EVENT-RELATED POTENTIAL CORRELATES OF TWENTY-FOUR HOUR AUDITORY RETENTION AND MEMORY REACTIVATION IN THREE-MONTH-OLD INFANTS

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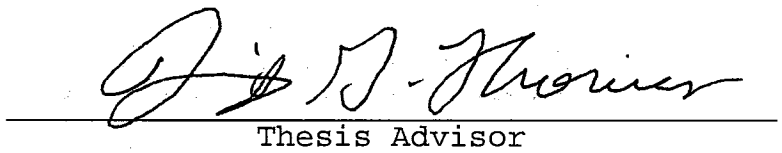

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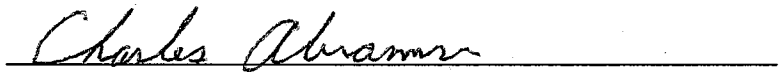

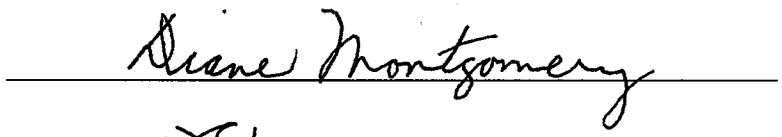

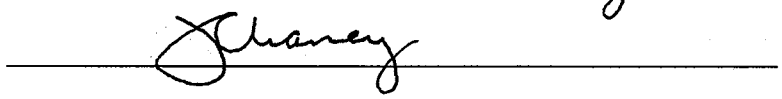

Dean of the Graduate College

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I

INTRODUCTION

The development of infant memory has become a major focus of neuropsychological research in an attempt to gain understanding of the underlying processes of human memory. Experiences occurring during the first years of life form the basis of a complex adult memory system. However, memories of actual early experiences are not retained into adulthood. Despite this phenomenon, called infantile amnesia, research has shown infants are quite capable of long-term recognition memory starting at birth (DeCasper & Fifer, 1980).

Over the last several years a growing body of behavioral research has shown infants to be very skilled at perceiving and interacting with their environment in a manner representative of memory. Behavioral changes are assumed necessary to ascertain memory development. However, identifying behavioral changes in infants is difficult at best and at times impossible. Several behavioral methods (e.g. non-nutritive sucking, habituation, conjugate reinforcement, and object search) have demonstrated that long-term memory skills are present at birth and improve during infancy (Fagan, 1984). However, due to rapid physical and cognitive growth, several different experimental techniques must be used at different ages during infancy, thereby confounding developmental comparisons of long-term

memory. Conflicting results reported on the memory capabilities of infants may be due to differences in experimental tasks, not actual developmental differences (Hill, Borovsky, & Rovee-Collier, 1988).

There has been a growing interest in using event-related potentials (ERPs) to observe ongoing brain function, as well as to establish relationships between brain organization and cognitive processes in infants. ERPs measure changes in electrical activity of large groups of neurons in response to a stimulus event. These changes reflect both response to the physical characteristics of the stimulus as well as cognitive processing of the stimulus experience. Studies have consistently shown that ERPs reflect differences in stimulus discrimination for both short-term memory (Hoffman, Salapatek, & Kuskowski, 1981; Hoffman & Salapatek, 1981; Courchesne, Ganz, & Norcia, 1981; Nelson & Salapatek, 1986) and long-term memory (Molfese & Wetzel, 1992; Thomas, Shucard, Shucard, & Campos, 1989; Thomas, & Lykins, 1995). The use of ERPs to test memory capabilities allows for consistent procedures across ages, as well as adding insight on developmental neural changes underlying memory processes. Replicating developmental phenomena found in the behavioral data with ERPs would help answer questions on underlying brain development throughout infancy.

The purpose of the present study is to further utilize ERPs in the study of infant recognition memory. Recognition

memory is operationally defined as differential responding to two stimuli when previous experience is only given to one stimulus (Thomas & Lykins, 1995). Specifically, it will focus on two different issues: 1) a comparison of a previous ERP discrimination study (Thomas, & Lykins, 1995) on long-term recognition memory with a younger subject population and 2) the modification of the ERP paradigm to test the behaviorally established developmental phenomena of reactivation.

II

REVIEW OF THE LITERATURE

Historical Perspective of Developmental Infant Memory Research

Early research in infant memory was often based on the assumption that infants go through striking transformations or stages during the first two years of life (Hill et al., 1988). The transformations proposed correspond with Piaget's (1952) stages of infant cognitive development. Infants during the Sensorimotor stage (birth - 2 years) undergo three distinct periods. Infants below 4 to 8 months of age act solely on the basis of sensory functions. Body movements are reflexive without the involvement of mental activity such as recognition memory. Infants between the ages of 4 - 8 months develop the ability to recognize a familiar object denoting a primitive mental representation of an object. Infants 18 to 24 months of age finally develop the ability to picture and follow events indicating recall. Piaget defined recall as the ability of an infant to find a hidden object unassisted.

Early studies of infant recognition memory utilized two different research paradigms, novelty-preference and habituation. In a novelty-preference task, infants are familiarized for a predetermined period of time with a single stimulus. Following familiarization, infants are

shown both the familiar stimulus and a similar novel stimulus. If an infant shows a preference for the novel stimulus, then it is inferred that information about the familiar stimulus has been stored in memory. In the habituation task an infant is shown a stimulus until he/she discontinues looking at that stimulus (habituation). The infant is then shown a novel stimulus. If the infant looks at the novel stimulus (dishabituation), this is interpreted as memory for the familiar stimulus since the infant recognizes the novel stimulus as being different.

Early studies using the above methodologies have supported a stage model of infant memory development but modified the ages defined in Piaget's theory. Dannemiller and Banks (1983) found preference for the familiar object in infants up to 2 to 3 months and novelty preference in older infants. These findings were interpreted to show a change in memory ability which occurred between the age of 2 to 3 months. Younger infants used sensory adaptation while older infants used a cognitive-oriented model. Several studies had previously shown an absence of recognition before the age of 2 to 3 months (Franz & Nevis, 1967; Wetherford & Cohen, 1973; Milewshi, 1978).

More recent theories of infant memory abilities find developmental continuity for the first year with differences only in age-related length of retention and the amount of initial experience (Diamond, 1992; Rovee-Collier, 1990). For example, in an effort to examine the presumed developmental

shift from familiarity to novelty, Rose, Gottfried, Melloy-Carminar, and Bridger (1982) reported the results of the two separate studies using a novelty-preference task. In the first experiment, using the same amount of familiarization time for all ages, infants age 3.5 months preferred the familiar stimulus, while infants 4.5 and 6.5 months showed a preference for the novel. In the second study, using 3.5- and 6.5-month-olds, the amount of familiarization time was manipulated. Both ages preferred the familiar with a 5 sec stimulus presentation. A shift to novelty preference was found at 15 seconds of familiarity at 6.5 months and 30 seconds at 3.5 months. The results of the second study indicated the processes underlying recognition memory appeared to be the same at both ages with differences due to amount of initial experience.

The conflict between discontinuity (stage) and continuity theories continues to be a major focus of developmental research. One major reason developmental research has not been able to resolve this issue is the discontinuity in methodologies used. Memory interacts with many cognitive processes which may influence experimental results differently depending on the memory task used (e.g., object search, visual attention). For example, a longitudinal study by Fagan and Ohr (1986) using different memory tasks at different ages found no differences in learning rate at 3, 7, and 11 months of age with increased retention found only for the 11 month-old infants. However,

in a series of studies using a single testing method, Rovee-Collier and colleagues found differences in both learning rate and retention between 3- and 6- to 7-month olds (Rovee-Collier & Sullivan, 1980; Hill et al., 1988). These conflicting results demonstrate the difficulty in gaining an understanding of infant memory development. However, the work by Rovee-Collier and colleagues is a strong foundation upon which to link the development of additional methods for testing the development of infant memory.

Research of Rovee-Collier and Colleagues on Learning and Memory

Rovee-Collier and colleagues developed the conjugate reinforcement technique allowing comparisons across ages 2 to 7 months on retention, reactivation, and context determinants of memory retrieval. Conjugate reinforcement uses a learned kicking response to measure memory. A mobile is placed above an infant's crib with an attached ribbon that will rotate the mobile when pulled. A baseline measurement of kicking is first established with the ribbon on the infants ankle but not attached to the mobile to disallow activation. Acquisition is accomplished by allowing kicking to move the mobile. A 9-minute period of acquisition is allowed for 3-month-old infants. An immediate retention test is then taken during a 3-minute period when kicking will again not move the mobile. This procedure is repeated 24 hours later with the 3-minute retention test being used

to determine subsequent long-term retention.

This method overcomes three problems inherent in developmental studies of learning and memory with infants (Greco, Rovee-Collier, Hayne, Griesler, & Earley, 1986.):

> ...(1) Conditioning is very rapid, and the efficacy of a complex mobile reinforcer does not wane within(Rovee & Rovee, 1969) or across Rovee-Collier & Gekoski, 1979)sessions;(2) attention to the mobile is either asymptotic or nearly asymptotic throughout conditioning sessions lasting 15 min or more (Rovee-Collier, Griesler, & Earley, 1985; Sullivan, Rovee-Collier, & Tynes, 1979); and (3) the problem of equating reinforcing efficacy or motivation both within and across subjects of different ages is eliminated because each infant controls the intensity of his/her own reinforcing stimulation (for review, see Rovee-Collier & Gekoski, 1979). (p. 443).

Cross-sectional studies by Rovee-Collier and colleagues have examined long-term retention for 2-, 3-, and 6- to 7-month-old infants. All infants were tested in an identical manner except the 6- to 7-month-olds had proportionately shorter training sessions and increased reinforcement stimulation by increasing the number of stimuli. The results of the 6- to 7- month-olds were adjusted to compensate for normal increases in activity level (Hill et al., 1988).

Infants at 2 months of age remembered the learned

contingency for one to two days following a two day training paradigm and exhibited forgetting by the third day (Greco, Rovee-Collier, Hayne, Griesler, & Early, 1986). Three-month-old infants, after two days of training, remembered the contingency for eight days with complete forgetting by the 13th day (Rovee-Collier & Sullivan, 1980). Six- and 7-month-old infants' memory for the contingency was found to last for two weeks after a two day session, with complete forgetting by the end of three weeks (Hill et al, 1988). These data indicate age differences in the length of time of retention of a learned contingency. Also, the older group learned the contingency within one minute while the younger group required 4-6 minutes to learn, indicating substantial differences in the rate of acquisition.

Research of Rovee-Collier and Colleagues on Infant Reactivation

Forgotten information is not necessarily lost, but may only be unavailable for immediate retrieval. The information is available but only accessible under facilitating circumstances such as reactivation. Reactivation refers to the process of priming an inactive memory (i.e., one which is not available for immediate use and therefore appears forgotten) through the presentation of a reminder stimulus. Reactivation uses the same conjugate reinforcement technique for acquisition as described above. The infants are then exposed to a reminder (the mobile) after a period of time

when forgetting is known to have taken place. The mobile is placed within sight of the infant and moved at the same rate of rotation as during the infants' final acquisition test. A retention test which measures noncontingent kicks is given after a set interval of time following exposure to the mobile. Comparisons between original retention and retention following priming are used to establish the reactivation of memory which, when found, indicates a retrieval deficit rather than a storage deficit (forgetting). Reactivation of memory is a key paradigm in memory research since it assesses the storage of memory beyond the period when it is available for immediate use.

In cross-sectional studies, Rovee-Collier and colleagues have examined two time factors in reactivation: 1) length of time until the memory is no longer available even with priming (Rovee-Collier & Sullivan, 1980; Davis & Rovee-Collier, 1983; Boller, Rovee-Collier, Borousky, O'Connor, & Shyi, 1990), and 2) length of time from presentation of the prime (reminder cue) until the memory is again accessible (Fagen & Rovee-Collier, 1983, Boller et al., 1990). The infants tested were 2-,3-, and 6-month olds. The only change made in the testing procedure was a decrease in exposure time to the priming cue from 3 minutes to 2 minutes for the 6-month-olds.

The length of time memory is available with priming differs based on age. Two-month-olds will remember the learned contingency for one to two days after acquisition

with forgetting exhibited by the third day. Reactivation is possible for 14-15 days after forgetting; 17 days after acquisition. Three-month-olds will remember the learned contingency for 8 days after acquisition with complete forgetting by the 13th day. Reactivation is possible for 14-18 days after forgetting; 27 days after acquisition (Davis & Rovee-Collier, 1983; Rovee-Collier & Sullivan, 1980).

The duration of time the memory is still accessible through reactivation is constant across ages (approximately 14 days). However, the reactivation window ends 16 days after acquisition for 2-month-olds and 27 days after acquisition for 3-month-olds. Greco et al. (1986) proposed the critical determinant of accessibility is the time since the memory was initially forgotten. This hypothesis was tested with 6-month-old infants (Boller et al., 1990) and was not supported. The infants did not show reactivation at 28 days after original training (14 days after forgetting was complete). Reactivation was found for 6-month-olds at 21 days after original testing (7 days after forgetting was complete). Boller et al. concluded the fundamental memory process over the period from two to six months is the same; however, the temporal patterns are quite different. The window for reactivation for 6-month-olds is less than that of the 2- and 3-month-old infants. This may be due to the more rapid modification of existing memories based on their application in a rapidly changing environment corresponding to the development of self-locomotion. The more rapid

forgetting of the required memory is not necessarily forgetting in the more passive sense but a decrease in accessibility caused by interference from subsequent information. This would serve an adaptive purpose for an infant experiencing a rapidly changing environment.

The length of time from prime presentation until the memory is accessible is also age dependent. Reactivation is not spontaneous in producing access to previously forgotten contingencies. The time course for memory retrieval has been mapped for both 3- month-olds (Fagen & Rovee-Collier, 1983) and for 6- month-olds (Boller et al., 1990). Three-month-olds showed no reactivation of memory at 15 minutes or one hour after presentation of the reminder. At eight hours these infants showed a degree of recovery. At 24 hours the infants performed at the same level as at the completion of the original testing. It is interesting to note that the extent of recovery at 8 hours correlated with the amount of time the infant had spent napping between the presentation of the reminder cue and test.

Six-month-olds showed no retention at 30 minutes or eight hours after the reminder. Minimal retention was shown at one hour and 24 hours with complete reactivation of memory present at four hours. Variability among subjects on amount of reactivation was present at all of the different time intervals except 30 minutes and eight hours. None of the infants showed memory activation at either time. The lack of reactivation at eight hours was attributed to

possible changes in internal state at the time of testing relative to the state at the time the memory was encoded (Boller et al., 1990). Vastly different activities were normally in the schedule for these infants at the time of the original reminder and the eight hour retention test. Since memory was still evident at 24 hours after the reminder, the findings were attributed to a retrieval failure and not to faster forgetting after the reminder. Subsequent reactivation studies have found a stronger, more consistent retention level at 24 hours for 6-month-olds (Boller & Rovee-Collier, 1992). The results showed the rate of retrieval was much faster for older infants.

The research by Rovee-Collier and her colleagues has demonstrated reactivation is present in 2-, 3-, and 6-month-old infants. Once forgetting is complete, 2- and 3-month-olds have roughly a 14 day period in which a stimulus reminder makes an inactive memory active. This period is approximately seven days for 6-month-olds. The speed in which memory becomes active after priming increases with age. At three months of age, recovery begins at eight hours and is complete at 24 hours. At six months, recovery begins at one hour and is complete at four hours. However, memory for the reactivated contingency was not found at eight hours following priming and ranged from minimal to completely active at 24 hours.

Rovee-Collier and colleagues have also explored the effects of multiple stimulus presentations during

acquisition and reactivation. Mobiles consisted of multiple blocks containing either As or 2s. Yellow was used as the background color for all blocks while the color of the alphanumeric category varied across mobiles. Three-month-old infants were exposed to three different colors of a single alphanumeric category (As or 2s) over three sessions and then tested, after forgetting, in a reactivation paradigm (Hayne, Rovee-Collier, & Perris, 1987). The mobile used as the prime was a novel color mobile from the same alphanumeric category used for acquisition as was the new testing mobile presented 24 hours later. The results showed reactivation generalized to the novel mobile from the same category. However, if a novel mobile from a different alphanumeric category was used for priming then no reactivation took place.

In a follow-up study of 3-month-olds, Greco, Hayne, & Rovee-Collier (1990, Exp. 2) used multiple mobiles of different colors (variable training) or a single mobile of one color (constant training) across three sessions. After forgetting was complete, the infants were shown either a mobile judged to be similar to the training mobiles or one judged to be distinctively different. Infants who had experienced variable training transferred responding to the similar novel mobile but not the novel mobile rated distinctively different. The infants who received constant training showed no reactivation for either mobile. These studies indicated experience with more than one stimulus

during acquisition may effect generalization to similar novel stimuli during reactivation.

Boller (1992) looked at the effects of a passive presentation of novel stimuli on reactivation with 3-month-old infants. Infants were trained in a normal acquisition paradigm and then passively exposed to a novel mobile. They were shown the mobile for a brief period, once at the end of the training session, and never interacted with the mobile. Infants who were passively exposed to a novel stimulus did not show reactivation when tested, after forgetting, with the original mobile. The passive presentation appeared to block later access to the originally learned mobile. Passive presentation of a mobile before acquisition training on a different mobile did not affect later reactivation with the training mobile. Research is not available on multiple presentation of passive novel stimuli.

The conjugate reinforcement method has been highly effective in providing information on infant long-term memory development. Long-term retention increases in number of days in relation to increased age. The number of days after acquisition when reactivation is possible increases with retention but the number of days over which the window of reactivation is open decreases with age. Also, the rate of retrieval following prime presentation increases with age.

While the work of Rovee-Collier and colleagues has added to the body of knowledge on memory development during

infancy, it is limited due to the age limitations of the conjugate reinforcement technique. Information on retention and reactivation for infants below the age of two months and above the age of seven month must be gathered using alternate techniques. Also, changes must be made in the experimental design to accommodate developmental differences between 3- and 6-month-olds. Acquisition time must be shortened and additional stimuli added to the mobile when testing the 6-month-olds. Also results must be adjusted for 6-month-olds to compensate for natural increases in activity when testing reactivation. The development of a method which could keep experimental manipulations consistent across all ages would be an important factor in furthering knowledge of developmental changes in infant memory.

History of Event-Related Potential Research

The electroencephalogram (EEG) has been an available method for noninvasive real-time measurement of electrical brain activities since the 1930's. EEG activity represents the activity of enormous numbers of neurons at any given moment. However, until the development of digital signal averaging techniques in the 1960's, brain wave activity could not be linked to specific cognitive processes.

Signal averaging techniques allow for the EEG activity related to a specific time-locked stimulus to be extracted from this background EEG. Event-related potentials (ERPs) reflect the systematic change in brain activity in response

to a specific environmental stimulus. ERPs are extracted from the ongoing EEG by time-locking a sample portion of the recorded activity to a specific stimulus event over several trials. These separate trials are then averaged to give the net effect associated with the stimulus event.

ERPs can be distinguished based on differences in timing, activated structures, and sensory processing engaged (Steinschneider, Kurtzberg, & Vaughan, 1994). The portion of the ERP occurring approximately 15 ms after stimulus onset reflects the brainstem response to the stimulus. The period occurring between 15 ms and 80 ms after stimulus onset, the middle latency response, reflects the initial activation of the cerebral cortex. Sensory processing ERPs (SERPs) follow the middle latency response and reflect the brains obligatory response to the physical characteristics of the stimulus. These cortical components can last for several hundred ms and reflect changes in the physical characteristics of the stimulus including intensity, duration, and wavelength. SERPs in infants can be classified by maturational stages based on polarity over the frontocentral and lateral temporal regions. There is a progressive decrease in latency with maturation which is normally complete by three months of age (Thomas and Crow, 1994; Steinschneider et al., 1994).

Processing contingent potentials (PCPs) are associated with processing demands of a task which go beyond the physical properties of a stimulus and include both active,

attention dependent as well as automatic processing by perceptual or cognitive systems. These potentials occur at longer latencies and are believed to reflect nonactive discrimination by infants and active discrimination by adults and children (Courchesne et al, 1981). Infant nonactive PCPs undergo maturational processes that show increases in amplitude in the component until approximately one year of age, then decreases until it disappears entirely (Steinschneider et al., 1994).

Infant ERP research has focused on the use of PCPs to gain an understanding of memory processing. The largest body of research has focused on short-term memory using nonactive stimulus discrimination. More recent research has begun to focus on long-term memory processing using presentation of familiar and novel stimuli.

History of Event-Related Potential Research on Short-term Memory

Early infant research in PCPs used oddball methodology, frequent presentation of one stimulus which is occasionally replaced by a different stimulus. In research on short-term memory, the PCPs only occurred when the less frequent stimulus is presented and not when the more frequent "familiar" stimulus is given repeatedly. These processing contingent potentials have been the focus of most ERP research dealing with short-term memory in infants. Two studies, using an oddball paradigm after a familiarization

period, have looked at visual recognition in 3-month-olds.

Hoffman, Salapateki, and Kuskowski (1981), using an oddball task with spectral frequency discrimination, presented 40 familiarization trials with a vertical square wave grating of one spectral frequency and then tested with an 80% occurrence of the familiar frequency and 20% occurrence of a novel frequency. A late positive component from 300 to 600 ms at the occipital electrodes (Oz and Opz) was recorded only for the novel frequency occurrence. This effect was also found when the spectral frequency of the two stimuli were kept the same and the orientation of the grating (horizontal or vertical) was different for the familiar vs novel stimulus presentation. Hoffman et al. interpreted this late processing component to be equivalent to the late positive enhancement found in adults when an infrequent (low probability) or unexpected stimulus is presented in an active paradigm.

Hoffman and Salapetek (1981) presented a low-high probability discrimination task with familiarization trials which contained both a tone and vertical square grating with one spectral frequency. The 20% novel presentation contained either a change in only the tone, only the spectral frequency or both. Results showed a late positive component (300 - 600 ms) for the visual change (at Oz, Cz and Pz) and the changes in both visual and auditory stimuli at Oz and Pz. A late component was not apparent for a change in only the auditory stimulus. Research using only auditory stimuli

in a low-high probability discrimination has not been done with 3-month-old infants.

Discrimination effects have also been shown in older infants using an oddball method without familiarization. Courchesne, Ganz, and Norcia (1981) presented female faces to 4- and 7-month-old infants using a high (88%) - low (12%) probability task. The low probability face was distinguished by a late negative component (700ms) with a larger amplitude and longer latency than the high probability face. This effect, which was strongest at the frontal electrode, was interpreted to represent the process of discrimination involving the comparison of a novel stimulus with the memory trace of a stimulus previously made familiar. Karrer and Ackles (1988) tested stimulus discrimination in 6-week-old and 6-, 12-, and 18-month-old infants using an 80% - 20% oddball paradigm without a previous familiarization period. They found a large negative component (770 - 800ms) which was larger for the infrequent stimuli. This effect was only present in the 6-month-old subjects. These results support the interpretation of a late processing component representing non-active discrimination using information in short term memory. The high probability stimulus becomes familiar and is held in short term memory. The large negative component reflects discrimination of the low probability (novel) stimulus from the stimulus presently stored in short term memory.

A series of experiments by Nelson and Salapatek (1986)

examined differences in stimulus probability and familiarization. The first experiment was a typical high (80%) - low (20%) oddball paradigm using pictures of faces shown after 40 familiarization trials. Results showed a large positive component (850 - 1000ms) which discriminated stimuli. They also found a negative component (550 - 700ms) which discriminated the novel from the familiar stimulus. However, this effect was only apparent when the novel ERP was compared to the familiar ERP recorded during the familiarization period. A second experiment presented the familiar and novel stimuli on an equal basis (50%- 50%) again after 40 familiarization trials. A late positive component was not present; however, a negative component (550 - 700ms) again discriminated the familiar from the novel when the familiarization trials were used for comparison. A third experiment used an equal presentation of stimuli without a familiarization period. No differences were found between the ERPs for the two stimuli. Nelson and Salapatek proposed that the earlier negative component represented a discrimination component based on updating working memory. Updating could only take place when previous information obtained during familiarization could be checked.

History of Event-Related Potential Research on Long-term Memory

Only recently has long-term memory become a focus of ERP research. Long-term memory is operationally defined as memory recognition tested 24 hours or more after initial familiarization. Molfese and Wetzel (1992) presented bisyllabic nonsense syllables to 14-month-old infants over a two day familiarization period. Stimulus presentation took place in the home and consisted of three, 15-minute familiarization periods each day. On the third day the infants were brought into the laboratory where ERPs were recorded for both the familiar and novel nonsense syllables which had been counterbalanced across subjects. An ERP component occurring between 280 and 470 ms was determined by a principle component analysis to discriminate between the familiar and novel syllables. Similar results were found when the infants were tested one week later. This component, however, occurred at an earlier time period (200 to 320 ms). Thus ERP discrimination between familiar and novel stimuli appears to continue over retention periods of at least one week.

In a study to determine the effects of repeated laboratory experience on ERP recordings, Thomas, Shucard, Shucard, and Compos (1989) tested 5- to 6-month old infants over a two day period. One group of infants was presented with 80 tone pips on the first day and again 24 hours later. A second group underwent the identical procedure except that no actual tone presentations were heard on the first day. Results showed an increase in amplitude from day one to day

two for the group that had received tones on both days. This effect was found for a measurement of amplitude between 350 and 450 ms. This represents the area of the waveform from the second negative peak (N2) to the third positive peak (P3). The ERP waveform was the same for the first day of stimulus presentation for both groups. Experience with the stimulus on day one appears to have served to establish a memory trace which was reflected 24 hours later and was not a day effect due to experience in the laboratory.

To investigate whether the above findings would be specific only to the stimulus presented or would generalize to other auditory stimuli, a second study was undertaken with 5-month-old infants (Thomas & Lykins, 1995, Exp. 1). Table 1 shows the expected results for the stimulus general and specific Hypotheses. Infants heard either 100 auditory presentations of a click or tone on the first day and 50 random presentations of both on the second day. Results showed a significant average peak amplitude increase in the N2 peak for the repeated stimulus on the second day in comparison to the first day of presentation and the novel stimulus given on the second day. The results supported a stimulus specific hypothesis. The memory trace established on day one was specific to the stimulus (tone or click) originally presented.

To investigate if stimulus specificity would also be found using very similar stimuli, Thomas and Lykins (1995, Exp. 2) replicated the above study using two tones differing

only in frequency. Five-month-old infants heard 100 tone presentations (400 Hz or 700 Hz) on Day 1 and a randomly-ordered presentation of both tones on Day 2. The results again supported the stimulus specific hypothesis. A significant increase in average peak amplitude was found for the repeated stimulus on Day 2 in comparison to both the Day 1 presentation and the novel presentation on Day 2 which were statistically equal. Stimulus specificity was again found for N2 at Fz. Unlike the previous study this effect was also found for P2 at both the Cz and Fz electrodes.

To gain a greater understanding of how familiarization can lead to increased average peak amplitude, Thomas and Lykins (1995) examined the nature of the measure itself. An average ERP waveform is the mean of many single-trial waveforms. The amplitude of an average ERP is influenced by both the amplitude of the single-trial waveform and the trial-to-trial consistency of the positive and negative peaks of the wave form. As can be seen in Figure 1, the less trial-to-trial variability in the latency of a peak, the larger the resulting amplitude of that peak in the average ERP. Therefore, the three possible explanations for the increase in amplitude for the repeated stimulus on Day 2 were (a) a true increase in amplitude, (b) a decrease in variability across days, (c) a combination of both a and b.

Analysis of the P2 single trial amplitude measure (the average amplitude of the single-trials based on a template-matching procedure in which the latency of the peak varies)

showed a true increase in amplitude for the familiar stimulus on Day 2 in comparison to the tone presentations on Day 1 and the Day 2 novel tone on Day 2 at the Fz electrode. N2 analysis showed an increase in true amplitude at the Fz electrode for the familiar stimulus on Day 2 in comparison to the Day 2 novel stimulus, but neither differed from Day 1 stimulus presentations. Trial-to trial latency variability results showed decreased variability for the Day 2 familiar stimulus in comparison to Day 1 and the Day 2 novel stimulus for both P2 and N2 at Fz.

Increases in the average peak amplitude to familiar stimuli appear to be due to both true increases in amplitude and decreases in variability (Thomas & Lykins, 1995). A true increase in amplitude found in the single-trial-amplitude analysis suggests more neural elements (e.g. synapses, neurons, or groups of neurons) are recruited into the neural ensemble representative of the repeated stimulus as a result of familiarization. The decrease in variability suggests the influence of familiarization on Day 1 stabilizes the neural ensemble which responds to a given stimulus. Consequently, when that stimulus is encountered on Day 2, it evokes a more "experienced," more stable, less variable ensemble.

Summary of ERP Research

ERP research has consistently shown stimulus discrimination in a late processing component for both short- and long-term memory. Studies of short-term memory

ERP research using an oddball paradigm have found increased amplitude for the low percentage stimuli in both a visual (Hoffman et al., 1981) and visual coupled with auditory stimuli (Hoffman & Salapetek, 1981) following familiarization in 3-month-old infants. Amplitude differences have also been found, both with (Nelson & Salapetek, 1986) and without (Couchesne et al., 1981) a familiarization period, for the low percentage stimulus in 6-month-olds. Effects were found for equal presentations of a familiar and novel stimuli only after a familiarization period and then only for the novel compared to the familiar during familiarization trials (Nelson & Salapetek, 1986). These results have been interpreted to indicate a form of updating or checking information being held in short-term and/or working memory.

The findings on long-term memory have consistently shown discrimination between the familiar and novel stimulus tested 24 hours (Thomas & Lykins, 1995) and one week (Molfese & Wetzel, 1992) after familiarization. Thomas and colleagues have examined the long-term effects of familiarization on ERPs through three major studies. First, to ascertain if repeated laboratory experience attributed to increased amplitude for a familiar stimulus (Thomas et al., 1989). The results showed an increase in amplitude on the second day for the group which received stimuli on both days. The results appeared to rule out a day-of-testing effect. The experience with the stimulus on the first day

established a memory trace which was reflected 24 hours later. Second, to determine if the increase in amplitude would be specific only to the stimulus given on the first day or would generalize to other auditory stimuli two additional experiments were undertaken (Thomas & Lykins, 1995). The first experiment presented a tone frequency and click. The results showed an increased amplitude for the specific stimulus given on Day 1. The second experiment tested whether this specificity would also be found for two very similar stimuli (two tone frequencies). The results again showed an increase on Day 2 only for the stimulus presented on Day 1. The increase found for the familiar stimulus on Day 2 was due to both an increase in amplitude and a decrease in latency variability. The true increase in amplitude suggested more neural elements were recruited into the neural ensemble representative of the familiar stimulus. The decrease in latency variability suggested a more experienced, more stable, less variable representative ensemble.

Incorporating knowledge gained from the behavioral research on retention and reactivation into an ERP paradigm would allow for a greater understanding of ERP amplitude changes and their relationship to memory. Reactivation represents a memory retrieval problem that can be corrected by priming with the appropriate stimulus. Differences in ERP amplitudes between subjects who had received reactivation priming and those who had not would support the premise that

differences are due to organization changes in the neuronal ensemble representing a stimulus in long-term memory.

III

Statement of the Problem

To date, infant ERP research on memory has looked only at recognition by examining discrimination between familiar and novel stimuli. Results have consistently shown the capabilities of ERPs to discriminate, but integration of the results is complicated by differences in experimental design across studies. While it is well accepted that the changes apparent in the ERP waveform relate to cognitive processes, combining proven cognitive phenomena with ERP methodology is a fairly new experimental approach in infant ERP research. This methodology would help clarify the psychological processes represented by changes in ERPs during experimental manipulation.

The present study compared developmental differences between 3- and 5-month-old infants and integrated the memory phenomena of reactivation into the experimental design used by Thomas & Lykins (1995). The first two-day session replicated the design using 3-month-old infants. Infants were presented one of three auditory stimuli on the first day with equal random presentation of familiar and novel stimuli 24 hours later. ERPs were recorded for both sessions. Three weeks later, a long enough period to assume forgetting is complete but reactivation is still possible (Rovee-Collier & Sullivan, 1980), the infants returned for another two day session. They were randomly assigned to one

of 4 groups: reacquisition, reactivation, generalization or control. The reacquisition group (Grp. 1) represented normal reacquisition learning. They received an identical procedure as the first two day session. On Day 3, they received 100 presentations of the same familiar stimulus as given on Day 1 followed 24 hours later (Day 4) by random presentation of the familiar stimulus and a new novel stimulus. The reactivation group (Grp. 2) received only 10 presentations of the original familiar stimulus on Day 3 followed 24 hours later by random presentations of the familiar and new novel stimulus. This group represents reactivation to the original stimulus presented on Day 1. The generalization group (Grp. 3) received 10 presentations of the new novel stimulus followed 24 hours later by random presentations of the novel stimulus from Day 3 and the original familiar stimulus from Day 1. Since two different stimuli were given on the second day, reactivation may generalize to a novel stimulus and not be present to the original stimulus. The control group (Grp. 4) underwent the Day 3 procedure without any stimulus presentations followed 24 hours later by equal presentations of the new novel stimulus and the familiar stimulus from Day 1. See Table 2 for the design of the stimuli presentations for the different groups.

The selection of a 3-month-old population would allow for the best incorporation of reactivation into the Thomas and Lykins (1995) procedures. Research has shown mature classification of ERPs in normal 3-month-olds (Thomas &

Crow, 1995; Steinschneider et al, 1994) and consistent discrimination results (Hoffman, Salapatek, & Kuskowski, 1981; Hoffman & Salapatek, 1981). Reactivation of stimulus memory is highest 24 hours after stimulus presentation for 3-month-old (Fagen & Rovee-Collier, 1983) which would fit the experimental design already established. Differences in learning acquisition between the active conjugate reinforcement method and passive auditory learning makes predicting the period when forgetting has taken place difficult. However, the fact the reactivation window lasts 14-15 days for 3-month-olds allows greater confidence that forgetting has occurred and reactivation is possible 21 days after original acquisition.

Hypotheses for Days One and Two

To answer the question of the effect of auditory stimulus familiarization on ERP amplitude 24 hours after stimulus presentation, two separate hypotheses were tested: stimulus general and stimulus specific. The stimulus general hypothesis states that familiarization with the stimulus on the first day would generalize to both the repeated familiar stimulus and the novel stimulus. In other words, an increase in ERP amplitude would be found on the second day for both the repeated familiar and the novel stimuli compared to the first day presentation of the familiar stimulus. This result would suggest the process involved would enhance the second day amplitude to many, if not all, similar auditory stimuli.

The stimulus specific hypothesis states that familiarization would be specific only to the familiar stimulus on the second day. That is, ERP amplitude would be greater for the second day familiar stimulus than the first day presentation and the novel stimulus on the second day. ERP amplitudes would be equal for the first day familiar and second day novel stimuli. This result would indicate that the processes involved would be specific only to the stimulus with which there had been prior experience. See Table 1 for a representation of the two hypotheses.

Day Three Hypotheses

To determine the ability of ERP measures to reflect the behaviorally established phenomenon of reactivation two important questions must be answered. First, using a much simpler auditory paradigm, will forgetting occur within the same time period as was found using an operant conditioning technique (Rovee-Collier & Sullivan, 1980)? Second, what influence will the presentation of a small number of stimuli on the third day have on ERP amplitude for the familiar and novel stimuli 24 hours later?

Forgetting Hypotheses

Two different groups were included in the study to test if forgetting had taken place: reacquisition and control. The reacquisition group received 100 presentations of the familiar stimulus on the third day. The control group

underwent the experimental procedure without presentation of stimuli.

Reacquisition Group

If forgetting has not occurred (non-forgetting) then an increased amplitude would be expected for the familiar stimulus on the third day compared to those given on the first day. If forgetting has occurred, an increase in amplitude would not be expected (see Table 3).

Control Group

Since no stimuli were given on the third day, any increase in amplitude for the two stimuli given on Day 4 compared to Day 1 would indicate forgetting had not occurred (non-forgetting). Forgetting would be indicated if the amplitude for both the Day 4 stimuli was equal to the Day 1 amplitude (see Table 4).

Reactivation Hypotheses

The presentation of multiple stimuli can affect reactivation results. When multiple stimuli were used for acquisition, reactivation generalized to new novel stimuli (Greco et al., 1990). A single passive presentation of a novel stimulus blocked reactivation for the acquisition stimulus. At present, reactivation studies which include equal presentation of two stimuli during acquisition has not been undertaken.

Two groups were included to test the ability of ERPs to measure reactivation. The first group (Reactivation) was given 10 presentations of the familiar stimulus on Day 3. The second group (Generalization) was given 10 presentations of a novel stimulus. Twenty-four hours later both groups received equal presentations of the familiar stimulus from the first day and the new novel stimulus. The reactivation group was experiencing the novel stimulus for the first time, while the generalization group had experienced 10 presentations of the novel stimulus on Day 3.

Reactivation Group

If reactivation occurred and is specific to the familiar stimulus given on Day 3, then a larger amplitude would be expected for the familiar stimulus on Day 4 compared to the first day presentation. Also, the familiar stimulus should be larger than the novel stimulus on Day 4. The Day 1-Familiar and the Day 4-Novel should be equal. However, if reactivation generalizes to similar stimuli then an increased amplitude would be expected for both the familiar and novel stimuli given on Day 4 compared to the familiar stimulus on Day 1. Also, the two stimuli on Day 4 would be equal in amplitude (see Table 5).

Generalization Group

If reactivation occurred and is specific to the novel stimulus given on Day 3, then a larger amplitude would be

expected for the novel stimulus on Day 4 compared to the Day 1 familiar presentation. Also, the novel stimulus should be larger than the familiar stimulus on the fourth day. The Day 1-Familiar and the Day 4-Familiar should be equal. However, if reactivation generalizes to similar stimuli, then an increase in amplitude would be expected for both the novel and familiar stimuli given on Day 4 compared to the familiar stimulus on the first day. Also, the two stimuli on Day 4 would be equal in amplitude (see Table 6). A difference in results must be present between the reactivation and generalization groups or reactivation cannot be inferred. Also, a difference must be present between the control group and either the reactivation and/or generalization group to infer the experience on Day 3 contributed to differences on Day 4.

IV

METHOD

Subjects

All subjects were recruited from birth announcements published in the local newspaper. Contact with parents was made by phone and the full experimental procedure was explained and participation requested. Only healthy, full term infants without any known auditory or neurological problems were used in the study. Parents were paid $5 per session to participate.

A total of 48 infants (28 males, 20 females) who met the following criteria were included in the final analysis. These criteria were (a) complete all four sessions, (b) have comparable states across sessions, and (c) have a minimum of 20 artifact-free trials for each auditory condition used for analysis. Data from an additional 23 infants were discarded for the following reasons: one due to experimenter error, one due to equipment problems, two because parents requested the procedure be stopped, 12 unable to complete all four sessions due to illness or family emergency, and seven with state differences across days. The mean age on the first day of testing for the 48 infants included in the data analysis was 96 days.

Stimuli

Three different tone frequencies of 400, 700, and 1000

Hz each with a duration of 100 ms and a rise/fall time of 2 ms were used as stimuli. Tone amplitude was 70 dB sound pressure level measured at the earphone.

Apparatus

The auditory stimuli were presented binaurally using headphones specially designed for use with infants. An elastic strap encircled the head keeping each of the earphones in place.

The EEG was recorded from the prefrontal (Fpz), the frontal (Fz), and central (Cz) areas according to the International 10-20 system (Jasper, 1958) using tin electrodes sewn into an elastic cap made for infants. The three electrodes were each referenced to both linked earlobes with the ground located on the left lateral temporal (T3) area. Eye movements (EOG) were monitored using miniature tin electrodes placed above and to the left of the left eye. Impedances for all electrodes were kept below 10 Kohms.

EEG and EOG data were collected for 102 ms prior to stimulus onset and for 1200 ms following stimulus onset. Amplification of the data was accomplished using Grass Model 7P511 amplifiers with bandpasses of 1-100 Hz. After amplification the EEG was digitized and stored using the ASYST program. The data were stored at the rate of one sample every 6 ms. The raw data for all subjects from Day 1 consisted of 100 single-trial ERPs recorded to the familiar

stimulus. Day 2 consisted of 50 single-trial ERPs from both the familiar stimulus and a novel stimulus. Day 3 trials, collected for the reactivation group only, consisted of 100 single-trial ERPs from the familiar stimulus. Day 4 trials included 50 single trial ERPs from both the familiar stimulus and 50 for the novel stimulus not presented on Day 2.

A 2-step procedure was used to remove ERP trials contaminated by EOG or other artifact to insure artifact-free data. First, if any trial contained a voltage which exceeded 100 μV in any channel of bioelectric activity (EEG or EOG), that trial was automatically discarded. Step 2 examined each 200 ms window of the EOG channel. If a deflection exceeding 60 μV was found in a given window, each EEG channel was searched. If a 60 μV deflection was then found in that window in any EEG channel, the trial was discarded. This method was developed so that EEG voltages which result from eye artifact are detected while minimizing the number of false positive rejections that can occur. Artifact rejection methods which simply discard trials on the basis of a maximum or minimum voltage being found in any channel stand to produce many false positives considering the relatively large-amplitude EEGs found in young infants.

Data from subjects with fewer than 20 artifact free trials for any condition were discarded. The quantity of trials from the blocks of 50 trials for Days 2 and 4 were

matched in number by randomly eliminating trials from the larger sets to match the block with the smallest number of artifact free trials. The same number of artifact free trials were randomly selected from Day 1 (and Day 3 for the reacquisition group) as selected for Days 2 and 4. Thus, for each subject, the same number of trials were used to compute the average ERP for each condition. The number of trials used for data analysis ranged between 24 and 45.

Procedure

Parents brought their child to the laboratory when the infant was most likely to be alert and nurse or take a bottle. Upon arrival, informed consent was obtained and the parent told they could halt the procedure at any time. The parent was seated in a reclining chair with the infant in the parent's lap. First the infant's scalp and face were cleaned and the cap, other electrodes, and earphones were put in place. The experimenter explained the procedure to the parent(s) during each step. Impedances on the electrodes were checked and, if below the 10 Kohms maximum, recorded. Any electrode above 10 Kohms was removed, cleaned, and then replaced until it was below the allowed maximum. If upon completion of stimulus presentation any of the channels registered above 10 Kohms the subject's data were discarded.

The infant began to nurse or bottle feed and the experimenter retired to the control room. Before stimulus presentation, EEG was checked to insure the optimal

amplifier gain and then stimulus delivery began. Stimuli were presented only when the subject was judged to be awake and not moving. Minimum inter-stimulus interval was 4 sec. An assistant viewed the infant on a video monitor and recorded changes in the infant's state using the following classifications:

1 -- asleep

2 -- drowsy/eyes closed

3 -- drowsy/eyes open

4 -- quiet alert/eyes closed

5 -- quiet alert/eyes open

6 -- active alert

7 -- drowsy agitated

8 -- crying

The state classifications were used to help determine if the infant had comparable states across experimental sessions (i.e., the percentage of trials spent in the modal state must be within 20% across all four sessions). The experimenter and assistant independently described the infant's behavior both during preparation and stimulus presentation. The parent was asked questions about the babies alertness during stimulus presentation when the session was over. All of these factors were used to determine comparable states across sessions.

On the first day of testing the infants were randomly assigned to receive 100 presentations of either the 400, 700, or 1000 Hz tone with the restriction of an equal number

of subjects in each condition. On Day 2 all infants received a random order presentation of 50 familiar stimuli and 50 novel stimuli with the constraint of no more than three consecutive presentations of the same stimuli. On Day 3 the infants were randomly assigned to one of four conditions, Reacquisition, Reactivation, Generalization, or Control with the restriction there were 12 subjects per group. Within each group all possible combinations of the three tone frequencies were equally represented. The reacquisition group received 100 presentations of the stimulus given on Day 1. The reactivation group received 10 presentations of the stimulus given on Day 1 during trials 41 to 51 with the remaining trials given without stimulus presentation. The generalization group received 10 presentations of the novel stimulus not given on Day 2 meeting the same criterion placed on the reactivation trials. The control group underwent the full Day 3 procedure without presentation of any stimuli. On Day 4 all subjects received 50 presentations of the familiar stimulus from Day 1 and 50 presentations of the novel stimulus not given on Day 2. The stimuli were presented randomly except for the constraint of no more than three consecutive presentations of the same stimulus. The experimenters were blind to the group membership of any subject.

Design

This study tested the infants on four different days.

On Day 1 the infants were randomly assigned to receive 100 presentations of either the 400, 700, or 1000 Hz tone (Day 1-Familiar) with the restriction of an equal number of subjects in each group. Twenty-four hours later all subjects received 50 presentations of the stimulus presented on Day 1 (D-2 Familiar) and 50 presentations of one of the remaining two tones (D-2 Novel). The infants returned in three weeks (19-23 days) after Day 1. The amount and type of stimulus received on Day 3 distinguished the four groups. Group A (Reacquisition) again received 100 presentations of the Day 1 and 2 familiar stimulus (D-3 Familiar). Group B (Reactivation) received 10 presentations of the Day 1 and 2 familiar stimulus. Group C (Generalization) received 10 presentations of the stimulus not previously presented. Group D (Control) received no stimuli on Day 3. Day 4 sessions were 24 hours following the Day 3 session. On Day 4, all subjects received 50 presentations of the familiar stimulus from Day 1 (D-4 Familiar), along with 50 presentations of the stimulus not presented during Day 1 and Day 2 (D-4 Novel).

To test the proposed hypotheses, different factorial designs were used. The independent variables varied according to design and included: location of electrode (Location), day presented and familiarity of stimulus (Day), and Day 3 group membership (Group). There were three levels of Location: Fpz, Fz, and Cz; six levels of Day: D-1 Familiar, D-2 Familiar, D-2 Novel, D-3 Familiar, D-4

Familiar, and D-4 Novel; and four levels of Group: Reacquisition, Reactivation, Generalization, and Control. The factorial designs varied based on the inclusion of Group and the levels of Day.

To examine the possible developmental differences between 3- and 5-month-old infants in ERP amplitude for familiar and novel stimuli, data from only the first three levels of Day (Day-1 Familiar, Day-2 Familiar, Day-2 Novel) were included. Analyses were completed for all three Locations (Fpz, Fz, and Cz) independently.

To address the hypotheses of changes in amplitude due to group membership on Day 3, all levels of Group (Reacquisition, Reactivation, Generalization, and Control) were analyzed independently. The hypothesis for reacquisition included the levels of Day, Day-1 Familiar and Day-3 Familiar, for all three Locations. The analysis of the two reactivation and the control hypotheses included the levels of Day, Day 1-Familiar, Day 4-Familiar and Day 4-Novel, for all Locations.

To ascertain any additional group trends across days, a one-way analysis of variance was run for each Location by Peak. All levels of Day were entered in the ANOVA including those used for hypothesis testing to maintain an acceptable familywise error rate.

Four different categories of dependent measures were derived from the data: peak amplitude; amplitude variability; and single-trial amplitude and latency

variability.

Peak amplitude. Peaks designated P2, N2, and P3 were identified in the average ERPs in the following way based on the criteria of Ohlrich and Barnet (1972): P2 as the largest positive peak between 150 and 350 ms (P2 is the most prominent peak in the auditory ERP of infants; see Thomas & Crow, 1994); N2 as the largest negative peak following P2 within the time window 200-600 ms; and P3 as the largest positive peak following N2 within the time window 300-800 ms. Amplitude was measured baseline-to-peak, with the baseline being the mean EEG amplitude for the 500 ms preceding stimulus onset.

Single-trial analysis. These analyses were carried out on all average peak ERPs (P2, N2, or P3). The method used was based on the cross-correlational technique described by Michalewski, Prasher, and Starr (1986) and Thomas, Neer, and Price (1989). The method first created a template for each of the relevant peaks (P2, N2, and P3). This template was then moved across a time window in each single-trial waveform one data point at a time. A Pearson correlation coefficient was calculated between the voltage values of the template and the corresponding data points. The point in the search window with the highest correlation between the template and the single-trial waveform was designated as the peak component within that single trial. The single-trial amplitude and latency were then measured. The mean amplitude was used to estimate single-trial amplitude and the standard

deviation of the latency values used to estimate latency variability.

The width of the template and the length of the search window varied for each peak. The P2 template was computed by determining the number of data points in the average latency between the P2 and N2 peaks for all subjects across Location and levels of Days 1, 2, and 4. The average was then divided in half and, assuming symmetry for the P2 peak, doubled, with the stipulation of an odd number of data points making up the final template. The template consisted of a 23 data points (138 ms) segment of the average ERP with the point of highest peak amplitude at the midpoint of the segment. The search window (37 data points, 222 ms) was determined by adding $\pm$ one standard deviation of the average deviation for all subjects across Location and Days 1, 2, and 4. The single-trial peak latencies form a normal distribution (Thomas, Neer, and Price 1989) thereby, using $\pm$ one standard deviation allowed for the capture of approximately 68% of the peaks but limited the search window to decrease the likelihood of the wrong positive or negative peak being identified in a single trial. The search window consisted of the 111 ms preceding and following the latency of the peak in the average ERP.

The above procedure was duplicated for P3 using the average latency between N2 an P3. Symmetry for P3 was again assumed, resulting in a template of 102 ms (17 data points) and a search window of 234 ms (39 data points). An identical

procedure was used for N2 with the exception that half the distance between P2 and N2 and half the distance between N2 and P3 were added together to determine the template width. This resulted in a template of 21 data points (126 ms) and a search window of 28 data points (210 ms).

Amplitude Variability. This analysis looked at the variability in absolute amplitude for designed sections of the full waveform. A ratio between an individual subject's pre-stimulus amplitude and the mean aptitude for each waveform sections was computed and used for comparison.

The waveform was divided into two sections, 0 - 600 ms and 606 - 1206 ms for comparison. This division was chosen to ascertain if differences were present between conditions not specifically accounted for by the peak analyses.

V

Results

Days One and Two

All *a priori* tests of experimental hypotheses utilized planned comparisons using two-tailed Bonferroni tests with the Keppel modification method (Hays, 1988). This method adjusts the overall error rate as if only orthoginal comparisons were performed while keeping the familywise error rate at the .05 level. The adjusted t values of 1.98 were used for all Day 1 and 2 comparisons.

The average peak latency results were nonsignificant for all comparisons tested both in Day 1 and 2 hypotheses and the Day 3 hypotheses. Also, the amplitude variability results were nonsignificant for all comparisons. Therefore, the average latency and amplitude variability results are not included in the individual hypotheses sections.

P2 Peak Analyses

The grand average waveforms for Days 1 and 2 at all three electrodes is shown in Figure 2. The average peak amplitude supported the stimulus general hypothesis (see Table 7 for means, standard deviations, t, and p values). Both Day 2-Familiar and Day 2-Novel had a significant increase in amplitude when compared to Day 1-Familiar, while Day 2-Familiar and Novel were statistically equal. This

finding was consistent for all three electrodes (CZ, Fz, and Fpz). Figure 3 shows the P2 average peak amplitude results.

Single trial amplitude and latency variability analyses were undertaken to establish their effect on the increase in amplitude found for the stimuli on Day 2. Single-trial amplitude results indicated a true increase in amplitude for both the familiar and novel stimuli on Day 2 in comparison to Day 1. The increase was present at all three electrode locations. See Table 8 for all means, standard deviations, t, and p values. Again, both Day 2 stimuli were found to be statistically equal (see Figure 4).

A decrease in latency variability was found from Day 1-Familiar to Day 2-Familiar at all three locations. A significant decrease in variability was found for Day 2-Novel to Day 1-Familiar at the Fz electrode. A marginal decrease between the two days was also found at Cz, with nonsignificant results for Fpz (see Table 9 for all means, standard deviations, t, and p values). Nonsignificant results were found for the comparisons between Day 2-Familiar and Novel at all three electrodes. See Figure 5 for a depiction of the latency variability results.

The increase in amplitude from Day 1 to Day 2 for the familiar stimulus was found to be due to a combination of both a true increase in amplitude and a decrease in the variability of the P2 peak occurrence. The increase in amplitude for the novel stimulus on the second day was also due to a true increase in amplitude. However, a significant

decrease in latency variability was found only at the Fz electrode indicating a true increase in amplitude played a greater role in the overall increase for the novel stimulus.

N2 Peak Analyses

The results of the average peak amplitude analyses for the N2 peak supported neither the stimulus general or specific hypotheses. Comparisons between the first day stimulus and both second day stimuli were nonsignificant at all three locations. A significantly larger peak amplitude was found for Day 2-Familiar in comparison to Day 2-Novel at the Cz and Fz electrodes. Nonsignificant results were found for Fpz (see Table 10 for all means, standard deviations, *t*, and *p* values). The N2 peak results indicated a discrimination between the two second day stimuli (see Figure 6), a very different finding than that of P2.

The single-trial amplitude results also showed an true increase in amplitude for Day 2-Familiar in comparison to Day 2-Novel at the Cz and Fz electrodes, with nonsignificant results at Fpz. A significant increase was also found for Day 2-Familiar in comparison to Day 1-Familiar at Fpz with a marginal increase at Fz. All other comparisons were nonsignificant. See Table 11 for all means, standard deviations, *t*, and *p* values. The results of the single-trial amplitude analyses showed a discrimination between stimuli on Day 2 at Cz and Fz (see Figure 7.)

Latency variability results were found to be consistent

with the stimulus specific hypothesis. A decrease in latency variability was found for the Day 2-Familiar when compared to both Day 1-Familiar and Day 2-Novel at all three electrode locations. See Table 12 for all means, standard deviations, t, and p values. Day 1-Famaliar and Day 2-Novel were statistically equal (see Figure 8). The stimulus specificity of the latency variability analyses may indicate overlying processes represented by the N2 results.

P3 Peak Analyses

An increase in amplitude was found for the Day 2-Familiar and Day 2-Novel stimuli in comparison to the Day 1-Familiar at Cz. A marginally significant increase in amplitude from Day 1 to Day 2-Familiar was present at FZ and Fpz. A marginally significant increase in peak amplitude was found for the familiar stimulus in comparison to the novel on the second day at Fpz. All other comparisons were nonsignificant (see Table 13). The significance found at Cz supports the stimulus general hypothesis but this finding is not consistent across the different electrode locations. The trend present at Fz and Fpz was of stimulus specificity (see Figure 9).

A true increase in amplitude was present in the single-trial amplitude analysis from Day 1 to Day 2 for the familiar stimulus at Fz and Fpz with a statistically marginal increase at Cz. A significant increase was also found for the novel stimulus in comparison to the familiar

stimulus on the first day at Cz (see Figure 10). No other significance was found (see Table 14). No differences were found for the latency variability analyses. See Table 15 for means and standard deviations.

Summary of Days One and Two Results

Support for the stimulus general hypothesis was present at P2 in all three statistical measures. Results for N2, however, showed varying results. An ability for the ERP measure to discriminate the familiar from the novel only on the second day was present in both the average peak amplitude and single-trial amplitude measures. Latency variability results supported a stimulus specific hypothesis. The varying findings for the N2 peak may indicate more than one process was influencing the ERP waveform. The findings at P3 supported a stimulus general hypothesis, at the Cz electrode, for the average peak amplitude and single-trial amplitude measures. The single-trial amplitude measure also showed an increase in amplitude from the first day to the second for the familiar stimulus at Fz and Fpz.

Day Three Hypotheses Results

Bonferroni tests with the Keppel modification method (Hays, 1988) were used for all *a priori* hypotheses comparisons. The adjusted t value for all Group 1 (Reactivation) comparisons was 1.96. All other group

comparisons had an adjusted t = 2.01. Post hoc contrasts were run across days for each group at all three locations using Newman-Keuls statistical analysis.

Reacquisition Group Results

The results from the reacquisition group tested the hypotheses to determine if forgetting had or had not taken place. Non-forgetting was inferred if the amplitude of Day 3-Familiar was greater than Day 1-Familiar. Forgetting was inferred if the amplitude for Day 3-Familiar was not greater than Day 1-Familiar.

P2 Peak Analyses

Average peak amplitude analyses showed nonsignificant differences between Day 1-Familiar and Day 3-Familiar at all three locations. Nonsignificant results were also found for the single-trial amplitude and latency variability measures. The results support the hypothesis that forgetting had occurred. See Table 16 for means and standard deviations for all statistical measures.

N2 Peak Analyses

Average peak amplitude results showed a decrease in amplitude for the familiar stimulus on Day 3 when compared to Day 1 at Fz ($t(11) = 4.61$, $p < .001$), and Fpz ($t(11) = 6.1$, $p < .001$). Days 1 and 3 were statistically equal at Cz ($t(11) = 1.17$, $p > .05$). See Table 17 for means and standard

deviations for all statistical measures. The average peak amplitude results also supported forgetting (see Figure 11).

The single-trial amplitude results showed a significant decrease in amplitude from Day 1- to Day 3-Familiar also indicating forgetting occurred. This decrease was found at all three locations (Cz, $t(11) = 2.46$, $p < .05$; Fz, $t(11) = 2.43$, $p < .05$; Fpz, $t(11) = 2.71$, $p < .05$). See Figure 12 for a graphic representation of the N2 single-trial amplitude analyses.

Latency variability results were nonsignificant at all three electrode locations, thus the decrease in average amplitude for the Day 3-Familiar in comparison to the Day 1-Familiar was due to a decrease in true amplitude.

P3 Peak Analyses

A larger amplitude was found for the familiar stimulus on the third day when compared to the first day in the average peak analyses. A significantly larger amplitude was found at Fz ($t(11) = 4.03$, $p < .001$). A marginal significance was found for Cz ($t(11) = 1.96$, $p < .1$) and Fpz ($t(11) = 1.96$, $p < .1$). See Figure 13.

Single-trial amplitude analysis also showed a larger amplitude for Day 3-Familiar in comparison to Day 1 (see Figure 14). Significance was found at all three locations (Cz, $t(11) = 2.17$, $p < .05$; Fz, $t(11) = 3.39$, $p < .005$; Fpz, $t(11) = 3.48$, $p < .005$).

Latency variability results were nonsignificant at all

three electrode locations. The decrease in average amplitude for the Day 3-Familiar in comparison to the Day 1-Familiar was due to a decrease in true amplitude. See Table 18 for means and standard deviations for all statistical analyses.

Summary of Reacquisition Results

No significant differences were found between Day 1-Familiar and Day 3-Familiar for the P2 peak. N2 showed a larger amplitude for the Day 1-Familiar compared to the Day 3-Familiar. The results at P3 showed the opposite effect. Day 3-Familiar was larger in amplitude than Day 1-Familiar. The results for P2 and N2 support forgetting.

Reactivation Group Results

The results of the reactivation group tested whether reactivation was specific to the familiar stimulus given on Day 3 or generalized to similar stimuli. A larger amplitude would be expected for Day 4-Familiar than Day 1-Familiar and Day 4-Novel if reactivation was specific. However, if reactivation generalizes to similar stimuli then an increased amplitude would be expected for both the Day 4-Familiar and Novel stimuli compared to Day 1-Familiar (see Table 5).

P2 Peak Analyses

A larger amplitude was found for Day 4-Familiar in comparison to the Day 1-Familiar in the average peak

amplitude analysis. The increase was significant at Cz ($t(11) = 3.08$, $p < .01$) and marginal significance at Fz ($t(11) = 1.82$, $p < .1$) and Fpz ($t(11) = 1.92$, $p < .1$). A significantly larger amplitude was also found for Day 4-Novel in comparison to Day 1-Familiar at Cz ($t(11) = 2.1$, $p \leq .05$). All other comparisons were nonsignificant. See Table 19 for all means, standard deviations, t, and p values. The findings at Cz support a generalization of reactivation. However, the trend shown by all three locations was a larger amplitude for the familiar stimulus when compared to the novel stimulus on Day 4 (see Figure 15). Nonsignificance between the two Day 4 stimuli may be due to the greater variability in amplitude represented by a large standard deviation for the familiar stimulus. The trend of a larger amplitude for the familiar stimulus than the novel shown by all three electrodes and the nonsignificant findings at Fz and Fpz does not conclusively rule out specific reactivation.

The single-trial amplitude results were nonsignificant for all comparisons except between Day 4-Familiar and Novel at Cz ($t(11) = 2.01$, $p \leq .05$). The familiar stimulus had a larger amplitude than the novel stimulus. The amplitude of Day 1-Familiar fell midway between the two fourth day stimuli. See Table 20 for all means, standard deviations, t, and p values. The trend present at Fz and Fpz in the single-trial amplitude mirrored that present in the average peak amplitude. The Day 4-Familiar had the largest amplitude, Day

1-Familiar the lowest, and Day 4-Novel falling midway between the two (see Figure 16).

The latency variability results showed a decrease in variability for Day 4-Familiar in comparison to Day 1-Familiar at Fz ($t(11) = 2.05$, $p < .05$) and Fpz ($t(11) = 2.11$, $p < .05$). Marginal significance was found for Cz ($t(11) = 1.97$, $p < .1$). See Table 21 for all means, standard deviations, t, and p values. Nonsignificant differences were found for all other comparisons. As seen in Figure 17, a decrease in variability was present for both the familiar and novel stimuli on Day 4, however, there was greater individual variability for the novel stimulus as represented by the standard deviations.

N2 Peak Analyses

Average peak amplitude results were nonsignificant for all comparisons. Nonsignificant results were also found for the single-trial amplitude analysis (see Table 22 for all means and standard deviations for both amplitude analyses).

Latency variability results showed a significant decrease in variability for the familiar stimulus compared to the novel stimulus on Day 4 at Fz ($t(11) = 2.36$, $p < .05$) and Fpz ($t(11) = 2.02$, $p < .05$). Marginal significance was found for Cz ($t(11) = 1.77$, $p < .1$). See Figure 18 for a graphic representation. All other comparisons were nonsignificant. See Table 23 for all means, standard deviations, t, and p values.

P3 Peak Analyses

Nonsignificant results were found for all three statistical measures for P3. While the single-trial amplitude showed a trend very similar to that of P2, there was again high individual subject variability seen in the standard deviations. See Table 24 for all means and standard deviations.

Summary of Reactivation Results

None of the individual peak results fully supported either the stimulus specific or general hypotheses (refer to Table 4). While the presentation of the 10 familiar stimuli on Day 3 appeared to have a greater effect on the familiar stimulus, some generalization also occurred. These findings were most apparent at the P2 and N2 peaks.

Generalization Group Results

The results of the generalization group tested whether reactivation was specific to the novel stimulus given on the third day or generalized to both the novel and familiar stimuli. A larger amplitude would be expected for Day 4-Novel compared to Day 1- and 4-Familiar if reactivation was specific. However, if reactivation generalized to similar stimuli, then an increased amplitude would be expected for both Day 4-Novel and Familiar stimuli compared to Day 1-Familiar (see Table 6).

P2 Peak Analyses

A significant increase in peak amplitude was found for Day 4-Familiar compared to Day 1-Familiar at Fz ($t(11) = 2.36$, $p < .05$) and Fpz ($t(11) = 2.19$, $p < .05$). A marginally significant increase was found for Day 4-Novel compared to Day 1-Familiar at Fpz ($t(11) = 1.71$, $p < .1$). All other comparisons were nonsignificant (see Table 25 for all means, standard deviations, t, and p values). While Cz showed no differences across days, both Fz and Fpz showed a trend toward generalization (see Figure 19).

The single-trial amplitude results also showed a significant increase in amplitude for Day 4-Familiar compared to Day 1-Familiar at Fz ($t(11) = 2.36$, $p < .05$) and Fpz ($t(11) = 2.57$, $p < .05$). A significant increase was also found for Day 4-Novel compared to Day 1-Familiar at Fpz ($t(11) = 2.84$, $p < .01$). All other comparisons were nonsignificant (see Table 26). Cz showed no significant differences across days while Fz and Fpz showed a trend toward stimulus generalization (see Figure 20).

A significant decrease in latency variability was found for both Day 4-Familiar and Day 4-Novel compared to Day 1-Familiar at all three locations. Day 4-Familiar was also significantly less variable than Day 4-Novel at Cz. See Table 27 for all means, standard deviations, t, and p values. Fz and Fpz supported a stimulus generalization interpretation. However, the findings at Cz are inconclusive (see Figure 21).

N2 Peak Analyses

Nonsignificant results were found for all three statistical measures for N2. There were no consistent trends at any of the peaks which would support either hypotheses. See Table 28 for all means and standard deviations.

P3 Peak Analyses

A marginally significant increase ($p < .1$) in amplitude was found for the Day 4-Familiar when compared to Day 1-Familiar at Cz and Fpz. A significant increase was found for Day 4-Novel when compared to Day 1-Familiar at Cz ($p < .05$) with marginal significance at Fpz ($p < .1$). While the same trend is present at Fz it did not reach significance (see Figure 22). Day 4-Familiar and Day 4-Novel were statistically equal for all locations. See Table 29 for all means, standard deviations, t, and p values. Again the results supported a stimulus generalization.

Single-trial amplitude results showed a significant increase in amplitude for Day 4-Novel compared to Day 1-Familiar at Fpz ($t(11) = 2.05$, $p < .05$) and a marginal significance at Fpz ($t(11) = 1.76$ $p < .1$). All other comparisons were nonsignificant (see Table 30). These findings indicated that the increase in amplitude for the average peak findings for Day 4-Novel was partially attributable to a true increase in amplitude. While Day 4-Familiar also showed an increase, it was not significantly different from Day 1-Familiar (see Figure 23).

The latency variability result showed a decrease in variability for Day 4-Novel compared to both Day 1 and 4-Familiar indicating specificity to only the novel stimulus. All other comparisons were nonsignificant (see Table 31). No trends were apparent at either Fz or Fpz (see Figure 24).

Summary of Generalization Results

The results from the analysis of peak P2 supported a stimulus generalization interpretation. The presentation of 10 novel stimuli on Day 3 affected both the familiar and novel stimuli given on Day 4. The average peak amplitude results for P3 also supported this interpretation. However, the single-trial amplitude and latency variability tended to support a stimulus specific interpretation where the novel were favored over the familiar. These differing results may have indicated different processes were present in the ERP.

Control Group Results

Since no stimuli were given on the third day, any increase in amplitude for either Day 4-Familiar or Novel stimuli when compared to Day 1-Familiar would indicate forgetting had not occurred (non-forgetting). Forgetting would be indicated if the amplitude for both Day 4 stimuli were equal to the Day 1-Familiar amplitude (see table 4).

P2 Peak Analyses

The results for the average peak amplitude showed a

significant increase in amplitude for Day 4-Familiar compared to Day 1-Familiar at Fz ($t(11) = 2.77$, $p = 2.77$) and Fpz ($t(11) = 2.65$, $p < .05$). A significant increase for Day 4-Novel compared to Day 1-Familiar was found at Cz ($t(11) = 2.54$, $p < .05$). Marginally significant increases were found at Fz ($t(11) = 1.97$, $p < .1$) and Fpz ($t(11) = 1.81$, $p < .1$). Nonsignificant differences were found between Day 4-Familiar and Day 1-Familiar at Cz and between Day 4-Familiar and Novel at all locations. See Table 32 for all means, standard deviations, t, and p values. The increase in amplitude for Day 4-Familiar and Novel indicated forgetting had not taken place (see Figure 25).

The single-trial analysis replicated the average peak results. A significant increase in amplitude was found for Day 4-Familiar compared to Day 1 at Fz ($t(11) = 2.34$, $p < .05$). A marginal increase was shown for Fpz ($t(11) = 1.84$, $p < .1$). A significant increase was also found for Day 4-Novel compared to Day 1-Familiar at Cz ($t(11) = 3.05$, $p < .01$) and Fz ($t(11) = 2.11$, $p < .05$) with a marginal increase at Fpz ($t(11) = 1.98$, $p < .1$). All other comparisons were nonsignificant. See Table 33 for all means, standard deviations, t, and p values. Again the results supported a non-forgetting hypothesis (see Figure 26).

The latency variability results showed a significant decrease in variability for Day 4-Familiar compared to Day 1-Familiar for all three electrodes. A significant decrease was also found between Day 4-Novel and Day 1-Familiar at Cz

and Fz with a marginal decrease found at Fpz. Day 4-Familiar and Novel were statistically equal. See Table 34 for all means, standard deviations, t, and p values. Non-forgetting was again interpreted from the latency variability results (see Figure 27).

N2 Peak Analyses

The results for average peak amplitude were nonsignificant for all comparisons. See Table 35 for means and standard deviations. Single-trial amplitude analyses showed a significant increase in amplitude for the Day 4-Familiar compared to Day 1-Familiar at Fz ($t(11) = 2.19$, $p < .05$) and Fpz ($t(11) = 2.19$, $p < .05$). All other comparisons were nonsignificant (see Table 36). Figure 28 gives a graphic representation of the single-trial amplitude results.

The results of the latency variability showed nonsignificance for all comparisons. See Table 37 for all means and standard deviations.

P3 Peak Analyses

Average Peak amplitude results showed an increase in amplitude for Day 4-Familiar compared to Day 1-Familiar at Cz ($t(11) = 2.86$, $p < .05$) and Fpz ($t(11) = 2.16$, $p < .05$). A significant increase in amplitude for Day 4-Novel compared to Day 1-Familiar occurred at Cz ($t(11) = 3.09$, $p < .01$). All other comparisons were nonsignificant. See Table 38 for

all means, standard deviations, t, and p values. As Figure 29 shows, the non-forgetting hypothesis was again supported.

The results for single-trial amplitude again showed significant differences not expected if forgetting had taken place (see Figure 30). A significant increase in true amplitude was found for Day 4-Familiar when compared to Day 1-familiar at Cz ($t(11) = 2.88$, $p < .05$) with marginal significance at Fz ($t(11) = 1.84$, $p < .1$) and Fpz ($t(11) = 1.79$, $p < .1$). Significance was also found for Day 4-Novel compared to Day 1-Familiar at Cz ($t(11) = 3.64$, $p < .005$). Marginal significance was found for Fz ($t(11) = 1.98$, $p < .1$) and Fpz ($t(11) = 1.82$, $p < .1$). Nonsignificant results were found between Day 4-Familiar and Novel (see Table 39).

The results of the latency variability showed nonsignificant results for all comparisons. See Table 40 for all means and standard deviations.

Summary of Control Results

The results for all peaks indicated forgetting had not taken place. The results for the control group were very similar to those of the generalization group which received 10 novel stimulus on Day 3.

Post Hoc Analyses

Individual ANOVAS were run for each of the three dependent measures: average peak amplitude, single-trial amplitude and latency variability for all three peaks (P2,

N2, and P3) and for all three levels of Location (Cz, Fz, and Fpz). While all levels of Day were included in the analysis to insure a familywise error rate of .05, only those comparisons not reported in the *a priori* hypotheses results were included in the following results.

Reacquisition Group Results

P2 Peak Analyses

The average peak amplitude ANOVA was significant for the main effect for Day at the Cz electrode ($F(5,55) = 3,24$, $p \leq .05$). The post hoc comparisons showed the amplitude for Day 4-Familiar was significantly greater than Day 3-Familiar. All other comparisons were nonsignificant at the .05 level.

A significant ANOVA for the average peak amplitude was also found for the main effect of Day at Fz ($F(5,55) = 4.08$, $p < .005$). A significant increase in amplitude for Day 4-Familiar compared to Day 2-Familiar ($p < .02$), Day 2-Novel ($p < .02$) and Day 3-Familiar ($p < .005$). All other comparisons were nonsignificant.

A third ANOVA at the Fpz location also had a significant main effect for Day ($F(5,55) = 3.30$, $p < .02$). An increase in peak amplitude was again found for Day 4-Familiar when compared to Day 1-Familiar ($p < .05$), Day 2-Familiar ($p < .02$) and Day 3-Familiar ($p < .02$). Table 41 gives the means for all levels of Day at all Locations.

All three analyses showed an increase for the Day 4-Familiar in comparison to Day 3-Familiar (see Figure 31). Also, an increase was found for Day 4-Familiar in comparison to Day 2-Familiar at Fz and Fpz. The presentation of 100 familiar stimuli on Day 3 caused a marked increase in amplitude for the familiar stimulus on Day 4.

Single trial amplitude analysis at Cz resulted in a significant Day effect ($F(5,55) = 4.57$, $p < .002$). Multiple comparisons showed an increase in amplitude for Day 4-Familiar compared to Day 1-Familiar ($p < .005$) and Day 3-Familiar ($p < .005$). A significant increase was also found for Day 4-Novel ($p < .05$) compared to Day 3-Familiar.

The single-trial ANOVA for Fz also showed a main effect for Day ($F(5,55) = 4.73$, $p < .005$). The comparisons reflected those found in the average peak amplitude results. Day 4-Familiar was larger in amplitude than Day 1-Familiar ($p < .002$), Day 2-Familiar ($p < .03$), Day 2-Novel ($p < .02$), and Day 3-Familiar ($p < .005$).

The Day effect for Fpz was also significant ($F(5,55) = 5.57$, $p < .0005$). Day 4-Familiar was found again to be greater in amplitude than Day 1-Familiar ($p < .005$), Day 2-Familiar ($p < .01$), Day 2-Novel ($p < .05$), and Day 3-Familiar ($p < .005$). Table 42 gives the means for all levels of Day for all Locations.

The single-trial analysis reflected the findings of the average peak amplitude results. The presentation of 100 familiar stimuli on Day 3 caused a marked increase in true

amplitude for the familiar stimulus on Day 4 (see Figure 32).

The latency variability results were nonsignificant at all three locations (Cz, $F(5,55) = 1.23$, $p > .05$; Fz, $F(5,55) = 1.32$, $p > .05$; Fpz $F(5,55) = 1.39$, $p > .05$). These findings indicated that the increase in Day 4-Familiar was due to a true increase in amplitude and not a decrease in variability.

N2 Peak Analyses

A significant ANOVA was present for the average peak analysis for Cz ($F(5,55)$, $p < .05$) and Fz ($F(5,55) = 2.55$, $p < .05$) for Day. However, the multiple comparisons for both locations did not yield significant comparisons at the .05 level. The ANOVA for the Day effect was nonsignificant at Fpz ($F(5,55) = 1.89$, $p > .05$).

Single-trial amplitude analysis for a Day effect was nonsignificant at Cz ($F(5,55) = .88$, $p > .05$). A significant Day effect was found at Fz ($F(5,55) = 3.7$, $p < .01$) and Fpz ($F(5,55) = 2.88$, $p < .05$). Multiple comparisons for Fz showed Day 3-Familiar to be smaller in amplitude than Day 2-Familiar ($p < .01$), Day 2-Novel ($p < .05$), Day 4-Familiar ($p < .01$) and Day 4-Novel ($p < .05$). The results for Fpz showed a smaller amplitude for Day 3-Familiar compared to Day 2-Familiar ($p < .05$), Day 4-Familiar ($p < .05$), and Day 4-Novel ($p < .05$). See Table 43 for means for Fz and Fpz. The results again indicated a damping of the Day 3 amplitude for

Fz and Fpz (see Figure 33).

The latency variability results were nonsignificant at all three locations (Cz, $F(5,55) = .34$, $p > .05$; Fz, $F(5,55) = .47$, $p > .05$; Fpz $F(5,55) = .59$, $p > .05$). These findings once more indicated the increase in Day 4-Familiar is due to a true increase in amplitude and not a decrease in variability.

P3 Peak Analyses

All of the analyses for the P3 peak, average peak amplitude, single-trial amplitude, and latency were nonsignificant.

Reactivation Group Results

P2 Peak Analyses

A Day main effect was found for P2 at Cz ($F(4,44) = 3.1$, $p < .05$), Fz ($F(4,44) = 2,6$ $p < .05$), and Fpz ($F(4,44) = 3.07$, $p < .05$). However there were no significant comparisons at the .05 level not reported in the *a priori* hypotheses results. See Figure 34 for the average peak amplitudes across days.

Single-trial analyses were nonsignificant at all Locations (Cz, $F(4,44) = 1.99$, $p > .05$; Fz, $F(4,44) = .5$, $p > .05$; Fpz $F(4,44) = 1.21$, $p > .05$). The P2 latency variability results were also nonsignificant for Cz ($F(4,44) = 1.42$, $p > .05$) and Fz ($F(4,44) = 1.02$, $p > .05$). A

significance was found for Fpz ($F(4,44) = 3.1$, $p < .05$). The comparisons showed an increase in amplitude for Day 2-Novel compared to Day 2-Familiar.

N2 and P3 Analyses

N2 and P3 analyses were nonsignificant for the reactivation group. Table 45 gives the F values and probabilities for the individual ANOVAS.

Generalization Group Results

P2 Peak Analyses

The analysis of the average peak amplitude measure resulted in nonsignificant Day effects at all three locations (Cz, $F(4,44) = .97$, $p > .05$; Fz, $F(4,44) = 2.3$, $p > .05$; Fpz $F(4,44) = 1.97$, $p > .05$). Nonsignificant results were also found in the single-trial amplitude analyses at Cz ($F(4,44) = .25$, $p > .05$) and Fz ($F(4,44) = 2.57$, $p > .05$). A significant ANOVA was found for Day effect at Fpz ($F(4,44) = 3.77$, $p < .01$). Multiple comparisons showed a greater amplitude for Day 2-Familiar ($p < .01$) and Day 2-Novel ($p < .01$) when compared to Day 1-Familiar.

A Day effect was found in the latency variability analysis for all locations (Cz, $F(4,44) = 4.21$, $p < .0005$; Fz, $F(44,44) = 5,76$, $p < .001$; Fpz, $F(4,44) = 4.29$, $p < .005$). At Cz, a decrease in latency variability was found for Day 2-Familiar compared to Day 1-Familiar ($p < .05$) and for Day 4-Novel compared to Day 2-Novel ($p < .05$). Fz showed

a significant decrease in variability for Day 2-Familiar (p < .005) and Day 2-Novel (p < .05) when compared to Day 1-Familiar. A decrease in variability was also found for Day 2-Familiar when compared to Day 1-Familiar (p < .05) at Fpz (see Figure 35).

N2 and P3

Nonsignificant analyses were found for all measures for N2 and P3 peaks. See Table 46 for the F and p values.

Control Group Results

P2 Peak Analyses

All analyses for the average peak amplitude and single-trial amplitude were nonsignificant. See Table 46 for the F and probability values for both measures.

The latency variability measure had a significant Day effect at all locations (Cz, $F(4,44) = 8.9$, p < .00005; Fz, $F(4,44) = 3.48$, p < .02; Fpz $F(4,44) = 3.03$, p < .03). Multiple comparisons at Cz showed a significant decrease in variability for both Day 4-Familiar (p < .01) and Day 4-Novel (p < .01) in comparison to Day 1-Familiar (see Figure 36 for the 3 Locations). The results for Fz showed a decrease in variability for Day 4-Familiar compared to Day 1-Familiar (p < .001), Day 2-Familiar (p < .01), and Day 2-Novel (p < .01). A decrease in variability was also present for Day 4-Novel compared to Day 1-Familiar (p < .001), Day 2-Familiar (p < .01) and Day 2-Novel (p < .01). Comparisons

for Fpz did not show significant comparisons not already covered in the *a priori* results.

N2 Peak Analyses

A significant ANOVA was present for the Day main effect at Fz ($F(4,44) = 3.09$, $p < .03$). An increase in amplitude was found for Day 4-Familiar compared to Day 2-Novel ($p < .02$). All other comparisons were nonsignificant. Nonsignificant results were found at both Cz ($F(4,44) = .43$, $p > .05$) and Fpz ($F(4,44) = .31$, $p > .05$) See Table 46.

The single-trial amplitude results showed a significant Day effect at Cz ($F(4,44) = 3.19$, $p < .03$) and Fz ($F(4,44) = 3.08$, $p < .03$). A significantly larger amplitude was found for Day 4-Familiar compared to Day 2-Novel at Cz ($p < .02$) and Fz ($p < .02$). All other comparisons were nonsignificant (see Figure 37). A significant ANOVA was found for Fpz ($F(4,44) = 2.61$, $p < .05$), however, the multiple comparisons were all nonsignificant at the .05 level. The latency variability results were nonsignificant at all three locations (Cz, $F(4,44) = .61$, $p > .05$; Fz, $F(4,44) = 1.2$, $p > .05$; Fpz $F(4,44) = 1.89$, $p > .05$).

P3 Peak Analyses

A significance was found for single-trial amplitude at Cz ($F(4,44) = 2.85$, $p < .04$). However, the significant comparisons have already been discussed in the *a priori* results. Nonsignificant results were found for Fz ($F(4,44) =$

1.95, $p > .05$) and Fpz ($F(4,44) = 2.2$, $p > .05$. The average amplitude and latency variability analyses were nonsignificant (see Table 47).

VI

Discussion

Days One and Two

The findings of the effects of familiarization 24 hours prior to testing showed varied results for the different peaks. All ERP measures of the P2 peak supported a stimulus general hypothesis. On the other hand, for N2, amplitude measures showed discrimination between the two stimuli on the second day but neither differed from the familiarization period on the first day. The latency variability measure, however, supported a stimulus specific hypothesis. The P3 peak results were much less straight forward. The amplitude measures indicated a stimulus general response at Cz, while Fz and Fpz showed a trend toward stimulus specificity.

Developmental Differences

The major difference found between the results of the present 3-month-old study and the previous results using 5-month-old infants (Thomas & Lykins, 1995) were the findings at the P2 peak. Familiarization with the Day 1 stimulus increased amplitude for both stimuli presented on Day 2 in 3-month-olds, while familiarization with the Day 1 stimulus increased amplitude for only the Familiar stimulus on Day 2 in 5-month-olds.

Thomas and Lykins (1995) concluded, for 5-month-olds, stimulus experience on Day 1 helped strengthen the neural

elements and increased the stability of the representative ensemble 24 hours later. In other words, the increase in true amplitude shown in the single-trial results suggests possible mechanisms such as greater ionization and/or transmitter release in neurons involved in the representative ensemble (Fuster, 1995). The decrease in latency variability may have been due to the pruning away of excessive synapses (Greenough, Black, & Wallace, 1987) and/or greater synchronization of the neurons in the ensemble (Levitt, 1995). These neuronal changes were specific only to the familiar stimulus for 5-month-olds. In the bounds of this interpretation what then is happening with the 3-month-olds? Can experience with one stimulus cause changes in the neural ensemble of the other similar stimuli?

Two concepts are important to help answer this question. First, storage of a single stimulus is not contained in one cell but a grouping of cells. A single neuron shares dendritic connections with several other cells and, therefore, participates in the storage of information of more than a single stimulus. This theoretical position, known as assembly coding, substantially reduces the number of neurons necessary to represent a stimulus feature, allowing greater flexibility in the generalization of new representations (Singer, 1995).

This theory of neuronal connectionism is not new and was first postulated by Hebb (1949). His neurophysiological

principle states if an axon of one neuron is near enough to a second neuron and consistently takes part in firing the second neuron then some pre-synaptic and/or post-synaptic growth process (learning) takes place. Hebb's basic concept has been supported with empirical proof (Fuster, 1995). This basic postulate has been expanded to take into account findings which show a single axon can connect to more than just one neuron and the dendrites of a single neuron are connected to many other neurons. While the presented tone frequency will excite neurons representative of other frequency ensemble, after repeated activity, the neurons in the ensemble representing the experienced frequency become more synchronous. In other words, the presynaptic neuronal firing which causes the ensemble for the experienced tone to fire (recognition) becomes convergent in time.

Second, the P2 peak has been strongly associated with sensory processing and reflects the brain's response to physical characteristics of the stimulus (Steinschneider et al., 1994). The neurons which will become the auditory system from the brainstem to the cerebral cortex are present in the human embryo by the end of the second trimester (Konishi, 1995). Some areas of the brain which store auditory memory are pre-wired, others are awaiting environmental experience to facilitate their development. While the developmental course leading to a mature auditory system is not known, mature auditory frequency resolution is reached by the age of 6-months (Spetner & Olsho, 1990). Even

though the infants at three months of age have not developed a mature system, they are able to easily make frequency distinctions below 4000 Hz.

Taking these concepts into account, the stimulus generalization found in 3-month-olds lends itself to the neuronal process interpretation of Thomas and Lykins (1995). Familiarization with an auditory tone on the first day helped not only to increase connections within the ensemble for the familiar stimulus but also for other tone frequencies as reflected in the single-trial amplitude increase. The Day 1 experience also aided in pruning away excess neuronal connections for both stimulus ensembles as reflected in the latency variability results. While both stimuli decreased significantly in latency variability on Day 2, the familiar stimulus effect was stronger than the novel (refer to Figure 4). This may indicate synchronization took place within the familiar ensemble.

The differences between the two ages may be attributed to one of two theoretical positions. The 3-month-old findings may represent a difference in stage development from that of the 5-month-olds. This interpretation would make intuitive sense from the standpoint experience with a single stimulus would generalize to similar stimuli and more quickly stabilize the neural representation of closely related stimuli information for the younger infants. The ability to categorize and respond to novel stimuli from the same category is present by 3-months (Greco et al., 1990,

Exp. 2). By 5-months, the additional experience with the environment has developed an organized system of related stimuli. The neural response now becomes specific to the actual stimulus encountered in the environment. Maturation of auditory frequency resolution may also account for the stimulus specificity found for 5-month-olds. Experience with the environment helped to form a more uniform auditory system. Experience with a given auditory stimulus would now be specific to that stimulus.

The second theoretical interpretation states experience with the familiar stimulus on Day 1 would lead to stimulus specificity in the 3-month-olds given more familiarization. This interpretation is based on behavioral findings of memory which showed consistent processes across ages which differed only in age-related length of retention and the amount of initial experience necessary to evoke similar behavioral responses (Diamond, 1995; Rose et al., 1982).

The present study cannot give a conclusive answer to which theoretical interpretation is correct, or, if in fact, the two theoretical positions are mutually exclusive. It is possible some memory processes are stage dependent and others continuous from birth. Additional ERP studies which vary the amount of experience on Day 1 would give us additional information in the development of simple auditory retention.

The findings at the N2 peak were similar for both the 3- and 5-month olds (Thomas & Lykins, 1995). See Table 48

for a comparison of ages for both the P2 and N2 peaks. While the average amplitude results showed different findings, discrimination versus a specific response, the single-trial waveform measures exhibited the same findings between ages. The differing results found at the P2 and N2 peaks may indicate two or more separate processes influence the ERP waveform.

One theoretical distinction which may play a role in the differences found between P2 and N2 for the 3-month-olds is of learning versus memory. Learning is the process in which new information about the world is acquired, while memory is the process by which knowledge is retained (Bailey & Kandel, 1995). The P2 peak may represent a continuation of the learning process. The experience with both stimuli on Day 2 increases amplitude for both stimuli. The N2 peak reflects the retention and retrieval of the familiar frequency memory trace. The 5-month-olds also showed the retrieval of memory at N2 but, due the maturation of the auditory system involved, did not show generalized learning at P2.

A second theoretical construct which may attribute to the differences between the findings at P2 and N2 is the presence of both exogenous and endogenous waveforms in the ERP recordings. As stated earlier, the P2 portion of the waveform is related to processing physical characteristics of a stimulus (Steinschneider et al., 1994). These exogenous waves tend to be faster frequencies and respond to bottom-up

processing. In other words, they reflect information which comes from the environment. A slower frequency endogenous wave may have been superimposed over the faster exogenous wave starting with the N2 component. Endogenous properties relate to internal cognitive processes such as working memory and discrimination (Hillyard & Hansen, 1986). These top-down processes represent internal brain function as opposed to sensory stimulus processing.

The N2 results may also reflect both endogenous and exogenous processes. In this interpretation the single-trial amplitude represents an endogenous wave which may be processing discrimination between the two stimuli on Day 2 denoting the information storage system typically referred to as working memory. The familiar stimulus is held in working memory, resulting in an increase in amplitude attributed to the endogenous process, while the novel stimulus is compared to the familiar (Molfese & Wetzel, 1992). The latency variability results may indicate exogenous processing of the stimuli. While the P2 component represents the storage process of incoming information (learning), the N2 component may reflect the retrieval of stored information representative of the environmental stimuli (memory). The Day 1 familiarization established a more consistent ensemble indicated by the decrease in latency variability found for the familiar stimulus at N2. In other words, the physical stimuli are presented (eg. random presentation of 400 and 700 Hz tones) with the

incoming information causing changes in the representative ensembles (learning) which is reflected in the P2 peak. Retrieval of the information previously learned and stored for the familiar stimulus (memory) takes place as reflected by the decrease in latency variability found in N2. The retrieved information for the familiar stimulus is placed in working memory and the endogenous process of discrimination occurs as reflected in the N2 single-trial amplitude.

The findings at P3 for 3-month-olds were unexpected since all results for 5-month-olds were not significant (Thomas & Lykins, 1995). The P3 component has mainly been interpreted as representing solely endogenous processes. The results at Cz for average peak amplitude indicated generalization. However, Fz and Fpz showed a stimulus specific trend. The single-trial amplitude analysis indicated a true increase in amplitude for both the familiar and novel at Cz. An increase in amplitude for only the familiar was found at Fz and Fpz. The novel fell between the Day 1- and 2-Familiar. Thus, lack of reliable findings prohibits any firm conclusions.

Days Three and Four

Forgetting

The findings at the P2 and N2 peaks for the Reacquisition group indicated forgetting had occurred. Day 1-Familiar was larger in amplitude than Day 3-Familiar. However, the P3 peak findings showed the opposite. The

results of the Control group showed increased amplitudes for both the familiar and novel stimulus on the fourth day when compared to the first. Latency variability showed a decrease for both Day 4-Familiar and Novel compared to Day 1-Familiar. All of the results for the Control group indicated forgetting had not occurred. These mixed results made a conclusion about forgetting impossible to make.

If forgetting is not responsible for the decreased (dampened) amplitude at Fz and Fpz for the familiar stimulus on Day 3, what different neuronal response underlies the difference between Days 1 and 3 for the Reacquisition group? Behavioral studies have consistently found habituation to a familiar stimulus after repeated exposure in infants (Fagan, 1984). That is, the infant stops responding to the stimulus presentations. This habituation could lead to a decrease in amplitude of the ERP if the infant stops attending to the tone presentations. However, increased true amplitude for the Day 4-Familiar in comparison to Days 1-, 2- and 3-Familiar would not be expected if habituation to the familiar stimulus was occurring. Still, it might be argued habituation occurs only when the familiar stimulus is presented by itself, as on Day 3. When two stimuli are presented simultaneously, an attentional factor which allows for discrimination between familiar and novel might be responsible for the increase in amplitude to both stimuli. If this were the case, then differences between the P2 and N2 measures should be present. If the P2 peak is processing

exogenous stimulus information and N2 is influenced by an attentional component, then differences would be expected in the peak results on Day 4. A decrease in amplitude for the familiar stimulus due to a habituation factor and/or an increase in amplitude for the novel stimulus due to greater attention would be expected in N2. These findings were not present. In fact, the familiar stimulus tended to produce greater amplitude than the novel stimulus at both peaks. The findings of Thomas et al. (1989) also tend to discount a habituation hypothesis. Equal numbers of the same stimulus were given over two days without the presentation of a novel stimulus on the second day. An increase in amplitude was still present for the familiar stimulus on the second day, not the decrease expected if habituation occurred.

An additional argument against habituation was the true increase in amplitude found for the Reactivation group for Day 4-Familiar compared to all Day 1 and 2 conditions and to Day 3-Familiar at the Fz and Fpz electrodes for the P2 peak. This finding was not present for the Day 4-Novel. Given that the P2 peak represents sensory processing, the additional experience on Day 3 served to strengthen the representative ensemble connections for the familiar stimulus beyond their Day 2 level. While the novel stimulus tended to also produce an increase in amplitude, it did not reach a significant level for the P2 peak. If the decrease for Day 3 had been due to habituation, then the Day 4-Familiar would have been expected to be equal to the Day 2-Familiar. This premise is

based on the idea habituation would occur because additional experience was not needed to strengthen the neuronal ensemble.

Another possible explanation for the dampened Day 3 amplitude comes from the work of Rovee-Collier and colleagues who have shown that a period of time exists when information is unavailable for immediate retrieval and appears forgotten. The dampened amplitude of the familiar stimulus on Day 3 may represent this retrieval problem. The representative ensemble established for the Day 1-Familiar stimulus, due to an absence of use, did not respond as efficiently as it had 24 hours after initial familiarization. However, the results of this study can neither support nor disprove this interpretation. Additional studies are needed to address the ERP results for Day 3.

Reactivation

Without firm evidence of forgetting, reactivation cannot be said to have occurred conclusively. Furthermore, the results of the Reactivation group did not fully support either stimulus general or specific reactivation. The average peak amplitude results at P2 showed generalization to both the familiar and novel stimuli on Day 4 at Cz. However, all three leads showed a trend for increased amplitude for the familiar stimulus on Day 4. The Day 4-Familiar stimulus showed a true (single-trial) increase in amplitude for the familiar stimulus compared to the novel on

Day 4 at Cz. While not significant, this trend was also found at Fz and Fpz. These results support stimulus specific reactivation.

A decrease in latency was found for Day 4-Familiar compared to Day 1 at P2 and for Day 4-Familiar compared to Day 4-Novel at N2. While neither peak meets all the criteria for stimulus specific reactivation, again the trend is present.

The results of the Generalization group were again mixed between generalization and specificity to the novel stimulus. The P2 peak results tend to support stimulus generalization for the two stimuli on Day 4. Increased amplitude and decreased variability were found for both the familiar and novel stimuli when compared to Day 1.

The P3 peak significant results tended to support stimulus specific reactivation. The single-trial amplitude showed a significant increase in amplitude for Day 4-Novel compared to Day 1-Familiar at Fz and Fpz. Decreased variability was found for Day 4-Novel compared to Day 1- and Day 4-Familiar. However, this trend was not consistent across all electrodes.

The mixed results for both forgetting and reactivation do not show conclusively one way or another if reactivation occurred. The generalization found in the Day 1 and 2 results compound the difficulty in interpreting the reactivation results. Is the generalization found in the Reactivation and Generalization groups due to the experience

given on Day 3 or is it a replication of the Days 1 and 2 results? However, some differences are reflected in the Day 4 results, implying the experience on Day 3 does appear to have an effect on the ERP waveform.

Day Three Stimulus Experience

The results of the *a priori* hypothesis testing for Days 3 and 4 may have been affected by the small group size. ERP measures are often quite variable within, as well as, between subjects. Not all groups reflected the overall findings for Days 1 and 2 which could have influenced the results of the *a priori* hypotheses testing. A comparison within each group, across all days, may give a better understanding of the influence of the different stimulus conditions on Day 3.

To ascertain the overall effects of the Day 3 experience on the Reacquisition group, the comparisons across all days were considered. If the additional experience with the 100 familiar stimuli helped to organize the representative ensemble, then we would expect Day 4-Familiar to be greater in amplitude than Day 2-Familiar and Day 2-Novel. Day 4-Novel should be equal to Day 2-Familiar and Novel. The results at P2 supported this premise. Day 4-Familiar was larger in amplitude than the Day 2 stimuli at both Fz and Fpz. Day 4-Familiar was also larger in amplitude than Day 4-Novel at Fpz. The Day 4-Novel ERPs were equal to both Day 2 stimuli at all electrodes. These findings

indicate the experience on Day 3 influenced the organization of the neuronal ensemble for the familiar stimulus. Even though a dampened amplitude for the familiar stimulus was found on Day 3, learning still appeared to take place resulting in the increased amplitude for the familiar stimulus on Day 4. The novel stimulus was not significantly different from either the Day 2 stimuli or the Day 4-Familiar (refer to Figure 31) indicating some learning did take place but not enough to be significant.

Differences found between Day 2 and 4 for the Reacquisition group at N2 should also be noted. An increase in amplitude was found for both the familiar and novel stimuli on Day 4 compared to an increase only for the familiar stimulus on Day 2 at Fz and Fpz (refer to Figure 33). Since the N2 peak appears to represent a combination of exogenous and endogenous components, the differences between Day 2 and Day 4 may be due to endogenous components since a significant increase in amplitude was not found for the novel stimulus at P2 on Day 4. One explanation for this increase may be a switching from a familiar to a novelty preference a some point during stimulus presentation. The novel stimulus became the template held in working memory for the purpose of discrimination. Using the novel stimulus as the template to check incoming stimulus information would help increase memory for the novel stimulus.

If the presentation of even a small number of familiar stimuli on Day 3 would also help organize the neuronal

ensemble for the familiar stimulus, then a difference between Day 4-Familiar and the Day 2 stimuli would be expected, with no differences for the Day 4-Novel. The P2 peak showed no differences for either the Day 4-Familiar or Novel compared to the Day 2 stimuli. However, a decrease in variability was present for the Day 4-Familiar compared to the Day 4-Novel at P2 and N2. While the presentation of a small number of stimuli did not increase the amplitude for the familiar stimulus on Day 4, as was found in the Reacquisition group, it appears a priming effect did take place. The limited exposure to the familiar stimulus helped to stabilize the neuronal ensemble which was reflected in the decreased latency variability.

The generalization group received a small number of novel stimuli on Day 3. If this limited experience helped to organize the neuronal ensemble of the new stimulus, then differences would be expected between the Day 4-Novel and Day 2 stimuli. No differences were found in any of the comparisons. The presentation of the novel stimuli appeared to have no affect on the ERPs for the Day 4 stimuli. In fact, the presentation of the novel stimulus on Day 3 may have interfered with the stimulus given on Day 4 (Boller, 1992).

The findings of the Control group are difficult to interpret within the confines of experience. As would be expected, since no stimulus presentations were received on Day 3, differences were not found in amplitude at the P2

peak for either of the Day 4 stimuli compared to the Day 2 stimuli. However, a decrease in latency variability was present for both Day 4 stimuli compared to Day 2-Familiar at Fz. Also, a decrease in variability was found for Day 4-Novel compared to Day 2-Novel at Fpz. These results may indicate the experience on Day 4 showed limited learning which is reflected in the decreased variability for both stimuli at P2. This generalization is not as strong as that found on Day 2 because stimuli were not presented 24 hours earlier.

Conclusions

As previously stated, recognition memory, also referred to as retention, is operationally defined as differential responding to two stimuli when previous experience is given with one stimulus (Thomas & Lykins, 1995). In general, the Day 2 results have supported the presence of recognition memory in 3-month-old infants. However, the findings of generalization at the P2 peak may call this definition into question for ERP interpretation.

The operational definition given earlier was based on behavioral research in memory recognition. In behavioral studies, a difference in behavior is needed to ascertain change. Without a contrasting difference in behavior between two stimuli, an interpretation of recognition memory cannot be made. However, this constraint is not necessarily present for ERP research. If a period of familiarization is given,

then recognition memory may be defined as differential responding between the familiarization ERPs and those from the stimuli given after familiarization.

Three-month-old infants were expected to recognize a stimulus 24 hours after familiarization since many studies have shown this capability in infants of all ages (DeCasper & Fifer, 1980; Fagan, 1984). However, the different findings at the P2 and N2 peaks in 3-month-olds may allow us to begin to pull apart the endogenous and exogenous influences upon the infant ERP waveform. The developmental differences found between 3- and 5-month-olds at the P2 peak indicate the important role ERPs can play in determining the maturation course of different brain processes. Three-month-old infants showed generalized learning compared to the specific learning found in 5-month-olds, while the retrieval process was specific for both ages. These findings indicate a different maturational time course for the processing of incoming stimulus information than for memory retrieval.

The inconclusive ERP findings for forgetting and reactivation may be due to the different forms of learning used between this study and the behavioral work of Rovee-Collier and colleagues. The ERP invokes passive recognition as opposed to a contingent behavior. However, due to the apparent group trends found in the ERP measures, the lack of clear findings may be due to the small number of subjects per group.

While ERP findings for forgetting and reactivation were

inconclusive, group differences were found based on the Day 3 experience. The additional experience with familiar stimuli on Day 3 did result in neuronal changes in the representative ensemble on Day 4.

The results of this study have shown the important role of ERP research in understanding the development of infant memory. The use of a consistent paradigm across ages allows for an interpretation of brain processes which cannot be concluded from behavioral work alone. Because of the noninvasive nature of ERP measures, a single experimental paradigm can be used across infancy to gain a better understanding of developmental changes in memory, as well as other cognitive processes. The use of single-trial ERP analyses allows for the beginning of a theoretical interpretation of the neuronal processes underlying memory.

Future Research

The findings at the P2 peak indicated developmental differences between the 3- and 5-month-olds. However, whether these findings were due to changes in developmental stages of differences due to the amount of experience needed for stimulus specificity could not be determined. Additional studies which vary the amount of familiarization are needed to clarify this issue. If an increased amount of familiarization with 3-month-olds resulted in stimulus specificity, then a continuous concept of development would be supported. This would also be true if a smaller amount of

familiarization for 5-month-olds resulted in generalization. Studies varying the amount of familiarization for both ages would also add conceptual insight into the separation of exogenous and endogenous processes. Additional recognition memory ERP studies are also needed to develop a conceptual framework for the P3 peak findings.

While the results from Days 3 and 4 showed experience plays a role in neuronal changes, two important questions remain unanswered. First, what is the cause behind the dampened amplitude for Day 3-Familiar in the reacquisition group? Second, can reactivation be measured using ERPs?

The arguments presented appear to discount habituation as the process which dampened the amplitude on Day 3. However, support for retrieval interference was not present. Studies are needed to identify the Day 3 dampened results.

The determination of the efficacy of ERPs to measure reactivation needs continued research. The ability to compare behavioral and ERP results will help to establish neural processes which represent behavior. Two different approaches could be undertaken to investigate further ERP measures of reactivation. Replication of the present study with larger group membership and/or a 5-month-old population would allow for interpretation of the results within an established paradigm. The second approach would be the development of an ERP paradigm based on a contingent behavior which more closely relates to the behavioral paradigms.

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Table 1.

Representation of the Stimulus General and Specific Hypotheses.

Hypotheses

Hypothesis	Prediction
Stimulus general	Day 2-Familiar > Day 1-Familiar
	Day 2-Novel > Day 1-Familiar
	Day 2-Familiar = Day 2-Novel
Stimulus specific	Day 2-Familiar > Day 1-Familiar
	Day 2-Novel = Day 1-Familiar
	Day 2-Familiar > Day 2-Novel

Table 2.

The Six Possible Combinations of the Three Auditory Tone Frequencies (rows). The Day 3 Stimulus Presentation Differences Which Define Each Group Are Shown In Columns 3-6.

Day 1 (all)	Day 2 (all)	Day 3 (Grp 1)	Day 3 (Grp 2)	Day 3 (Grp 3)	Day 3 (Grp 4)	Day 4 (all)
400	400/ 700	400 (100)	400 (10)	1000 (10)	---	400/ 1000
400	400/ 1000	400 (100)	400 (10)	700 (10)	---	400/ 700
700	700/ 400	700 (100)	700 (10)	1000 (10)	---	700/ 1000
700	700/ 1000	700 (100)	700 (10)	400 (10)	---	700/ 400
1000	1000/ 400	1000 (100)	1000 (10)	700 (10)	---	1000/ 700
1000	1000/ 700	1000 (100)	1000 (10)	400 (10)	---	1000/ 400

Table 3.

Representation of Day 3 Reacquisition Hypotheses.

Hypotheses

Hypothesis	Prediction
Non-forgetting	Day 1-Familiar < Day 3-Familiar
Forgetting	Day 1-Familiar $\geq$ Day 3-Familiar

Table 4.

Representation of Day 3 Control Group Hypotheses.

Hypotheses	
Hypothesis	Prediction
Non-forgetting	Day 1-Familiar < Day 4-Familiar
	Day 1-Familiar = Day 4-Novel
	Day 4-Familiar > Day 4-Novel
Forgetting	Day 1-Familiar = Day 4-Familiar
	Day 1-Familiar = Day 4-Novel
	Day 4-Familiar = Day 4-Novel

Table 5.

Representation of Day 3 Reactivation Hypotheses.

Hypotheses	
Hypothesis	Prediction
Stimulus Specific	Day 1-Familiar < Day 4-Familiar
	Day 4-Familiar > Day 4-Novel
	Day 1-Familiar = Day 4-Novel
Stimulus Generalization	Day 1-Familiar < Day 4-Familiar
	Day 4-Familiar = Day 4-Novel
	Day 1-Familiar < Day 4-Novel

Table 6.

Representation of Day 3 Generalization Hypotheses.

Hypotheses

Hypothesis	Prediction
Stimulus Specific	Day 1-Familiar = Day 4-Familiar
	Day 4-Novel > Day 1-Familiar
	Day 4-Novel > Day 4-Familiar
Stimulus Generalization	Day 1-Familiar < Day 4-Familiar
	Day 1-Familiar < Day 4-Novel
	Day 4-Familiar = Day 4-Novel

Table 7

Means, Standard Deviations, t and p Values for the Average Peak Amplitude on Days 1 and 2 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	3.5	3.6	5.6	4.2	5.5	4.1
Day 2-F	6.1	4.0	9.1	4.8	8.3	5.5
Day 2-N	6.3	4.7	8.4	4.5	8.3	4.5

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D2-F	3.4	.001	3.85	.001	3.18	.005
D1-F vs D2-N	3.58	.001	3.51	.001	4.19	.001
D2-F vs D2-N	.2	>.05	.73	>.05	.04	>.05

Table 8

Means, Standard Deviations, t and p Values for Single-Trial Amplitude on Days 1 and 2 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	8.6	5.0	10.5	5.1	9.7	5.0
Day 2-F	11.0	5.0	14.1	5.8	13.8	6.8
Day 2-N	11.4	5.3	13.7	4.4	13.8	4.8

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D2-F	2.59	.01	3.42	.001	4.47	.001
D1-F vs D2-N	3.15	.005	4.11	.001	5.83	.001
D2-F vs D2-N	.37	>.05	.39	>.05	.01	>.05

Table 9

Means, Standard Deviations, t and p Values for Latency Variability on Days 1 and 2 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	36.0	5.2	34.8	4.7	34.5	4.8
Day 2-F	33.9	4.7	32.6	5.0	32.8	4.8
Day 2-N	34.7	5.4	33.1	5.0	33.6	4.7

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D2-F	3.56	.001	3.52	.001	2.98	.005
D1-F vs D2-N	1.88	.1*	2.1	.05	1.33	>.05
D2-F vs D2-N	1.26	>.05	.82	>.05	1.21	>.05

* Statistically marginal significance.

Table 10

Means, Standard Deviations, t and p Values for the Average Peak Amplitude on Days 1 and 2 for N2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	-4.6	5.5	-6.4	5.1	-6.3	4.9
Day 2-F	-6.0	4.6	-7.6	6.3	-7.9	6.3
Day 2-N	-3.6	4.9	-5.2	5.2	-6.7	3.8

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D2-F	1.35	>.05	1.10	>.05	1.48	>.05
D1-F vs D2-N	1.04	>.05	1.11	>.05	.52	>.05
D2-F vs D2-N	2.75	.01	2.38	.05	1.16	>.05

Table 11

Means, Standard Deviations, t and p Values for Single-Trial Amplitude on Days 1 and 2 for N2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	-10.8	4.3	-11.0	6.1	-10.8	5.5
Day 2-F	-11.2	4.9	-13.1	5.6	-12.9	6.0
Day 2-N	-9.4	4.3	-10.4	6.2	-11.6	4.8

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D2-F	.52	>.05	1.9	.1*	2.13	.05
D1-F vs D2-N	1.62	>.05	.5	>.05	.86	>.05
D2-F vs D2-N	2.03	.05	2.09	.05	1.22	>.05

* Statistically marginal significance

Table 12

Means, Standard Deviations, t and p Values for Latency Variability on Days 1 and 2 for N2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	35.7	5.0	34.6	5.0	34.9	5.0
Day 2-F	34.2	4.2	33.0	5.4	33.0	4.8
Day 2-N	35.8	4.5	34.2	4.9	34.2	4.7

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D2-F	2.55	.01	2.33	.05	3.34	.005
D1-F vs D2-N	.18	>.05	.59	>.05	1.18	>.05
D2-F vs D2-N	3.04	.005	1.98	.05	2.52	.05

Table 13

Means, Standard Deviations, t and p Values for the Average Peak Amplitude on Days 1 and 2 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	.5	5.1	.6	4.9	.4	4.9
Day 2-F	2.9	4.4	2.0	4.3	1.8	4.3
Day 2-N	2.9	5.4	.9	4.9	.5	4.5

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D2-F	2.7	.01	1.75	.1*	1.82	.1*
D1-F vs D2-N	2.49	.05	.29	>.05	.1	>.05
D2-F vs D2-N	.12	>.05	1.44	>.05	1.85	.1*

* Statistically marginal significance.

Table 14

Means, Standard Deviations, t and p Values for the Single-Trial Amplitude on Days 1 and 2 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	5.7	7.0	5.3	6.7	4.8	5.7
Day 2-F	7.9	5.4	7.6	5.0	7.6	5.1
Day 2-N	8.4	6.2	6.7	5.6	6.0	5.5

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D2-F	1.83	.1*	2.17	.05	2.81	.01
D1-F vs D2-N	2.08	.05	1.18	>.05	1.1	>.05
D2-F vs D2-N	.5	>.05	1.02	>.05	1.73	>.05

* Statistically marginal significance.

Table 15

Means and Standard Deviations for Latency Variability on Days 1 and 2 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	41.7	4.0	40.4	4.5	40.4	4.6
Day 2-F	41.2	4.3	41.0	6.3	40.4	4.7
Day 2-N	41.2	4.2	40.2	4.0	40.5	3.8

Table 16

Reacquisition Group Means and Standard Deviations for the Average Peak Amplitude, Single-Trial Amplitude, and Latency Variability for Days 1 and 3 for P2.

	Average Peak Amplitude					
	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	3.3	3.7	6.4	3.9	5.6	4.1
Day 3-F	1.8	4.8	5.5	4.4	5.7	4.5
	Single-trial Amplitude					
	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	7.3	3.3	10.2	4.0	8.6	4.0
Day 3-F	6.8	6.0	10.1	5.7	10.4	5.1
	Latency Variability					
	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	33.6	5.6	33.2	4.7	33.0	3.8
Day 3-F	30.2	10.1	30.0	10.1	29.4	9.8

Table 17

Reacquisition Group Means and Standard Deviations for the Average Peak Amplitude, Single-Trial Amplitude, and Latency Variability for Days 1 and 3 for N2.

	Average Peak Amplitude					
	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	-5.7	5.0	-7.9	4.5	-7.8	4.2
Day 3-F	-3.9	3.7	-3.4	3.5	-2.8	3.0
	Single-trial Amplitude					
	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	-11.3	2.8	-11.7	5.0	-11.6	4.6
Day 3-F	-8.2	6.0	-6.6	6.6	-6.8	5.4
	Latency Variability					
	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	33.6	5.1	31.9	5.2	32.5	5.1
Day 3-F	32.0	11.5	30.7	11.6	30.8	12.0

Table 18

Reacquisition Group Means and Standard Deviations for the Average Peak Amplitude, Single-Trial Amplitude, and Latency Variability for Days 1 and 3 for P3.

	Average Peak Amplitude					
	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	.6	4.0	.2	2.6	1.0	3.7
Day 3-F	3.8	4.3	5.0	3.4	4.3	3.5

	Single-trial Amplitude					
	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	5.3	5.6	4.3	5.6	3.2	5.3
Day 3-F	9.6	6.0	11.5	5.3	10.9	5.5

	Latency Variability					
	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	33.6	5.6	43.2	5.0	43.6	4.4
Day 3-F	38.7	12.5	38.1	12.4	38.6	12.7

Table 19

Reactivation Group Means, Standard Deviations, t and p Values for the Average Peak Amplitude on Days 1 and 4 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	2.7	3.3	4.4	3.9	4.0	3.6
Day 4-F	8.5	5.8	9.4	7.7	9.6	8.7
Day 4-N	5.6	3.8	5.8	3.6	5.9	3.5

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	3.08	.05	1.80	.1*	1.92	.1*
D1-F vs D4-N	2.15	.05	.89	>.05	1.38	>.05
D4-F vs D4-N	1.62	>.05	1.55	>.05	1.54	>.05

* Statistically marginal significance.

Table 20

Reactivation Group Means, Standard Deviations, t and p Values for the Single-Trial Amplitude on Days 1 and 4 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	10.1	3.3	11.5	3.6	10.6	4.0
Day 4-F	13.9	8.1	15.1	8.0	14.9	8.5
Day 4-N	7.7	6.0	13.6	8.0	13.6	7.6

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	1.4	>.05	1.37	>.05	1.47	>.05
D1-F vs D4-N	1.27	>.05	.79	>.05	1.26	>.05
D4-F vs D4-N	2.01	.05	.81	>.05	.62	>.05

Table 21

Reactivation Group Means, Standard Deviations, t and p Values for Latency Variability on Days 1 and 4 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	36.9	4.8	35.6	5.0	36.0	5.2
Day 4-F	33.4	4.6	32.0	3.2	32.4	3.5
Day 4-N	33.5	5.4	33.4	6.1	33.2	5.3

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	1.97	<.10*	2.05	<.05	2.11	<.05
D1-F vs D4-N	2.05	>.05	1.02	>.05	1.42	>.05
D4-F vs D4-N	0.04	>.05	0.84	>.05	0.59	>.05

* Statistically marginal significance

Table 22

Reactivation Group Means and Standard Deviations for the Average Peak Amplitude and Single-Trial Amplitude on Days 1 and 4 for N2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	-4.5	6.9	-5.6	7.0	-6.2	6.5
Day 4-F	-4.6	6.8	-5.7	6.6	-5.5	6.7
Day 4-N	-3.5	5.8	-4.8	5.1	-6.4	5.3

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	-10.40	5.9	-11.47	7.0	-11.50	7.4
Day 4-F	-11.90	8.7	-13.10	8.7	-12.80	9.0
Day 4-N	-10.10	6.8	-13.20	7.3	-13.70	7.1

Table 23

Reactivation Group Means, Standard Deviations, t and p Values for Latency Variability on Days 1 and 4 for N2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	38.4	4.0	37.0	4.0	37.5	4.2
Day 4-F	36.8	4.2	35.0	4.7	35.2	5.0
Day 4-N	40.0	4.6	38.4	4.4	38.5	4.2

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	1.05	>.05	1.21	>.05	1.37	>.05
D1-F vs D4-N	1.24	>.05	0.98	>.05	0.77	>.05
D4-F vs D4-N	1.77	<.10*	2.36	<.05	2.02	<.05

* Statistically marginal significance

Table 24

Reactivation Group Means and Standard Deviations for the Average Peak Amplitude, Single-Trial Amplitude, and Latency Variability on Days 1 and 4 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	0.7	7.1	1.3	7.0	0.8	7.0
Day 4-F	3.7	6.0	4.5	5.1	4.4	5.1
Day 4-N	1.9	7.0	1.1	5.4	0.6	7.0

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	7.4	7.4	6.5	6.8	4.9	6.6
Day 4-F	10.3	8.2	9.0	5.8	9.1	5.7
Day 4-N	8.0	7.4	7.6	7.4	7.8	8.3

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	38.6	2.4	37.2	4.4	37.7	5.0
Day 4-F	40.5	3.2	39.5	3.5	39.4	2.7
Day 4-N	41.2	4.1	38.7	2.1	39.1	2.0

Table 25

Generalization Group Means, Standard Deviations, t and p Values for the Average Peak Amplitude on Days 1 and 4 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	4.9	2.7	6.6	3.8	6.4	3.9
Day 4-F	4.5	1.6	9.9	2.6	9.8	3.0
Day 4-N	4.8	2.6	9.2	4.4	9.1	4.6

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	0.43	>.05	2.36	<.05	2.19	<.05
D1-F vs D4-N	0.07	>.05	1.63	>.05	1.71	<.10***
D4-F vs D4-N	0.33	>.05	0.65	>.05	0.59	>.05

* Statistically marginal significance

Table 26

Generalization Group Means, Standard Deviations, t and p Values for Single-Trial Amplitude on Days 1 and 4 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	10.4	5.0	11.5	4.7	10.2	4.5
Day 4-F	10.2	3.1	15.3	3.7	15.3	4.0
Day 4-N	10.0	3.9	15.0	4.0	15.2	4.2

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	0.14	>.05	2.06	<.05	2.57	<.05
D1-F vs D4-N	0.20	>.05	1.65	>.05	2.84	>.01
D4-F vs D4-N	0.14	>.05	0.26	>.05	0.06	>.05

Table 27

Generalization Group Means, Standard Deviations, t and p Values for Latency Variability on Days 1 and 4 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	38.2	4.4	37.2	3.5	36.5	5.3
Day 4-F	32.7	3.4	31.4	2.7	31.7	3.3
Day 4-N	30.8	3.4	31.7	2.8	31.4	4.0

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	3.11	<.01	4.08	<.005	2.63	<.05
D1-F vs D4-N	4.03	<.005	3.79	<.005	2.99	<.01
D4-F vs D4-N	2.75	<.05	0.49	>.05	0.30	>.05

Table 28

Generalization Group Means and Standard Deviations for the Average Peak Amplitude Single-Trial Amplitude, and Latency Variability on Days 1 and 4 for N2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	-3.7	3.5	-5.3	4.7	-4.8	4.5
Day 4-F	-4.2	5.6	-6.5	7.1	-6.3	7.0
Day 4-N	-2.7	6.1	-3.9	6.7	-4.3	6.8

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	-9.4	3.5	-11.3	5.3	-9.7	4.7
Day 4-F	-10.6	6.0	-11.3	8.3	-10.7	8.8
Day 4-N	-7.4	7.1	-10.5	7.2	-10.4	7.0

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	37.3	4.8	36.5	3.3	35.8	3.7
Day 4-F	37.0	5.1	34.9	5.4	35.8	5.4
Day 4-N	36.7	4.4	35.9	4.3	35.5	4.1

Table 29

Generalization Group Means, Standard Deviations, t and p Values for Average Peak Amplitude on Days 1 and 4 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	1.4	5.4	0.6	5.1	0.1	4.5
Day 4-F	5.0	4.8	2.6	5.5	2.4	5.7
Day 4-N	7.0	6.4	4.8	6.9	4.4	7.0

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	1.94	<.10*	1.59	>.05	1.88	<.10*
D1-F vs D4-N	2.16	<.05	1.65	>.05	1.84	<.10*
D4-F vs D4-N	1.20	>.05	1.00	>.05	0.89	>.05

* Statistically marginal significance

Table 30

Generalization Group Means, Standard Deviations, t and p Values for Single-Trial Amplitude on Days 1 and 4 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	7.4	9.0	5.9	8.0	6.6	5.4
Day 4-F	12.4	5.0	8.0	6.7	7.7	7.1
Day 4-N	13.4	8.0	12.0	7.8	12.0	7.7

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	1.64	>.05	1.23	>.05	0.74	>.05
D1-F vs D4-N	1.62	>.05	1.76	<.10*	2.05	<.05
D4-F vs D4-N	0.60	>.05	1.41	>.05	1.46	>.05

* Statistically marginal significance

Table 31

Generalization Group Means, Standard Deviations, t and p Values for Latency Variability on Days 1 and 4 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	41.5	3.0	39.6	3.1	38.9	3.3
Day 4-F	42.6	3.8	39.6	4.2	35.7	10.6
Day 4-N	38.5	2.7	38.6	4.2	38.3	4.4

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	1.04	>.05	0.03	>.05	0.94	>.05
D1-F vs D4-N	2.55	<.05	0.74	>.05	0.41	>.05
D4-F vs D4-N	3.33	<.01	0.73	>.05	0.73	>.05

Table 32

Control Group Means, Standard Deviations, t and p Values for the Average Peak Amplitude on Days 1 and 4 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	2.6	4.3	5.01	5.3	5.9	4.9
Day 4-F	4.6	7.5	9.2	5.5	9.7	5.4
Day 4-N	6.6	5.2	9.6	5.3	10.0	5.5

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	0.93	>.05	2.77	<.05	2.65	<.05
D1-F vs D4-N	2.54	<.05	1.97	<.10*	1.81	<.10*
D4-F vs D4-N	0.88	>.05	0.23	>.05	0.13	>.05

* Statistically marginal significance

Table 33

Control Group Means, Standard Deviations, t and p Values for Single-Trial Amplitude on Days 1 and 4 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	6.4	6.7	8.7	7.3	9.3	7.2
Day 4-F	9.7	7.5	14.0	7.4	14.1	7.5
Day 4-N	12.1	4.7	14.3	4.6	14.6	6.0

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	1.20	>.05	2.34	<.05	1.84	<.10*
D1-F vs D4-N	3.05	<.01	2.11	<.05	1.98	<.10*
D4-F vs D4-N	1.10	>.05	0.19	>.05	0.48	>.05

* Statistically marginal significance

Table 34

Control Group Means, Standard Deviations, t and p Values for Latency Variability on Days 1 and 4 for P2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	35.2	5.3	33.3	4.7	32.5	3.8
Day 4-F	29.5	3.2	28.8	3.4	28.6	3.5
Day 4-N	29.8	3.4	29.6	3.4	29.6	3.8

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	5.03	<.001	3.55	<.005	3.06	<.01
D1-F vs D4-N	3.30	<.005	2.27	<.05	1.82	<.10*
D4-F vs D4-N	0.40	>.05	0.63	>.05	0.79	>.05

* Statistically marginal significance

Table 35

Control Group Means and Standard Deviations for the Average Peak Amplitude on Days 1 and 4 for N2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	4.6	6.3	6.6	4.2	6.4	4.1
Day 4-F	6.8	5.1	9.3	6.0	9.4	6.5
Day 4-N	6.0	3.6	7.9	4.1	7.8	4.1

Table 36

Control Group Means, Standard Deviations, t and p Values for Single-Trial Amplitude on Days 1 and 4 for N2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	11.6	4.4	9.5	7.2	10.3	5.4
Day 4-F	13.0	5.9	14.8	6.1	14.8	6.0
Day 4-N	12.0	4.3	13.0	4.0	13.0	4.0

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	0.81	>.05	2.19	<.05	2.19	<.05
D1-F vs D4-N	0.30	>.05	1.52	>.05	1.55	>.05
D4-F vs D4-N	0.58	>.05	0.91	>.05	0.94	>.05

Table 37

Control Group Means, Standard Deviations, t and p Values for Latency Variability on Days 1 and 4 for N2.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	33.5	4.8	32.7	5.6	33.7	5.8
Day 4-F	32.0	6.0	29.9	6.1	30.0	5.7
Day 4-N	33.3	6.1	31.8	6.0	31.7	6.5

Table 38

Control Group Means, Standard Deviations, t and p Values for Average Peak Amplitude on Days 1 and 4 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	0.7	3.5	0.3	4.6	0.4	4.0
Day 4-F	3.6	4.9	3.1	5.2	3.4	5.7
Day 4-N	3.6	5.8	1.9	5.8	2.1	5.9

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	2.86	<.05	1.36	>.05	2.16	<.05
D1-F vs D4-N	3.09	<.01	0.81	>.05	1.47	>.05
D4-F vs D4-N	0.03	>.05	1.03	>.05	1.08	>.05

Table 39

Control Group Means, Standard Deviations, t and p Values for Single-Trial Amplitude on Days 1 and 4 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	2.9	5.0	4.7	7.0	4.5	5.8
Day 4-F	8.9	6.6	9.3	6.7	8.7	6.4
Day 4-N	8.7	7.1	8.6	6.5	8.1	7.8

	Cz		Fz		Fpz	
	t	p	t	p	t	p
D1-F vs D4-F	2.88	<.05	1.84	<.10*	1.79	<.10*
D1-F vs D4-N	3.64	<.005	1.98	<.10*	1.82	<.10*
D4-F vs D4-N	0.15	>.05	0.48	>.05	0.33	>.05

* Statistically marginal significance

Table 40

Control Group Means and Standard Deviations for Latency Variability on Days 1 and 4 for P3.

	Cz		Fz		Fpz	
	x	s	x	s	x	s
Day 1-F	43.7	5.5	41.5	3.1	41.6	3.5
Day 4-F	42.4	5.1	39.6	7.1	39.6	6.6
Day 4-N	41.0	7.7	40.0	5.8	40.5	5.4

Table 41

Reacquisition Group Means for the Average Peak Amplitude on Days 1 through 5 for P2.

	Cz	Fz	Fpz
	x	x	x
Day 1-F	3.3	6.5	5.6
Day 2-F	4.9	6.4	4.8
Day 2-N	6.6	7.1	7.5
Day 3-F	1.8	5.5	5.7
Day 4-F	8.1	12.9	11.9
Day 4-N	6.9	9.7	9.0

Table 42

Reacquisition Group Means for Single-Trial Amplitude on Days 1 through 5 for P2.

	Cz	Fz	Fpz
	x	x	x
Day 1-F	7.3	10.2	8.6
Day 2-F	10.6	12.5	11.5
Day 2-N	11.4	12.5	13.2
Day 3-F	6.8	10.1	10.4
Day 4-F	15.3	19.0	19.0
Day 4-N	13.0	15.3	15.4

Table 43

Reacquisition Group Means for Average Peak Amplitude on Days 1 through 4 for N2 at Fz and Fpz.

	Fz	Fpz
	x	x
Day 1-F	-11.7	-11.6
Day 2-F	-14.7	-14.2
Day 2-N	-11.7	-10.9
Day 3-F	-6.6	-6.8
Day 4-F	-14.1	-13.8
Day 4-N	-13.4	-13.4

Table 44

N2 and P3 Average Peak Amplitude, Single-Trial Amplitude, and Latency Variability ANOVAS for the Reactivation Group.

	N2	P3
Average Peak Amplitude		
Cz	$F(4,44) = 0.61$, $p > .05$	$F(4,44) = 1.10$, $p > .05$
Fz	$F(4,44) = 0.24$, $p > .05$	$F(4,44) = 1.20$, $p > .05$
Fpz	$F(4,44) = 0.10$, $p > .05$	$F(4,44) = 1.19$, $p > .05$
Single-trial Amplitude		
Cz	$F(4,44) = 0.24$, $p > .05$	$F(4,44) = 1.14$, $p > .05$
Fz	$F(4,44) = 0.22$, $p > .05$	$F(4,44) = 0.78$, $p > .05$
Fpz	$F(4,44) = 0.34$, $p > .05$	$F(4,44) = 1.44$, $p > .05$
Latency Variability		
Cz	$F(4,44) = 2.28$, $p > .05$	$F(4,44) = 1.08$, $p > .05$
Fz	$F(4,44) = 1.74$, $p > .05$	$F(4,44) = 0.99$, $p > .05$
Fpz	$F(4,44) = 2.10$, $p > .05$	$F(4,44) = 0.52$, $p > .05$

Table 45

N2 and P3 Average Peak Amplitude, Single-Trial Amplitude, and Latency Variability ANOVAS for the Generalization Group.

	N2	P3
Average Peak Amplitude		
Cz	$F(4,44) = 1.72$, $p > .05$	$F(4,44) = 1.98$, $p > .05$
Fz	$F(4,44) = 1.60$, $p > .05$	$F(4,44) = 1.26$, $p > .05$
Fpz	$F(4,44) = 2.28$, $p > .05$	$F(4,44) = 1.28$, $p > .05$
Single-trial Amplitude		
Cz	$F(4,44) = 1.47$, $p > .05$	$F(4,44) = 1.62$, $p > .05$
Fz	$F(4,44) = 0.58$, $p > .05$	$F(4,44) = 1.43$, $p > .05$
Fpz	$F(4,44) = 2.24$, $p > .05$	$F(4,44) = 1.45$, $p > .05$
Latency Variability		
Cz	$F(4,44) = 1.83$, $p > .05$	$F(4,44) = 0.53$, $p > .05$
Fz	$F(4,44) = 2.95$, $p > .05$	$F(4,44) = 0.77$, $p > .05$
Fpz	$F(4,44) = 2.33$, $p > .05$	$F(4,44) = 0.83$, $p > .05$

Table 46

P2 Average Peak Amplitude and Single-Trial Amplitude ANOVAS for the Control Group.

Average Peak Amplitude	
Cz	$F(4,44) = 1.91$, $p > .05$
Fz	$F(4,44) = 2.10$, $p > .05$
Fpz	$F(4,44) = 1.28$, $p > .05$
Single-trial Amplitude	
Cz	$F(4,44) = 2.49$, $p > .05$
Fz	$F(4,44) = 2.57$, $p > .05$
Fpz	$F(4,44) = 1.67$, $p > .05$

Table 47

P3 Average Peak Amplitude and Latency Variability ANOVAS for the Control Group.

Average Peak Amplitude	
Cz	$F(4,44) = 2.37$, $p > .05$
Fz	$F(4,44) = 1.17$, $p > .05$
Fpz	$F(4,44) = 1.91$, $p > .05$
Latency Variability	
Cz	$F(4,44) = 0.55$, $p > .05$
Fz	$F(4,44) = 1.21$, $p > .05$
Fpz	$F(4,44) = 0.67$, $p > .05$

Table 48

Comparison Between the 3- and 5-Month-Old Infant Data for Peaks P2 and N2.

	Developmental Comparison	
	3 months	5 months
P2		
Avg. Amp.	General	Specific
Lat. Var.	General	Specific
S-T. Amp.	General	Specific
N2		
Avg. Amp.	Discriminates	Specific
Lat. Var.	Specific	Specific
S-T. Amp.	Discriminates	Discriminates

Figure 1

Diagrammatic Representation of the Influence of the Latency Variability of Single-trial Waveforms on the Average Event-Related Potential.

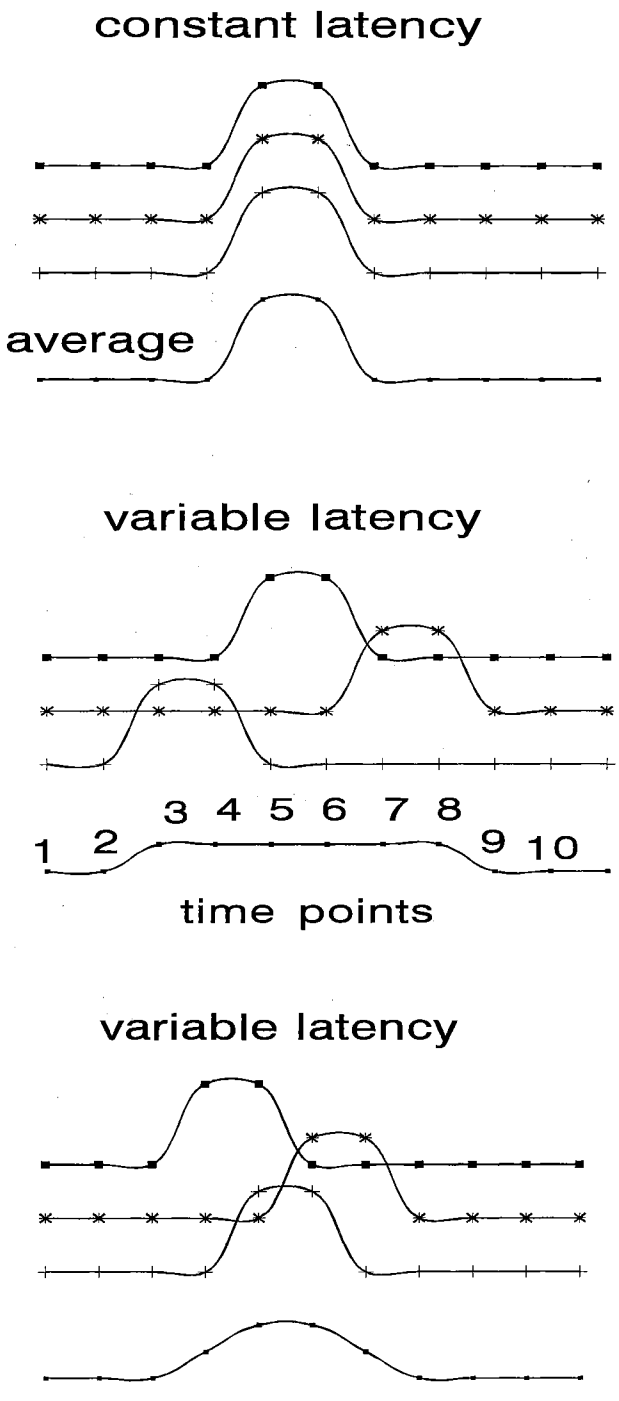


Figure 2

Grand Average Event-Related Potential Waveforms for Dats 1 and 2 at Each Scalp Electrode.

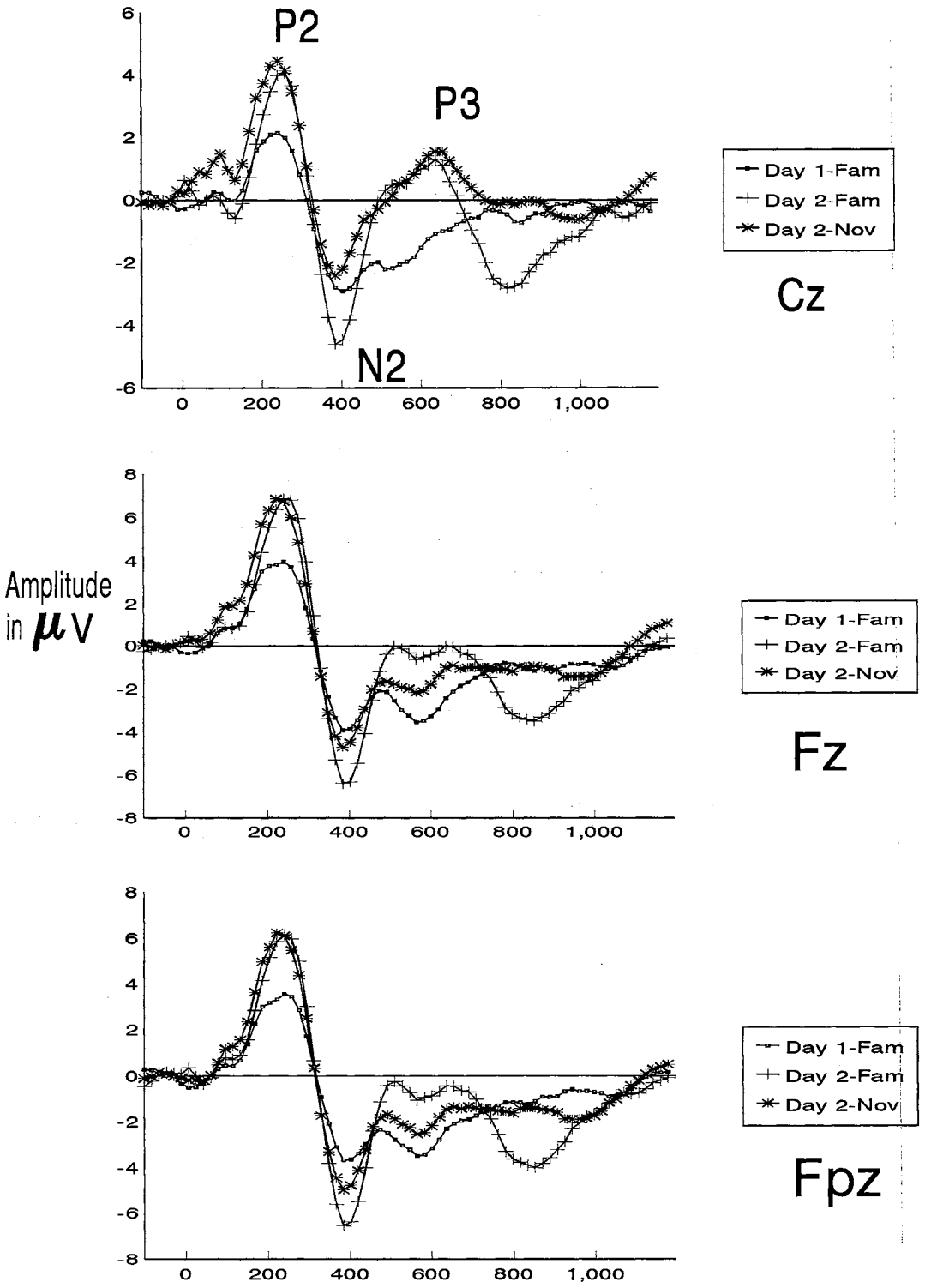


Figure 3

P2 Average Peak Amplitude for Days 1 and 2.

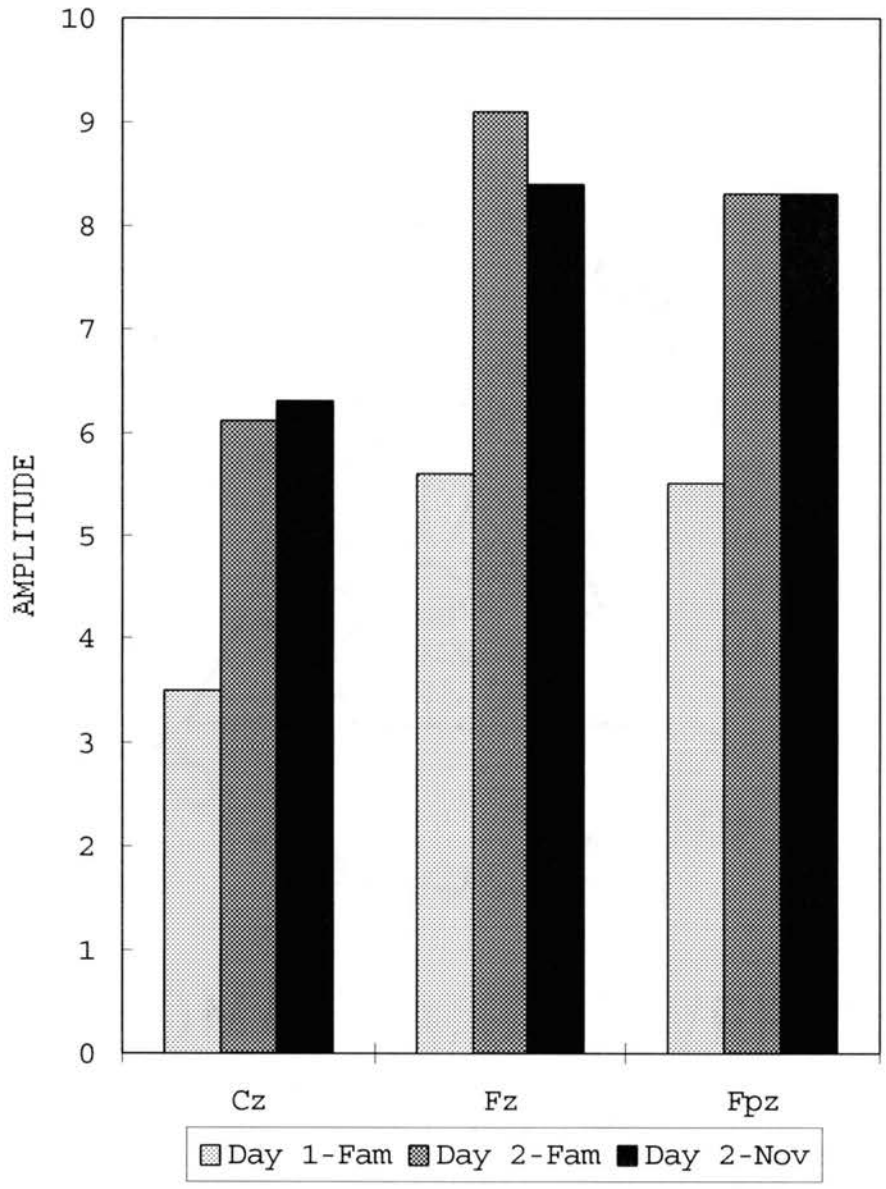


Figure 4

P2 Single-Trial Amplitude for Days 1 and 2.

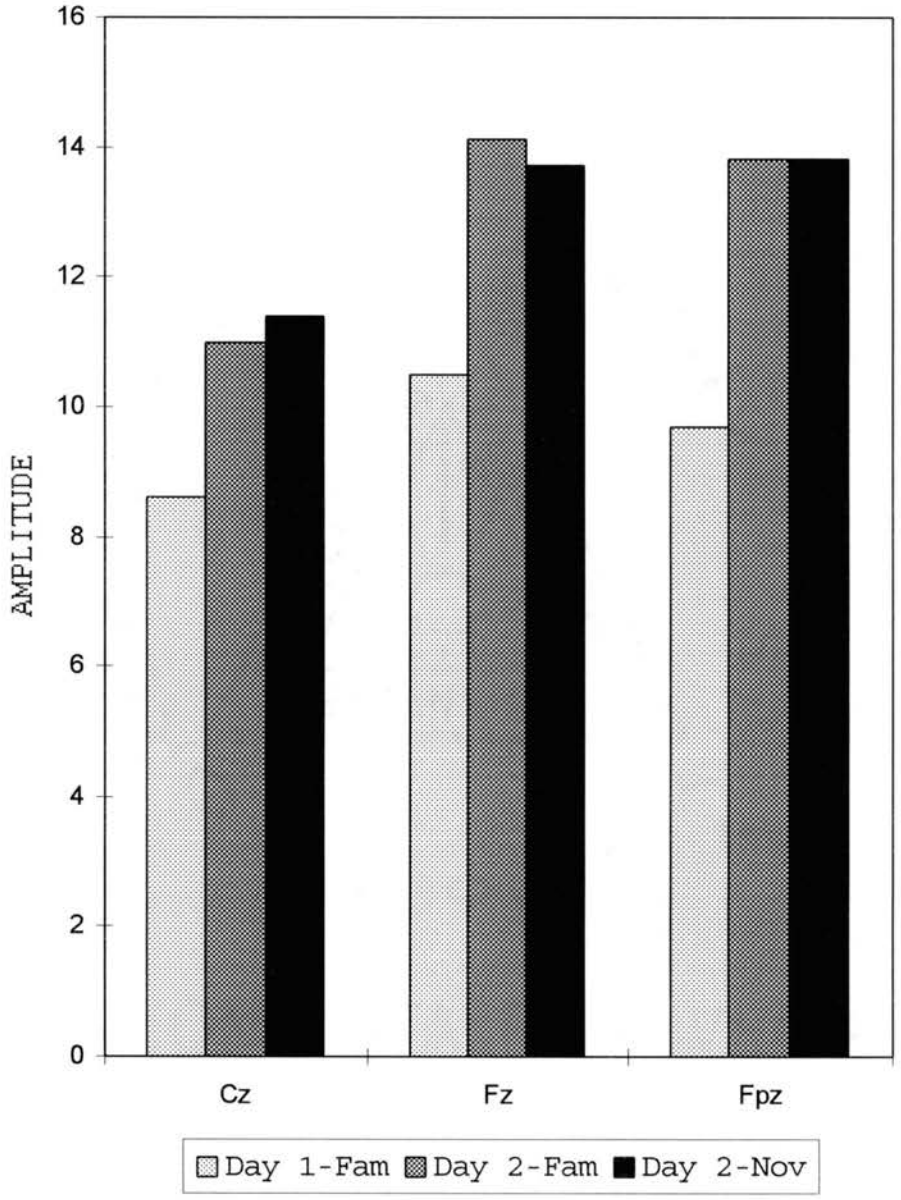


Figure 5

P2 Latency Variability for Days 1 and 2.

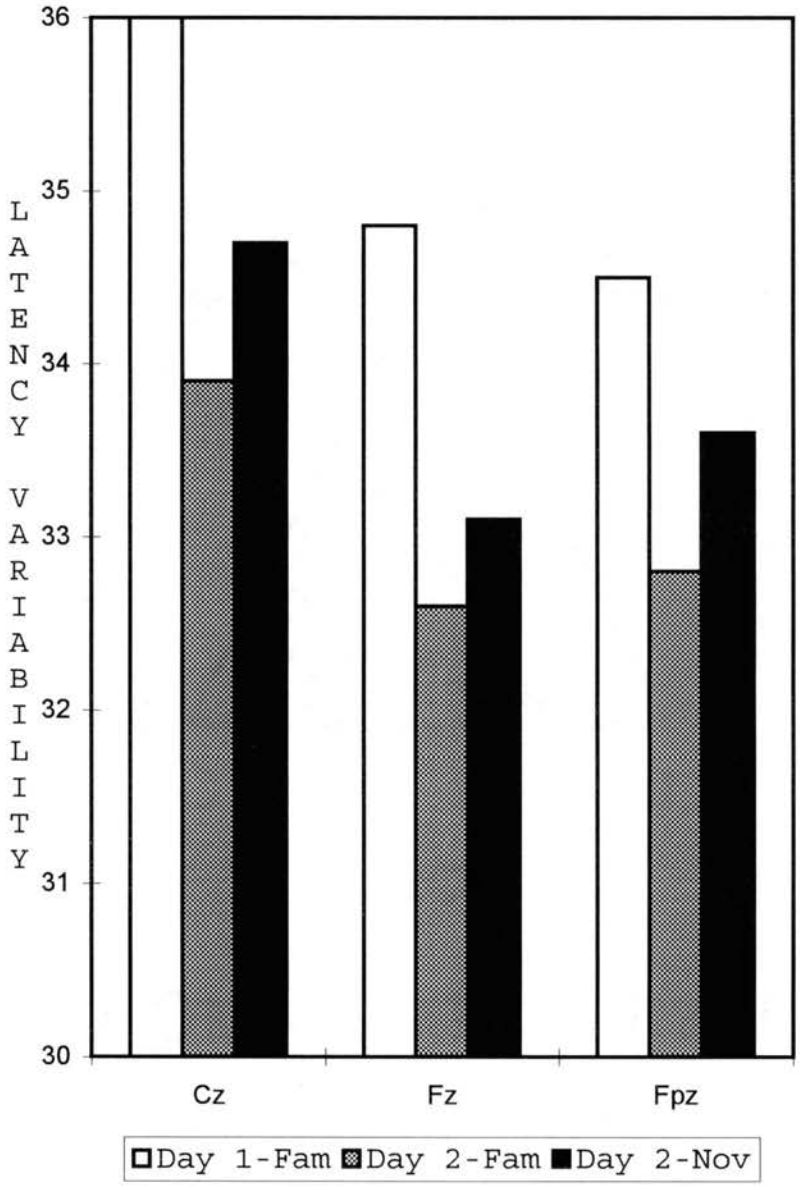


Figure 6

N2 Average Peak Amplitude for Days 1 and 2.

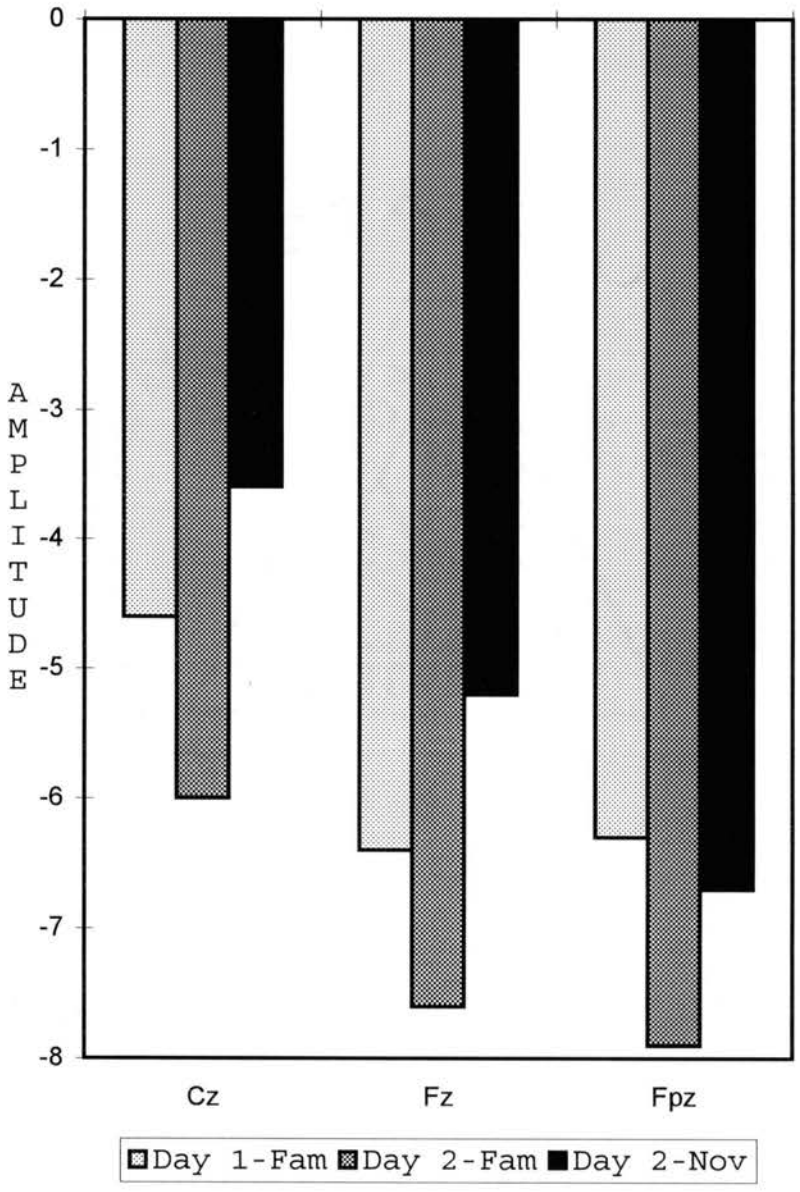


Figure 7

N2 Single-Trial Amplitude for Days 1 and 2.

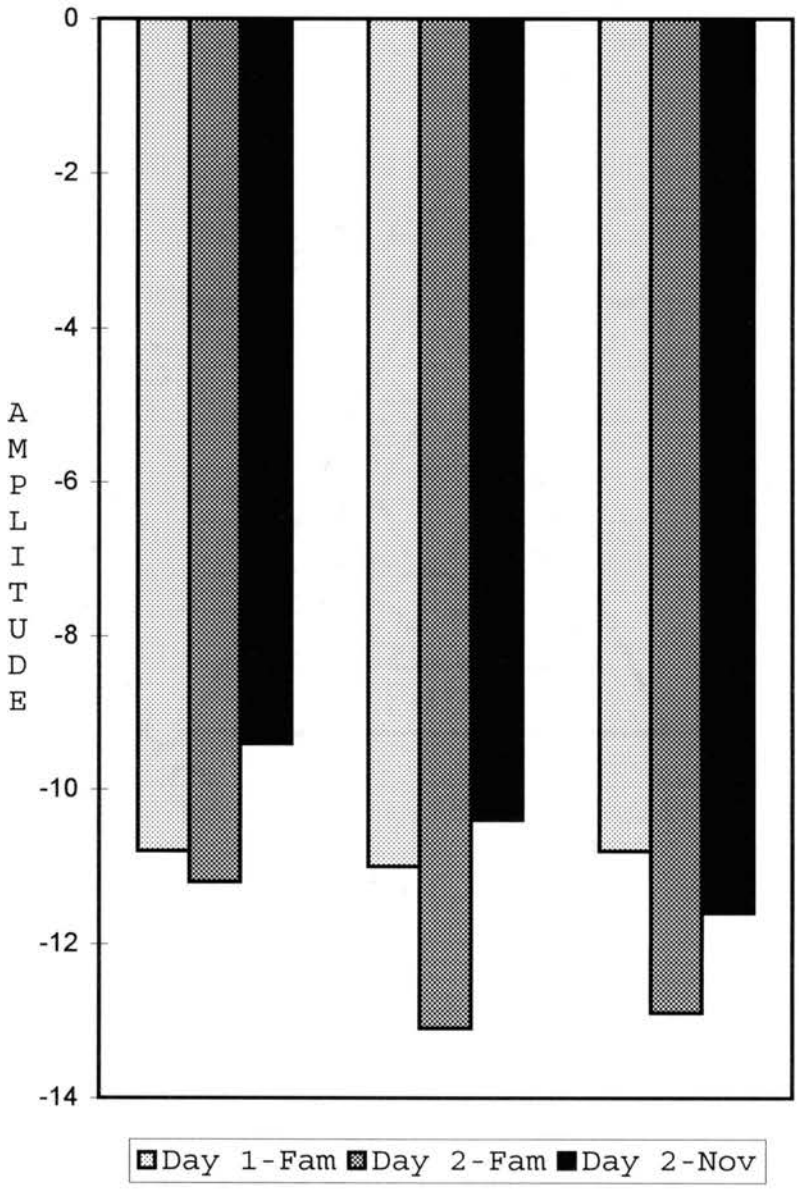


Figure 8

N2 Latency Variability for Days 1 and 2.

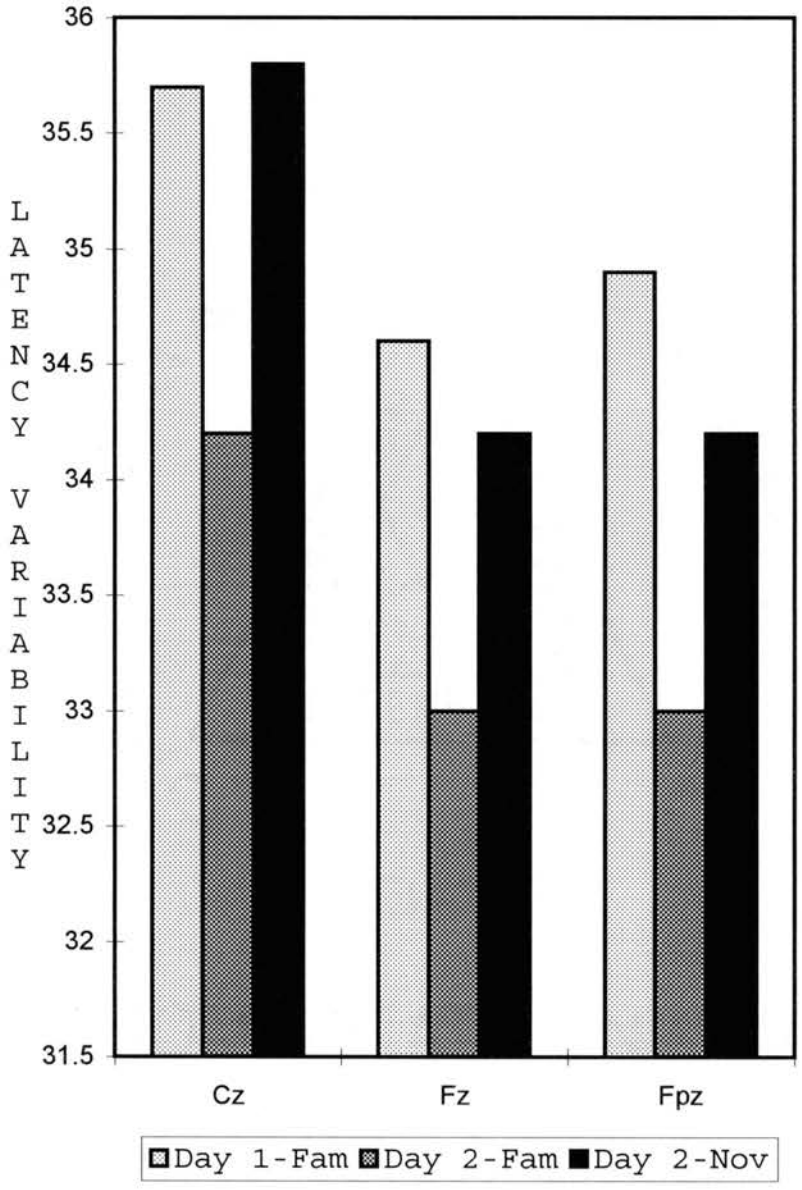


Figure 9

P3 Average Peak Amplitude for Days 1 and 2.

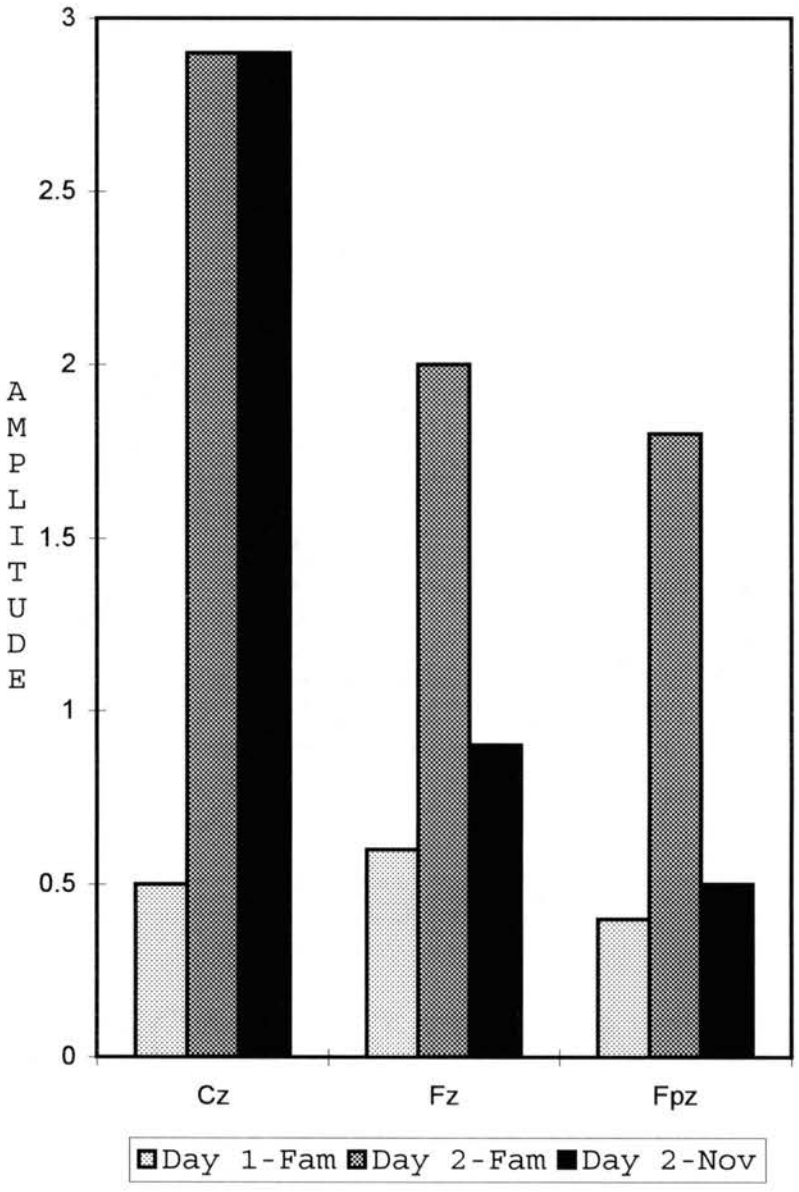


Figure 10

P3 Single-Trial Amplitude for Days 1 and 2.

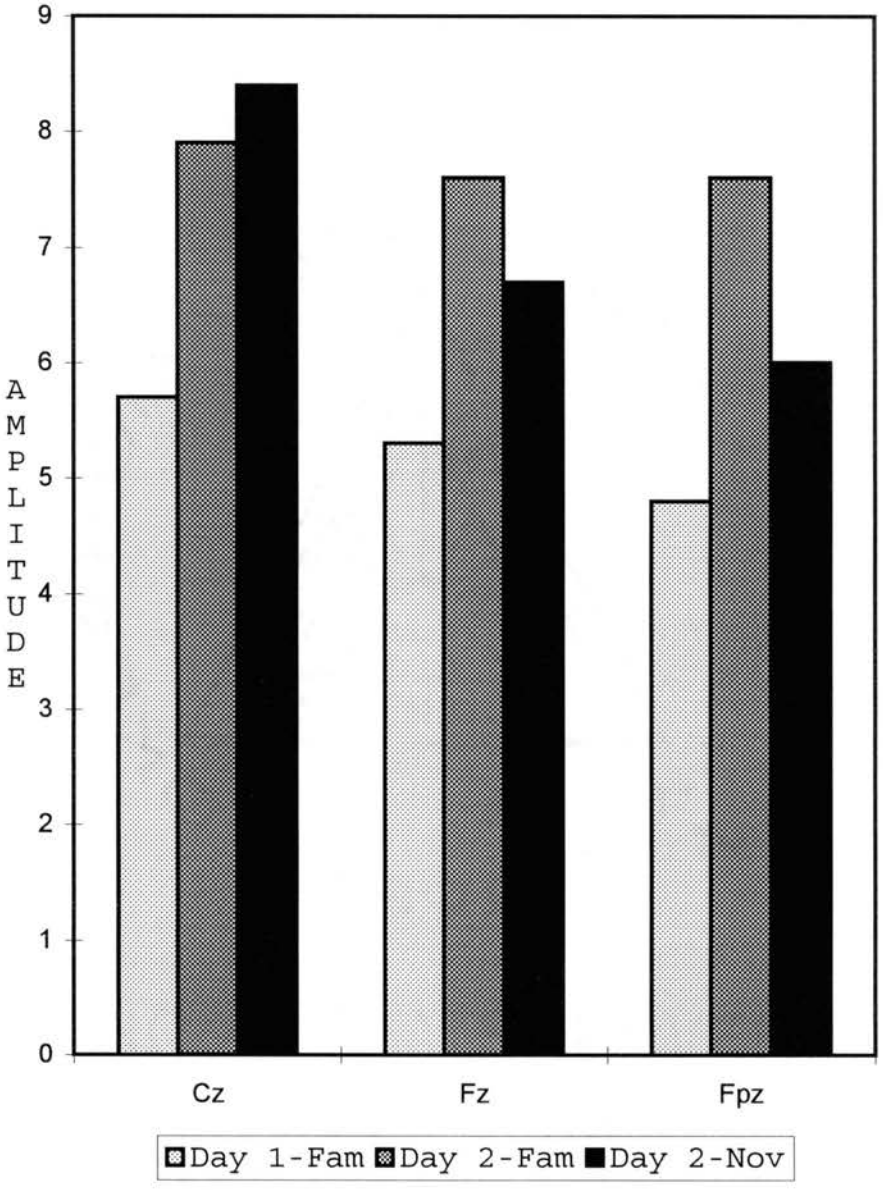


Figure 11

N2 Average Peak Amplitude for the Reacquisition Group.

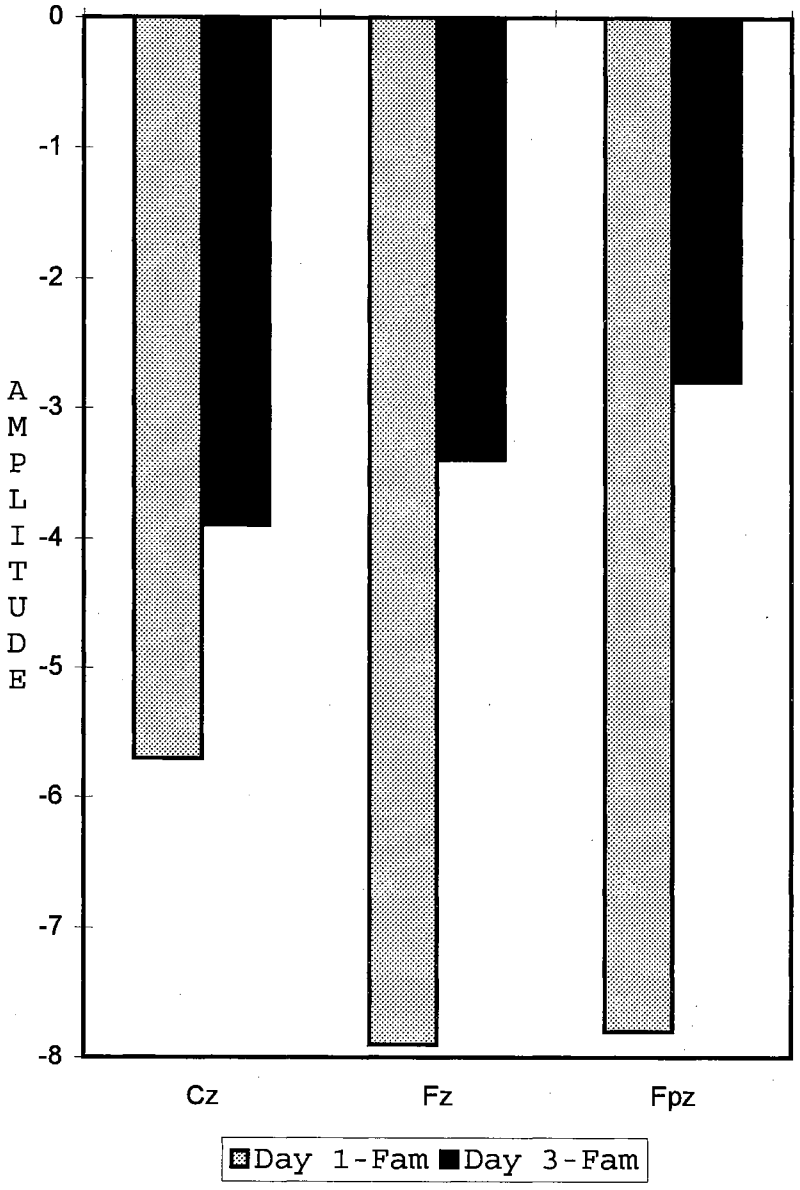


Figure 12

N2 Single-Trial Amplitude for the Reacquisition Group.

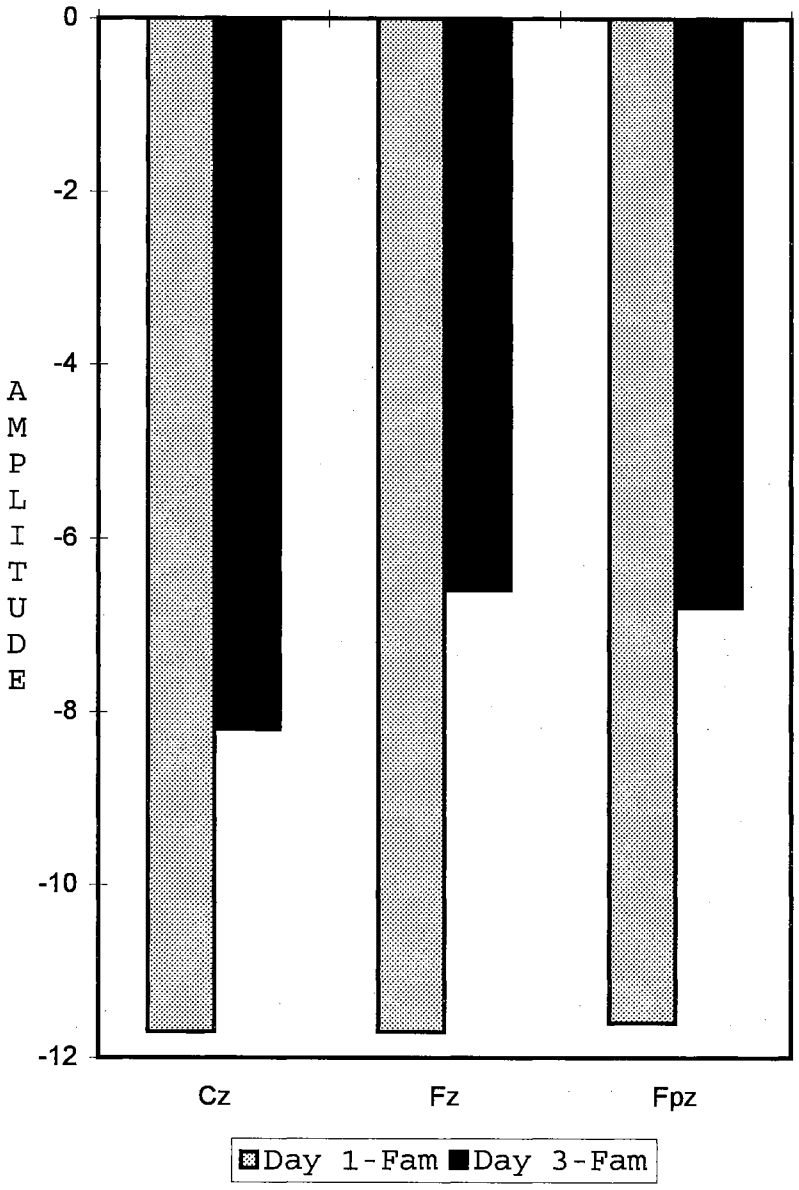


Figure 13

P3 Average Peak Amplitude for the Reacquisition Group.

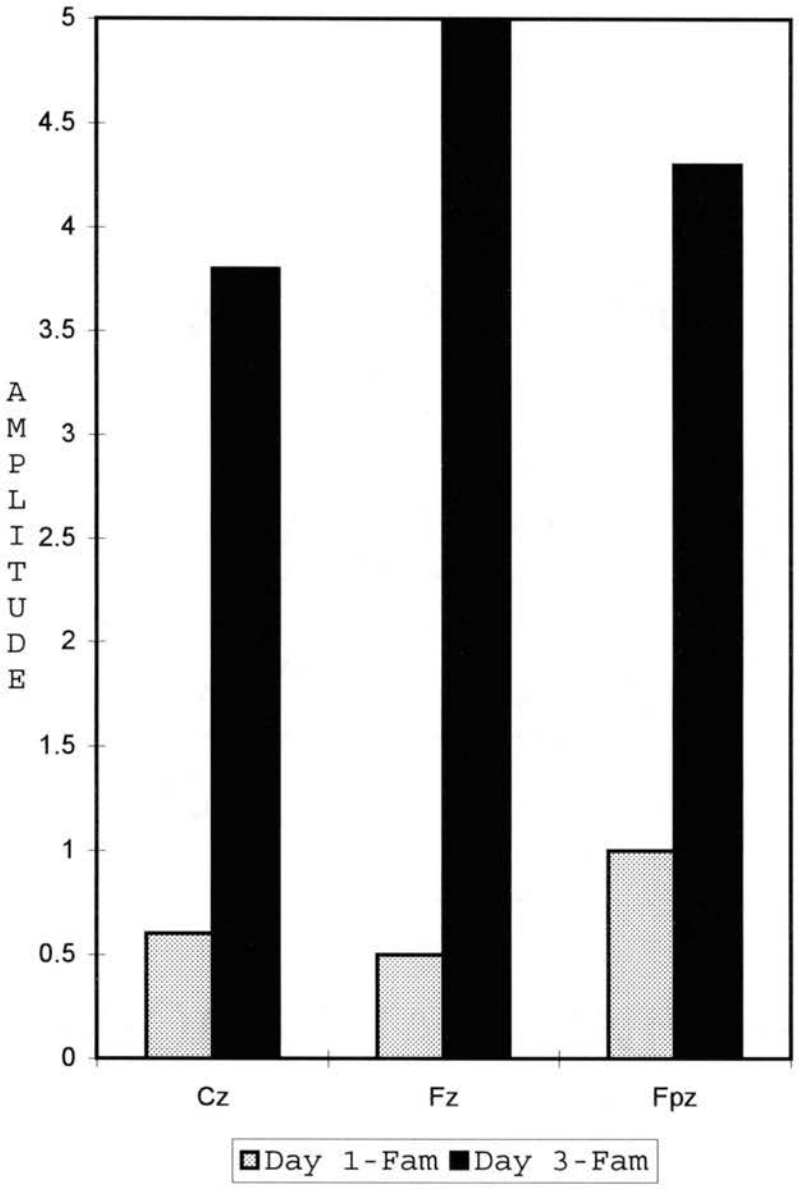


Figure 14

P3 Single-Trial Amplitude for the Reacquisition Group.

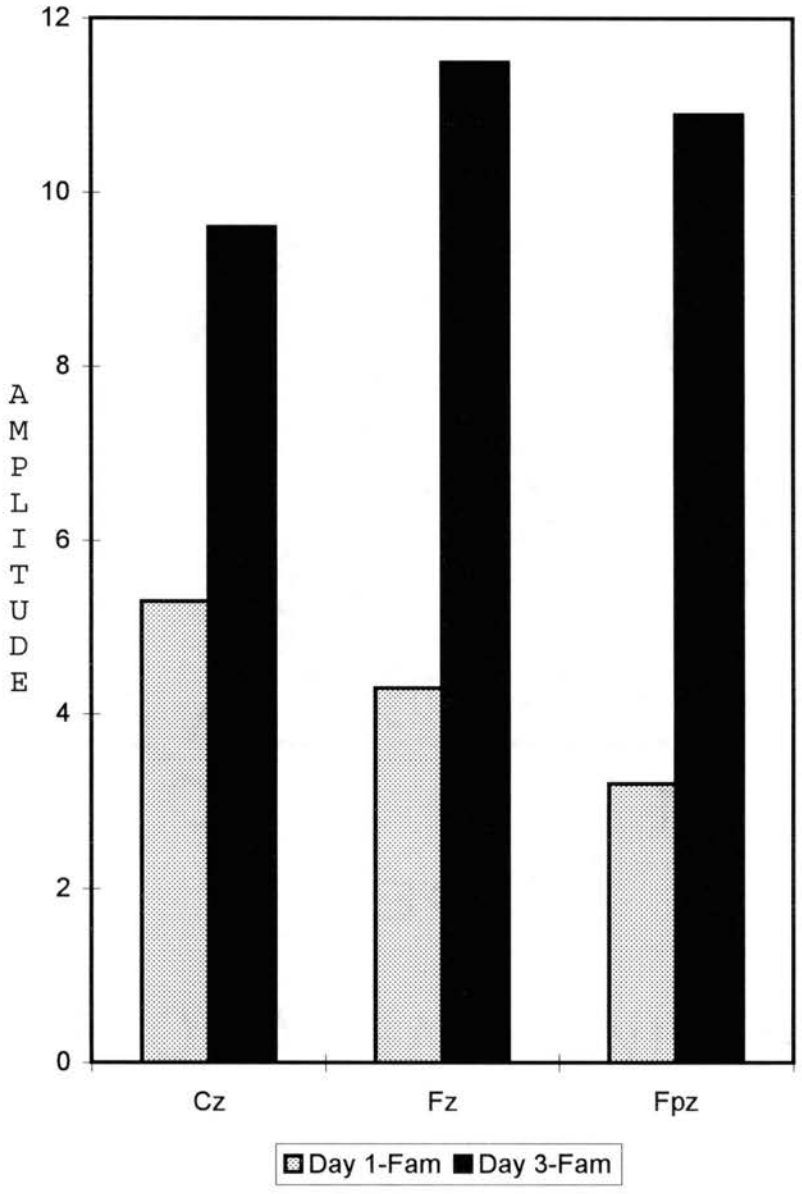


Figure 15

P2 Average Peak Amplitude for the Reactivation Group.

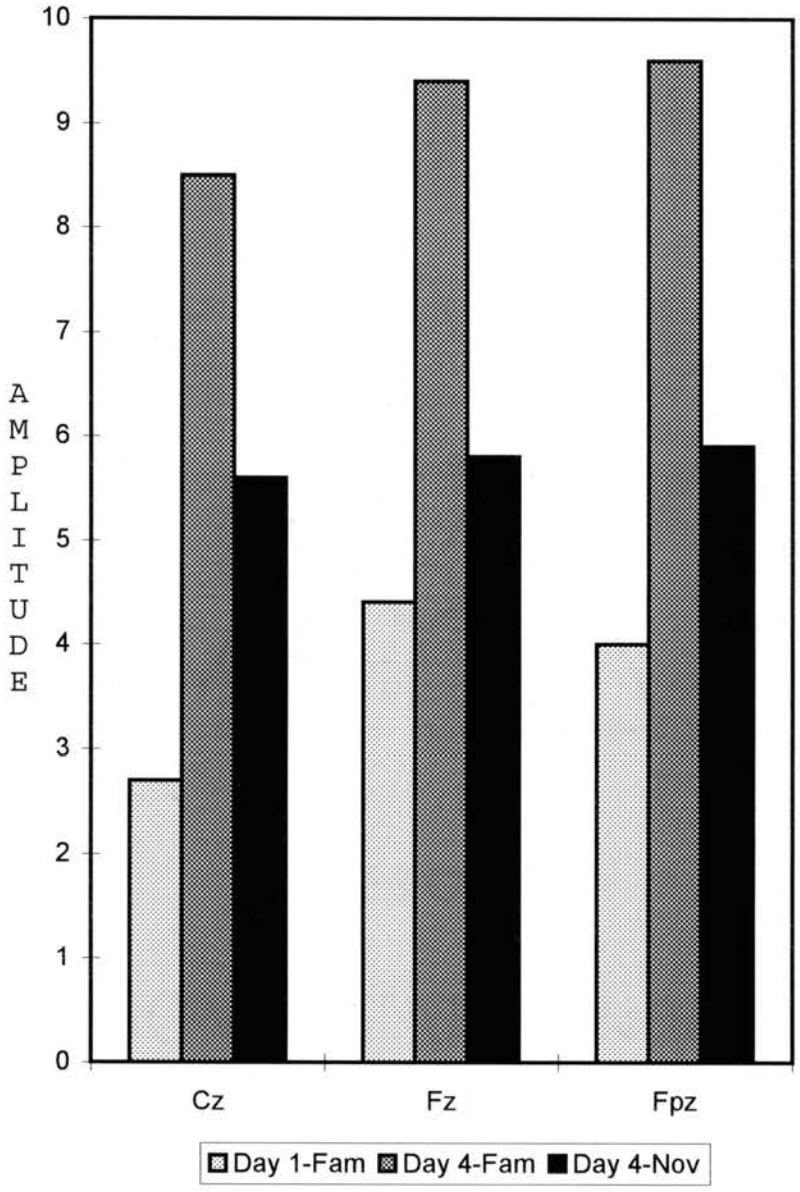


Figure 16

P2 Single-Trial Amplitude for the Reactivation Group.

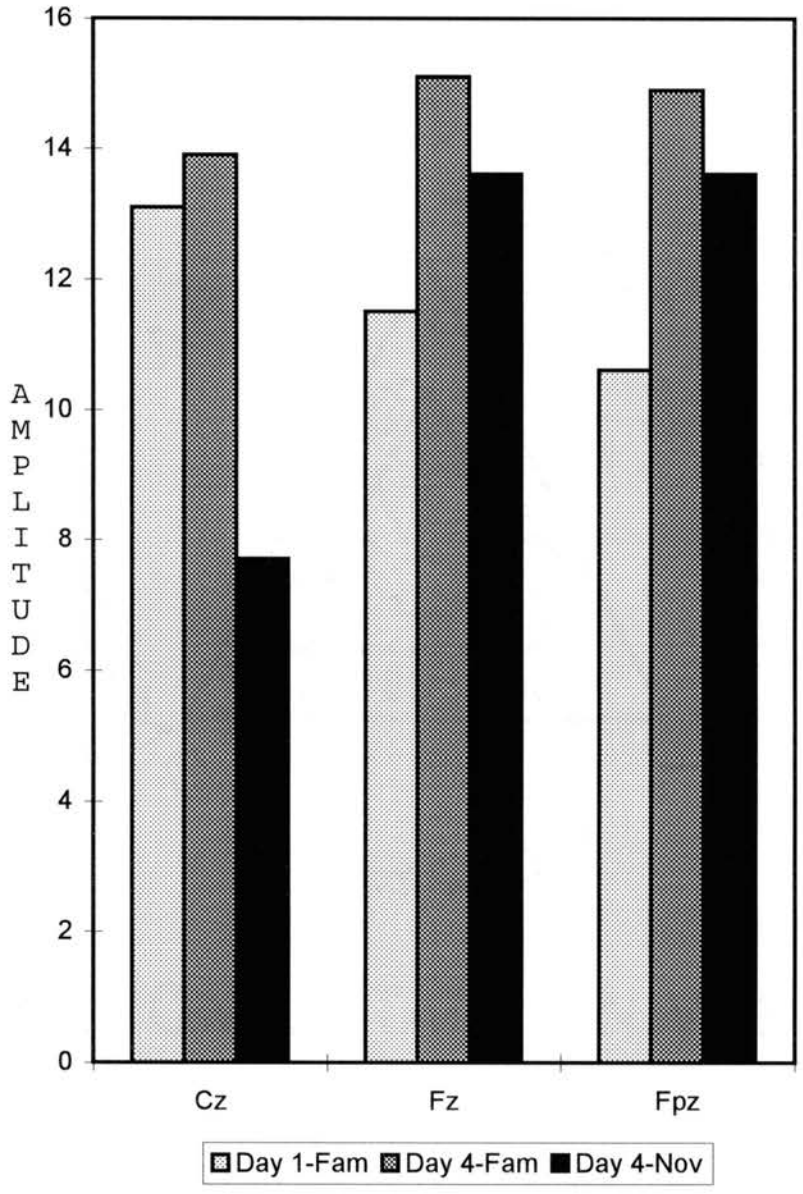


Figure 17

Ps Latency Variability for the Reactivation Group.

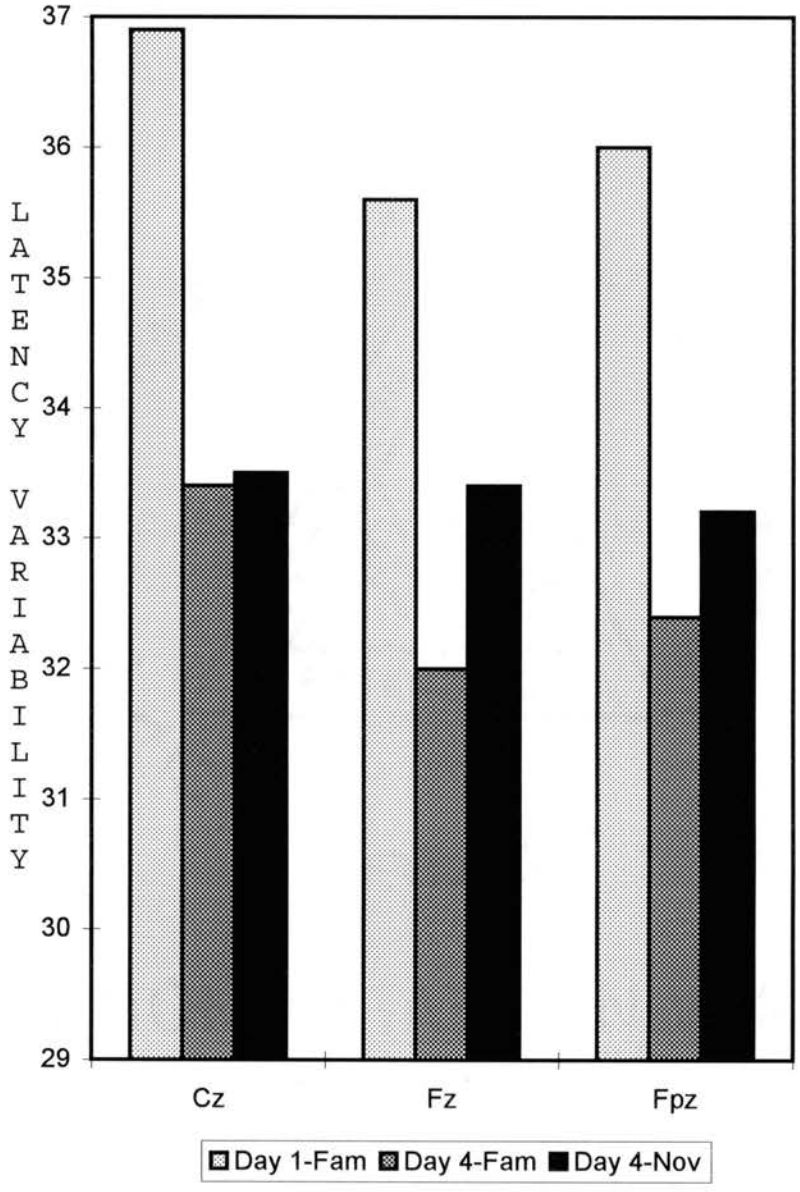


Figure 18

N2 Latency Variability for the Reactivation Group.

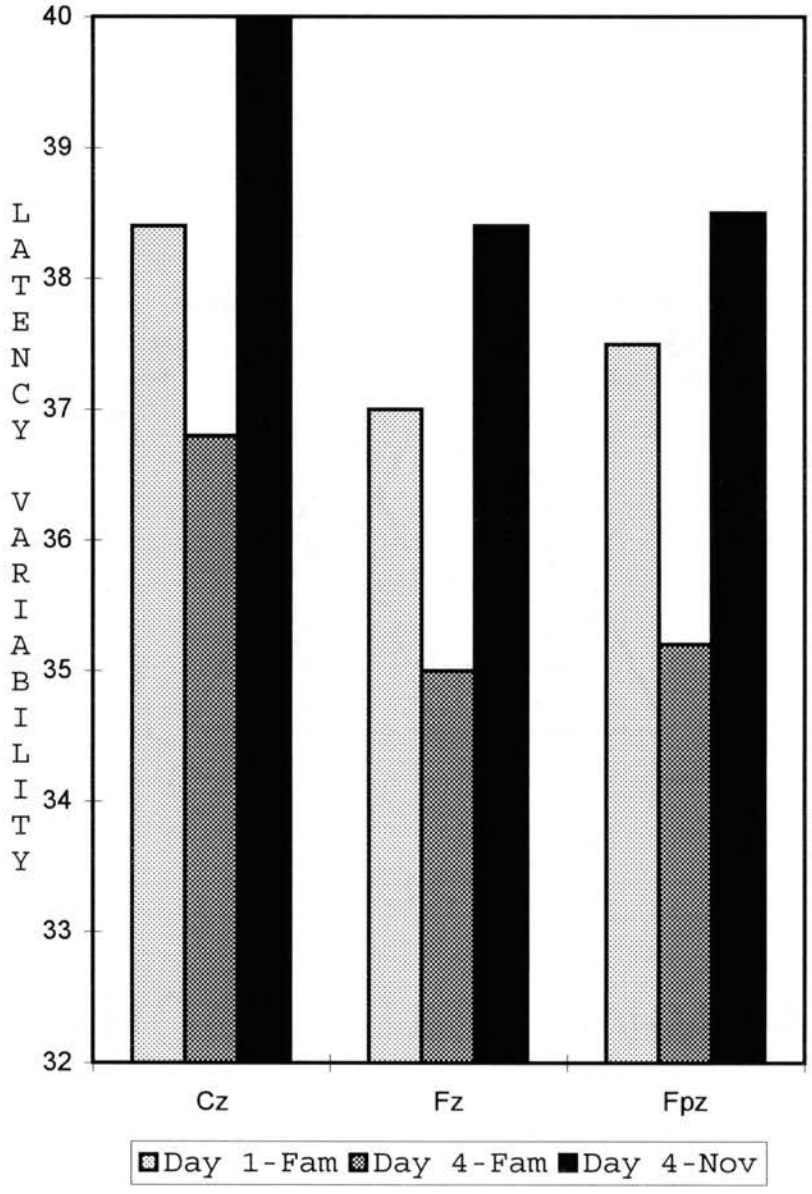


Figure 19

P2 Average Peak Amplitude for the Generalization Group.

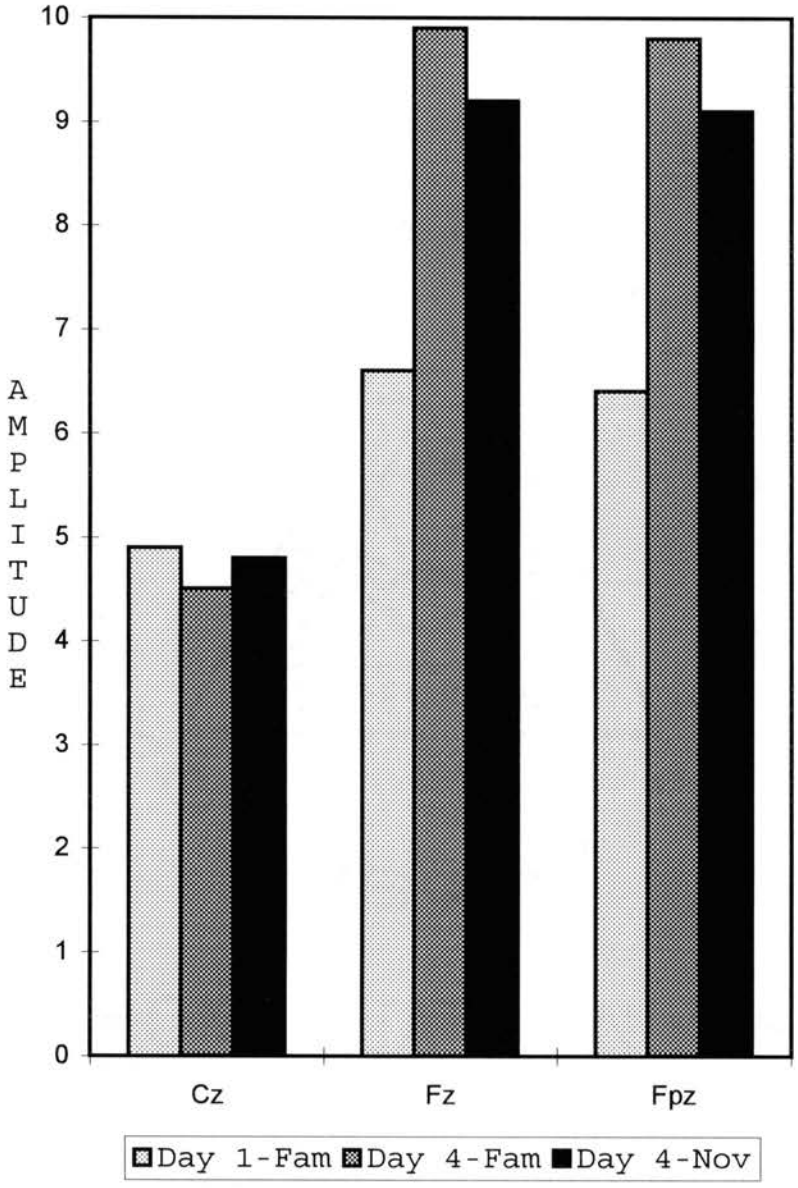


Figure 20

P2 Single-Trial Amplitude for the Generalization Group.

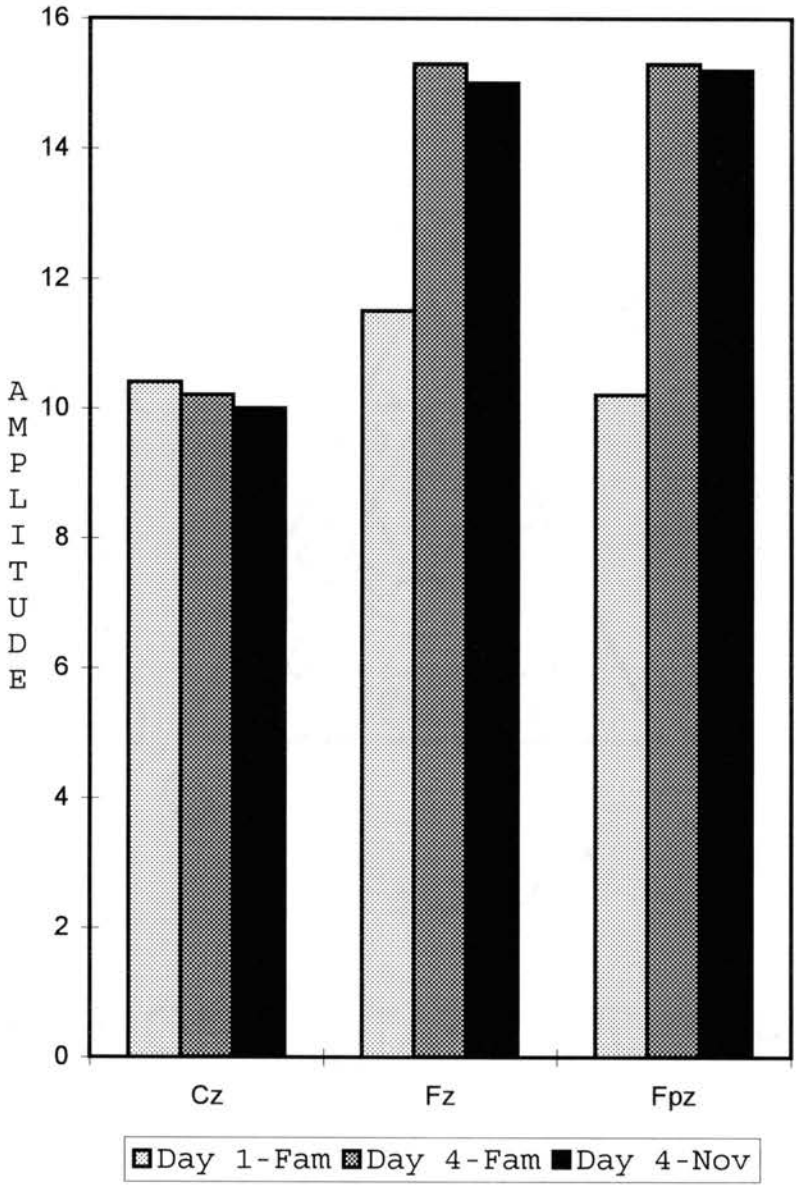


Figure 21

P2 Latency Variability for the Generalization Group.

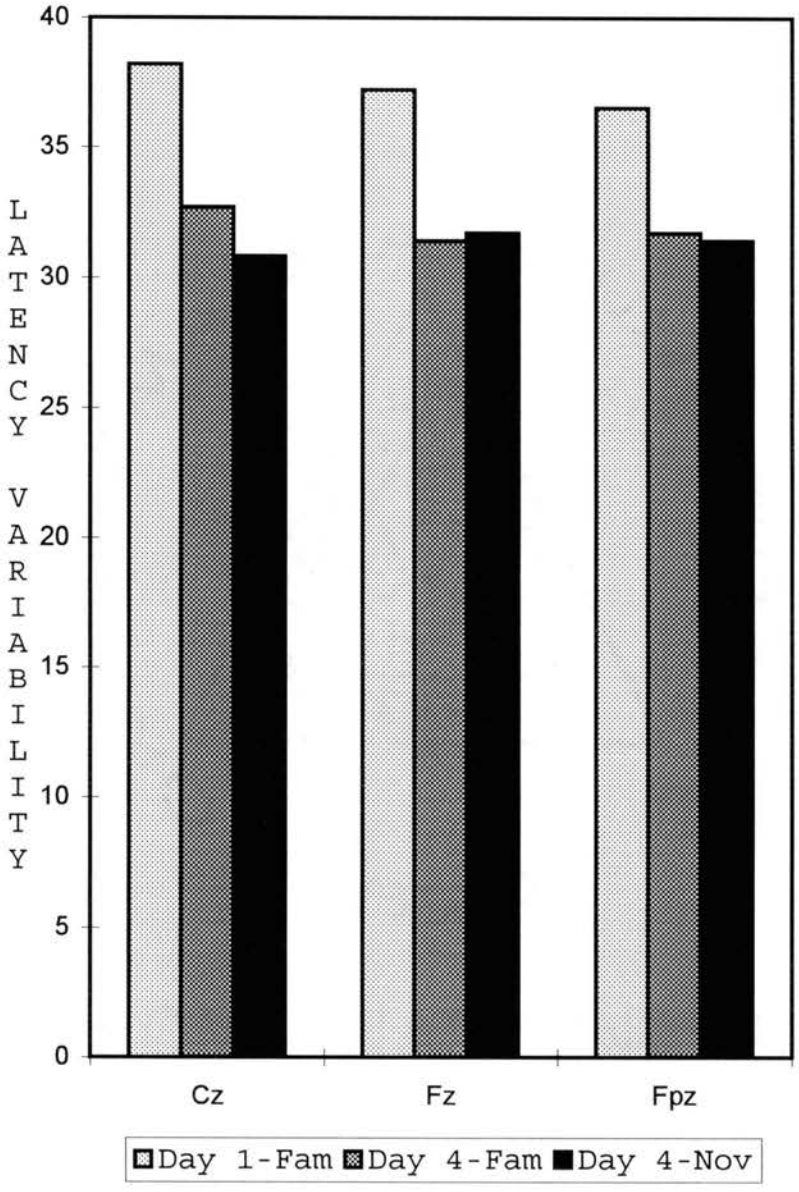


Figure 22

P3 Average Peak Amplitude for the Generalization Group.

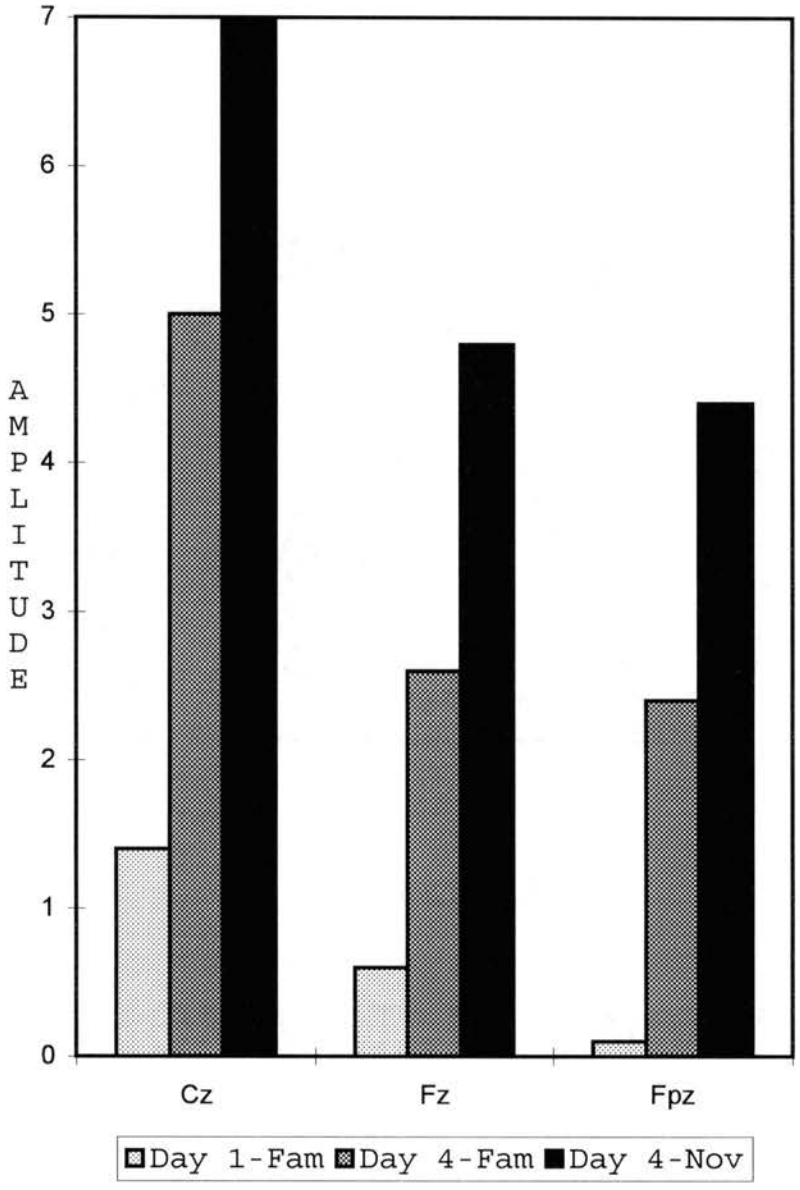


Figure 23

P3 Single-Trial Amplitude for the Generalization Group.

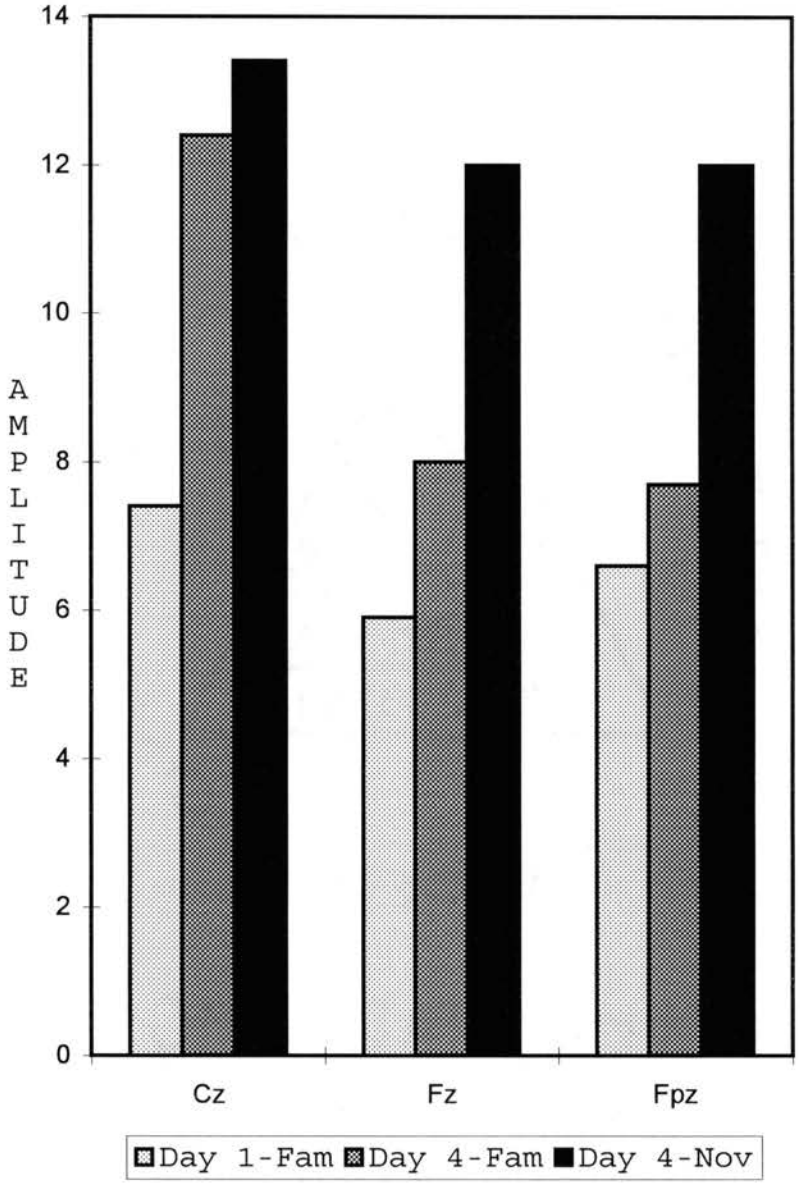


Figure 24

P3 Latency Variability for the Generalization Group.

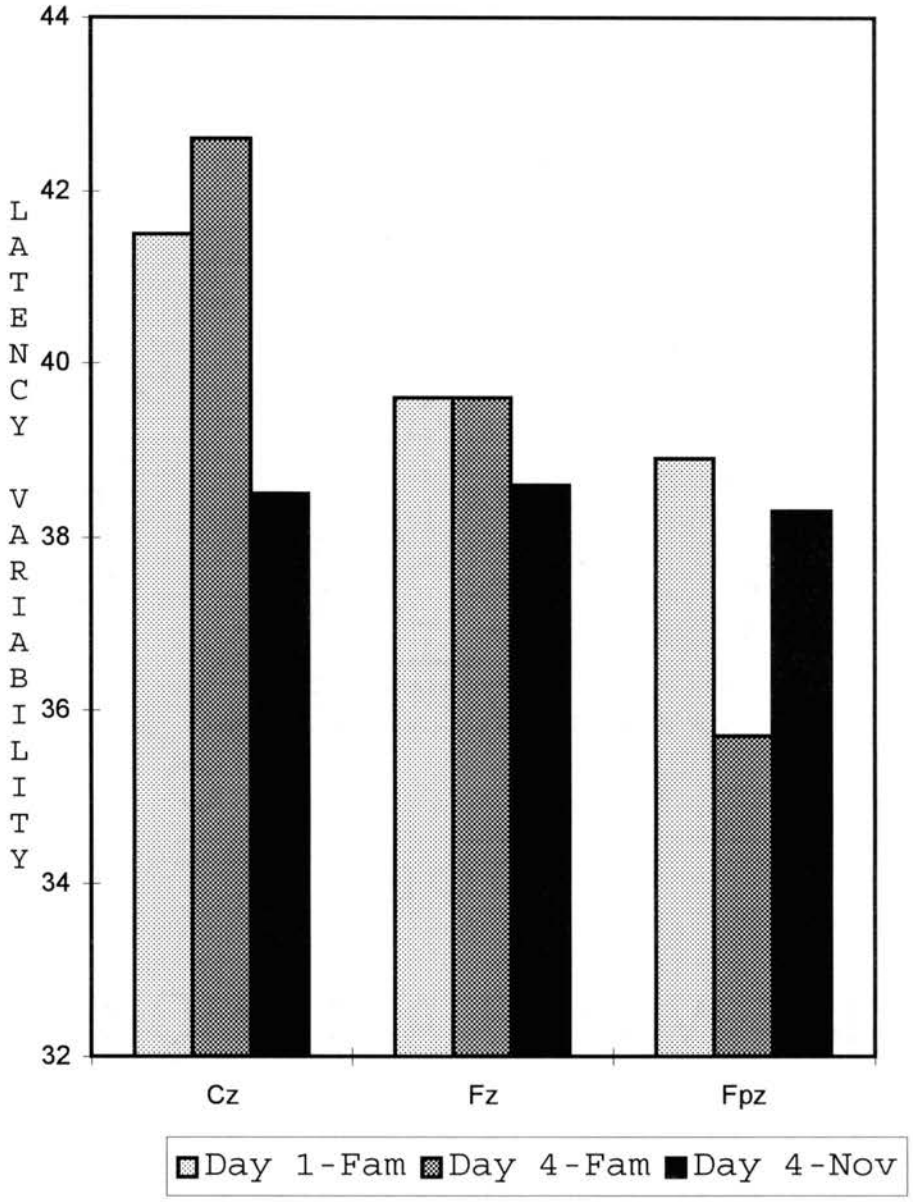


Figure 25

P2 Average Peak Amplitude for the Control Group.

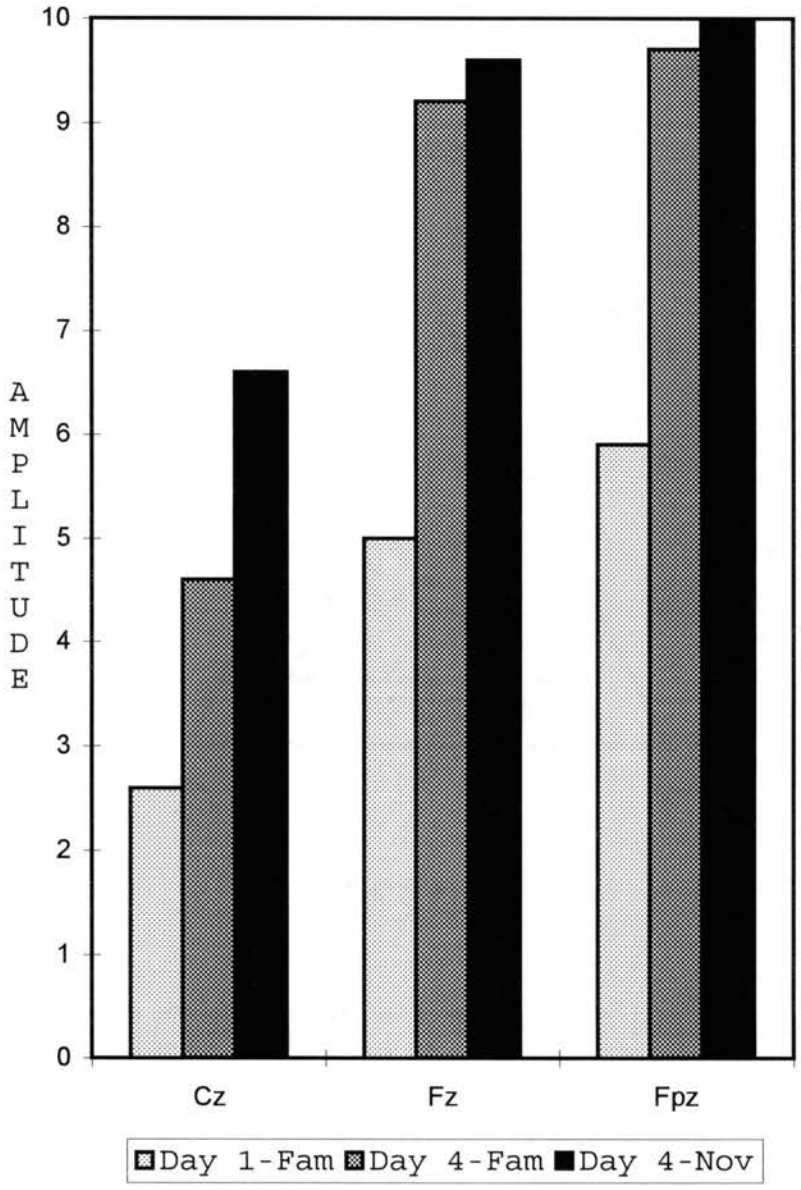


Figure 26

P2 Single-Trial Amplitude for the Control Group.

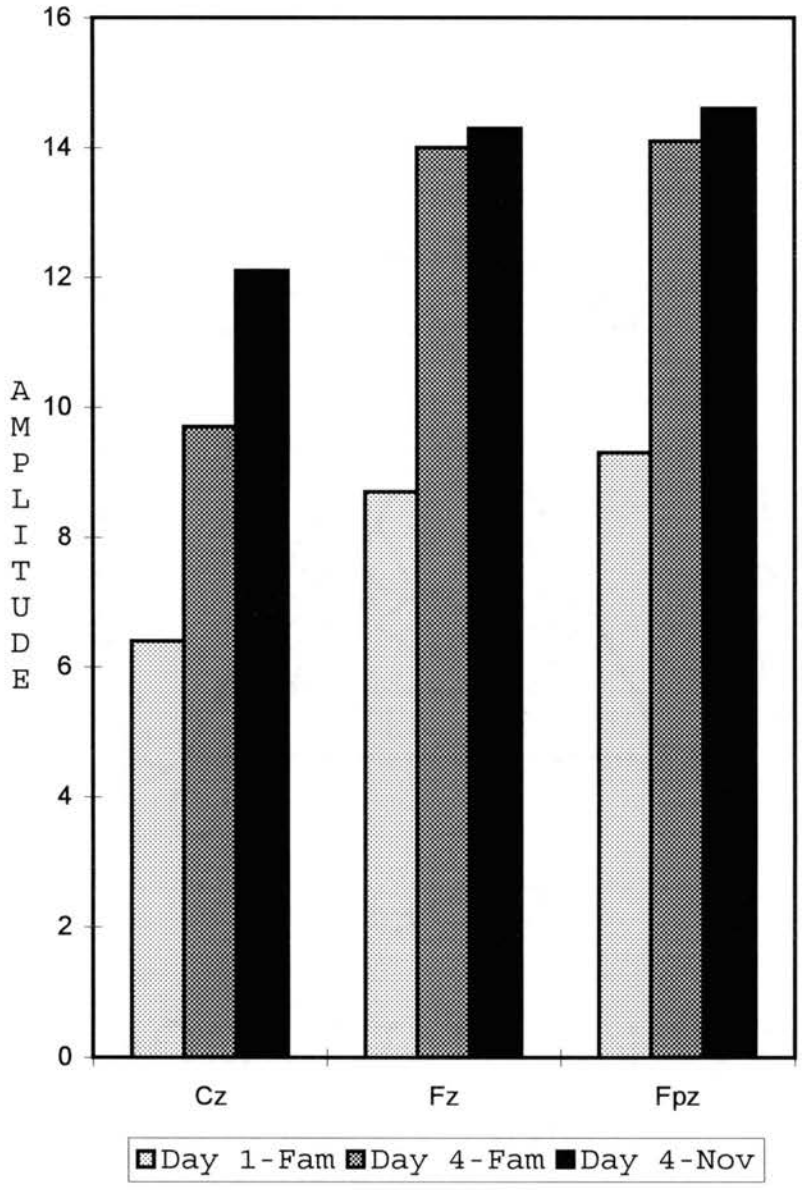


Figure 27

P2 Latency Variability for the Control Group.

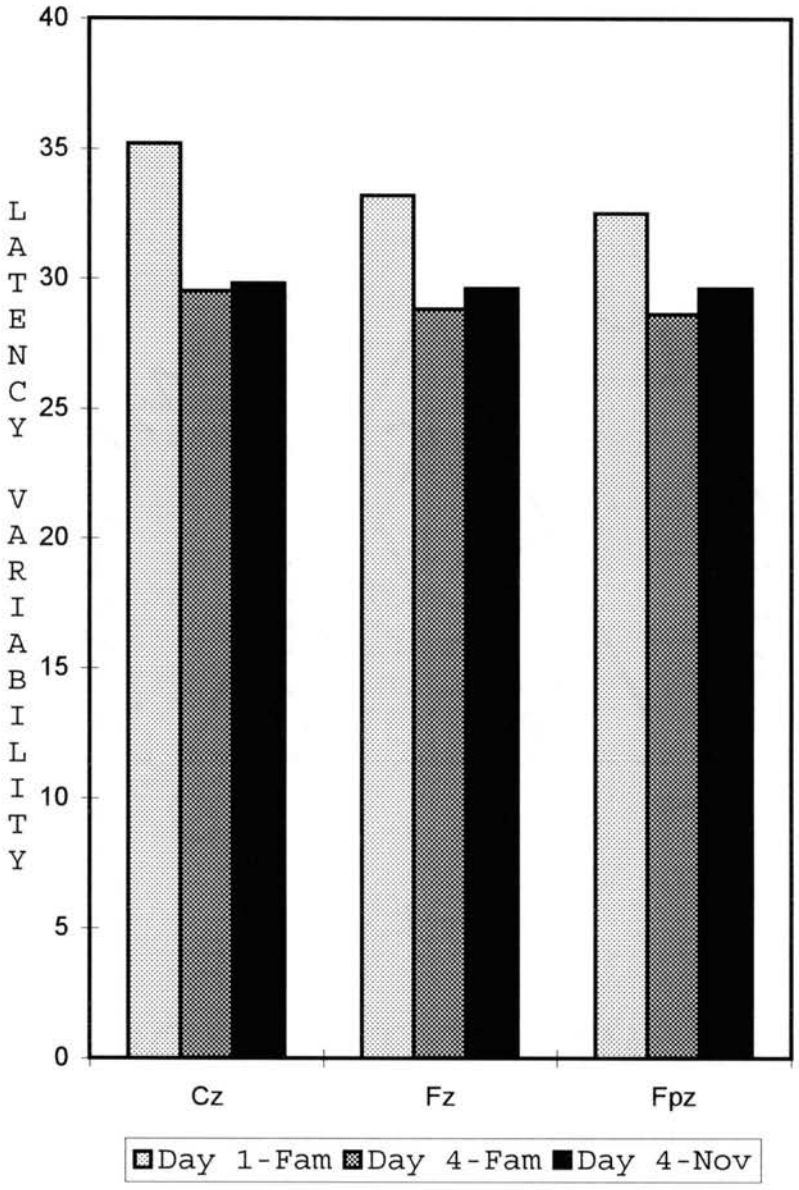


Figure 28

N2 Single-Trial Amplitude for the Control Group.

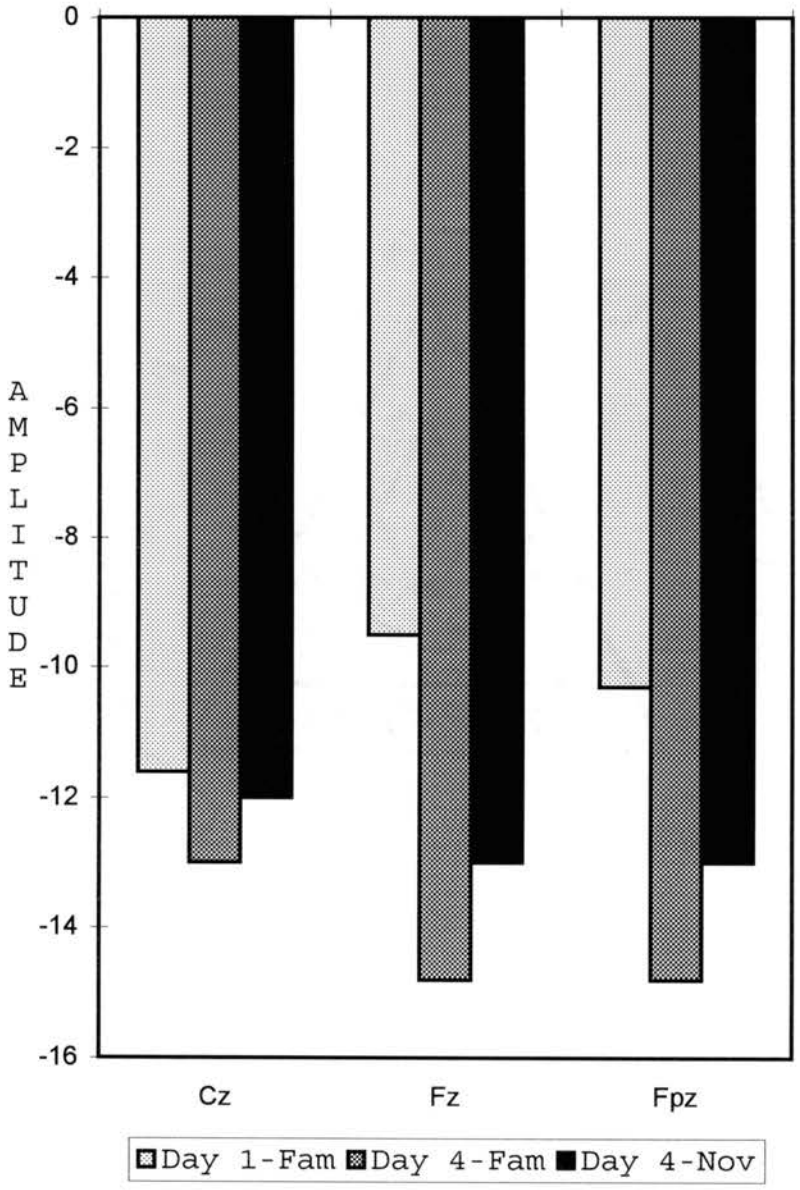


Figure 29

P3 Average Peak Amplitude for the Control Group.

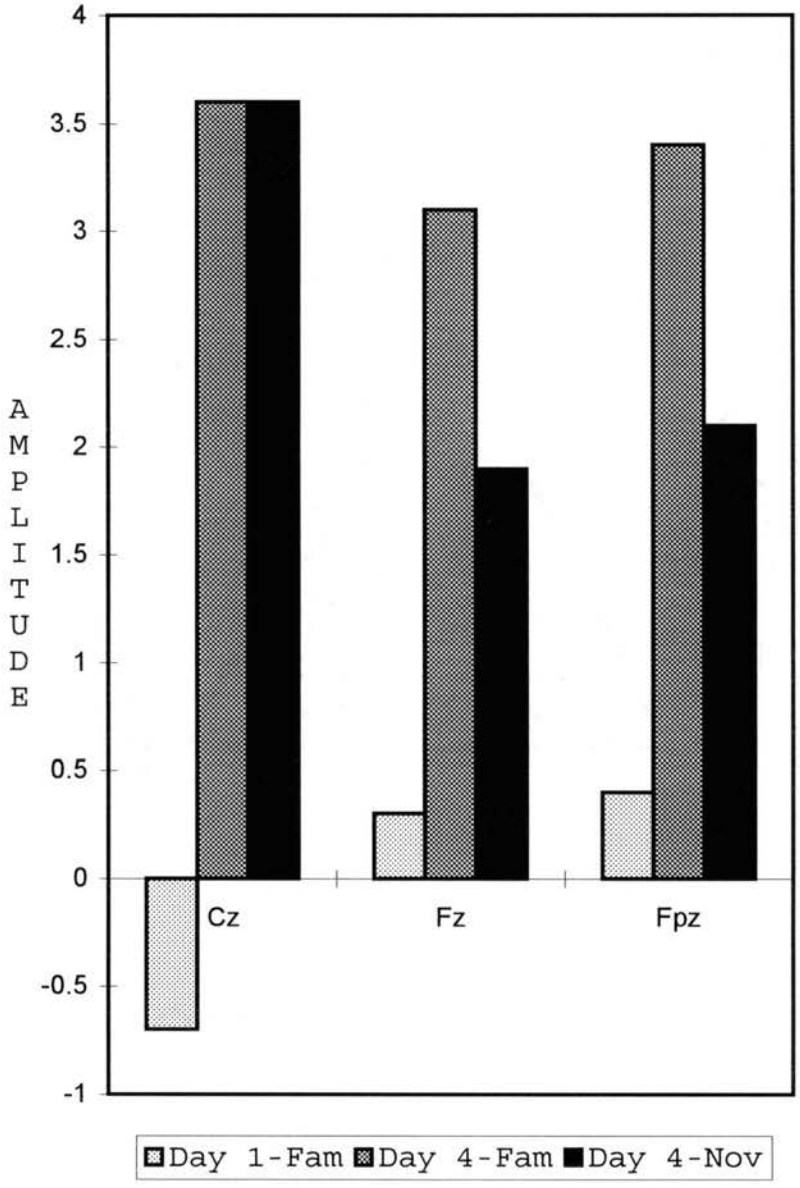


Figure 30

P3 Single-Trial Amplitude for the Control Group.

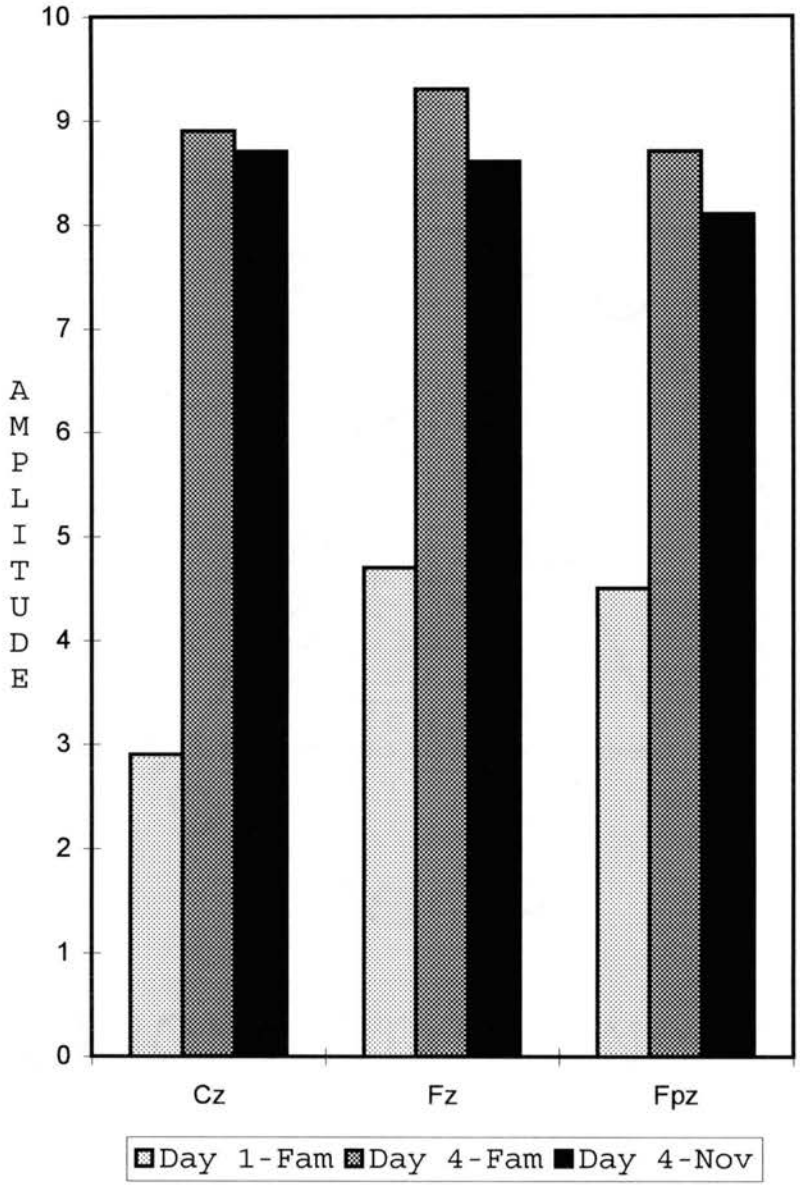


Figure 31

P2 Average Peak Amplitude for the Reacquisition Group Across All Levels of Day.

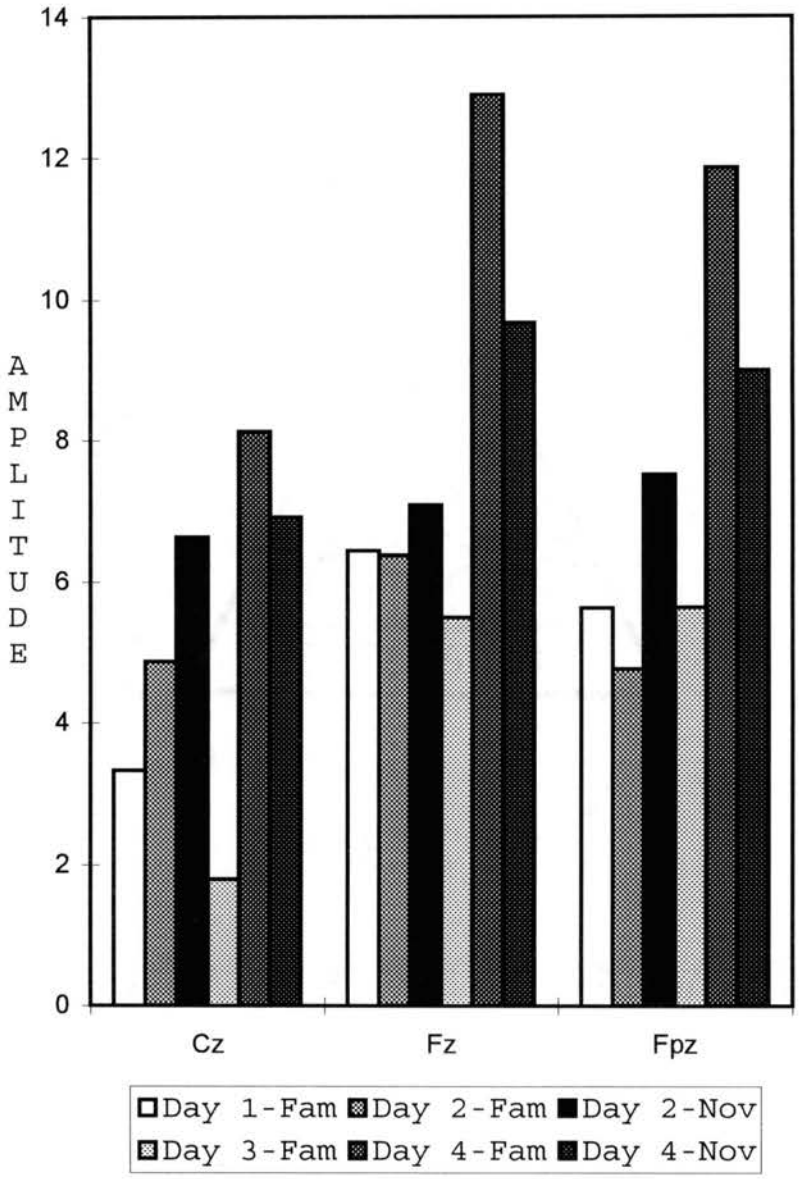


Figure 32

P2 Single-Trial Amplitude for the Reacquisition Group Across All Levels of Day.

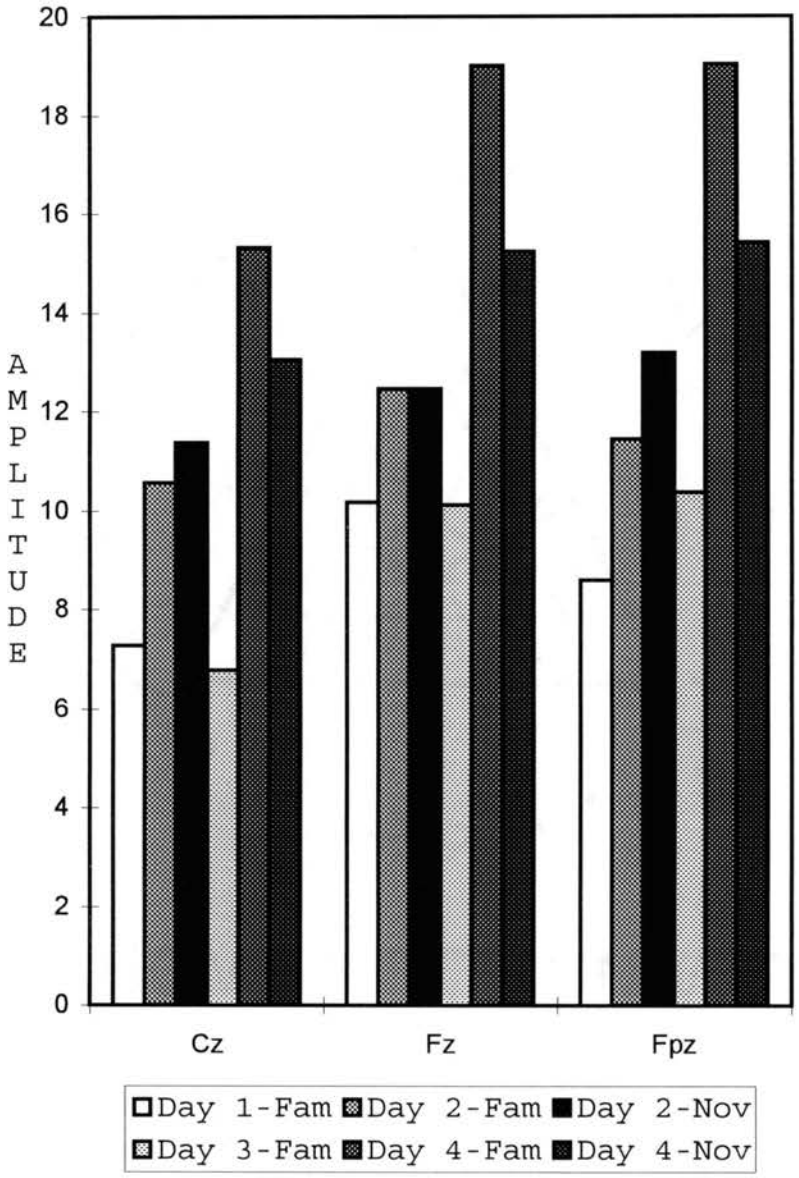


Figure 33

N2 Single-Trial Amplitude for the Reacquisition Group Across All Levels of Day at the Fz and Fpz Electrodes.

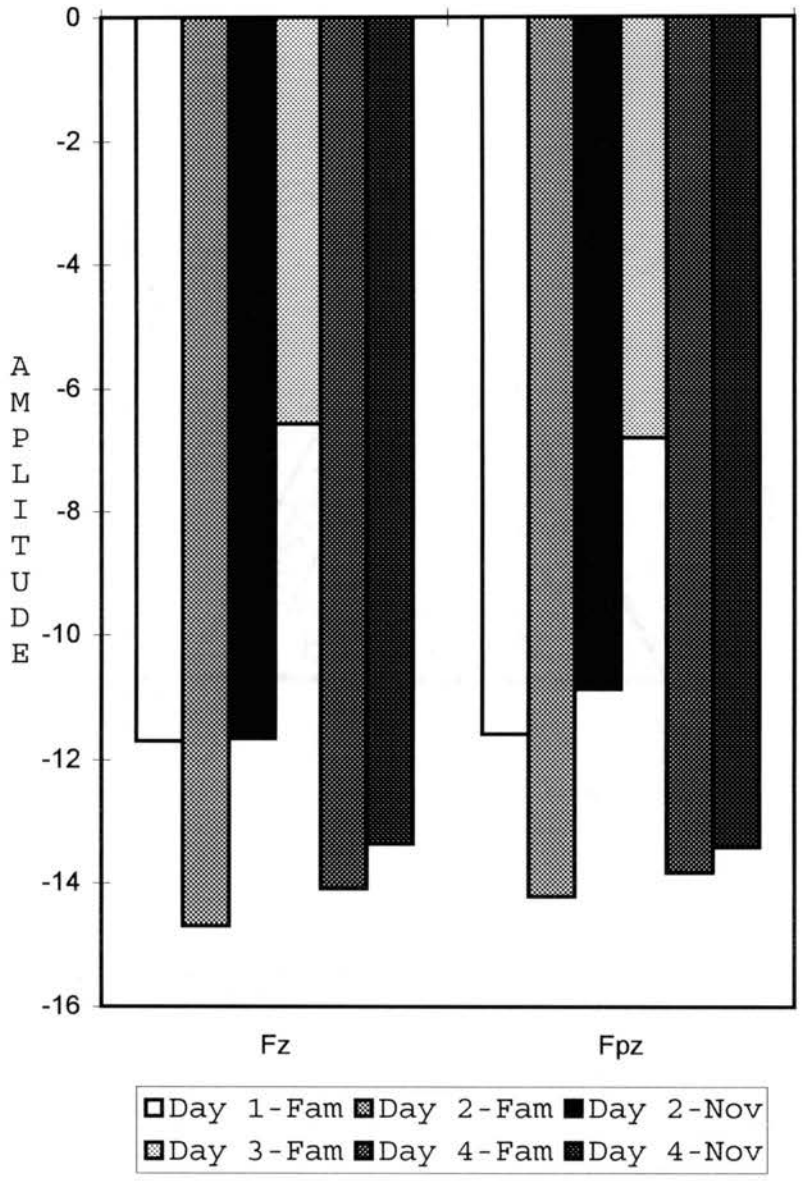


Figure 34

P2 Average Peak Amplitude for the Reactivation Group Across All Levels of Day.

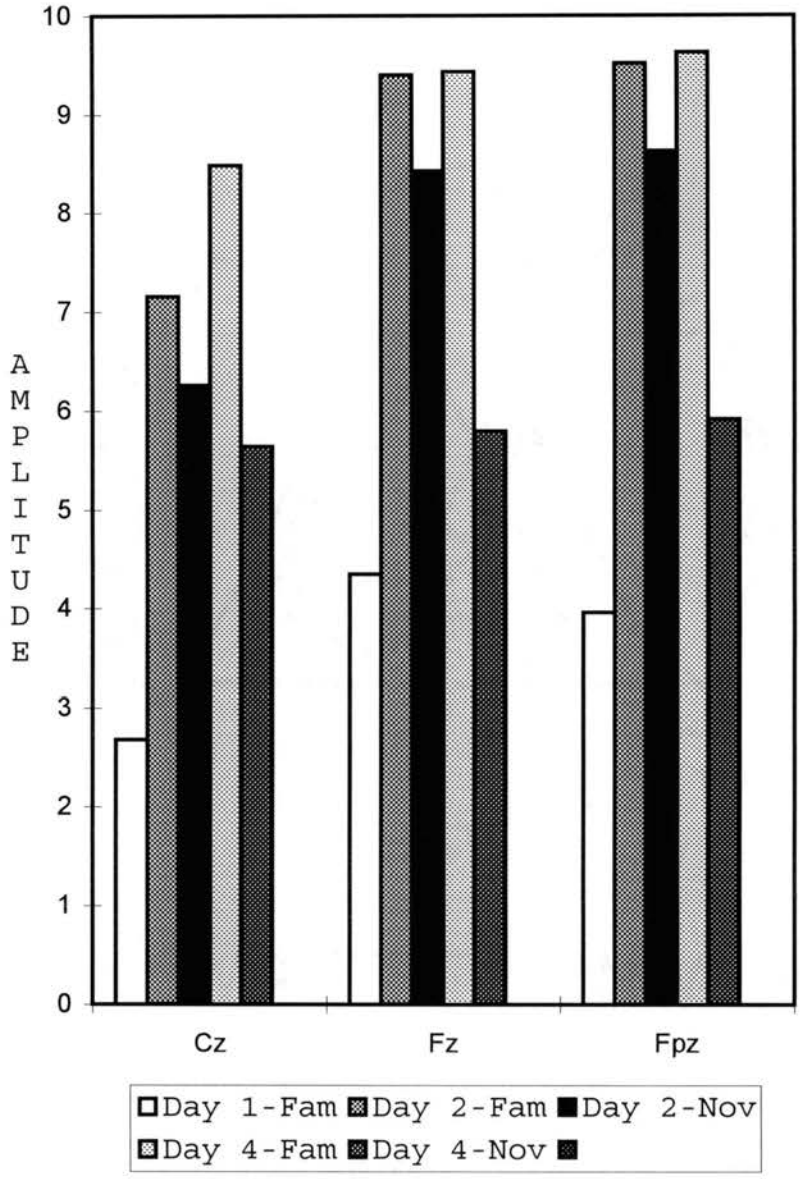


Figure 35

P2 Latency Variability for the Generalization Group Across All Levels of Day.

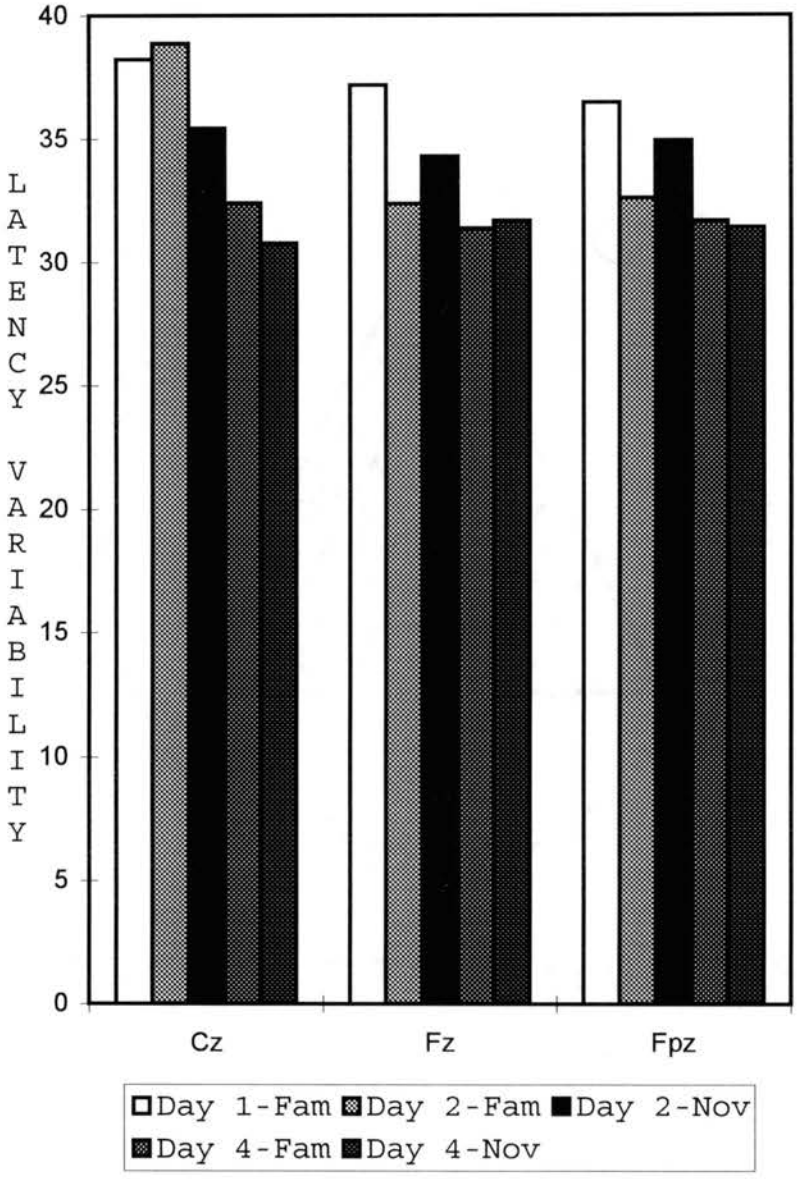


Figure 36

P2 Latency Variability for the Control Group Across All Levels of Day.

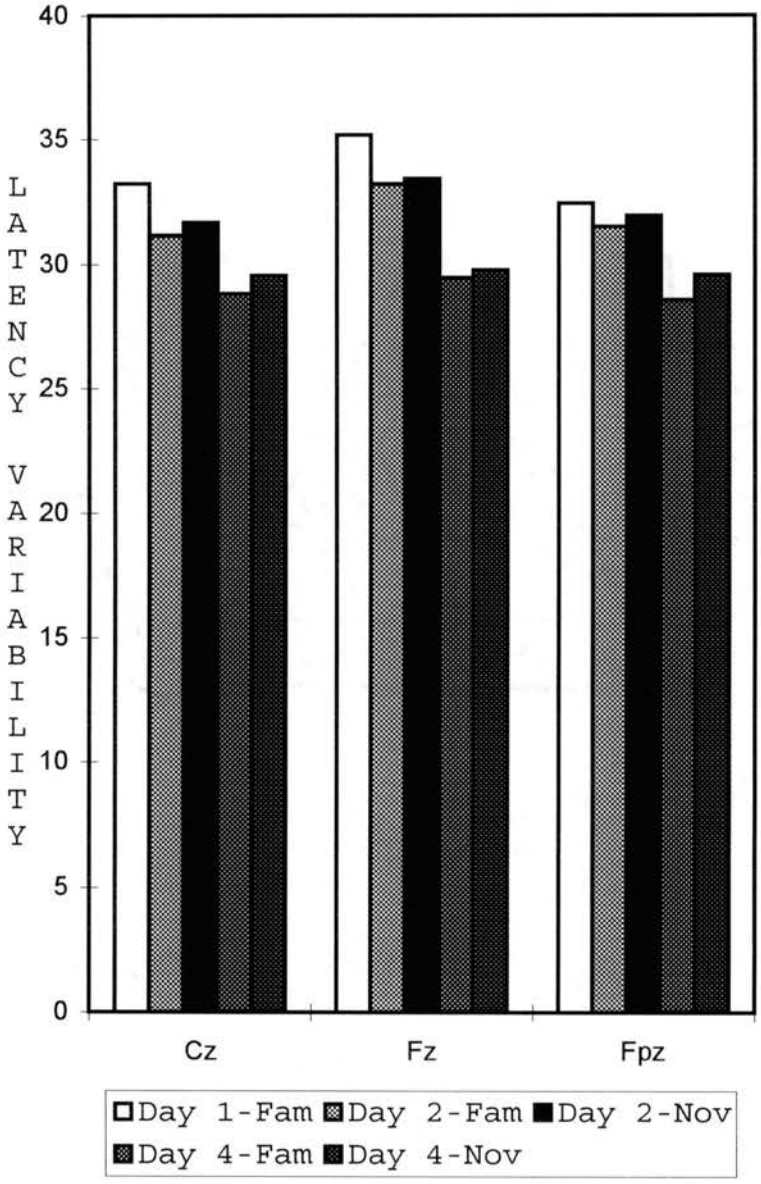
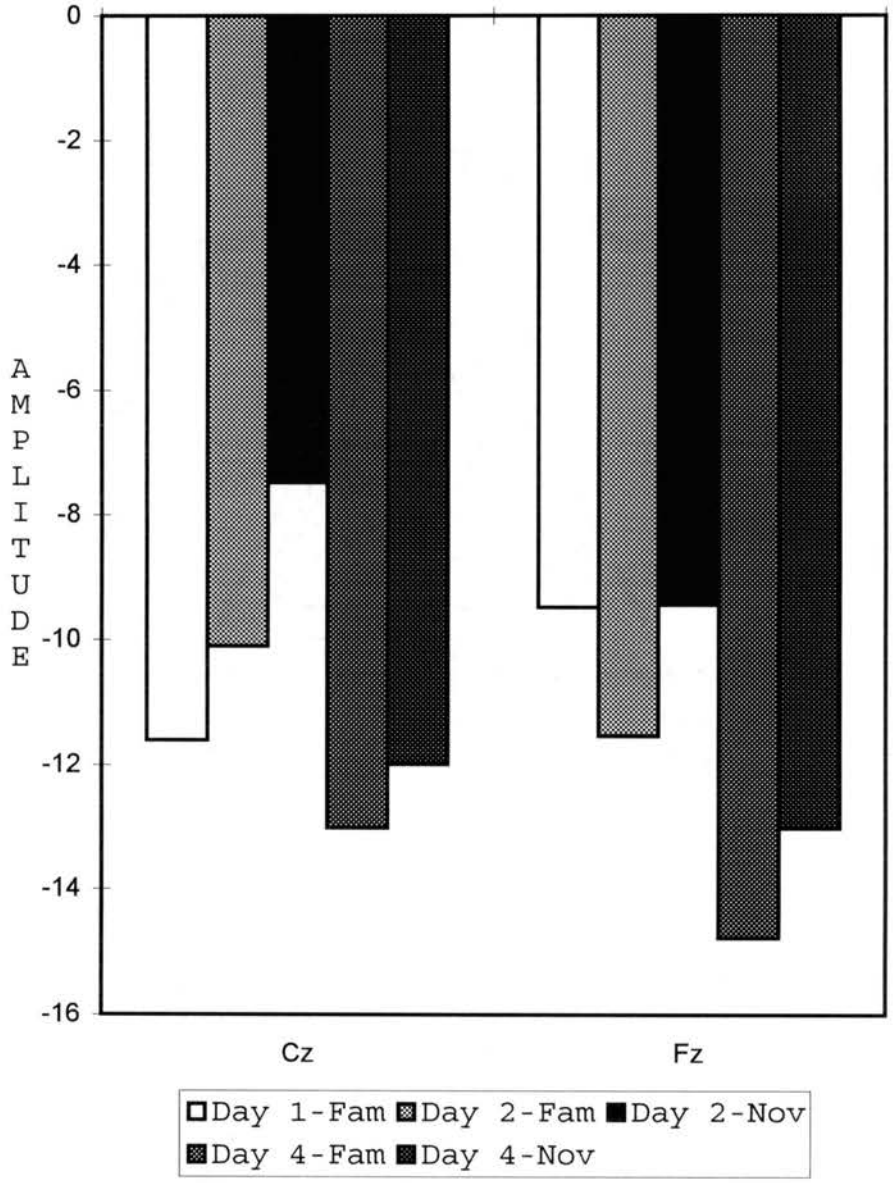


Figure 37

N2 Single-Trial Amplitude for the Control Group Across All Levels of Day at Cz and Fz.



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VITA

Margaret Susanne Lykins

Candidate for the Degree of

Doctor of Philosophy

Thesis: EVENT-RELATED POTENTIAL CORRELATES OF TWENTY-FOUR HOUR AUDITORY RETENTION AND MEMORY REACTIVATION IN THREE-MONTH-OLD INFANTS

Major Field: Psychology

Biographical:

Personal Data: Born in Santa Barbara, California, August 17, 1950; married Rex H. Lykins, Jr., July 12, 1970; mother of Colette Lykins Carballo, born July 4, 1971 and Joanne Lykins, born June 3, 1974; grandmother of Nathan A. and Michel A. Carballo, born November 17, 1995.

Education: Graduated from Santa Barbara High School, Santa Barbara, California, in June, 1968; received Bachelor of Education Degree from Central State University, Edmond, Oklahoma in May 1990; received Masters of Science Degree from Oklahoma State University, Stillwater, Oklahoma in December 1993; completed requirements for the Doctor of Philosophy Degree from Oklahoma State University in July, 1996.

Professional Experience:

Research: Research Assistant, Department of Psychology, Oklahoma State University, 1993-1996. Research consultant, Educational Testing Service, New Jersey, 1993-1995.

Teaching: Teaching Assistant, Department of Psychology, Central State University, 1989-1990; Teaching Assistant, Department of Psychology, Oklahoma State University, 1990-1994;

Professional Organizations: Southwestern Psychological Association, Oklahoma Psychological Society, American Psychological Society. Society for Research on Child Development.

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

Date: 01-11-95 **IRB#:** As-89-043C

Proposal Title: ELECTROPHYSIOLOGICAL MEASURES OF MEMORY IN INFANTS

Principal Investigator(s): David G. Thomas, Margaret Susanne Lykins

Reviewed and Processed as: Continuation

Approval Status Recommended by Reviewer(s): Approved

ALL APPROVALS MAY BE SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING.
APPROVAL STATUS PERIOD VALID FOR ONE CALENDAR YEAR AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL.
ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

Comments, Modifications/Conditions for Approval or Reasons for Deferral or Disapproval are as follows:

Signature: John H. Wyckoff Date: January 12, 1995

Chair of Institutional Review Board

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