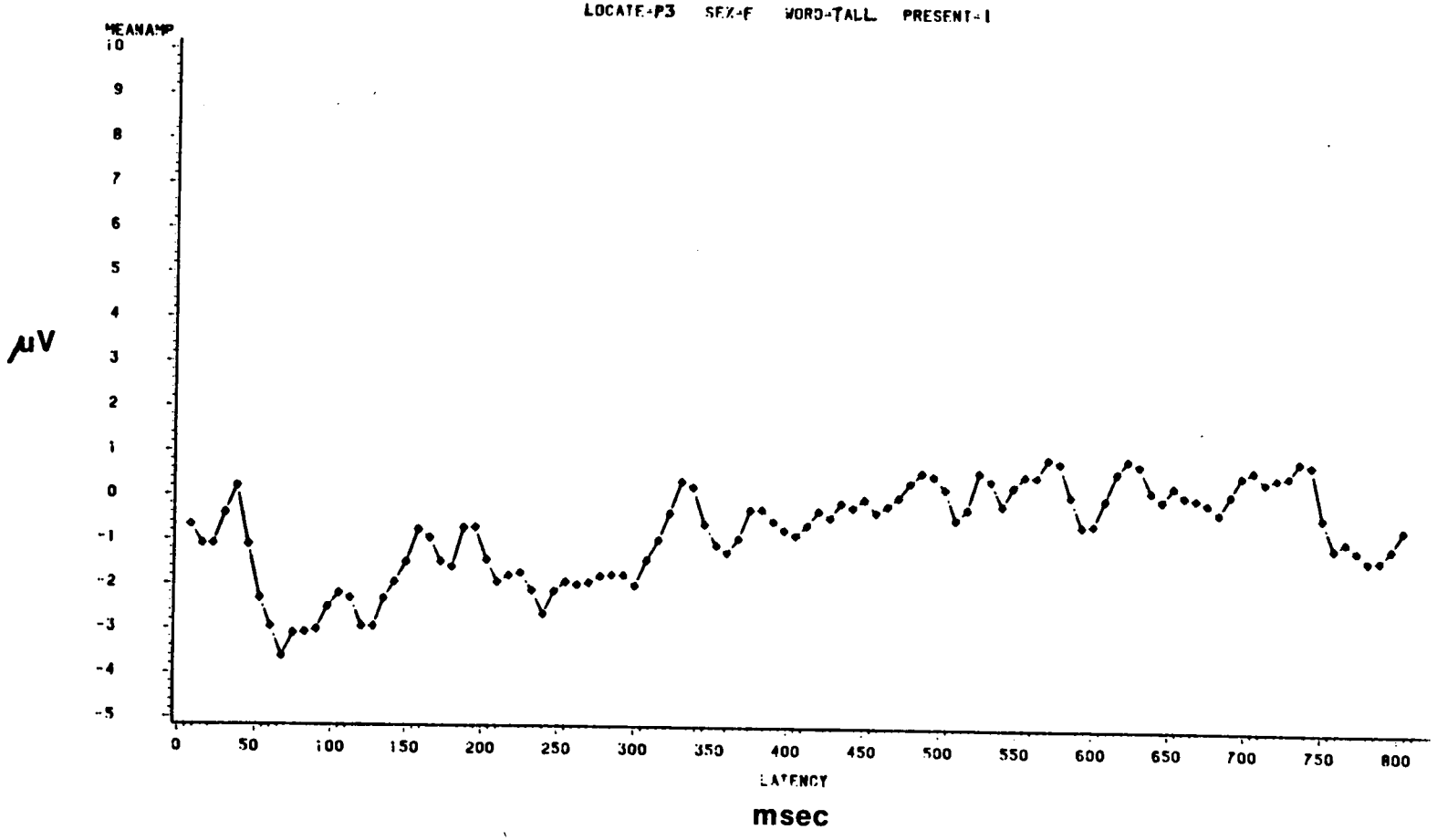

Figure D-65. Average ERP of the female subjects to the first presentation of, "The flowers smell tall," at P3.

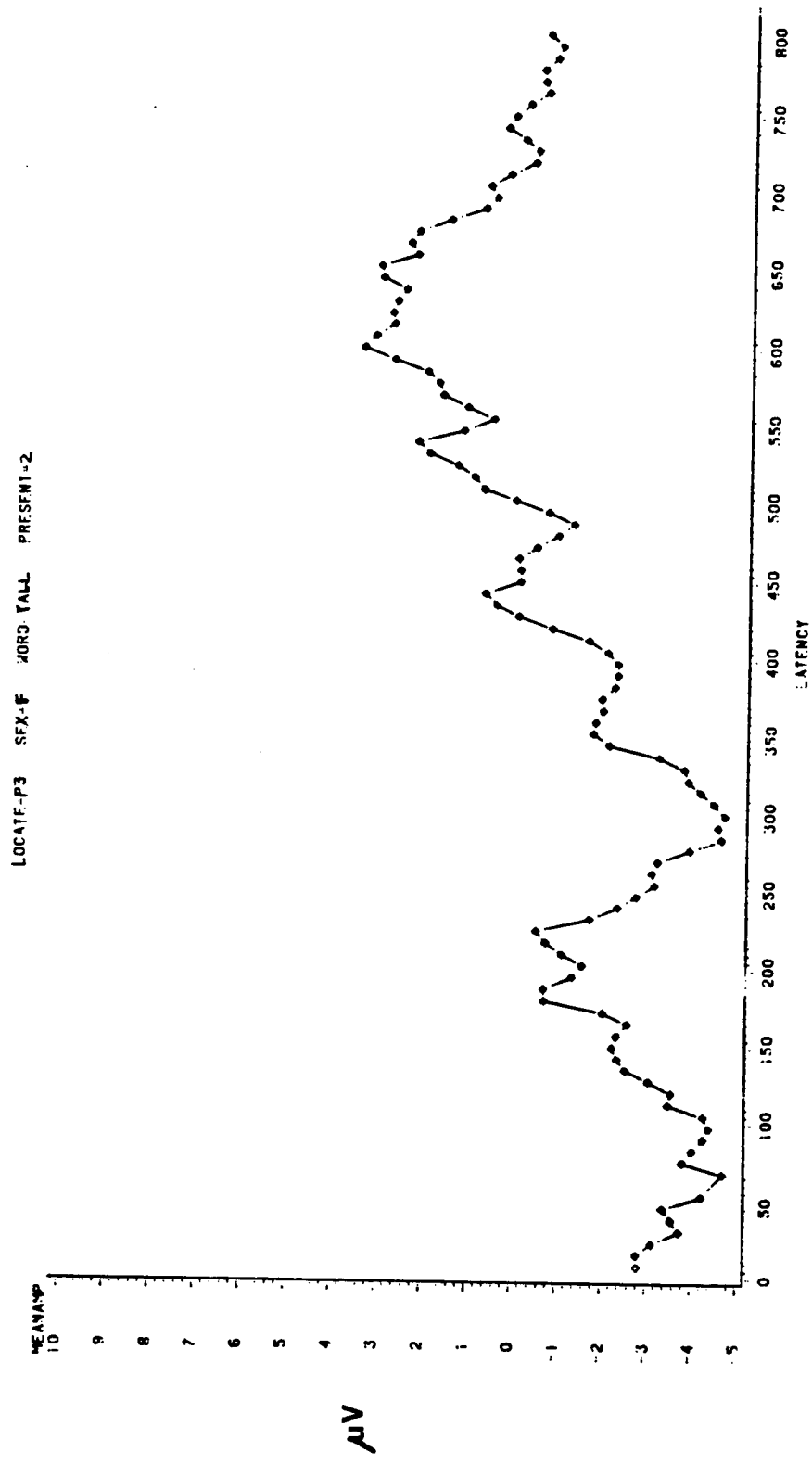

Figure D-66. Average ERP of the female subjects to the second presentation of, "The flowers smell tall," at P3.

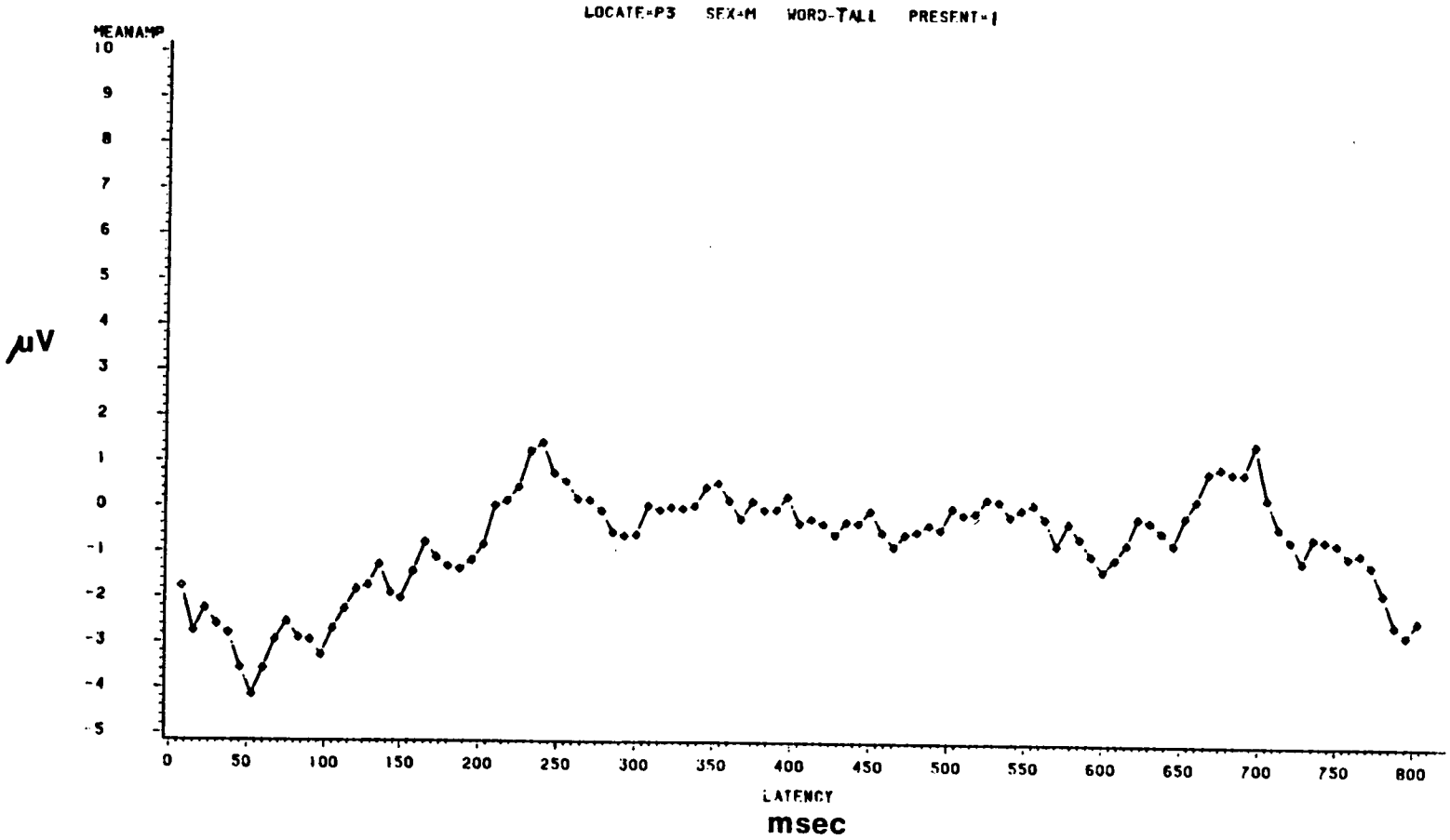

Figure D-67. Average ERP of the male subjects to the first presentation of, "The flowers smell tall," at P3.

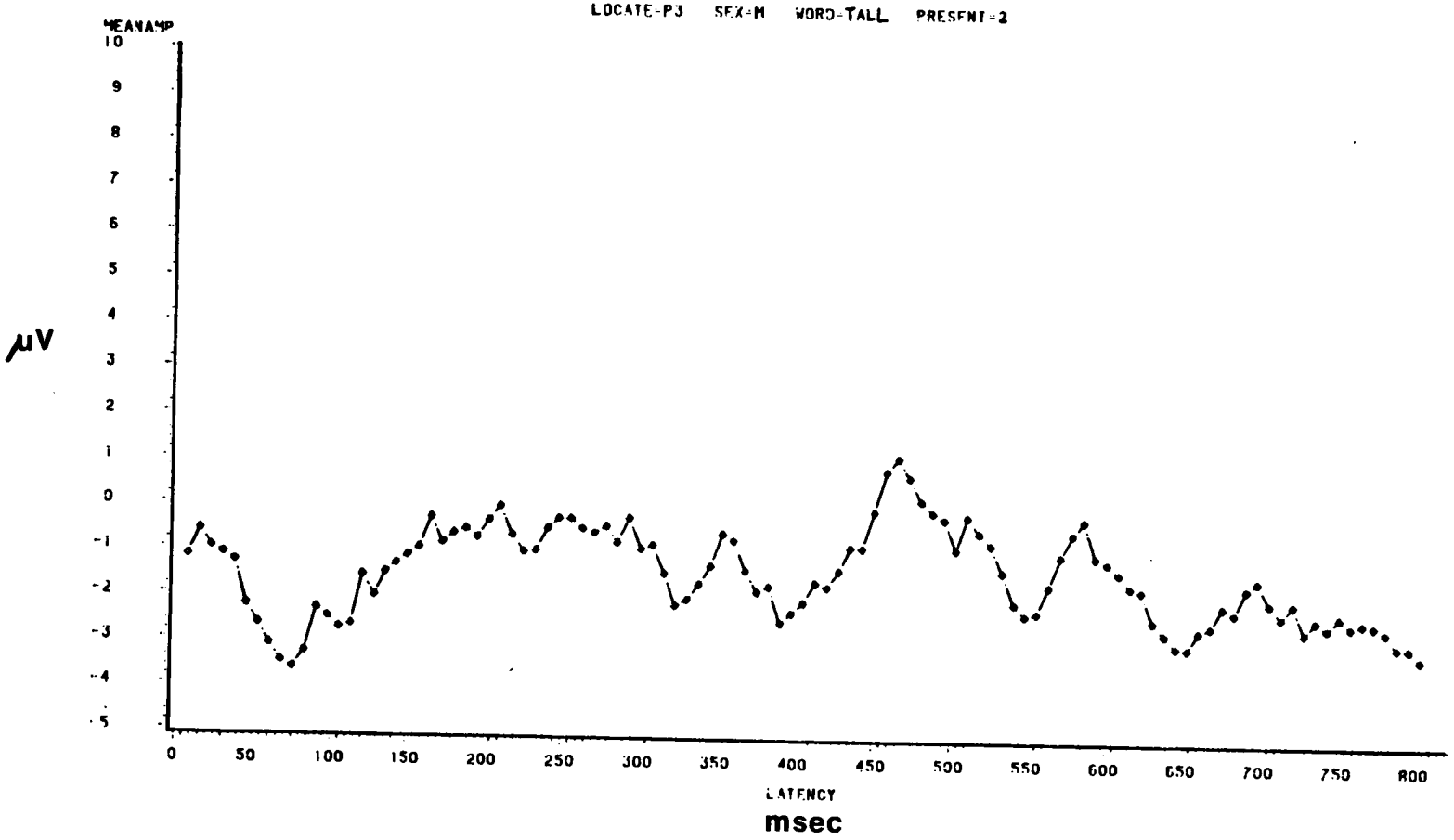

Figure D-68. Average ERP of the male subjects to the second presentation of, "The flowers smell tall," at P3.

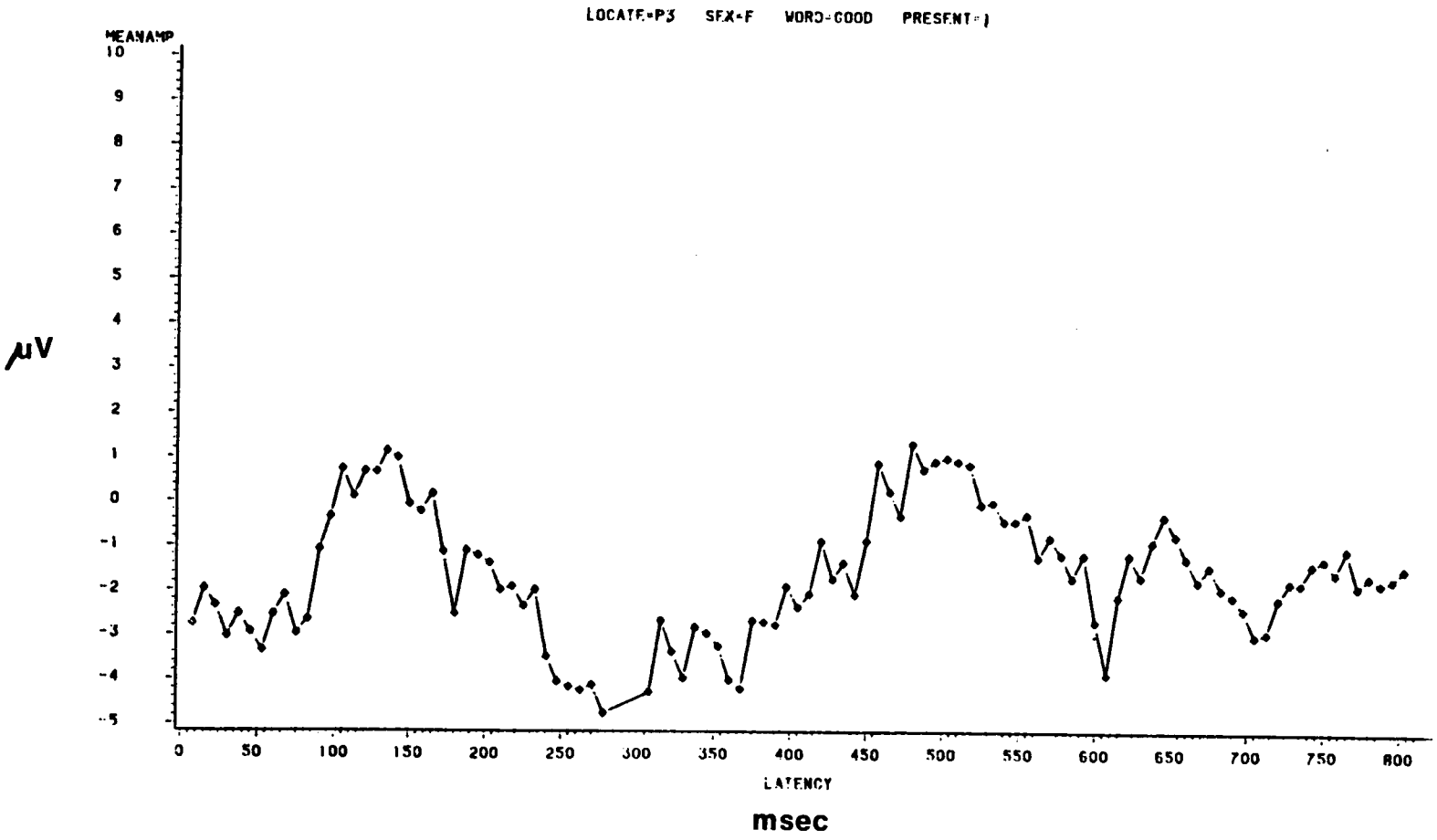

Figure D-69. Average ERP of the female subjects to the first presentation of, "The flowers smell good," at P3.

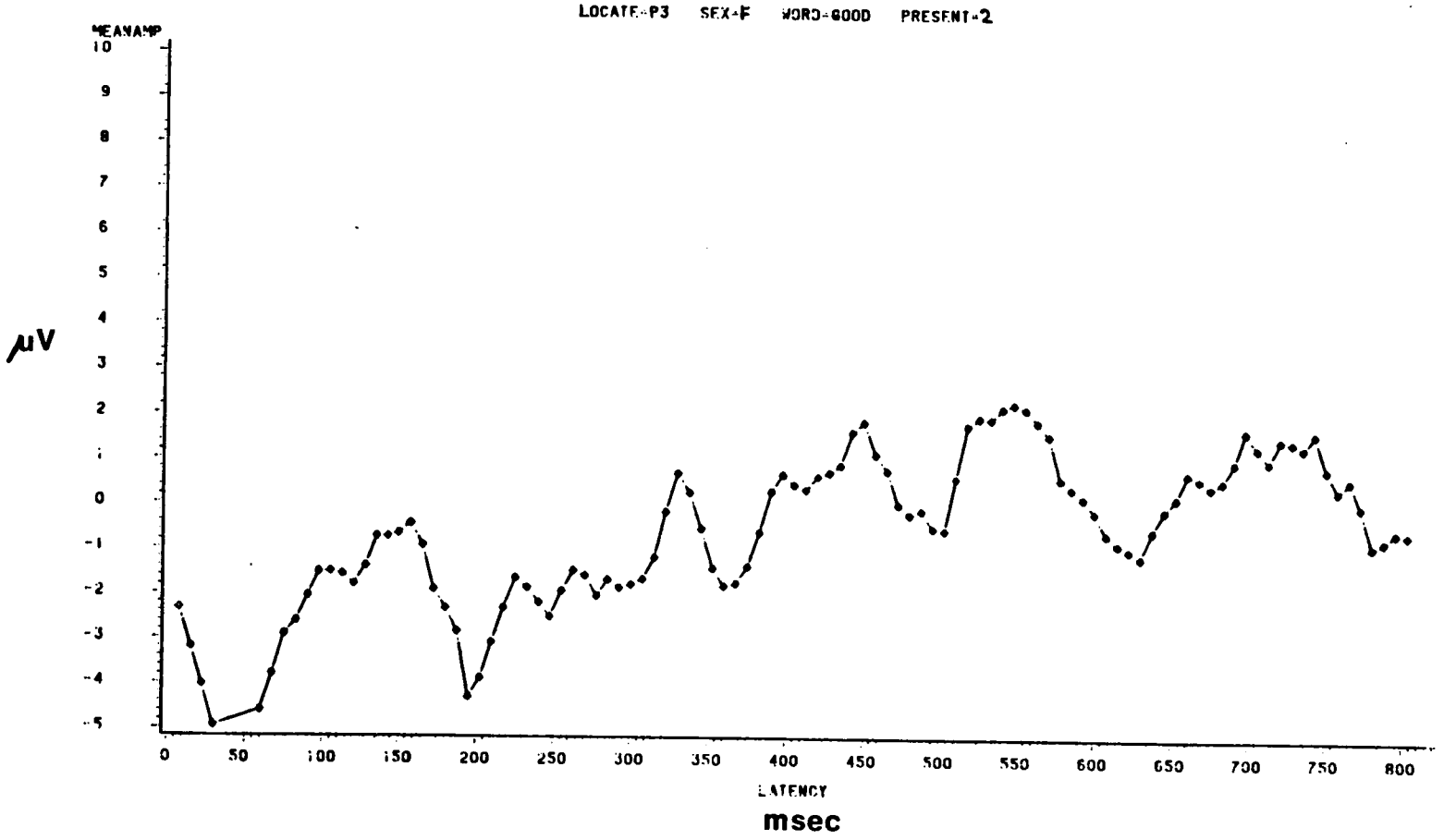

Figure D-70. Average ERP of the female subjects to the second presentation of, "The flowers smell good," at P3.

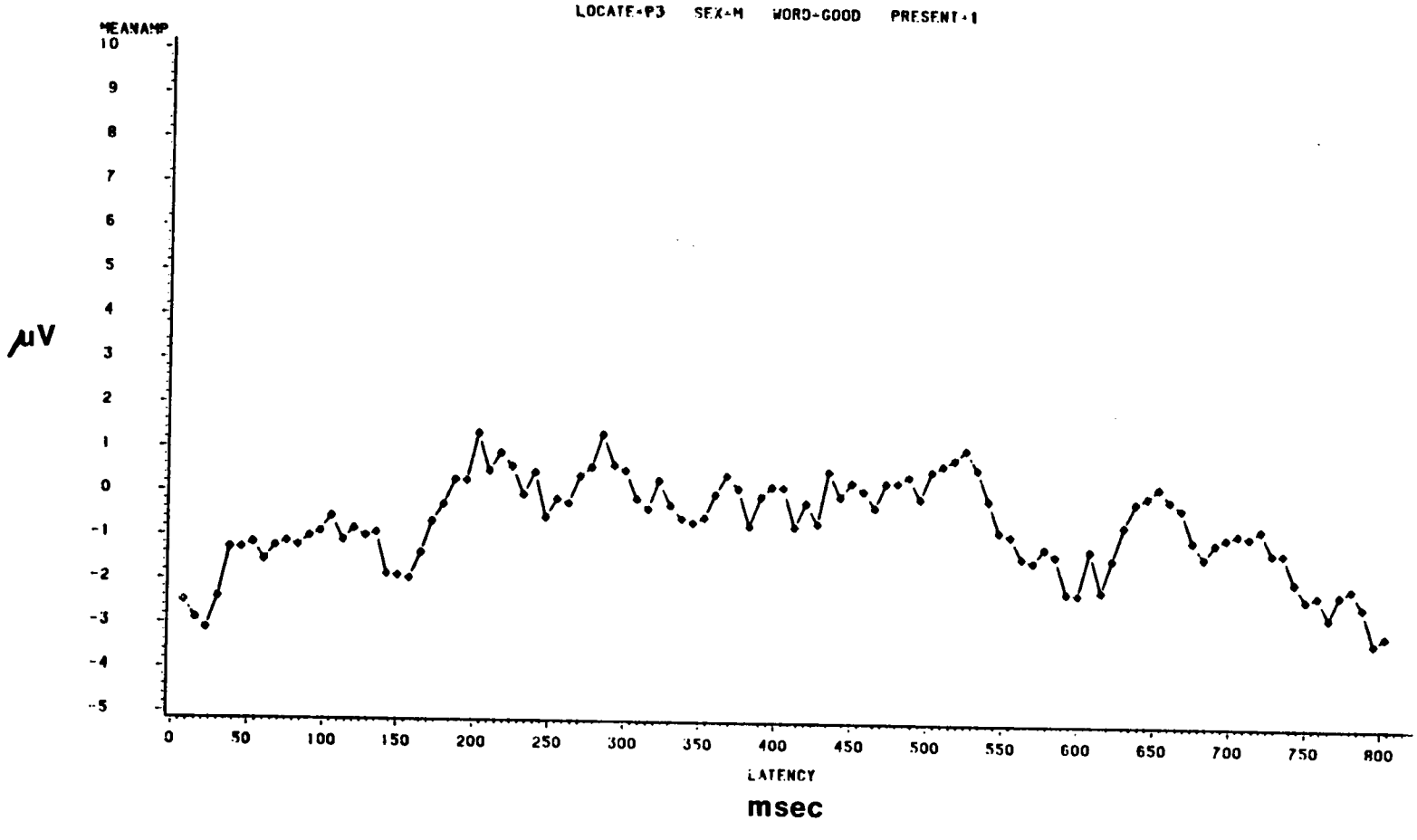

Figure D-71. Average ERP of the male subjects to the first presentation of, "The flowers smell <u>good</u>," at P3.

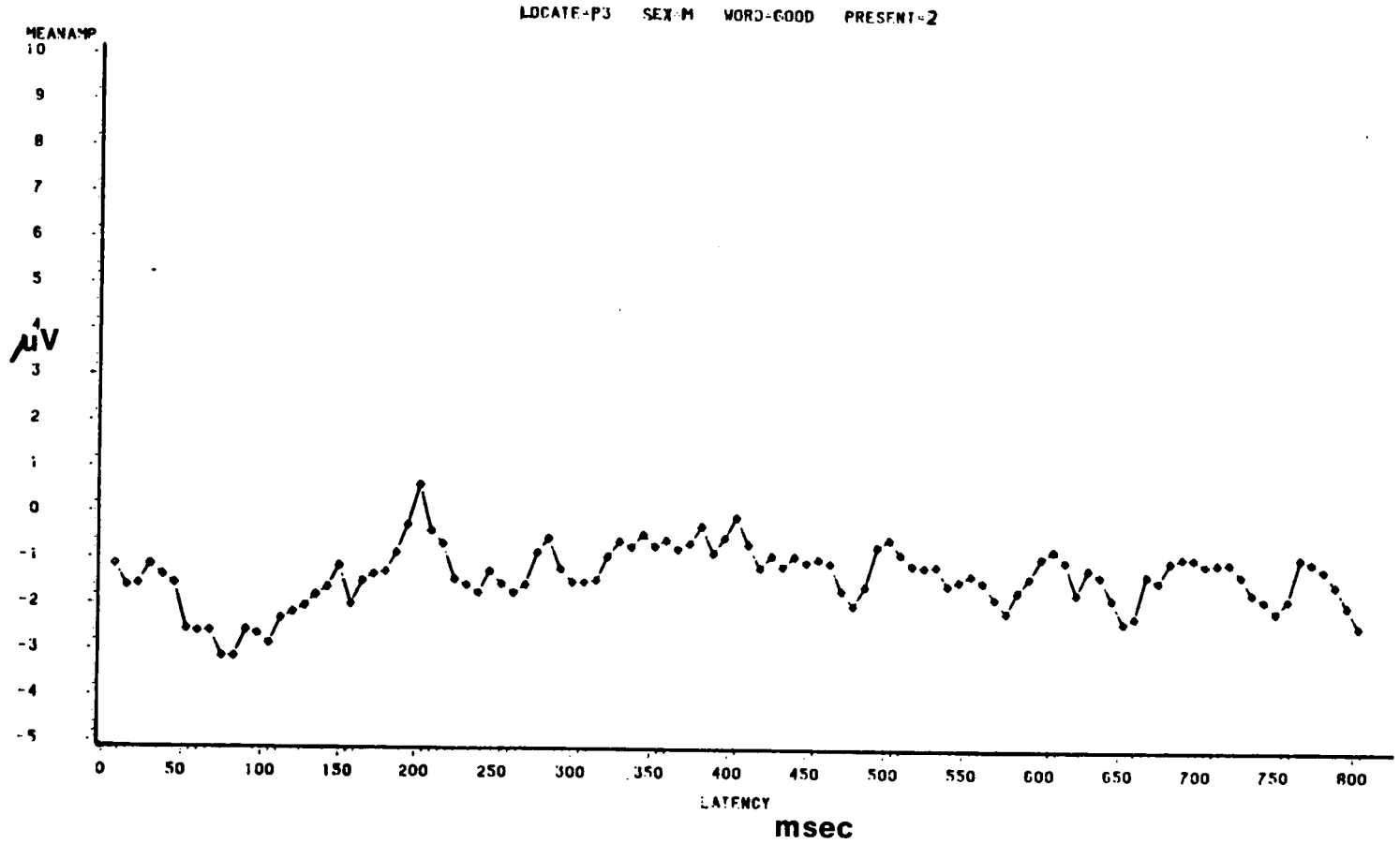

Figure D-72. Average ERP of the male subjects to the second presentation of, "The flowers smell <u>good</u>," at P3.

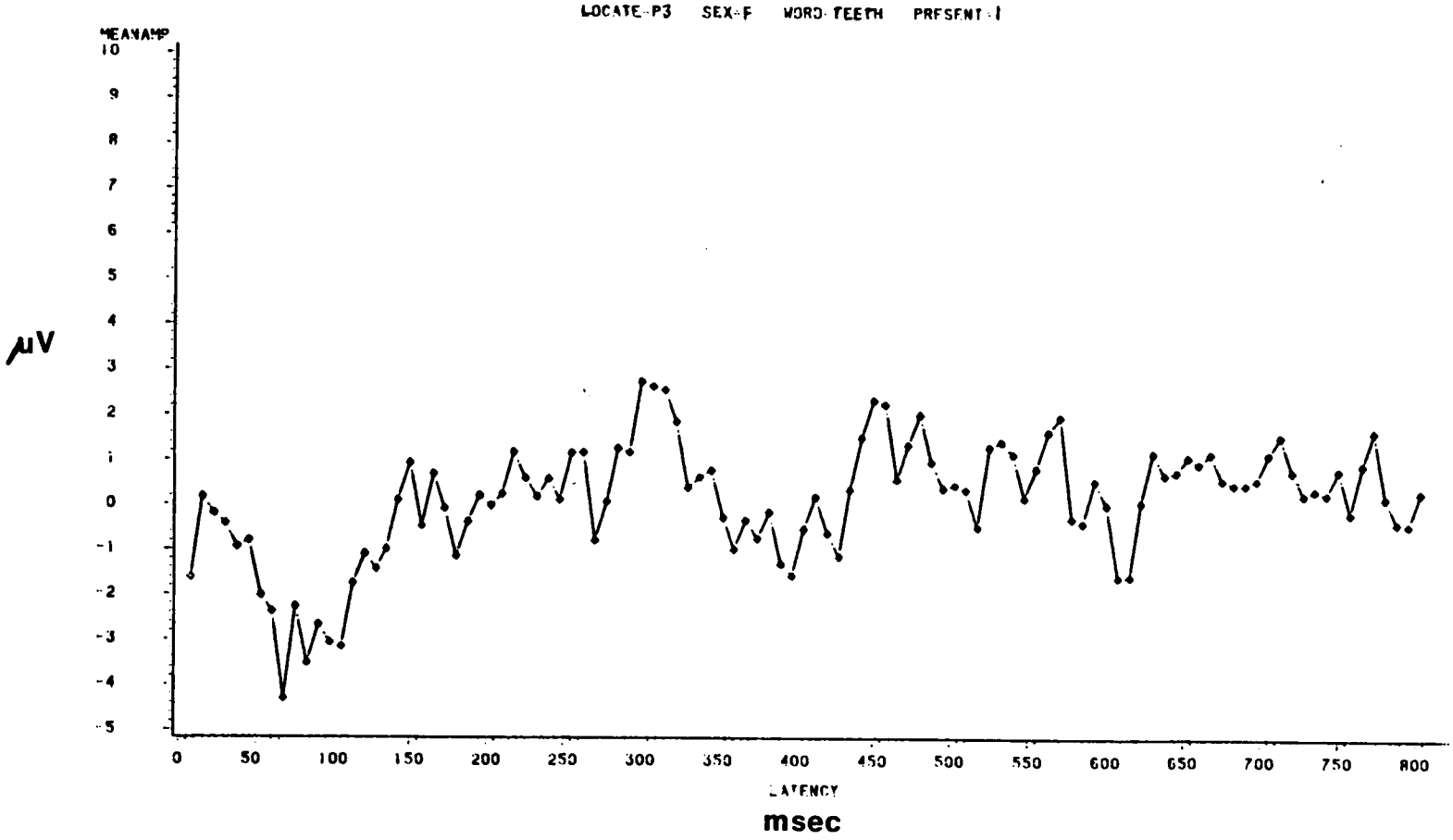

Figure D-73. Average ERP of the female subjects to the first presentation of, "Wash your face and comb your teeth," at P3.

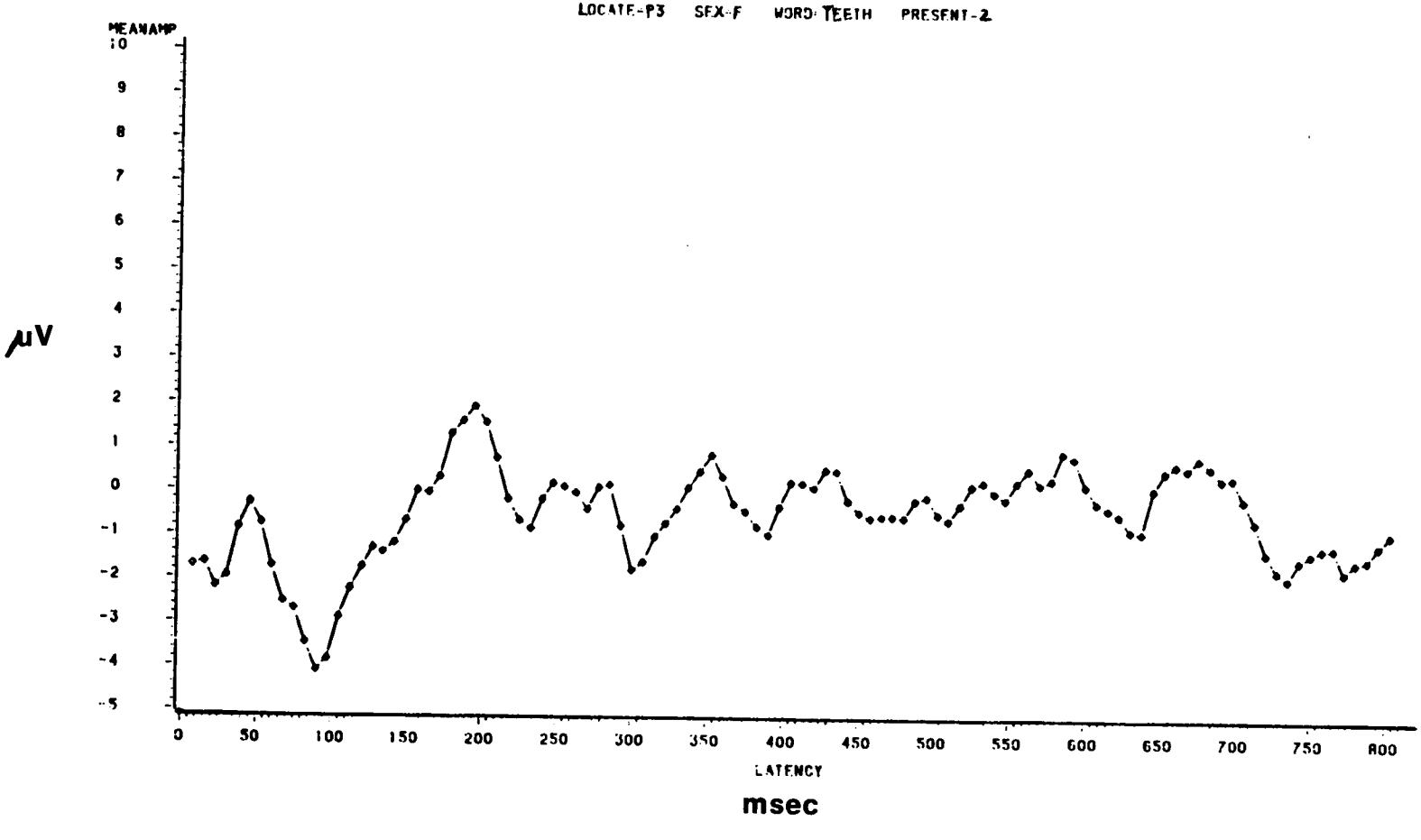

Figure D-74. Average ERP of the female subjects to the second presentation of, "Wash your face and comb your teeth," at P3.

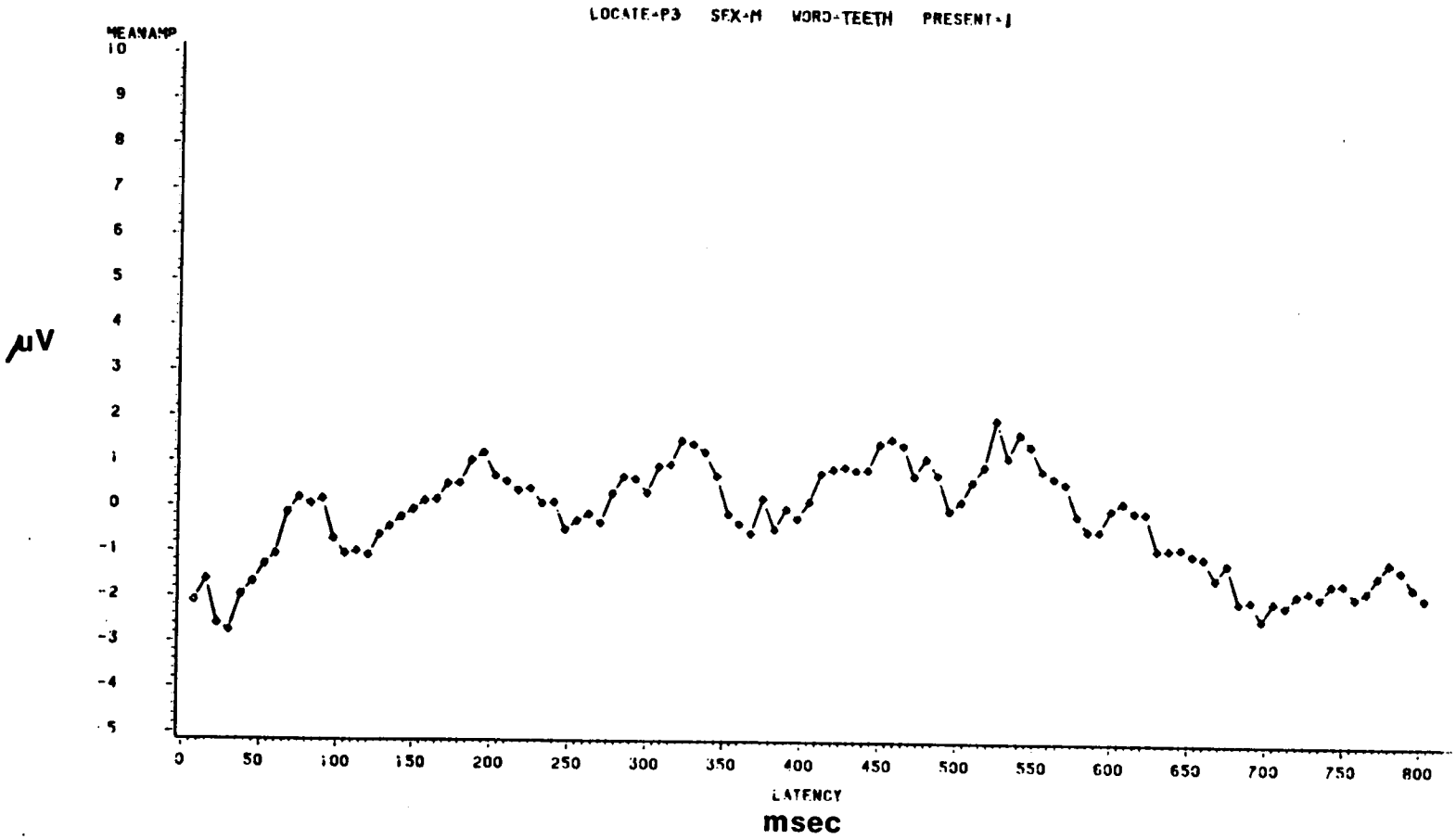

Figure D-75. Average ERP of the male subjects to the first presentation of, "Wash your face and comb your teeth," at P3.

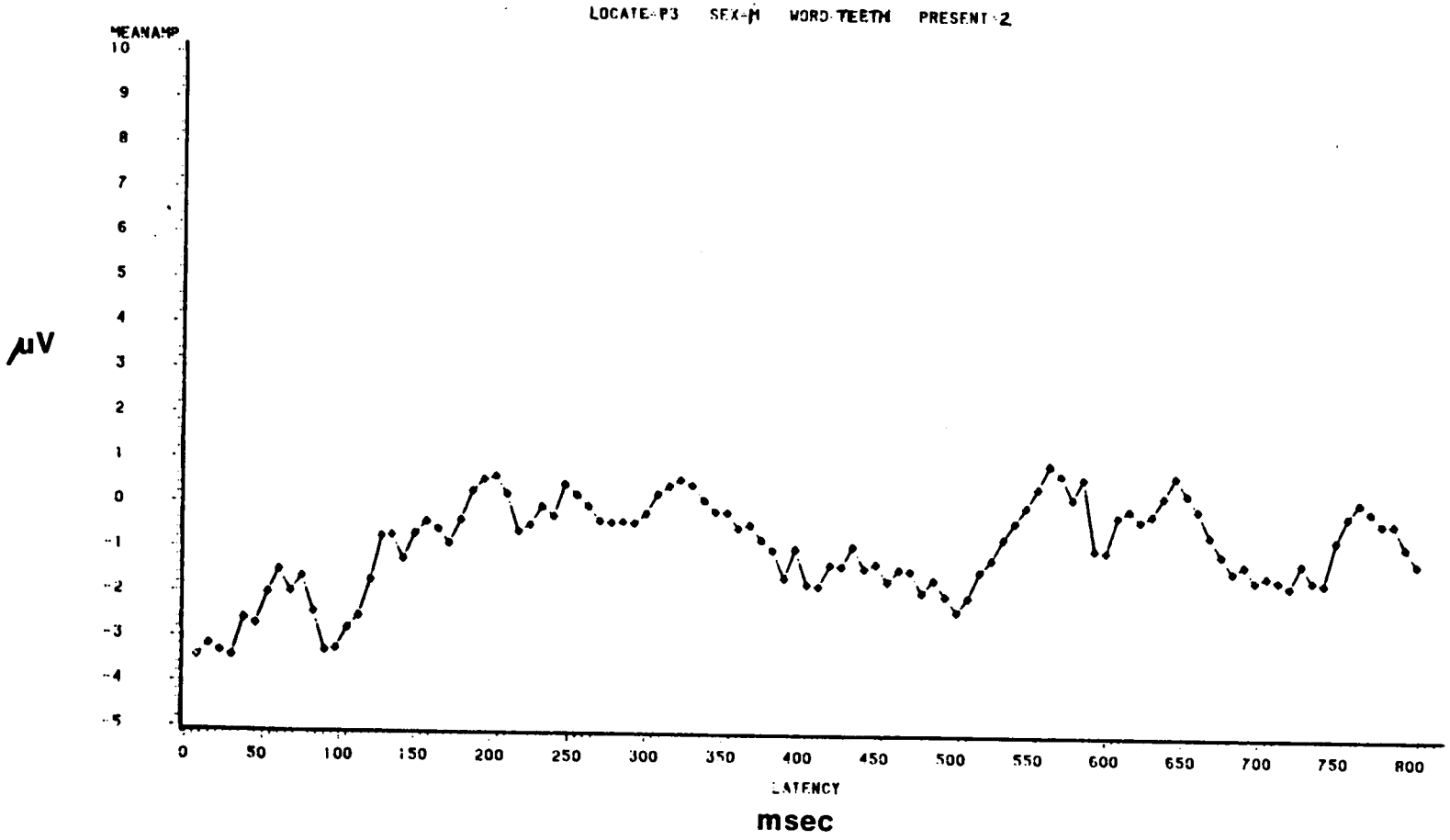

Figure D-76. Average ERP of the male subjects to the second presentation of, "Wash your face and comb your teeth," at P3.

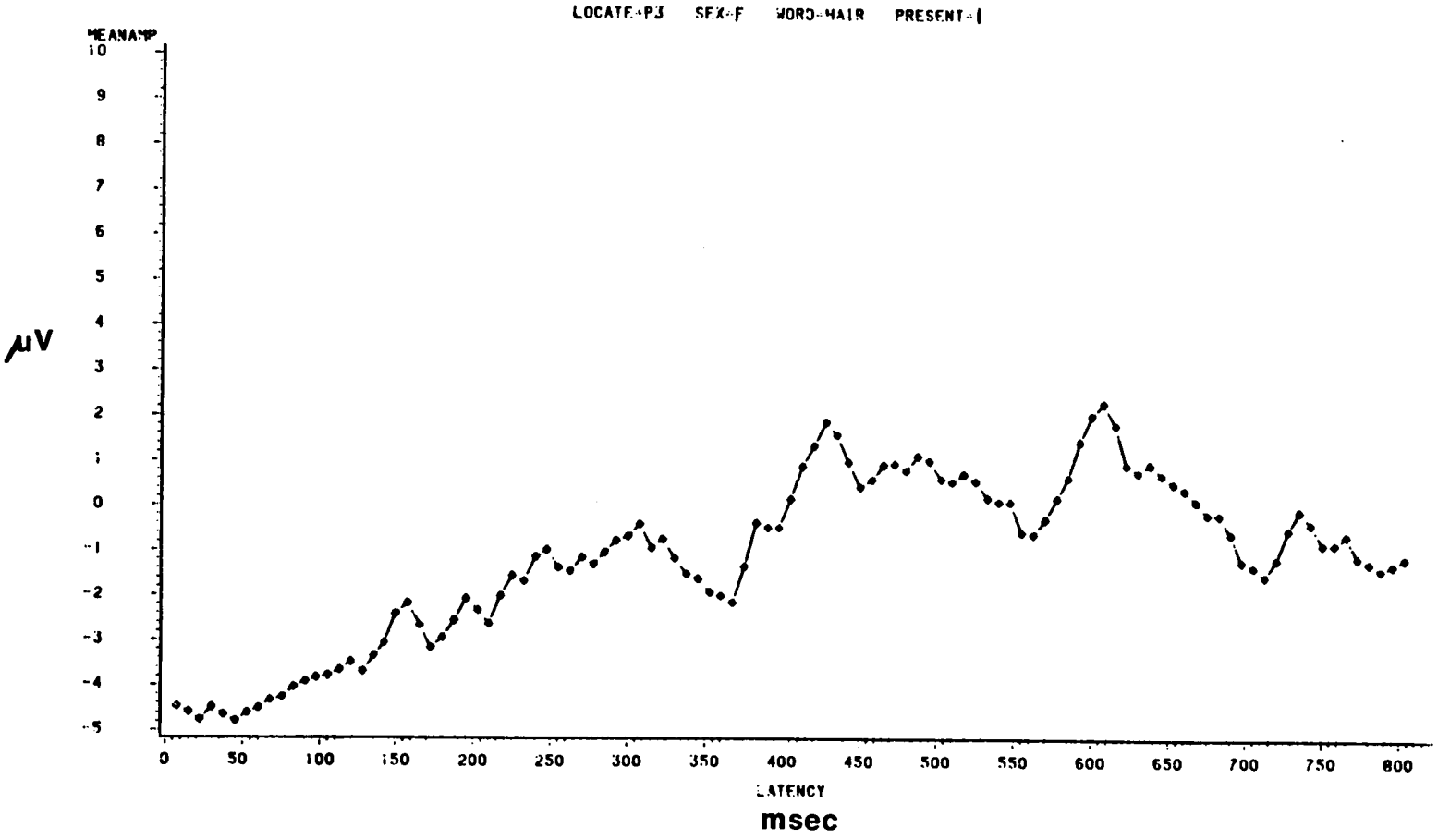

Figure D-77. Average ERP of the female subjects to the first presentation of, "Wash your face and comb your hair," at P3.

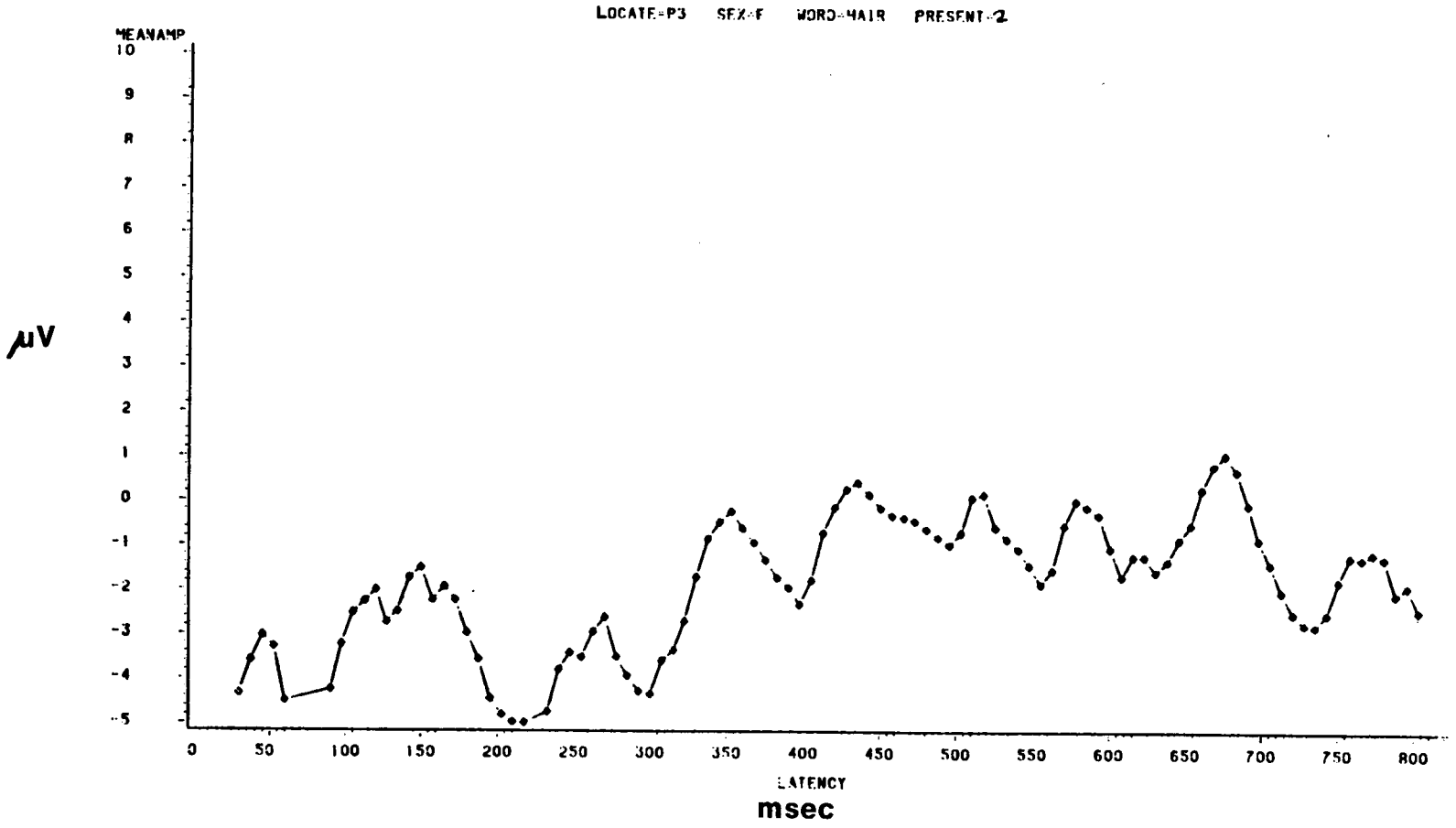

Figure D-78. Average ERP of the female subjects to the second presentation of, "Wash your face and comb your hair," at P3.

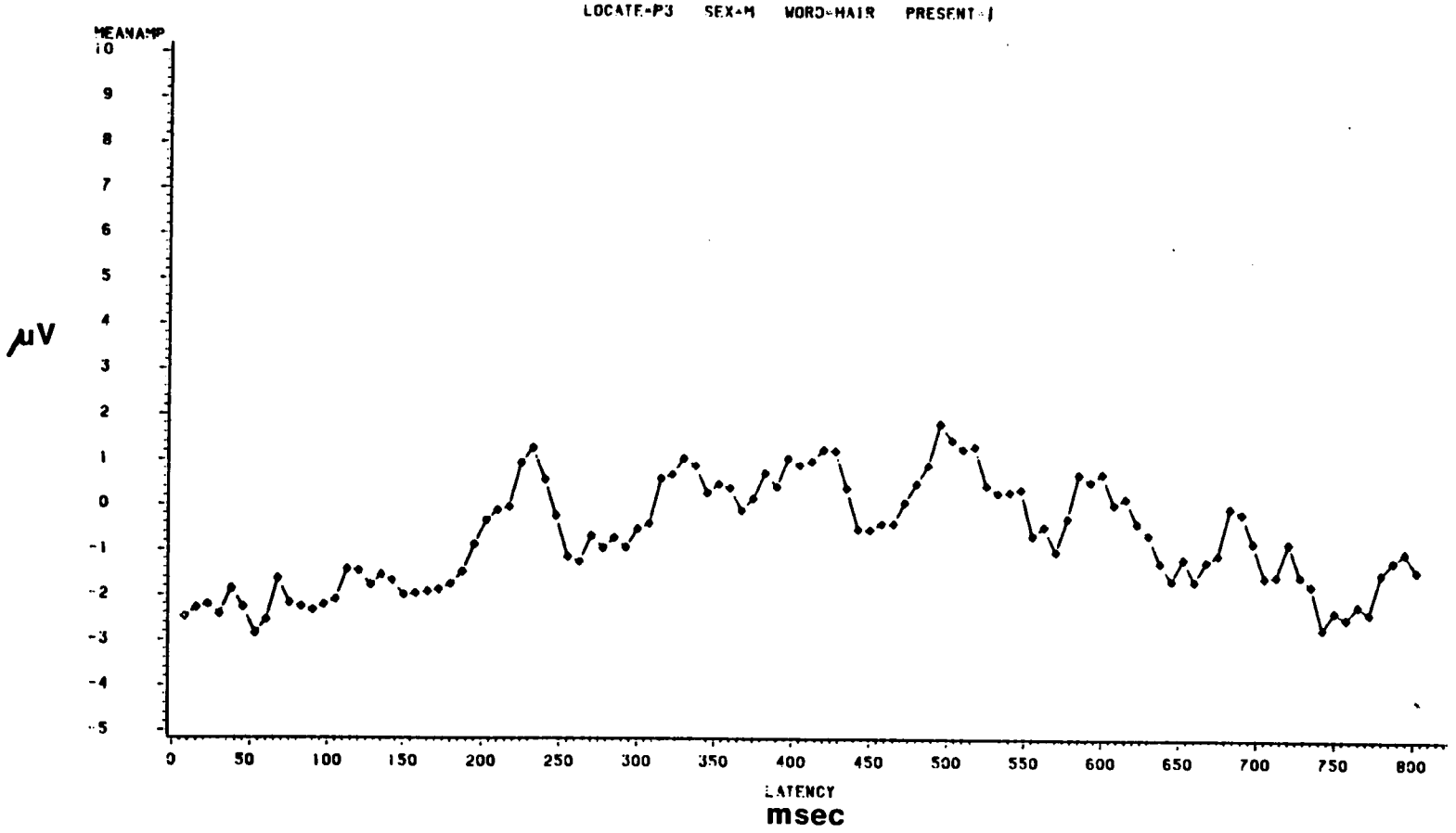

Figure D-79. Average ERP of the male subjects to the first presentation of, "Wash your face and comb your hair," at P3.

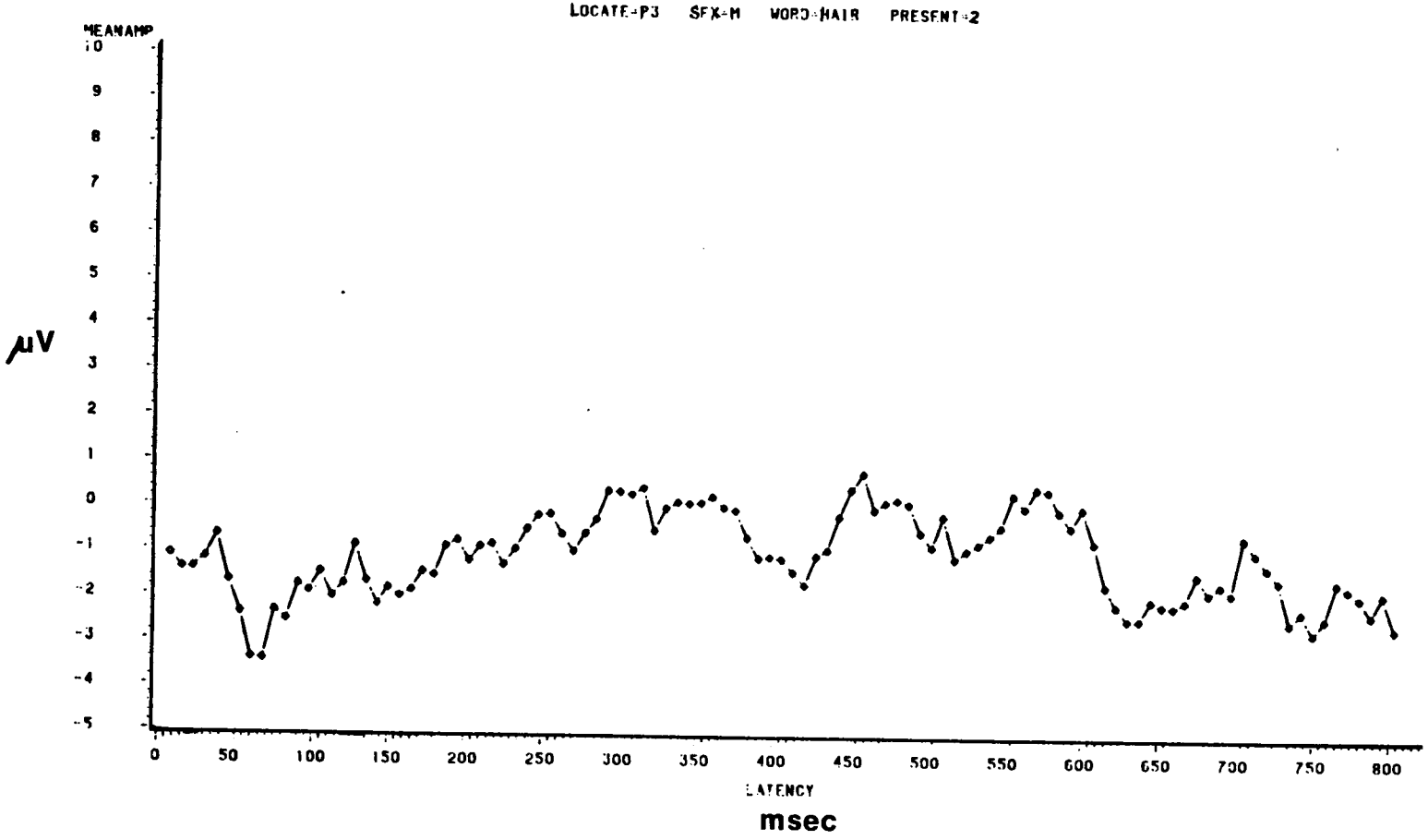

Figure D-80. Average ERP of the male subjects to the second presentation of, "Wash your face and comb your hair," at P3.

VITA

Celia Sue Bessel Hume was born in Middletown, Ohio, on October 12, 1948. She received her elementary and secondary education in Middletown and graduated from Middletown High School in 1966. In 1971 she graduated from Ohio State University with a Bachelor of Science degree in Speech Pathology and Audiology. In the same year she enrolled in the two-year Master of Medical Science degree program at the Emory University School of Medicine.

Following her graduation in 1973 she served as a speech pathologist with the Fulton County Health Department in Atlanta, Georgia. From 1974-1976 she was a speech and language pathologist with the Davison School, Inc.

In 1976 she enrolled in the doctoral program in Speech and Hearing Science at The University of Tennessee, Knoxville, Tennessee. After a brief interruption in her studies, she returned to the doctoral program and received the Doctor of Philosophy degree in Speech and Hearing Science in June, 1984.