THE RELATIONSHIP OF AUDITORY EVENT-RELATED POTENTIALS IN FULL-TERM INFANTS TO THE BAYLEY SCALES OF INFANT DEVELOPMENT

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CHAPTER I

INTRODUCTION

In the course of developing a dissertation one attempts to take a philosophical principle and decide how to measure it scientifically. One also hopes to develop a project that will in some way contribute to society as well as to the scientific community. Since the implementation of Public Law 99-457 (PL:99-457) it has become necessary for psychologists and educators to develop early screening devices to detect infants at-risk for developmental delay. The problem at present is the ongoing debate in developmental theory of the ablity of infancy measures to predict later deficits in children.

The present study was developed to assist understanding of the continuity versus discontinuity debate regarding predictability of infancy measures as applied to the field of cognitive development. The continuity theorists believe cognitive development in later Piagetian stages of cognitive functioning is predicted by functioning exhibited in previous stages (Fagan,1984a; Bower,1977). The discontinuity theorists purport that each Piagetian stage is a discreet stage, that is, that present cognitive functioning can not be predicted by functioning in previous

stages (Bayley, 1970; Oppenheim, 1981)

In an attempt to combine aspects of continuity and discontinuity models, Kagan (1984), proposes an integrative model. Kagan asserts that continuity can best be conceptualized as a within-stage process (as opposed to an across-stage process). Within the realm of cognitive development, this would mean that prediction of cognitive functioning could be made reliably if the prediction were made exclusively within one stage, e.g., Piaget's stage of sensorimotor development. This model has been applied in the present study to determine if an electrophysiological measures recorded early in infancy could predict later cognitive development in the same period.

The decision of which measure to use as the early infancy predictor variable was based on the growing field of electrophysiological recording. The development of the event-related potential (ERP) recording of cortical functioning in infancy has been well documented (Ohlrich & Barnet, 1972; Ohlrich, Barnet, Weiss, Shanks, 1978; Ornitz, Ritivio, Lee, Panman, Walter, & Mason, 1969; Shucard, Shucard, & Thomas, 1984; and Shucard, Shucard, & Thomas, 1988). However to date, its relationship to cognition in infancy had yet to be investigated.

The ERP could serve as a valid predictor variable for this study but an outcome variable was still necessary. At the present time, the most frequently used screening measure for infant cognitive assessment is the Bayley

Scales of Infant Development. Since the Bayley Scales can be adminstered to infants from 2 to 30 months, the Bayley Scales seemed to be a reasonable outcome variable.

The fosus of the present study was to measure the effectiveness of early infancy ERPs in predicting later infancy Bayley Scale scores. If ERPs at 4 and/or 16 weeks of age were predictive of the Bayley's Scales at 12 months of age, such early measurements would have some viability as a screening device for infants at-risk for developmental delay earlier than the presently used measures.

CHAPTER II

LITERATURE REVIEW AND HYPOTHESES

Continuity VS. Discontinuity

Two presumably incongruous basic assumptions underlying developmental theories that have been traditionally postulated--continuity and discontinuity. Continuity refers to connectedness in the process of development with the early behavior of an individual serving as a link to and predictor of later behavior (Emde & Harmon, 1984). Bower (1977) in his book, A Primer of Infant Development, takes the broadest view of continuity and presents it as a connected unfolding of life beginning at conception. He proposes that infancy, therefore, has permanent effects on all subsequent development.

The contrasting orientation to continuity in development is discontinuity. The philosophy of discontinuity focuses primarily on the idea that life is a series of separate stages (Emde & Harmon, 1984). These stages are separate from one another in that there are qualitative shifts in thought processes (Piaget, 1970) and task performance (Kagan, 1984). Stage theorists, therefore, believe that later behavior is not linked to

earlier behavior and not predicted by it.

The study of cognition is one area of debate between those who take a continuous, and those who take a discontinuous, perspective of development. Those who take a discontinuous view (Bayley, 1970) cite the findings of low correlations between psychometric tests of infant cognitive ability and later IQ tests as supportive of their position. When trying to determine the predictive validity of the Mental Development Index (MDI) of the Bayley Scales to the Wechsler Preschool and Primary Scale of Intelligence (WPPSI) given to four-year-olds, Bayley (1970) found that the correlations were -.16 at 4 months, .02 at 8 months, .27 at 11 months, .35 at 14 months and .49 at 21 months of age. Meanwhile, the WPPSI given at four years of age was found to have predictive validity correlations ranging from .46 to .82 with later tests of mental development such as the Stanford Binet L-M and the Wechsler Intelligence Test for Children (WISC). These findings seem to indicate that there is some continuity of cognitive ability between the Piagetian pre-operational stage (ages 2 to 5) and later Piagetian cognitive stages in children, but there is discontinuity between the Piagetian sensorimotor stage of infant development (birth to age 2) and the later cognitive stages (Harris, 1983). (Refer to Piaget, 1970 for a description of stages.)

Continuity theorists propose several explanations for these findings. Harris (1983) for example posits

that later IQ tests are primarily a measure of verbal ability and the infancy period is defined as the period of pre-verbal development. Therefore, it is likely that the predictive correlations would be low early in infancy and continue to improve as the child becomes more verbal in toddlerhood and through subsequent years. Fagan (Fagan & Singer, 1983; Fagan, 1984) asserts the position that the Bayley (1970) findings are not a definitive answer to the continuity vs. discontinuity debate concerning cognitive development, because the Bayley Scales may not be tapping elements that are indicative of continuous cognitive development. The Bayley MDI was specifically designed to measure sensorimotor task activities such as object permanence, imitation, object manipulation, and sociability (Kohen-Raz, 1967). Fagan (1984a) perceives more physiological based measures will tap the concept of cognitive functioning better than the behavioral measures that Bayley uses.

Fagan (1981) has asserted that the way to tap the essence of cognitive processing is to: a) focus on basic components of early information processing in infancy, as measured by both autonomic and motorically effortful skills, and b) analyze their relationship to later psychometric measures. From Fagan's point of view, measures other than the MDI, such as speed of response and detection of stimulus features, are likely to be more predictive of these later cognitive measures.

Fagan's theory has led him to use habituation and novelty preference as types of information processing to predict later scores on cognitive tests. Infants between three and five months of age were shown a picture until they habituated to it, as measured by cessation of pupil fixation on the picture. After a timed delay, the infants were presented the picture to which they habituated and a novel picture. A series of such paired items were presented. Novelty preference percentages were obtained for each infant. A significant positive relationship was found between novelty preference and scores on psychometric cognitive tests given to the children when they were 30 to 36 months of age (Fagan, 1984; Fagan & McGrath, 1981).

Integration of Continuity and Discontinuity

Rather than continuing to conceptualize from an "either-or" position concerning cognitive development, a different approach would be to use Kagan's (1984) theory which integrates the contintuity and discontinuity schools of thought. Kagan considers development as a series of "discrete," independent states that are predominantly independent from each other yet intra-dependent within each stage in their relationship to cognitive processes. Therefore, Kagan asserts that if one is interested in the concept of continuity of development, one should measure cognitive development within a certain developmental stage

rather than across different ones.

Kagan (1984) uses this within-stage continuity model to hypothesize about many aspects of cognitive development within the infancy period. There are two reasons Kagan focuses primarily on this stage: 1) infancy is an important stage in the continuity vs. discontinuity debate; and 2) infancy is an under-researched area of cognitive development in general.

A few studies have actually addressed this within-stage issue of cognitive development. These studies have tended to support the idea of continuity between early and late infancy. The principle underlying these studies is synonymous with Fagan's (1984a) theory that an early physiological response can predict functioning later as measured on psychometrically. In general, these studies that have used the Bayley Scales of Infant Development as the outcome variable predicted by earlier physiological measures.

Use of the Bayley Scales in Testing the Integrative Model

The Bayley Scales (Bayley, 1969) are among the oldest and most well-normed psychometric measures of infant development. These scales measure three different aspects of infant development: a) mental development as measured by the Mental Developmental Index (MDI); b) motor development as measured by the Psychomotor Development Index (PDI); and

c) social skills as measured by the Interpersonal Developmental Index (IDI).

The MDI predominantly measures object permanence, rudimentary writing and verbal skills, object manipulation and imitation (Kohen-Raz, 1967). The PDI measures gross- and fine-motor ability, coordination and balance, locomotion development, and perceptual ability (Bayley, 1969; Miller, 1990). The IDI measures attachment and social interaction with the primary caregiver (Bayley, 1969). The IDI tends to be much more subjective than the other two scales (Bayley 1970) and has not been used in studies to be predicted by physiological responses.

The primary physiological responses used to predict the Bayley Scale scores have been cardiac orienting responses (O'Conner, 1980) and object permanence (Rose & Wallace, 1985). O'Conner (1980) recorded the heart rate of four-month-old infants prior to and following the onset of a 70 decibel tone stimulus. Heart rate was measured as: a) the amount of deceleration that occured as the infants were initially exposed to the tone (orienting response), and b) the habituation to a second presentation of the stimulus as measured by the smallest amount of change in heart rate pre-and post-stimulus. When the infants were 18 months of age the Bayley MDI and PDI were administered. A significant correlation was found between the female infants' orienting response and the MDI, with greater deceleration indicating a higher MDI. No relationship was

found between neither the orienting response nor the habituation score and MDI for the male infants.

Rose and Wallace (1985) visually presented 12-month-old infants with a toy stimulus that the infants had only previously experienced tactually. A cross-modal score was obtained as the percentage of correct choices of visual recognition of the toy they had previously encountered tactually. These 12-month-old infants also received an intramodal score of visually recognizing a shape they had previously seen. The infants were administered the Bayley MDI when they were 24 months of age. Both cross-modal and intramodal scores were positively correlated with the MDI.

The paradigm of using an earlier physiological measure to predict later cognitive development within the infancy period has recently expanded to include using electrophysiological measures of brain functioning. Murray (1988) examined the relationship of evoked potentials to later Bayley Scale scores with high- and low-risk infants. She recorded the brainstem evoked response (BSER) to an auditory stimulus at birth and at 9 months of age. The BSER is recorded as the first 10 ms of brain activity in response to an auditory stimulus and represents the sequence of pre-cortical processing in the brain (Hillyard, 1985). The Bayley MDI and PDI were administered at three, six, and nine months of age. Murray categorized the infants into groups as having normal or abnormal brain

activity based on their neonatal BSERs. Using multivariate analysis of variance, she found that the newborn BSER classification was significantly predictive of the Bayley PDI; infants with normal BSERs scored significantly higher on the psychometric measures. Murray concluded that the BSER would be effective in predicting which infants were at-risk for psychomotor delays. In relation to the within-stage model of development, it would appear that sub-cortical measures of information processing are predictive of infancy measures of motor ability.

These studies suggest that further research of Fagan's asssertion that early autonomic responses are predictive of cognitive development is needed. Furthermore, since the brainstem evoked response was predictive of later Bayley Scale scores, it is likely infant cortical event-related potentials recorded early in infancy will also be predictive of those scores.

Cortical Processing of Stimuli in Infancy

Event-related Potentials -- Amplitude and Latency

The observation of brain activity by electrophysiological measures is not limited to subcortical activity. Evoked potentials also consist of cortical activity and are referred to as event-related potentials (ERPs). This measure of cortically generated responses to stimuli has been conceptualized as a series of exogenous

and endogenous components (Hillyard, 1985). The exogenous components, in general, are the early part of the ERP response. They are thought to represent the cortical processing elicited by the stimulus and are sensitive to parameters such as the intensity of the interstimulus interval. The endogenous components are the later part of the ERP waveform and are thought to represent the higher level cortical processing of the stimulus. They are conceptualized as being influenced by cognitive parameters such as the task relevancy of the stimulus. There are several modalities from which the ERPs can be obtained, with the most frequently used being auditory, visual, or somatosensory. This study will focus on auditory ERPs (AERP).

A primary way to analyze these waveforms in infants has been to measure the magnitude of each peak and trough of the ERP (amplitude) and the time each appears after stimulus onset (latency). Auditory stimuli have been used to determine the appearance of the waveform at birth and to determine when the infant waveform approximates the adult waveform (Ohlrich & Barnet, 1972; Ohlrich, Barnet, Weiss, & Shanks, 1978; Ornitz, Ritivo, Lee, Panman, Walter, & Mason, 1969; Shucard, Shucard, & Thomas, 1984; and Shucard, Shucard, & Thomas, 1988).

The general finding about the development of the waveform in infancy is that it approximates a near adult form by 12 months of age. As seen in Figure 1, the predominant

peak present in one-month old infants is a positive deflection occurring between 100-300 ms after stimulus presentation (Ohlrich & Barnet, 1972; and Ohlrich, et al., 1978). This peak is termed the P2 and is generally followed by an immediate negative deflection referred to as the N2 peak.

Insert Figure 1 about here

The infant AERP waveform at six months of age consists of a clearly defined positive peak that occurs 35 ms or more after stimulus onset (P1) and followed by a negative deflection known as N1. The N1 peak has been present in the AERP waveform prior to six months of age in some studies (Ohlrich & Barnett, 1972 and Shucard, Shucard & Thomas, 1988). In these instances the N1 peak is defined as the negative deflection prior to P2.

At six months of age there is also a a positive peak present that follows N2 and is known as the P3 peak. P3 in infants has been defined by Ohlrich and Barnet (1972) as either a positive peak followed by a negative deflection or a long positive waveform with no well defined peak. By the time an infant reaches one year of age, the waveform peaks are clearly present as P1, N1, P2, N2 and P3. At this age, the P3 peak is well formed enough to be clearly seen as a positive peak followed by a negative trough.

Ohlrich and Barnet (1972) were the first to begin to analyze individual differences in normal full-term infants

by using AERPs. They conducted a cross-sectional study with infants at 1, 6, and 12 months of age. The stimulus was a 65 dB click presented while the infants were asleep. The click stimulus was chosen because it is a simple sound that would keep confounding components to a minimum. They also chose to collect the data while the infant was sleeping in order to keep muscle activity from interfering in the AERP computation. The EEG was recorded from the middle of the scalp, a location called Cz according to the International 10-20 System of scalp locations (Jasper, 1958). Cz is the best location for recording overall cortical activity when using an auditory stimulus.

Ohlrich and Barnet (1972) found that the latency of the P1 and N1 components did not change across ages, whereas the P2, N2, and P3 latency decreased with age. One of their major findings concerning the amplitude of the waveform was that N1, which was present in half the infants at 1 month of age and was present in all infants by 6 months of age, had significantly increased in amplitude by 12 months. The other significant finding was that the P3 wave, though not present in 1-month-olds, had reached adult-like amplitude by 12 months of age.

In the attempts to further clarify the development of this AERP waveform, Ohlrich et al. (1978) conducted a longitudinal study using the same stimulus, recording location, and sleep condition. They also added more sleep conditions in order to further understand the development

of the AERP. The significant changes in the individual AERPs were a decrease in P1 latency with age in REM sleep and a decrease in N2 and P3 latencies in deep sleep, while the P1N1, P2N2, and N2P3 amplitudes all increased with age in all stages of sleep. Thus, the trends found in this study were similar to those found in the cross-sectional studies with the responses becoming more rapid and more well defined as a function of age.

Ohlrich et al. (1978) also examined gender as a variable related to the development of the AERP waveform. They found no gender difference in either the amount of latency decrease or the amount of amplitude increase when the waveform was measured as a whole. After analyzing individual components of the waveform, they found only two significant differences between males and females. Across the first year of life, the female infants had shorter P3 latencies and the male infants' P1 amplitude showed a greater degree of increase.

In addition to the studies of AERP in normal infants, other studies have examined the relationship of amplitude, latency, and variability of the AERP in infants, children and adults, with atypical developmental histories.

Kurtzberg, Hilbert, Kreuzer, and Vaughan (1984) compared the AERPs of two groups of three-month-old infants. One group was premature infants with very low birth weight (VLBW) the other, normal full term infants (NFT). They found that VLBW infants' AERPs to consonant-

vowel stimuli (e.g., "da") were much less developed than were those for the NFT group. The researchers concluded that there may be developmental delays in the VLBW group which might affect the development of cognitive ability. Based on the maturation of the cortical auditory processing system, Kurtzberg, et al. also speculated that one could predict a relationship between neonatal auditory orienting scores and measures of cognitive performance. However, no psychometric measures were administered; thus, the prediction could not be tested.

Shucard, Shucard and Thomas (1988) compared awake premature infants with NFT infants to determine if electrophysiological measures could differentiate maturational aspects of cortical processing between these two groups of infants. They found that during the first year of life th primary difference was in the latencies of premature versu NFT infants. The preterm infants tended to have longer BSER latencies; this effect became more apparent as the infants aged. Additionally, the AERP amplitude measures were significantly different for the groups, with the preterm infants having higher amplitudes at one, three and six months corrected age. These differences were attributed to the maturational processes of the brain. There were no significant differences in the AERP latency between the two groups.

Research by Barnet and Lodge (1967) also supports the assumption that amplitude is an important component of

cognitive processing. These authors, using the central cortical measurement of CZ, found that infants who were diagnosed as having Down's Syndrome had significantly higher amplitudes on the P2 and N2 components of the AERP waveform. This relationship of cognitive deficit and higher amplitude was hypothesized to result from the inability of the infant to habituate to incoming stimuli. The assumption was that these infants reacted to every stimulus as if it were a novel stimulus.

More recently, studies focusing on the development of ERPs from birth have found that amplitude changes more than latency during the first four months of life (Blom, Barth and Visser, 1980; Shucard et al., 1987; and Shucard et al., 1988). Blom et al. (1980) found that although the amplitude for the visual evoked potential (VEP) continues to increase throughout the first two years, no other ages have as a dramatic of an increase as the one occurring between the 2-4 month age level. Both Blom et al. (1980) and Shucard et al. (1987) attributed this drastic increase to the myelination of cortical axons in the brain which begins to occur during the second to fourth month of postnatal development. The myelination processes is hypothesized to lead to better connections in the brain's neural circuitry. The idea being that better connectivity thus produces higher amplitudes in the infant ERP.

Besides the development of latency in infancy, the latency of the AERP and its relationship to simultaneously

predicting cognition has been researched in the area of intelligence in older children. Ertl and Schafer (1969) found that the N2 and P3 latency were negatively correlated with the Wechsler Intelligence Test for Children (WISC). These results led them to speculate that cognitive ability was related to speed of processing. Donchin et al. (1986) have also stated that P3 latency is indicative of speed of information processing in adults.

Event-related Potentials -- Variability

Besides the traditional measures of AERP amplitude and latency, a few studies in the last two decades have attempted to determine if individual variability from trial-to-trial might be a suitable AERP measure. Hendrickson (1982a) proposed a model of intelligence that was based on the variability of the ERP. He speculated that less variability within the ERP response was indicative of higher intelligence. This speculation was based upon the assumption that intelligence is related to the degree to which information processing is free from error (i.e., responds consistently to stimuli).

Hendrickson's hypothesis was that if there was less variability there would be a more complex wave resulting in a higher amplitude waveform. Since the waveform is averaged across trials, he believed that if there were a great deal of variability the waveform would appear flat.

Hendrickson created a physical measurement of this variability based on the amplitude and complexity of the ERP waveform. Hendrickson (1982b) applied this paradigm to school-age children and found that those with longer, more complex, ERPs had higher IQs as measured by the WISC-R.

This idea of variability as a measure of cognitive ablity has also been researched in adults. Shucard and Callaway (1974) report on two studies of amplitude variability as a predictor of intelligence in "dull" and "bright" adults. Results of a pilot study conflicted with those from the main study. In the pilot study "dull" subjects exhibited more variability. In their main study no main effects were found for amplitude variability; the trend was toward the "dull" subjects having less variability. The authors suggest that further studies using this method are needed to clarify the relationship of AERPs and cognitive processing.

The Relationship of Infant AERPs to Cognition

Initial Research

In spite of Murray's (1988) findings that BSERs were predictive of the Bayley PDI and Kurtzberg's et al. (1984) hypothesis that the AERP may be predictive of cognitive development in the infancy period, at present no studies have been conducted to investigate the relationship of infant AERPs to any psychometric measures of cognitive

development. As an initial step to investigate the predictability of the AERP within the infancy period, a subset of infants from the previously noted Shucard, et al. (1988) study were administered the Bayley Scales (Thomas, Shucard, Crow, & Shucard, 1990). Bayley MDI and PDI scores were obtained when the infants were 12 months of age (adjusted for conceptual age). Correlation coefficients were calculated between the AERPs collected when the infants were 3 months of age and the Bayley measures. A significant relationship was found between the amplitude of the N1 peak and both the Bayley MDI and the PDI for the left hemisphere and only the PDI in the right hemisphere; the larger the N1 amplitude, the lower the Bayley Scale scores. In this study the AERP was found to be a better predictor of Bayley scores than gestational age.

One possible explanation for this finding is that the negative relationship with the N1 peak amplitude might have resulted from this population of predominantly premature infants continuing to respond as if every presentation were a novel stimulus. This assumption is based on: a) Barnet and Lodge (1967) findings that infants with a diagnosis of Down's syndrome showed the same pattern when compared to a normal population, and b) Fagan's (1984a) theory that habituation is an important predictor of later cognitive functioning.

Since the Thomas et al. (1990) study had a large number of subjects who were born prematurely, it was

difficult to generalize the findings to the general population. Further studies with full-term infants seemed warranted to better understand the relationship of AERP to cognitive processes in infancy as well as to assess the integrative model of continuity of development in the infancy period.

Cortical Response as a Predictor of Later Infant Cognition -- The Present Study

The primary focus of the present study was to explore the usefulness of the AERP as a predictor of psychometric measures of cognitive development in infancy using full-term infants with uneventful pre- and post-natal development. Since the primary psychometric measures of cognitive development in infancy used in previous studies are the Bayley MDI and PDI, these scales were used to compare and contrast the findings of this study with other studies using the integrative model.

An equal number of male and female subjects were studied in order to control for gender effects in the relationship of AERPs to cognitive development. In order to make the study comparable to the Thomas et al. (1990) study, the infants in this study were observed in an awake state. Analysis of the infant AERP of awake and asleep infants prior to data collection indicated that the infants who were awake during stimulus presentation had more well-

defined AERPs than those who are asleep.

This study differed from other previous AERP studies with infants in that the AERP data was collected at different ages prior to the administration of the Bayley Scales. All the previously cited research concerning development of the AERP indicated that waveform changes over time in the infant. Since the response latency decreases and the waveform becomes more well defined as a function of age, the differences of the waveform at various ages may provide more information about cognitive processing than a measure taken at one specific age. The previous studies that have correlated electrophysiological measures with psychometric measures of cognition have not investigated the relationship of such age-related change.

Besides the measures of amplitude and latency two measures of variability were used. One of these measures was amplitude variability. Amplitude variability consisted of measuring the amplitude of each digitized sample of the waveform (e.g., a 1000ms waveform might be sampled every 5ms for a total of 200 samples). Standard deviations for each time point were derived across trials, and the mean of all the standard deviations was calculated as the measure of amplitude variability for a given section of the waveform. The mean for that section of the waveform could then be compared to the prestimulus mean derived in the same manner to obtain a ratio of post-to pre-stimulus variability.

There are various ways to use amplitude variability. Since Hillyard (1985) conceptualizes the AERP waveform as consisting of early exogenous and later endogenous components, this study used amplitude variability as a measure by dividing the AERP into an "early" time window and a "late" time window. Once the amplitude variability for the early and late part of the waveform was determined, each time window could then be correlated with the Bayley MDI and PDI to determine if there was a relationship.

A second measure of variability, latency variability, was also used in the present study. Latency variability is a new measure that has been used in adult studies to analyze trial-to-trial variability to better understand the signal-to-noise relationship of the AERP (Thomas, Neer, & Price, 1989).

The procedure consisted of developing a template for each peak from the averaged AERP for an individual. Each individual trial was then compared to the template. A correlation was derived for predetermined sections of the individual waveform and the template. The highest positive correlation between the template and the individual trial was determined to be the time point for that peak. This matching procedure occured for all trials for one subject. The measure of latency variability for each infant was the standard deviation for the latencies across all trials.

This measure is considered to be comparable to Hendrickson's waveform variability measure; a small

standard deviation suggests that the peak is occurring in the same place across trials. Latency variability is a more accurate measure of Hendrickson's theory than his own string measure due to the consideration of individual trials versus an overall amplitude average (Thomas et al., 1989).

Hypotheses of the AERP Measures as Predictors of the Bayley Scales in the Present Study

Hypotheses Regarding Amplitude

Given the Thomas et al. (1990) finding of negative correlations between N1 amplitude and the Bayley MDI and PDI and the Barnet et al. (1967) finding of larger P2 and N2 amplitude being higher in Down's syndrome infants, it was hypothesized that the static measure of the averaged AERP at a particular age would be negatively correlated to the Bayley Scale scores. Such findings would also be consistent with Fagan's (1984a) premise that lower scores on later measures are indicative of the infant reacting physiologically to each presentation of a stimulus as if it were novel.

Since this study utilizes a full-term (FT) population a second hypothesis regarding the static measure is that a positive relationship between the AERP amplitude and the Bayley Scales may be found. This would indicate that in a no-risk population, the infants with higher voltage in

brain activity would score better on later cognitive measures.

Another relationship this study attempted to analyze is the predictive validity of dynamic measures--measurement of change in AERP amplitude over the first months of post-natal development. Ohlrich et al. (1978) reported that the amplitude of individual infant's N1, P2, and N2 peaks increase over the first six months of life in normal FT (NFT) infants. Other researchers such as Blom et al. (1980) and Shucard et al. (1987) suggest that this higher amplitude is indicative of neuronal brain maturation. Based on this premise, it was hypothsized that the present population of NFT infants would have a positive relationship between the amount of amplitude change and the scores on the MDI and PDI which are predominantly maturational measures (Bayley, 1969).

If a negative relationship between amplitude change and Bayley Scales occured, a possible explanation is that less change in amplitude means more consistency. This finding would mean the more constant the brain voltage over time the higher the performance on cognitive measures later.

If no relationship was found between the change in amplitude and these peaks, four possible reasons will be considered. The first is the fact that in this study there may have been too small a sample size to obtain significant relationships between the measures. A second possibility

is that Fagan's (1984a) assertion that the Bayley Scales may not be a good measure of cognitive continuity is valid The third possibility is that the AERP may not have any predictive validity within the integrative model of cognitive continuity. The last argument to consider if the null hypothesis is not rejected is that each measure has some predictability of cognitive continuity but that each measure taps very different aspects of this concept.

Hypotheses Regarding Latency

Since the pilot study (Thomas et al., 1990) indicated that neither the latency of N2 nor P3 at three months of age was correlated with either Bayley scale, a different way to measure such an effect in infancy seemed necessary. Ohlrich et al. (1978) and Shucard et al. (1988) in their longitudinal studies found differences in latency across ages in the waveform. These findings suggest that a dynamic measure of change across age in AERP latency may be a more effective measure in this study as a predictor of later performance on the Bayley Scales than static measures.

To date the latency of the N2 and P3 peaks are the only latency measures to have shown any relationship to psychometric measures of cognitive development (Ertl et al., 1969). These same two peaks were also found to show significant decreases in latency in both cross-sectional (Ohlrich et al., 1972) and longitudinal (Ohlrich et al.,

1978) studies of infant's AERP development. If Ohlrich et al. (1978) are correct in their assertion that decreases in these two peaks, especially the P3 peak, are the most likely measures of infant cognition, then the infants with the greater latency changes over time would have been positively correlated with the MDI and the PDI in the present study. If there was a negative relationship betweeen change in latency and the Bayley Scales, the idea of constancy over time in brain-wave development will be considered. Meanwhile, if neither a positive nor a negative relationship between change in latency and the Bayley Scales occured, the same possibilities presented in the amplitude section will again need to be considered. These hypotheses were: a) the possibility of too small of a sample size; b) the possibility of the Bayley Scales being an irrelevant outcome variable (Fagan, 1984a); c) the possibility that the AERP latency can not predict continuity within infancy; and/or d) the possibility that AERP latency and Bayley Scales are related to other aspects of cognitive continuity in infancy, but not to each other.

Hypotheses Regarding Amplitude Variability

As discussed earlier in this chapter, this study was to serve as a foundation in determining if variability of the infant brainwave could predict later cognitive development within the infancy period. One of the two measures used in this study was amplitude variability.

Amplitude variability was measured as the amount of change between the prestimulus state and a window that occured for the first 500 ms after stimulus onset as well as change between a second window of 501-1000ms and the prestimulus state. Since this was such a new measure both static and dynamic recordings were used to predict the Bayley Scales.

In analyzing this particular AERP measure it was important to consider whether one window was significantly related to the Bayley Scales when the other was not. If such a finding was found, Hillyard's (1985) assertion regarding adult populations will be considered. As presented earlier in this chapter, Hillyard conceptualizes the early components of the waveform as being stimulus driven while the later components would represent task relevant, decision making processes.

Since variability is a relatively new measure, both negative or positive relationships could be supported by previous research. Shucard et al.'s (1988) proposed that the neurological process of myelination of the axons in the early months of postnatal development would result in axon being at different levels of development. This process would result in more variability in the infants whose myelination process is occurring more quickly. Based on this assertion, it was hypothesized that amplitude variability would have been positively correlated with the Bayley Scales. This same explanation could also be applicable to the dynamic measure of an increase in

amplitude variabilty between the younger age to the older age. A positive correlation between the dynamic measure and the Bayley Scaless would have also been expected.

On the other hand, if Hendrickson's (1982a) theory of less variability being predictive of higher psychometric scores is applicable to the infant population, then the static measure of amplitude variability would have been negatively correlate with the Bayley Scales measured later. If Hendrickson's theory is also applicable to the dynamic measure, then the change in variability between the ages would be expected to negatively correlate to later Bayley Scale scores. This finding would suggest that as the cortical response becomes less variable over time the higher the infant will perform on later cognitive measures.

It is possible that there was no relationship found between the AERP amplitude variability and MDI nor the PDI. If the null hypothesis is confirmed, then the explanations of sample size and the inability of the instruments to measures continuity in infancy will again need to be considered.

Hypotheses Regarding Latency Variability

The second measure of variability analyzed in relationship to predicting later cognitive development was latency variability. As discussed earlier, this AERP measure was calculated from P2 peak since it is initially the most defined peak in the infant waveform (Ohlrich &

Barnet, 1972; and Ohlrich, et al., 1978).

Since latency variability is conceptualized as being the best measure of Hendrickson's (1982a) theory of less variability being indicative of higher cognitive functioning, the static measures of latency variability was expected to be negatively correlated with the Bayley Scale scores. As discussed earlier in the amplitude variability section, if Hendrickson's (1982a) theory is applicable to the dyanmic measure, then a negative relationship between change over time in this AERP measure and the MDI and the PDI would have been found.

If the there proved to be a positive relationship between latency variability and the Bayley Scale scores, either statically or dynamically, then the Shucard, et al. (1988) assertion of more variability indicating more rapid maturational processes will be considered as an explanation. If neither a positive nor a negative relationship was found, the previous presented explanations of sample size and the ability of these measures to tap continuity will need to be considered.

Hypothesis Regarding Motor versus Mental Development

Earlier in this chapter, findings were discussed regarding infant measures being predictive of the PDI and not the MDI (Murray, 1988 and Thomas et al. 1990). These findings are not so unusual when one considers the findings

of Kohen-Raz (1967), as well as Yarrow, Rubenstein, and Pederson (1975). These studies suggest that the MDI scale contains a variety of subscales rather than one unitary measure of cognitive development. Miller (1990), on the other hand, has performed a factor analytic study of the PDI and found that at twelve months of age all but the three items that are also on the MDI scale loaded on a single factor. Since the PDI scale at 12 months seems to be a more unitary measure of infant functioning than the MDI, it is hypothesized that AERP measures may have been more predictive of the Bayley PDI scale than the MDI.

CHAPTER III

METHOD

Subjects

The participants in this study were 16 full-term (FT) infants, eight females and eight males. These subjects were a subgroup of infants from a larger ongoing study that consisted of 34 infants recruited from the birth announcements in the Stillwater News Press. The larger group consisted of infants with gestational ages ranging from 37 to 43 weeks from whom auditory event-related potential (AERP) data were collected at 4, 7, 10, 13, and 16 weeks of age to a tone and a click stimulus. The subgroup of 16 infants were chosen because they reached 12 months of age between January 1989 and June 1990. The data collected from the tone stimulus for the 16 infants at 4 weeks (M = 29.8 days, SD = 2.7) and 16 weeks (M = 116.9 days, SD = 3.9) of age were used in this study. The infants returned for an administration of the Bayley Infant Developmental Scales at 12 months of age (M = 53.7 weeks, SD = 1.5 weeks).

Materials

Physical Space and Equipment

The EEG recording was conducted in two sound attenuated rooms, the "subject" room and the "experimenter" room. The subject room was sound attenuated and electronically shielded. It had a reclining chair, a video monitor, a two-way intercom system, and the recording equipment for the infant to wear.

There were four main pieces of equipment in the experimenter room. These components were a four channel Grass Instruments Co. Model 78 polygraph, a MetraBYTE Dash 16 analog to digital (A/D) conversion board, a Tektronix hard disk unit and an IBM PC-XT computer.

The room where the Bayley Scales were administered contained the Bayley test kit, several sheets of approximately 22 X 38 cm white paper, facial tissues, pencils, a floor table (mimicking a high-chair without legs) where the infant was administered the MDI, and a half set of stairs approximately 45 X 45 X 45 cm with each step being approximately 15 X 45 X 19 cm for the PDI.

The recording equipment used in the subject room included an Electro-cap International cap with tin electrodes sewn in at Cz, Fz, and ground, according to the International 10-20 System (Jasper, 1958), tin earclip, and two silver-silver chloride electrodes. The infant also wore Realistic headphones on an elastic headband that was

approximately 30 X 2 cm. The recording equipment also consisted of leads from the cap sensors which were connected to wires that extended into the "experimenter room."

Bayley Scales

The Mental Development Index (MDI) and the Psychomotor Development Index (PDI) of the Bayley Scales of Infant Development were used. (See Bayley Scales of Infant Development manual for reliability and validity information, Bayley, 1969).

Procedures

AERP Sessions

The infant and parent were comfortably seated on a recliner in the subject room. The infant was held by the parent throughout the session.

The infant wore the Electro-cap with the tin earclip used at A1 (left earlobe) as the reference electrode. The two silver-silver chloride electrodes were used to record eye movement artifact. One was placed super-orbitally and the other was placed over the outer canthus of the left eye (Cornwally & Kleerman, 1978). The EEG was then recorded between Cz-A1, and Fz-A1. Impedance was measured prior to and at the completion of stimulus presentation. Impedances of Cz and Fz were required to be below 5,000 ohms and the other electrodes below 10,000 ohms before the stimuli were

presented. The stimuli were presented to the infant through the headphones. The infants were observed by way of a video camera to determine infant state before and during stimulus presentation.

The data were collected on three channels of the polygraph (bandpass filters at 1 and 100 Hz). The stimuli were presented and the electrophysiological data collected by a IBM PC-XT. The EEG for each trial was stored on disk beginning at 500 ms before stimulus onset and continuing for 1000 ms after the onset. The EEG was sampled and digitized every 4 ms. The computer was interfaced with a Coulbourn Instrument panel that assisted in generation of the tones the infant received.

Tones Condition. The infants received 64 presentations of a 600Hz, 100 ms tone (70dB) presented binaurally at a minimum stimulus interval of 4.0 s at 4 weeks of age. At 16 weeks of age the infants returned to the lab for another 64 presentations of the tone. In the interim between 4 and 16 weeks sessions, the infants received either tones, clicks, or no stimulus, depending on group assignment in the larger study. Preliminary analysis of these three training conditions showed no training effects based on condition.

To assure a wakeful but calm state in the infant the parent was asked to bring the infant to the lab when the infant was most alert and hungry. This criterion led to the infant either nursing, taking a bottle, or sucking on a

pacifier during stimulus presentation. Any sucking artifact was monitired by using eye electrodes and the artifact detection system in the computer program.

Data collection only occurred when the infant was awake. The state of the infant was monitored through a video screen and by communicating with the parent during and after the session. If the infant fell asleep, the nap was undisturbed and testing was resumed after the infant awakened. If the infant did not awaken after approximately 45 minutes, another session was scheduled for that week and all 64 presentations of the stimulus were given at the new session. Two of the infants 16 infants were rescheduled at 4 weeks of age.

Bayley Session

At twelve months of age the infant and parent came to the Family and Child Science Center at Oklahoma State University for an administration of the Bayley Infant Development Scales consisting of the MDI and the PDI. The parent was in attendance while the scales were administered. The test procedure as outlined in the Bayley Manual (Bayley, 1969) was followed. Modifications recommended in the manual were used in order to keep the infant's attention. The PDI was administered first in order to have the child become familiar with the testing area. The PDI testing began at the 8.9 month age level and the MDI administration began at the 9.0 month level.

Testing continued with each scale until a basal and ceiling were established for both measures. Some of the PDI scale items were also contained within the the MDI and were administered during the MDI portion of testing.

Data Reduction

EEG data. In order to investigate the relationship between the AERPs and the Bayley Scales several different measures were used to reduce the evoked potential data for further analysis. The first step in data reduction was to reject any trials that had obvious extraneous influences for each infant. The trials where there was excessive eye movement were rejected off-line. The other criterion for trial rejection was if the waveform for any of the electrode comparisons, including the eye electrodes, was 75 microvolts or greater.

The second step was to use conventional averaging across trials to determine a mean latency and amplitude for each peak of interest (Buchsbaum & Coppola, 1979). Since the infant AERP is not as clearly developed as the adult AERP, the components that were used in this study were based on the Ohlrich and Barnet (1972) criteria progressing sequentially from a negative trough just previous to P2 (N1), the largest positive peak at approximately 150 to 350 ms (P2), the largest negative peak following P2 (N2) and the largest positive peak following N2 (P3).

Insert Figures 2 through 5 about here

The next step in data reduction was the estimate of amplitude variability. This measure calculates the amplitude variation for each of the 375 points derived from the digitized EP. Amplitude variability was calculated across a given time window rather than for each peak as in latency variability. A two dimensional array of the amplitude values were formed with the columns representing each of the 375 points in time and the rows representing each $k \leq 64$ artifact free trials for the particular condition, per infant, per session. The standard deviation of each of the 375 columns for each of the k rows was then calculated.

Since earlier research has indicated that there are endogenous and exogenous components to the AERP, the amplitude variability as the mean standard deviation in this study was calculated for three segments of the wave form: (a) the 500 ms (125 data points) before stimulus onset, (b) the first 500 ms after stimulus onset, and (c) the second 500 ms of the waveform after stimulus onset. Once these measures had been calculated, both the first 500 ms after stimulus onset, or early window, and the second 500 ms, late window, were divided by the prestimulus amplitude variability. Thus, an early window ratio and a late window ratio were calculated for each infant at both 4 and 16 weeks.

The other form of data reduction was the calculation of trial-to-trial latency variability of the P2 peak using the template-matching procedure, based on the Woody adaptive filter (Woody, 1967) and used by Michalewski, Prasher, and Starr (1986) and Thomas, Neer, and Price (1989). As the first step in this procedure, an average waveform across all artifact-free trials at each age was derived for each infant. Since P2 is the most clearly defined peak at the age of the infants in this study, it was used to form the template to derive the latency variability.

The process involved the identification of P2 in the AERP of each infant and make a template consisting of 18 data points on either side of the peak point. This process created a 37 point template that covered a 144 ms time window. This template was then moved across a 200 ms window of the individual trial on a point by point basis. The latency of the P2 peak in the average AERP served as the center of this window. As the template moved, a correlation coefficient was calculated between the template and each successive group of 37 points in the window. The point at which the maximum positive correlation was found between the template and the individual trial was determined to be the latency of the P2 for that particular trial. This latency was then taken for every trial and the standard deviation derived, which served as the estimate of latency variability for P2 for each infant at 4 and 16

weeks of age.

Bayley Scales. The reduction on the Bayley Scales consisted exclusively of deriving two subscales, the Mental Development Index (MDI) and the Psychomotor Development Index (PDI). These two measures are well standardized subscales and instructions for their derivation are clearly outlined in the Bayley manual.

CHAPTER IV

RESULTS

The independent variables for this study were age (4 and 16 weeks) and gender. Data at both ages were not always used as determinants of the relationship of the AERP to the Bayley Scales. The particular age or ages employed were those suggested by previous studies or, in some cases, where there were sufficient data on which to run statistical analysis.

T-tests

Gender

T-tests were used to assess gender differences. These analyzes were individually calculated for each predictor and outcome variable. Refer to Tables I through V for a summary of these analysis.

Insert Tables I through V about here

As seen in Table III, a significant gender difference was found for the mean amplitude variability at 4 weeks of age but not at 16 weeks. Females (M = 1.41 microvolts, SD = 18) showed more amplitude variability than males (M =

1.15 microvolts, SD = .08) in the late window measured at Cz at 4 weeks (t = -3.72, p < .001; d.f. = 14). Females also exhibited greater amplitude variability than males for the Fz lead at both the early window (-3.7, p <.002; d.f. = 14) (Females: M = 1.42 microvolts, SD = .11; males: M = 1.14 microvolts, SD = .09), and the late window (t = -4.0, p < .002) (females: M = 1.39 microvolts, SD = .15; males: M = 1.14 microvolts, SD = .09). A similar pattern of gender differences at four weeks of age were also exhibited in the ratio of change of amplitude variability between 4 and 16 weeks of age. At the Cz lead for the second window females (M = 16%, SD = 20) exhibited significantly more variability than males (M = -20%, SD = 23), t = 3.34, p < .001; d.f. = 14. The percentage change in amplitude variability at the Fz lead an the first window was also greater for females (M = 14%, SD= 12) than males (M = -10%, SD = 14), t =3.78, p < .001; d.f. = 14.

As delininated in Table IV significant gender differences were found for the latency variability measure at 16 weeks of age. Males exhibited greater variability at P2 (M = 58.0 ms, SD = 5.4) than did the females (M = 52.3 ms, SD = 4.5); t = 2.2, p < .048; d.f. = 11.8. The same pattern of the males (M = 1 %, SD = 13) having more latency variability than females (M = 14%, SD = 9) was also exhibited for the percentage change in latency varibility between 4 and 16 weeks of age at the Cz lead; t = 2.4, p ≤ .035; d.f. = 10.8).

Univariate Correlation and Multiple Regression Analyses

Pearson product moment correlation analyses were used to assess relationships between the AERP measures of amplitude, latency, amplitude variability, and latency variability and the two Bayley measures, the Bayley Mental Development Index (MDI) and the Psychomotor Development Index (PDI). Within each of AERP measures there were different families of univariate correlations performed. (Refer to Appendix A for a detatiled description of these.) Due to some of the peaks not being sufficiently defined to be measured in some of the infants at four and/or sixteen weeks of age, in some cases the correlation were based on data from less than 16 subjects.

Multiple regression techniques were used to assess whether a greater amount of the variance in MDI and PDI could be explained by combining families of variables. This statistical procedure was performed for amplitude, latency, and amplitude variability separately. The multiple regression analyses were also calculated separately for the Cz and Fz leads. Results for the correlation and regression analyses will be presented together, with seperate sections focusing upon each "family" of variables.

Amplitude

Correlation coefficients for the amplitude measures

are presented in Table VI. Amplitude of the N1, P2 and

Insert Table VI about here

P3 peaks at 16 weeks and the percentage change in amplitude between 4 and 16 weeks of age were correlated with the MDI and the PDI.

N1. When analyzing the eight correlations of the amplitude of N1 family at 16 weeks of age and the ratio of change in amplitude between the two ages, none of the members of this family were significantly correlated with the MDI nor the PDI.

P2. Of the eight correlations in the P2 family one was significant. The percentage change in amplitude between the two ages measured at the P2 peak was positively related to the PDI scale ($r = .67$, $p \leq .006$). As seen in Figure 6, the more the amplitude of P2 increases from age 4 to 16 weeks of age the higher the PDI score is later in the infancy period. This amplitude measure accounted for 45% of the variance in the PDI.

Insert Figure 6 about here

There was not a significant relationship between amplitude at 16 weeks of age and either Bayley's Scales.

N2. None of the eight correlations calculated on the amplitude of the N2 peak were significant.

Multiple Regression. One of sets of the multiple regression equations consisted of using the N1, P2, and N2 peaks at 16 weeks of age as predictor variables and the MDI and the PDI as seperate outcome variables. These analyses were calculated separately for the Cz and the Fz No significant predictors were found in these analyses

A second set of multiple regression analyses consisted of using the percentage change in amplitude for N1, P2, and N2 between 4 and 16 weeks of age as the predictor variables and the MDI and the PDI as outcome variables. Again the analyses were calculated separately for the Cz and Fz leads. The variables of percentage change in amplitude for N1, P2, and N2 peaks recorded from Cz were found to be significant predictors of the MDI measure by accounting for 83% of the variance ($F = 8.12$, $p < .02$; d.f. = 3). Refer to Table VII for a summary of this analysis.

Insert Table VII about here

These same three variables at the Fz recording lead were found to be significant predictors, accounting for 90 of the variance in the PDI ($F = 14.29$, $p \leq .007$; d.f. = 3). Refer to Table VIII for a summary of this analysis.

Insert Table VIII about here

Latency

The percentage change in AERP latency of peaks measured at 4 and 16 weeks yielded two families of correlations, N2 and P3, consisting of four correlations each. Both families were correlated with the MDI and the PDI. These findings are presented in Table IX.

Insert Table IX about here

N2. The first family consisted of using latency of the N2 peak as the predictor variable. No significant correlations were found for this family.

P3. One of the four correlations for the P3 family was significant. The P3 peak at the Cz lead was positively correlated with the MDI scale ($r = .54$, $p \leq .03$). As shown in Figure 7, the infants whose response changed the most in occurring more quickly for the P3 peak tended to have higher scores on the MDI. This latency measure accounted for 29% of the variance in the MDI.

Insert Figure 7 about here

Multiple Regression. The multiple regression formula for the latency measure of the AERP involved combining the percentage change in latency between 4 and 16 weeks of age for the N2 and P2 peaks as the predictor variables and the

MDI and the PDI as outcome variables. Analyses were calculated separately for the Cz and Fz leads. No significant relationship was found at either recording lead.

Amplitude Variability

The amplitude variability for the "early" and "late" window was analyzed as seperate families of relationships. Since variability of infant waveforms have seldom been investigated, the correlations at 4 and 16 weeks of age an the percentage change between the ages were all used to predict the MDI and the PDI for both variability measures. These findings are presented in Table X.

Insert Table X about here

Early Window. The early window consisted of 12 calculations. The early window at 16 weeks of age recorded from the Cz site was positively correlated with the PDI scale (r = .58, $p \leq .018$), accounting for 37% of the variance in the PDI. The Fz site was also significantly correlated with the PDI at 16 weeks of age (r = .55, $p \leq .026$). This variability measure accounted for 31% of the variance in PDI. As indicated in Figures 8 and 9 respectively, these two AERP measures indicates that the more variability in amplitude an infant exhibits in the early part of the response at 16 weeks of age, the higher

his or her score will be on the psychomotor measure.

Insert Figure 8 and 9 about here

Late Window. The last 500ms of the AERP were used to constitute the "late" window and there were 12 correlations calculated for this family. There was a significant relationship of the Fz site at 16 weeks of age being positively correlated with the PDI ($r = .55$, $p \leq .027$). This predictor variable accounted for 30% of the variance in PDI. As seen in Figure 10, the more variability in amplitude an infant has present in the second half of the waveform at 16 weeks of age the higher the score on the PD at 12 months.

Insert Figure 10 about here

Multiple Regression. Separate regression formulas were derived for the amplitude change at 4 weeks of age, 16 weeks of age, and the percentage change between these two ages. The predictor variables were the early and late windows with the MDI and the PDI being separate outcome variables. Analyses were calculated separately for the Cz and Fz lead. No significant relationships were found.

Latency variability

The predictor variables all came from one family based

on using the P2 peak as the template. Latency variability analyses were also calculated like the amplitude variability measures at 4 weeks of age, 16 weeks of age, and the percentage change in latency between the two ages. These different ages were correlated with the MDI and the PDI as outcome variables. The results are presented in Table XI.

Insert Table XI about here

P2. The family contained 12 correlations with one yielding a significant relationship. The standard deviation between trials measured at four weeks of age from the Cz site was negatively related with the PDI at 12 months of age ($r = -.61$, $p \leq .012$). As presented in Figure 11, this relationship shows that the less variability in the latency from trial to trial when an infant is 4 weeks of age is predictive of higher PDI scores later in the infancy period. This latency variability measure accounted for 37% of the variance in the PDI.

Insert Figure 11 about here

Multiple regression. There was no multiple regression analysis performed on this AERP measure due to there being only one peak used as a predictor variable in the initial correlations.

CHAPTER V

DISCUSSION

Amplitude Measures of AERP

One of the original hypotheses, based on the Thomas et al. (1990) study, was that AERP amplitude at 16 weeks would be predictive of the PDI. This hypothesis was not confirmed. Using a population of predominantly preterm infants, Thomas et al. (1990) found N1 amplitude measured from both hemispheres predicted PDI; MDI was predicted from the left hemisphere recording only. Using full-term (FT) infants in the present study, the N1 peak was not found to be significantly correlated with the MDI or the PDI. One interpretation of the differences between these two studies is that the N1 amplitude at 16 weeks can be effective in predicting later performance of infants that are already at-risk due to prematurity but not for FT infants. This interpretation of amplitude as a predictor for abnormal populations is supported by the findings of Barnet, Ohlrich, and Shanks (1971). They found that the AERPs of normal infants decreased in amplitude to a repetitive stimulus over time, whereas in Down syndrome infants amplitude remained constant. These data suggest AERP amplitude is sensitive to developmental delay, but not to

variation within a normal population. Methodology might account for the difference between the results of the Thomas et al. study and the present study. In the Thomas et al. (1990) study the preterm infants received a somewhat different auditory stimulus than that received by the infants in the present study. Moreover, recordings were taken hemispherically at T3 and T4 in the Thomas et al. study as compared to the Cz and Fz sites in the present study.

Although static measures of AERP amplitude did not correlate with the Bayley Scales, the dynamic measure of increase in the amplitude from 4 to 16 weeks for the P2 wave, appears to be a good predictor of later performance. By explaining 47 percent of the variance in the PDI, the amplitude change of P2 over time was the best single predictor for the later psychometric measures in this entire study. The utility of amplitude change as a predictor was further supported by the findings of the multiple regression analyses. When the percent change between 4 and 16 weeks of age for the three primary peaks of the AERP were used jointly as predictors, 83 percent of the variance of the MDI and 90 percent of the PDI were accounted for by these measures.

These findings are congruent with the assertion of Shucard et al. (1988) that higher amplitude is indicative of brain maturation, perhaps due to myelination resulting in more efficiency in the brain's neural circuitry. This

increased efficiency would be related to higher amplitudes in the infant ERP. Thus, infants with higher amplitudes would be expected to demonstrate higher scores on later developmental measures.

Also relevant here is the work of Vaughan and Kurtzberg (in press) made available after the present study was originally conceived. These authors assert that ERP amplitude changes in infancy are based on an increase in synapses during the first year of life. Increased ERP amplitude is indicative of the increased voltage that occurs in direct proportion to increased synaptic density. This logic has led them to speculate that the ERP is the preferred method of measuring the synaptic increase in humans; this method is less intrusive than those used in the animal research.

In previous work, Vaughan and Kurtzberg (in press) have charted the development of the amplitude of the ERP from birth to 12 months of age. Their previous studies, enumerated in their present chapter, indicate that the amplitude of visual ERPs is greatest at 4 months of age, and at 5-6 months of age using auditory ERPs. These findings lead them to speculate that the number of synapses present in the cortex reaches a maximum level by 4-6 months of age and then begins to decline.

This theory of increasing neural activity due to an increase in synapses can also be used to conceptualize the findings of the present study. The relationship between

amplitude increase from 4 to 16 weeks of age and later Bayley scores could be interpreted to mean that the infants with more synaptic connections developing during the first months of postnatal development are thus more likely to perform better on the Bayley Scales.

Latency Measures of AERP

When measuring the relationship of AERP latency and the Bayley Scale scores, the hypothesis was confirmed that the latency of the P3 peak was likely to be an important physiological variable. The change in the latency of the P3 peak from 4 to 16 weeks at the Cz lead was significantly positively correlated with the MDI scale.

This ability of the P3 latency decrease to predict the MDI is consistent with Ohlrich and Barnet's (1972) assertion that P3 peak would likely be the component of the AERP waveform to indicate cognitive development. This finding also coincides with the initial hypothesis concerning latency based on Ertl and Schafer's (1969) study. Ertl and Schafer found that the shorter the P3 latency in children, the higher were scores on the WISC-R.

The latency of the P3 peak as a predictor of cognitive performance as measured by intelligence tests in adults is well documented by Brown, Marsh and Larue (1982). This finding was strongly suspected to be applicable to the infant paradigm used in this study. Additional research using the latency measure should be conducted to determine

if the latency of the P3 peak is as robust of a predictor of infant cognitive functioning as it is in the adult population.

Amplitude Variability

The relationship of AERP amplitude variability to later scores found in the present study is not consistent with the the hypothesis that a negative relationship of variability with scores on psychometric tests would be found (Hendrickson, 1982a). In the present study greater variability in the wave form at 16 weeks of age was significantly related to higher scores on the PDI for both the Cz and Fz leads. Thus these results seem to confirm Shucard and Callaway's (1974) assertion that there needs to be an optimal amount of variability in order to adequately process the incoming stimuli.

The finding of more variability being indicative of higher Bayley Scale scores can also be related to the myelination process continuing to develop during the first months of post-natal development. This myelination process would result in different firing rates and different voltage levels from trial to trial as would be indicated by higher variability. The result of this process is that infants with myelination occurring more quickly would have higher scores on later measures of infant development.

Another related explanation for this finding would be Vaughan and Kurtzberg's (in press) theory that the

number of synapses are increasing at this age. This would lead to greater variability in the firing pattern from trial to trial. This second explanation is based on Vaughan and Kurtzberg consideration of Hebb's theory of "cell assemblies". Cell assemblies are conceived as the process by which information becomes stored most efficiently in the cortex for further use (Hebb, 1949). This process thus would result in the formation of groups of neurons which become consistent in their activation pattern due to repeatedly processing stimuli in a similar manner. Vaughan and Kurtzberg propose that in infancy the number of synapses develops to an optimal level and after which the most efficient pattern of neural connections are formed. Those synapses which are least effective would then cease to be part of the cell assembly. Given that the synaptic density is maximal at 4-5 months of age (Vaughan & Kurtzberg, in press), cell assemblies would be just beginning to be formed and a variety of firing patterns would be the norm at this age. Thus, high variability would be expected in the infants at 16 weeks of age.

Due to the limits of technology at the present time, it is not possible to state whether ERP changes are related to the myelination process or to the amount of synaptic activation. It seems probable that both processes are contributing to the relationship found in the present study. Further research is needed to ascertain the relevance of these theories in understanding of development

of cognition within the infancy period.

Besides the theoretical implications of the finding of a positive correlation between amplitude variability and the PDI, a second hypothesis regarding the implications of the "early" and/or "late windows" as predictors of the Bayley Scales was also proposed. Based on Hillyard's (1985) theory of the different parts of the waveform measuring different processes, this study attempted to determine if these differences coud predict later development in distinctive ways. The results of this study found that the "early" window at Cz and both windows at Fz were predictive of the PDI when the infants were 16 weeks of age. These three components explained 37%, 31%, and 30% of the variance in the PDI, respectively. Thus, the difference in the ability of the two parts of the waveform to predict later development was not confirmed.

One explanation why both the "early" and "late" windows account for similar amounts of variance in the PDI is that in this study they may be measuring the same thing. Kurtzberg et al. (1988) speculated that the infant cortical response could be conceptualized in much the same manner as adults. These researchers asserted that the first part of the AERP is the brain's response to physical stimulus features and is labeled "cortical response." This aspect of the AERP is synonymous with the "early" window in the present study. Kurzberg et al. also hypothesized that the peaks which occur later in the AERP represent the ability

of the brain to make decisions about the difference among stimuli when a choice paradigm is used. The later processing is referred to as the "cortical discriminative response (CDR)" and is synonymous with the "late window." In the present study the stimulus was consistent throughout the experiment so there was no need to process differences; therefore the "early" and "late" windows could be equally predictive of the Bayley Scales, which was the case in this study.

Latency Variability

The primary hypothesis regarding latency variability was that there would be a negative relationship between this AERP measure and the Bayley Scales. In this study, less variability of the P2 latency at four weeks of age was found to predict higher scores on the PDI later. Of the two electrode sites that were analyzed for this age, the Cz lead for the latency variability measure was the only significant correlation. No significant correlations were found at 16 weeks of age.

Overall, when analyzing the variability in the speed of response, the findings related to latency variability seem to confirm Hendrickson's (1985a; 1985b) theory of less variability resulting in higher psychometric scores. The fact that the correlation between latency variability and the PDI was significant at 4 weeks of age and not at 16 weeks should be further explored before definitive

statements of the full utility of the relatively new measure of AERP can be made.

PDI VS. MDI

It was hypothesized that the PDI scale would be more likely to be predicted by the AERP measures than would the MDI. In this study, eight significant correlations between the AERP and the Bayley Scales were found. Of these eight correlations, six AERP measures were predictive of the PDI scale and two were predictive of the MDI. These findings are consistent with earlier studies (McCall, Hogarty, & Hurlburt, 1972; Seigel, 1981; Murray, 1990) where PDI has been found to be more predictable and predictive than the MDI within the infancy period.

Three possible explanations are of interest here. One way to interpret the finding is that the PDI is a more unitary measure part of development. Since the PDI at 12 months of age is generally measuring one aspect of development, namely motor development, (Miller, 1990) versus the many the MDI measures (Kohan-Raz, 1967), the PDI has less of a chance of being confounded by other variables. This situation could result in the PDI being more easily predicted through linear analysis.

A second interpretation of the differential number of significant correlations of the AERP to the PDI and MDI is the idea that infancy is truly the period of sensoriomotor development Piaget (1970) has asserted it to be. This idea

is in contrast to cognition as measured by MDI which primaly consists of developmental milestones such as object permanency, imitative behaviors, and rudimentary speech (Kohen-Raz, 1967). Thus, all the early brain processes are predictive of later motor skills because psychomotor processes are the major form of cognition in the infancy period.

A third possible interpretation is that AERPs and the PDI are both measures of maturation. As discussed earlier, Shucard et al. (1988) conceive of AERPs as a measure of maturational processes. Reconsideration of Miller's (1990) findings of the PDI factor analysis indicates that each of her subscales is age dependent, thus the PDI is possibly another measure of maturational processes. If both AERPs and the PDI are maturational measures, the number of significant correlations between the two measures may be more influenced by maturational processes of infancy than by cognitive development. The problem with this argument is that Bayley (1969) developed both the MDI and the PDI as measures of maturational development with norms based on average age of onset for each task. If AERPs are simply measures of physical maturation, it would seem that they would correlate with both Bayley Scales at a similar rate. Since this was not the case in the present study, the two other theories discussed would appear to have more validity.

Although the preceding explanations were presented

separately, these three ideas are not necessarily mutually exclusive. It is possible that all three explanations could be influencing the results to some degree. Further studies of continuity within and beyond the infancy period using the AERP and measures of motor functioning are needed to more clearly understand what the PDI and MDI are differentially measuring.

Gender

Based on Ohlrich's et al. (1978) finding of gender differences in the development of the AERP waveform it was hypothesized that there might be differences between the AERP of males and females in this study. An equal number of male and female subjects were used to attempt to control for such influences.

Significant differences between genders were found for the variability measures but not for the amplitude and latency measures. Compared to males, females demonstrated a greater amount of amplitude variability at four weeks of age. This gender difference was also found for the percentage change in amplitude varibility but not for infants at 16 weeks of age. Additionally, when compared to females, males demonstrated greater latency variability in the Cz lead at both 16 weeks of age and the ratio of change between the two ages.

Gender was not a factor in the significant relationships between the AERP measures and the Bayley

Scales. None of the variables for which significant gender differences were found proved to be the variables that were significantly correlated with the MDI or the PDI. Therefore, although there are gender differences in the variability measures of the AERP as both static and dynamic measures, these differences do not affect the relationship of AERP variablity as a predictor of later cognitive functioning. Remarkably, the amplitude variablity factors that did predict later functioning are three of the six factors of this AERP measure that did not show gender differences in the present population. If future studies of the utility of amplitude variability are conducted, it seems necessary to consider whether the other amplitude variability measures might not also be predictive if one could more efficiently factor out gender effects.

Recording Sites as Predictors

Although there were no hypotheses made concerning the relationship of recording sites to the Bayley measures, certain patterns did occur that seem worthy of discussion. Of the correlations pertaining to the relationship of the AERP measures to the Bayley Scales, no definite pattern of relationships between these measures and the CZ and Fz lead were found. On the other hand, using multiple regression analyses for the predictor variable of precentage change in amplitude between the two ages, the Cz lead significantly predicted the MDI and the Fz lead predicted the PDI.

It is generally believed by physiological psychologists that the frontal area over which Fz is placed controls, among other things, the voluntary motor systems of the body. It is also believed that the posterior areas over which the Cz electrode is placed are related to general cognitive processing of sensory stimuli. The relationships between the electrode locations and the different Bayley Scales are consistent with these anatomical considerations.

Dynamic vs. Static AERP as a Predictor

Since static measures of AERP latency were not effective in predicting later Bayley Scale scores in the Thomas et al. (1990) study, this study attempted to consider the importance of change in cortical activity over time as a predictor for all the AERP measures. One hypothesis proposed was there would be a positive relationship between the change in amplitude from 4 to 16 weeks of age and the Bayley Scale scores. Another hypothesis was that a decrease in latency between 4 and 16 weeks would be positively correlated with the Bayley Scales. Both of these hypothesis were confirmed.

No specific hypothesis regarding the change in variability were proposed, but change over time in both amplitude variability and latency variability were used as exploratory measures in the present study as predictors of Bayley Scales. No relationship between either measure of

change in variability to later functioning were found.

The findings regarding the dynamic aspects of the AERP amplitude and latency provide strong support for Ohlrich's et al.'s (1978) suggestion that the importance of change of the AERP during early development might be useful to determine cognitive functioning. These same findings also suggest that researchers need to begin to consider the importance of change in cortical functioning as measured by AERPs in future studies of the ability of early infant development to predict later cognitive functioning. This dynamic component of AERPs seems especially important in light of the ongoing continuity versus discontinuity debate. Previously, most research concerning prediction of later development has been studied using static measures.

Aside from the scientific implications, it is important to consider the utility of dynamic aspects of the AERP at the clinical level. Since early assessment and intervention are now legally required in this country under Public Law 99-457 (Sattler, 1990), futher exploration of dynamic aspects of AERP development as a possible assessment tool needs to be considered.

Effectiveness of the Integration Model

The general premise for this study was to determine if the Kagan's (1984) integrative model of within-stage continuity has validity in explaining cognitive development in the infancy stage. The fact that each of the four

measures of the AERP (amplitude, latency, amplitude variability and latency variability) correlated with either or both of the Bayley Scales confirms the value of Kagan's model. The fact that AERP measures yielded higher correlations with the Bayley Scales than previously used measures (e.g. orienting response, and object permanancy) supports the utility of AERPs as a diagnostic measure. Future areas of investigation using AERP are: a) to determine the ability of AERPs in predicting infants at risk for developmental delay, and b) to determine whether the AERP can predict continuity across stages of cognitive development.

CHAPTER VI

SUMMARY

The original intent of this study was to determine whether Kagan's (1984) discrete stage continuity theory would be a viable way to conceptualize cognitive development. Overall, the findings of this study suggest that each of the four ways to measure AERPs (amplitude, latency, amplitude variability, and latency variability) have potential for contributing to the explanation of development later in the infancy period. An especially important finding was that traditional measures of amplitude and latency appear to be fruitful measures when they are considered as percentage change in cortical activity during the first months of life.

Additionally, the newer measures of variability would also seem to be of value. Further research is needed to assess the reliablity and validity of these measures as predictors of cognitive and motor development. Amplitude variability seems especially important in view of Vaughan and Kurtzberg's (in press) theory of neural development during the first year of life.

This study leads to further questions about what constitutes cognition in the infancy period. The fact that

cortical electrophysiological activity was correlated with motorically effortful processes fits well into the traditional view that infancy is the time of sensorimotor development. Left unclear are questions pertaining to the relationship of: a) the AERP to later infant cognition as measured by the MDI, b) the degree to which the AERP is measures maturational processes versus cognitive development, c) the importance of measuring change in cortical activity as a predictor, and d) the relationship of the specific localization of electrophysiological activity to later cognitive functioning. Further studies investigating these areas of infant development would be helpful in asertaining the continuity of cognitive development during the infancy period.

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TABLE I

T-TEST COMPARING MALE AND FEMALE SUBJECTS ON THE AUDITORY EVENT-RELATED POTENTIAL MEASURE OF AMPLITUDE

Variable	Condition			
	Male		Female	
	M	SD	M	SD
Amplitude at 16 weeks of age (μv)				
N1 Peak				
Cz Lead	-37.28 n=7	54.89	-58.12 n=8	49.15
FZ Lead	-20.71 n=7	50.08	-29.38 n=8	42.38
P2 Peak				
Cz Lead	85.00 n=7	15.16	77.62 n=8	44.67
Fz lead	99.28 n=7	38.43	92.88 n=8	67.77
N2 Peak				
Cz Lead	-103.62 n=8	69.97	-90.62 n=8	58.06
Fz lead	-78.62 n=8	39.95	-95.12 n=8	53.10
Ratio of change in amplitude between 4-16 weeks				
N1 Peak				
Cz Lead	-5.10 n=5	16.78	-0.79 n=4	1.73
Fz Lead	-0.27 n=4	4.26	-1.79 n=5	1.28

TABLE I (Continued)

Variable	Male		Female	
	M	SD	M	SD
P2 Peak				
Cz Lead	0.31 n=7	0.48	0.58 n=8	1.42
Fz lead	0.88 n=7	1.19	0.16 n=8	0.83
N2 Peak				
Cz Lead	-1.28 n=8	1.18	-0.53 n=8	1.52
Fz lead	-8.00 n=8	16.68	0.17 n=8	0.81

TABLE II

T-TEST COMPARING MALE AND FEMALE SUBJECTS ON THE AUDITORY EVENT-RELATED POTENTIAL MEASURE OF LATENCY

	Condition			
Variable	Male n=8		Female n=8	
	M	SD	M	SD
Ratio of change in latency between 4-16 weeks				
N2 Peak				
Cz Lead	-0.17	0.22	-0.29	0.12
FZ Lead	-0.09	0.23	-0.24	0.20
P3 Peak				
Cz Lead	-0.06	0.37	-0.34	0.24
Fz lead	0.10	0.37	-0.29	0.35

TABLE III

T-TEST COMPARING MALE AND FEMALE SUBJECTS ON THE AUDITORY EVENT-RELATED POTENTIAL MEASURE OF AMPLITUDE VARIABILITY

Variable	Condition				
	Male n=8		Female n=8		
	M	SD	M	SD	
Amplitude variability at 4 weeks of age					
1st window (1-500ms) divided by pre-stimulus window					
Cz Lead	1.27	0.12	1.42	0.11	**
Fz Lead	1.22	0.11	1.42	0.10	**
2nd window (501-1000ms) divided by pre-stimulus window					
Cz Lead	1.15	0.07	1.41	0.18	**
Fz Lead	1.14	0.09	1.38	0.15	**

TABLE III (Continued)

Variable	Male n=8		Female n=8		
	M	SD	M	SD	
Amplitude variability at 16 weeks of age					
1st window (ratio)					
Cz Lead	1.31	0.17	1.22	0.16	
Fz Lead	1.33	0.19	1.22	0.16	
2nd window (ratio)					
Cz Lead	1.18	0.36	1.16	0.31	
Fz Lead	1.28	0.22	1.13	0.22	
Change in amplitude variability ratio between 4-6 weeks of age					
1st window					
Cz Lead	0.06	0.11	0.09	0.19	
Fz Lead	0.10	0.14	0.14	0.12	**
2nd window					
Cz Lead	-0.20	0.23	0.16	0.20	**
Fz Lead	-0.07	0.16	0.11	0.28	

** $p < .01$

TABLE IV

T-TEST COMPARING MALE AND FEMALE SUBJECTS ON THE AUDITORY EVENT-RELATED POTENTIAL MEASURE OF LATENCY VARIABILITY

	Condition				
Variable	Male		Female		
	M	SD	M	SD	
Latency variability of P2 peak					
4 weeks of age (ms)					
Cz Lead	592.50 n=8	37.11	610.50 n=8	43.74	
Fz Lead	610.50 n=8	27.65	619.12 n=8	64.53	
16 weeks of age (ms)					
Cz Lead	579.86 n=7	53.73	522.88 n=8	44.87	*
Fz Lead	602.86 n=7	42.06	529.75 n=8	89.03	
Change in latency variability between 4-16 weeks of age					
Cz Lead	-0.001 n=7	0.13	-0.14 n=8	0.09	*
Fz Lead	-0.009 n=7	0.13	-0.13 n=8	0.16	

* $p < .05$

TABLE V

T-TEST COMPARING MALE AND FEMALE SUBJECTS ON THE BAYLEY SCALES OF INFANT DEVELOPMENT

	Condition			
Variable	Male n=8		Female n=8	
	M	SD	M	SD
Bayley Mental Development Index (MDI)	108.75	10.79	113.88	9.79
Bayley Psychomotor Development Index (PDI)	113.50	22.29	107.50	11.35

TABLE VI

CORRELATIONS OF AUDITORY EVENT-RELATED POTENTIAL AMPLITUDE AND BAYLEY SCALES

	N1 PEAK		P2 PEAK		N2 PEAK	
	Cz lead	Fz lead	Cz lead	Fz lead	Cz lead	Fz lead
16 wk X MDI						
r =	.03	.16	-.35	-.42	-.32	-.01
n =	15	15	15	15	16	16
16 wk X PDI						
r =	.09	.38	.10	.24	-.34	.07
n =	15	15	15	15	16	16
% change X MDI						
r =	.12	-.08	.04	-.02	-.17	.45
n =	9	9	15	15	16	16
% change X PDI						
r =	.11	.52	.14	.67**	-.22	.26
n =	9	9	15	15	16	16

** $p < .01$

MDI - Mental Developement Index

PDI - Psychomotor Developmental Index

TABLE VII

STEPWISE MULTIPLE REGRESSION ANAYLSIS
FOR THE MENTAL DEVELOPMENTAL INDEX
AT THE CZ LEAD

SOURCE	DF	SS	MS	F	WEIGHTS
Amplitude change	3	406.70	135.57	8.12	-
N1 % Change	1	5.13		.31	0.07
P2 % Change	1	132.18		7.91*	- 5.39
N2 % Change	1	399.00		23.89**	- 6.05
Intercept	-	-		-	111.54
Error	5	83.52			
Total	8	490.22			
R-Square = .83					

** $p < .01$

* $p < .05$

TABLE VIII

STEPWISE MULTIPLE REGRESSION ANAYLSIS FOR
THE PSYCHOMOTOR DEVELOPMENTAL INDEX
AT THE FZ LEAD

SOURCE	DF	SS	MS	F	WEIGHTS
Amplitude change	3	2415.27	805.09	14.29**	-
N1 % Change	1	741.79		13.17*	3.59
P2 % Change	1	1605.79		28.51**	16.38
N2 % Change	1	67.69		1.20	- .23
Intercept	-	-		-	105.32
Error	5	281.62			
Total	8	2696.89			
R-Square = .90					

** $p < .01$

* $p < .05$

TABLE IX

CORRELATIONS OF AUDITORY EVENT-RELATED POTENTIAL LATENCY AND BAYLEY SCALES

	N2 PEAK		P3 PEAK	
	Cz lead	Fz lead	Cz lead	Fz lead
% change X MDI				
r =	.43	.39	.54*	.37
n =	16	16	16	16
% change X PDI				
r =	.08	.24	.25	-.18
n =	16	16	16	16

* $p < .05$

MDI - Mental Development Index

PDI - Psychomotor Developmental Index

TABLE X

CORRELATIONS OF AUDITORY EVENT-RELATED POTENTIAL AMPLITUDE VARIABILITY AND BAYLEY SCALES

	EARLY WINDOW		LATE WINDOW	
	Cz lead	Fz lead	Cz lead	Fz lead
4 wk X MDI				
r =	.15	.13	.16	.24
n =	16	16	16	16
4 wk X PDI				
r =	-.08	.06	-.20	-.01
n =	16	16	16	16
16 wk X MDI				
r =	.10	-.04	-.21	-.17
n =	16	16	16	16
16 wk X PDI				
r =	.58*	.55*	.46	.55*
n =	16	16	16	16

TABLE X (Continued)

	EARLY WINDOW		LATE WINDOW	
	Cz lead	Fz lead	Cz lead	Fz lead
% change X MDI				
r =	-.02	-.10	-.23	-.24
n =	16	16	16	16
% change X PDI				
r =	.47	.41	.35	.39
n =	16	16	16	16

$p < .05$

MDI - Mental Developmental Index

PDI - Psychomotor Develpmental Index

TABLE XI

CORRELATIONS OF AUDITORY EVENT-RELATED POTENTIAL LATENCY VARIABILITY AND BAYLEY SCALES

	P2 PEAK (Standard deviation)	
	Cz lead	Fz lead
4 wk X MDI		
$\underline{r}$ =	.04	-.28
n =	16	16
4 wk X PDI		
$\underline{r}$ =	-.61*	-.19
n =	16	16
16 wk X MDI		
$\underline{r}$ =	-.36	-.38
n =	15	15
16 wk X PDI		
$\underline{r}$ =	.10	.05
n =	15	15

TABLE XI (Continued)

	P2 PEAK (Standard deviation)	
	Cz lead	Fz lead
% change X MDI		
$\underline{r}$ =	-.40	-.17
n =	15	15
% change X PDI		
$\underline{r}$ =	.34	.12
n =	15	15

** $\underline{p} < .05$

MDI - Mental Developmental Index

PDI - Psychomotor Developmental Index

FIGURE CAPTIONS

Figure 1. "Click-evoked responses showing response forms found in 1-,6-, and 12- month old infants. Wave components are labelled in some of the tracings. The stimulus occurred at the beginning of the tracing. Analysis time is 1 sec. Recorded from Cz-R, an upward deflection denotes positivity of Cz with respect to R (combined mastoids)." (Ohlrich and Barnet, 1972, p. 163)

Figure 2. Grand average AERP waveform for tones condition at CZ lead for all 16 subjects at 4 weeks of age.

Figure 3. Grand average AERP waveform for tones condition at FZ lead for all 16 subjects at 4 weeks of age.

Figure 4. Grand average AERP waveform for tones condition at CZ lead for all 16 subjects at 16 weeks of age.

Figure 5. Grand average AERP waveform for tones condition at FZ lead for all 16 subjects at 16 weeks of age.

Figure 6. Relationship of each the ratio of change of the amplitude of the P2 peak recorded from the Fz lead at 4 and 16 weeks of age to PDI score at 12 months of age.

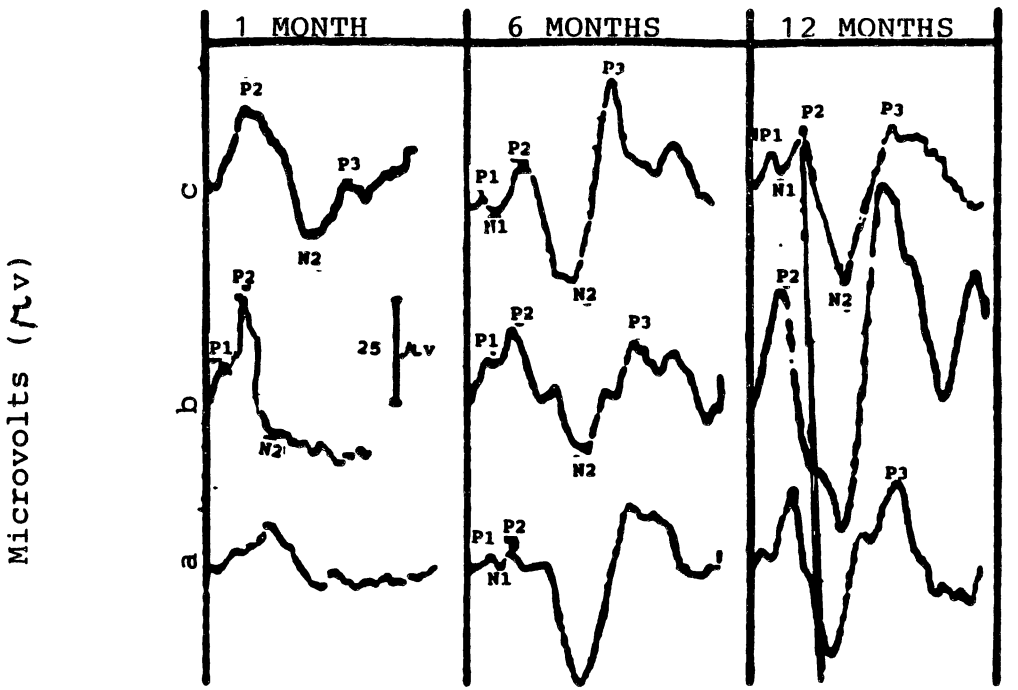
Figure 7. Relationship of the ratio of change of the latency of the P3 peak recorded from the Cz lead at 4 and 16 weeks of age to MDI score at 12 months of age.

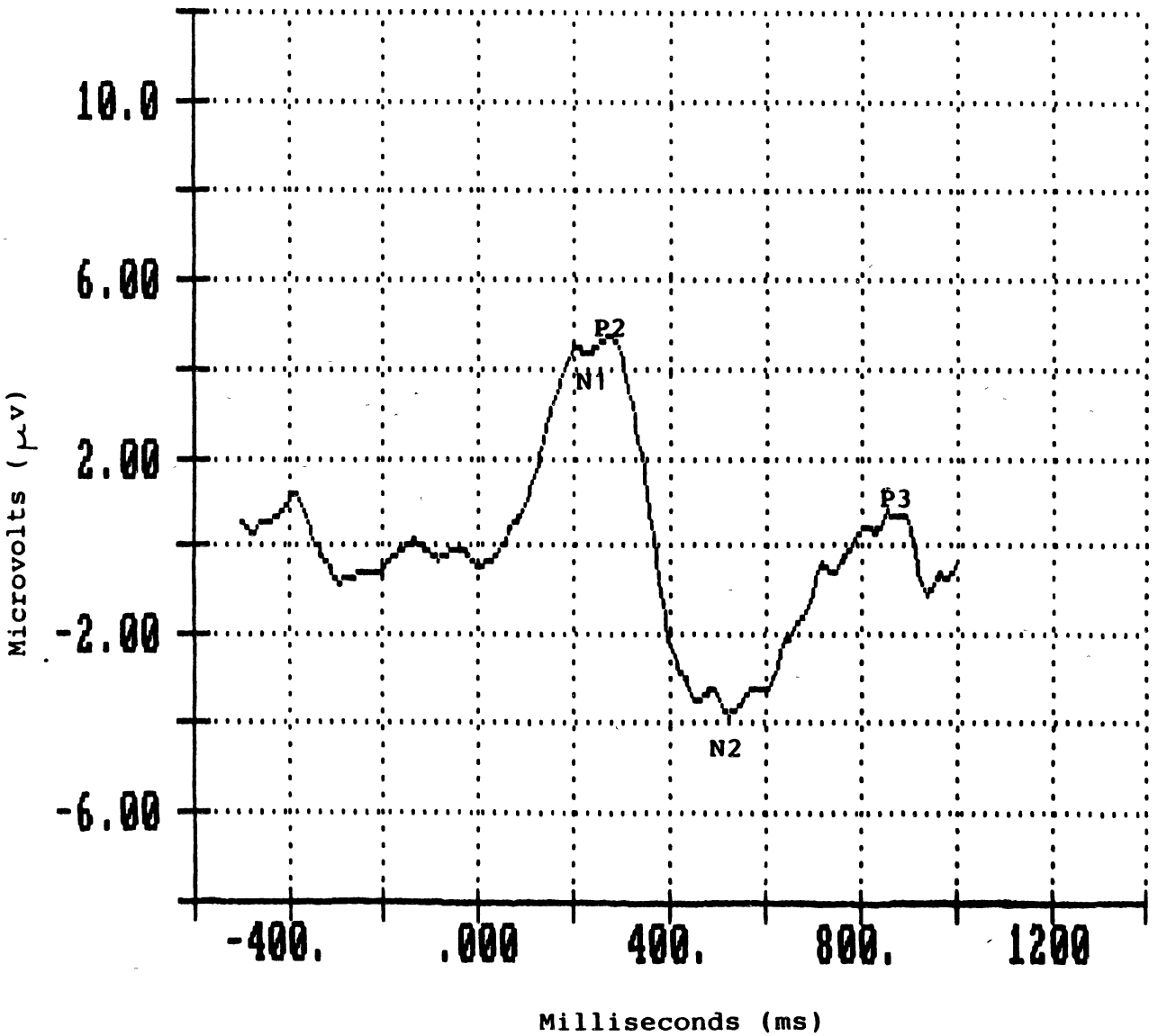
Figure 8. Relationship of amplitude variability, as measured by dividing post- by pre-stimulus change during the first 500 ms after stimulus onset, recorded from the Cz lead at 16 weeks of age to PDI score at 12 months of age.

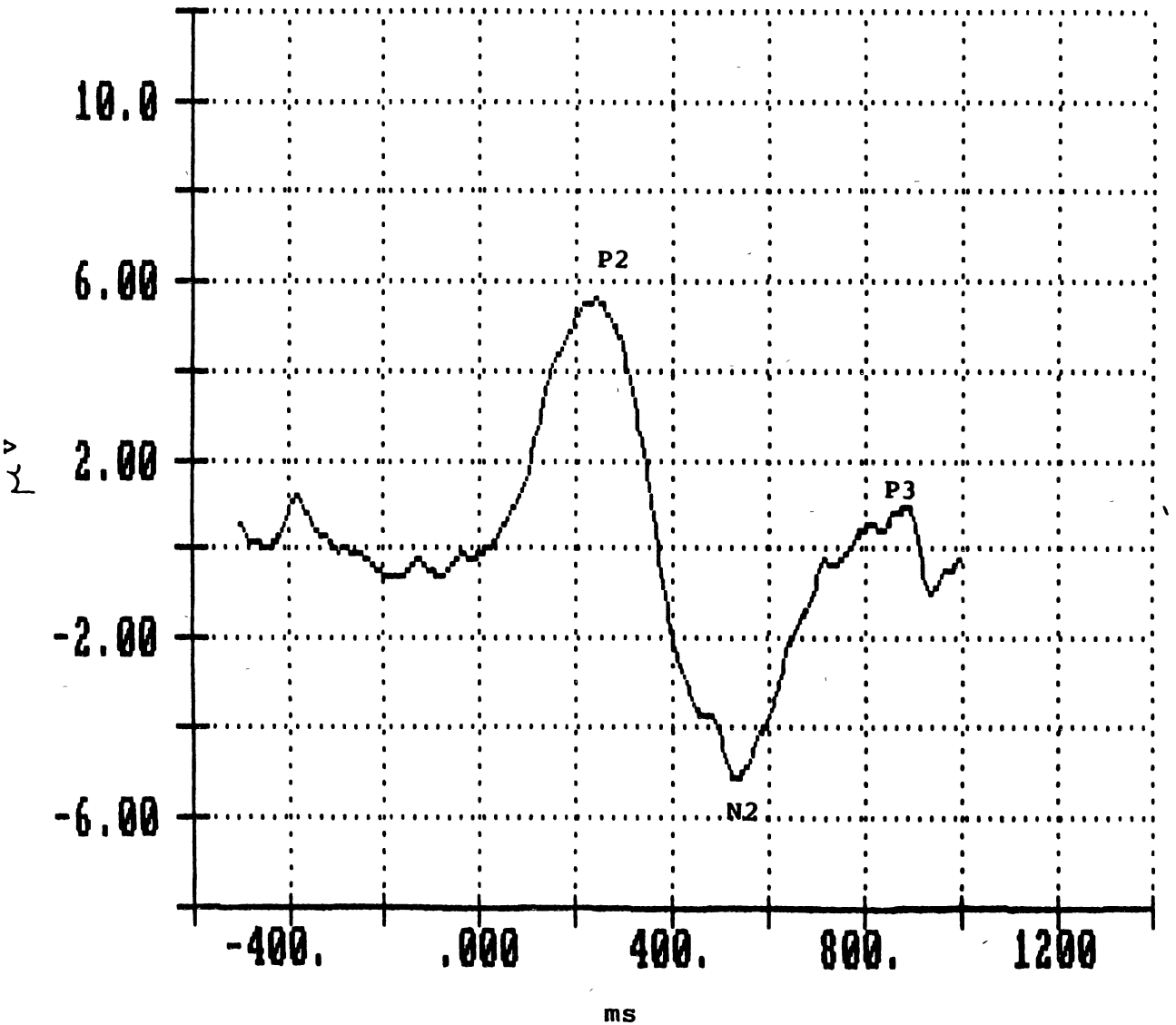
Figure 9. Relationship of amplitude variability, as measured by dividing post- by pre-stimulus change during the first 500 ms after stimulus onset, recorded from the Fz lead at 16 weeks of age to PDI score at 12 months of age.

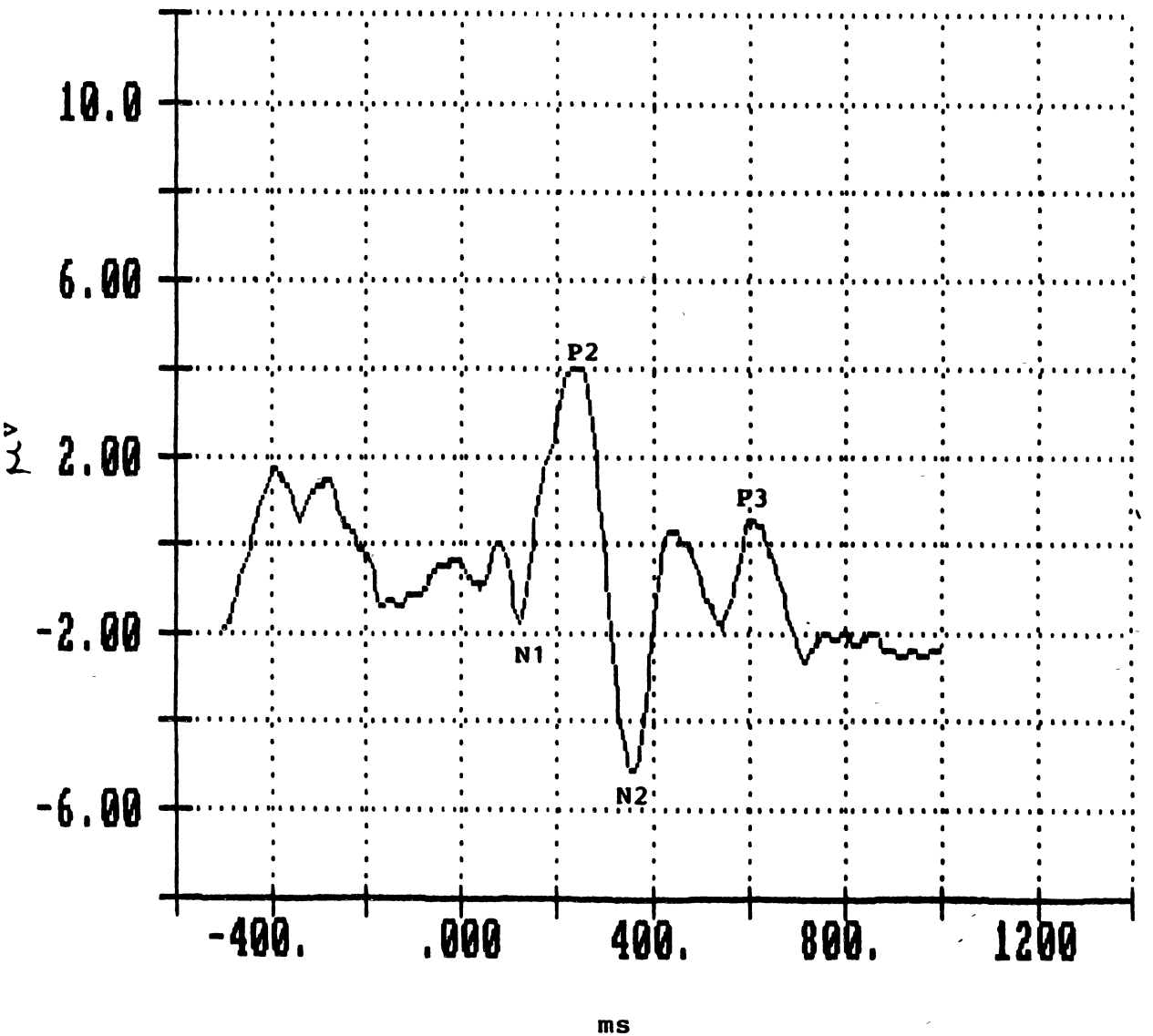
Figure 10. Relationship of amplitude variability, as measured by dividing post- by pre-stimulus change during the second 500 ms after stimulus onset, recorded from the Fz lead at 16 weeks of age to PDI score at 12 months of age.

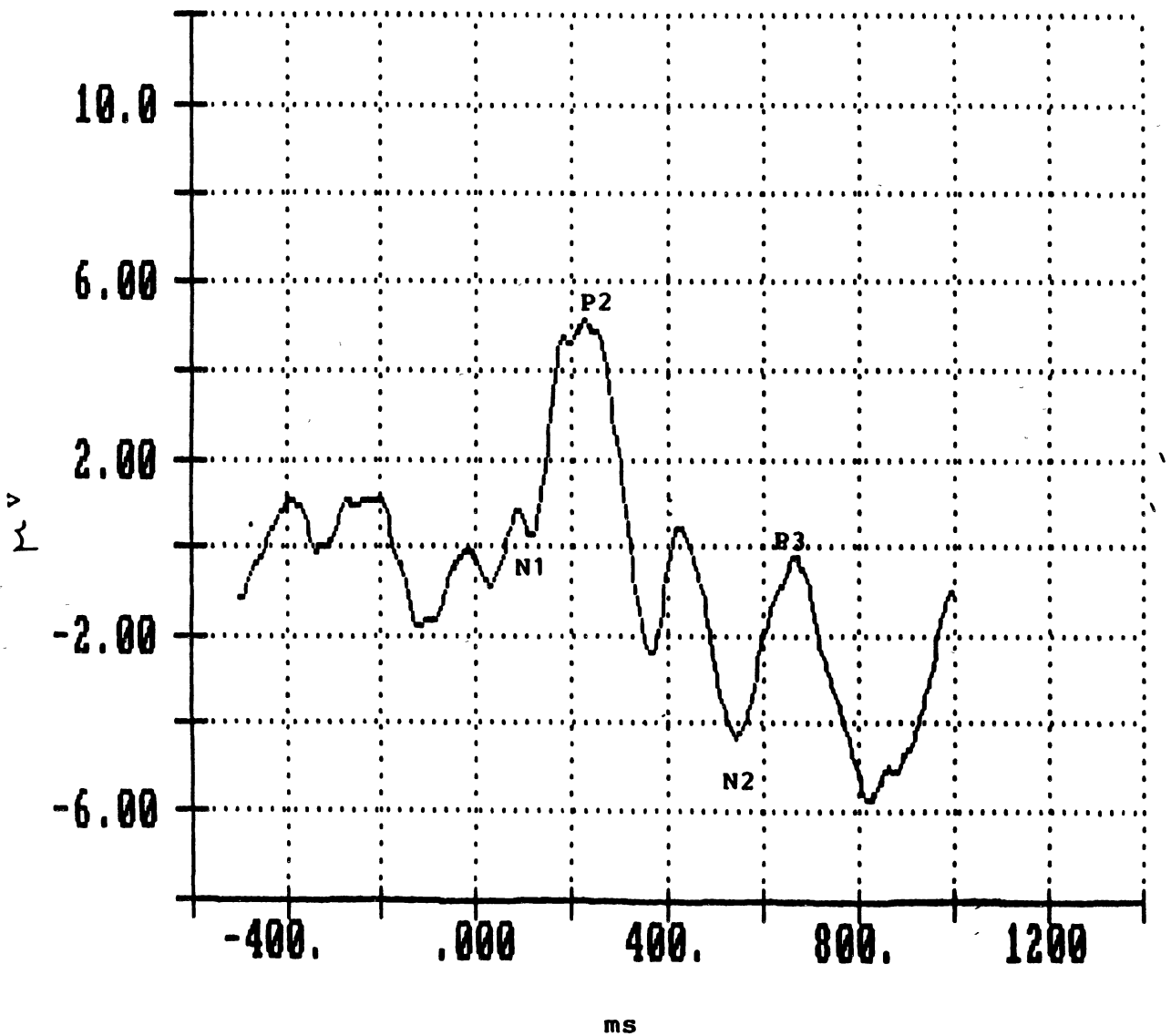
Figure 11. Relationship of amplitude variability, as measured as the standard deviation in milliseconds of all of the infant's individual trials compared to the template of P2, recorded at the Cz lead at 4 weeks of age to PDI score at 12 months of age.

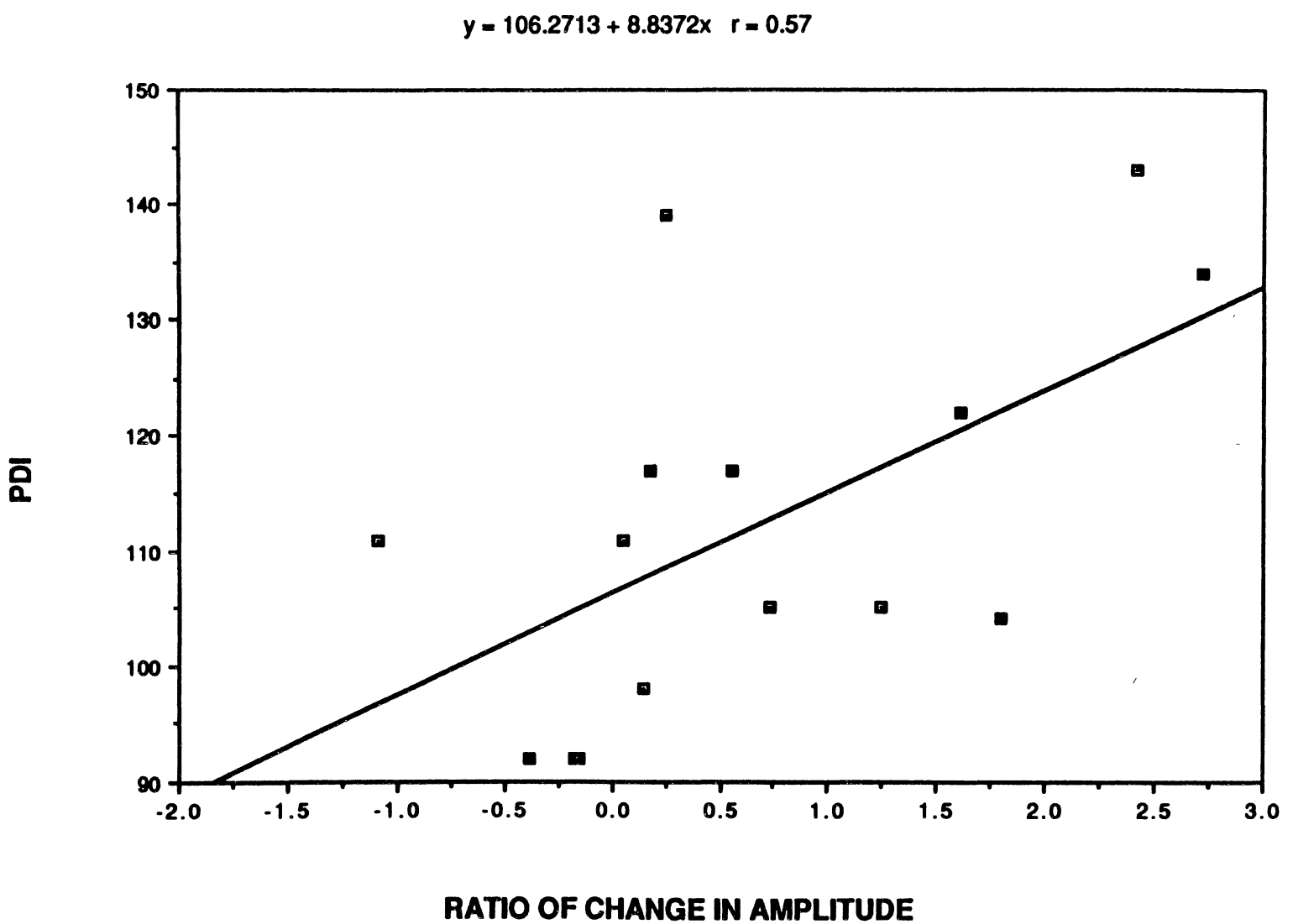

1 MONTH
6 MONTHS
12 MONTHS
c
b
a
P1
N1
P2
N2
P3
25 μv
Microvolts (μv)
Milliseconds (ms)

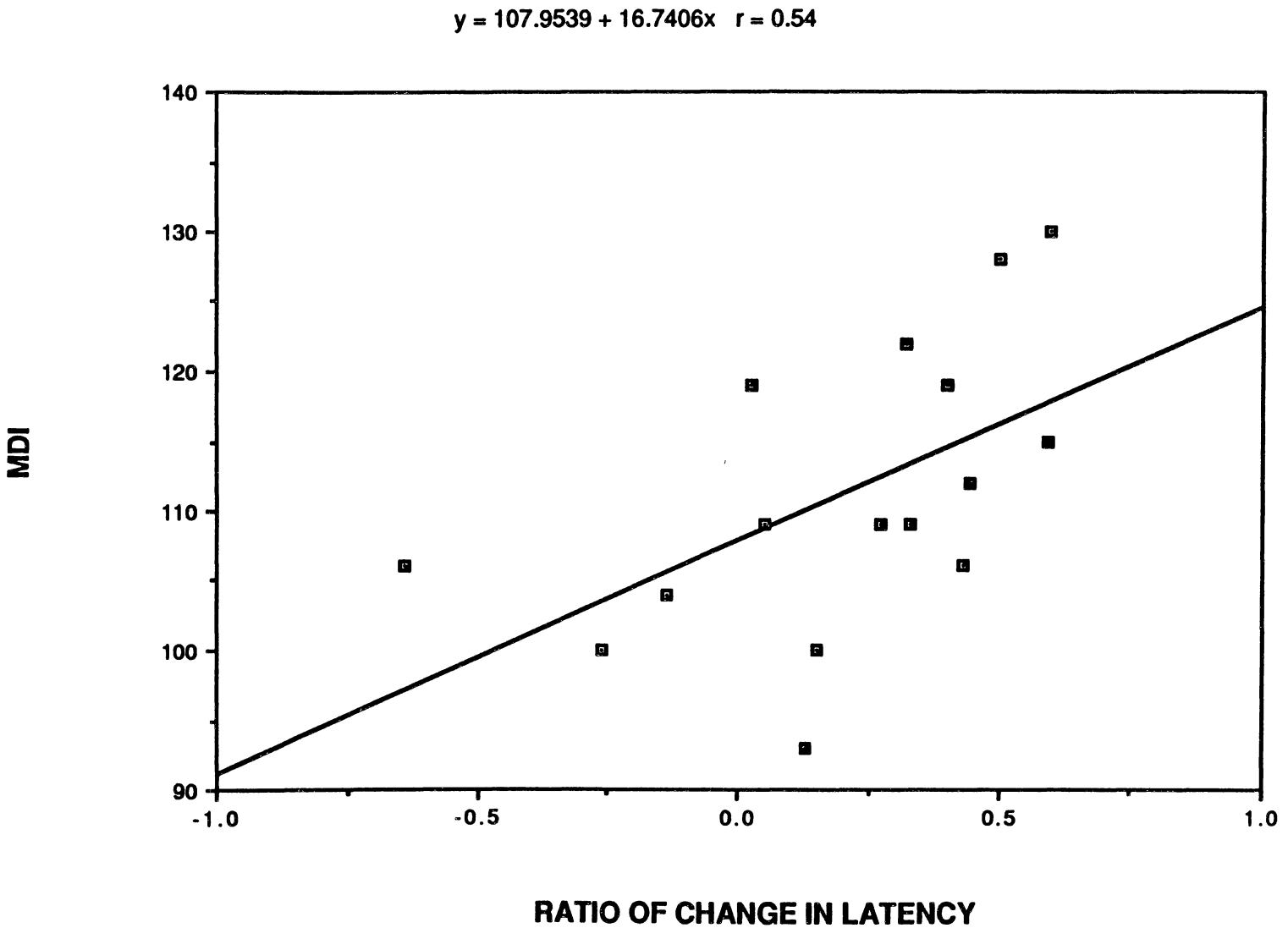

10.0
6.00
2.00
-2.00
-6.00
Microvolts (μV)
P2
N1
P3
N2
-400.
.000
400.
800.
1200
Milliseconds (ms)

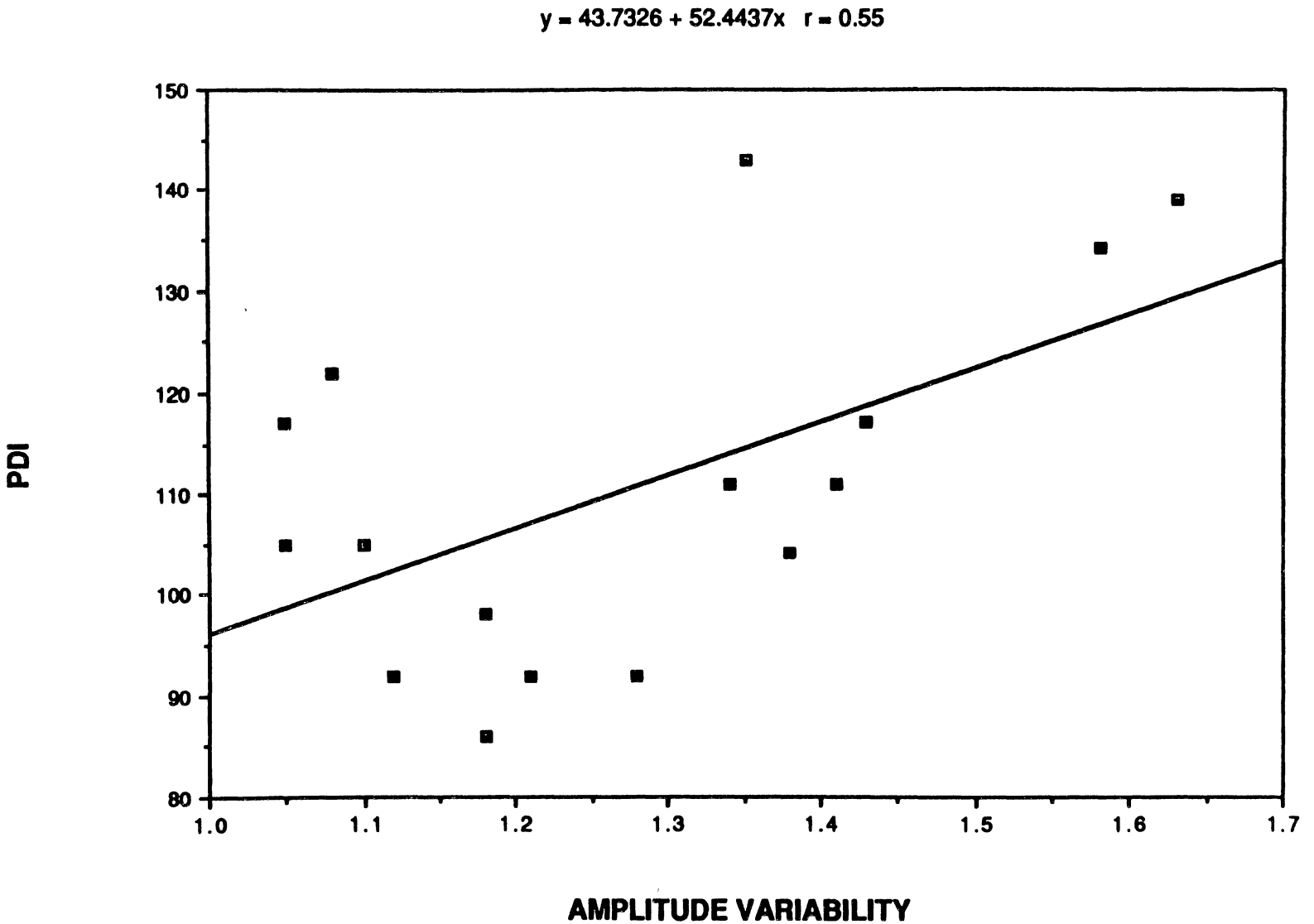

10.0
6.00
2.00
-2.00
-6.00
μv
P2
P3
N2
-400.
.000
400.
800.
1200
ms

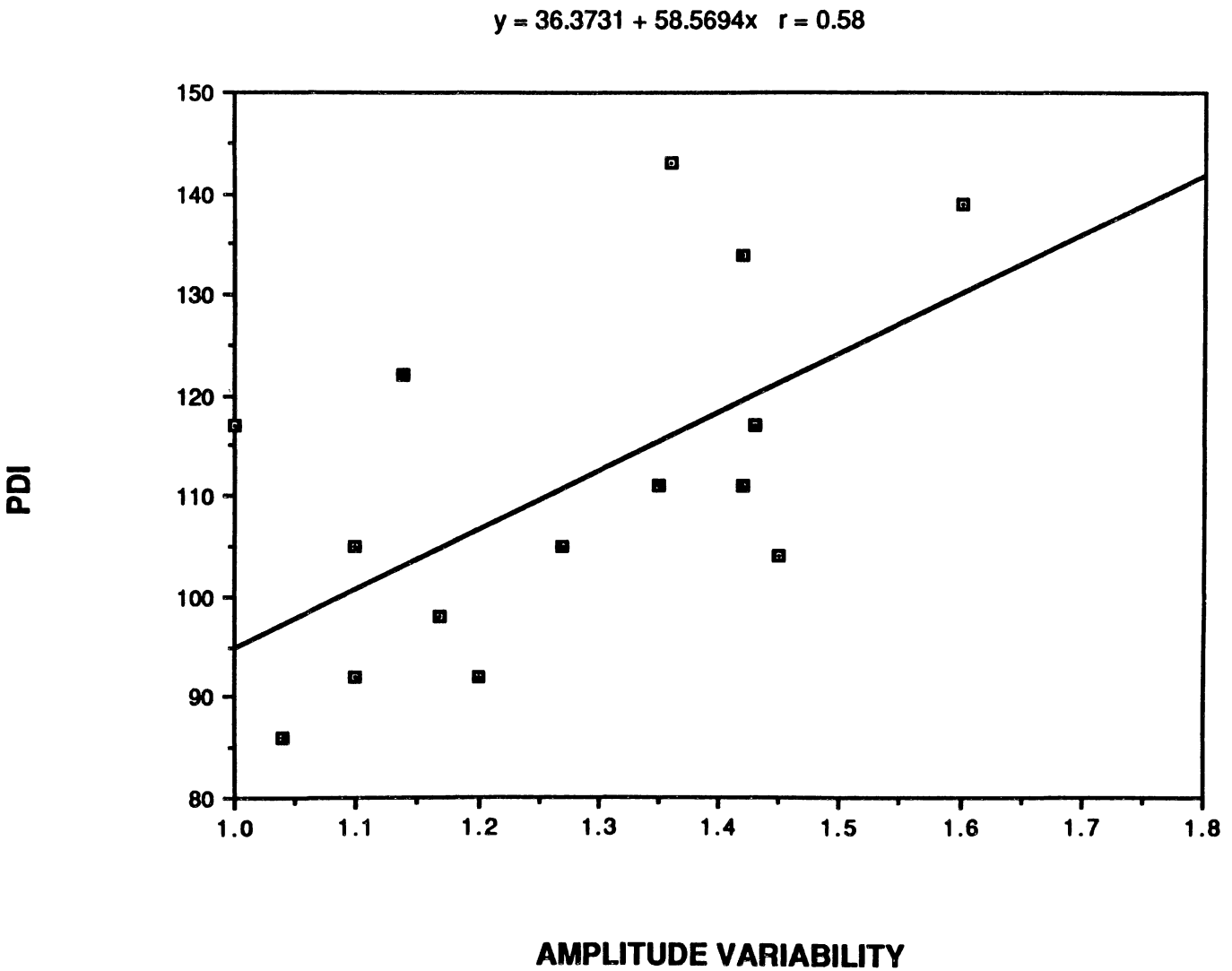

10.0
6.00
2.00
-2.00
-6.00
μv
P2
P3
N1
N2
-400.
.000
400.
800.
1200
ms

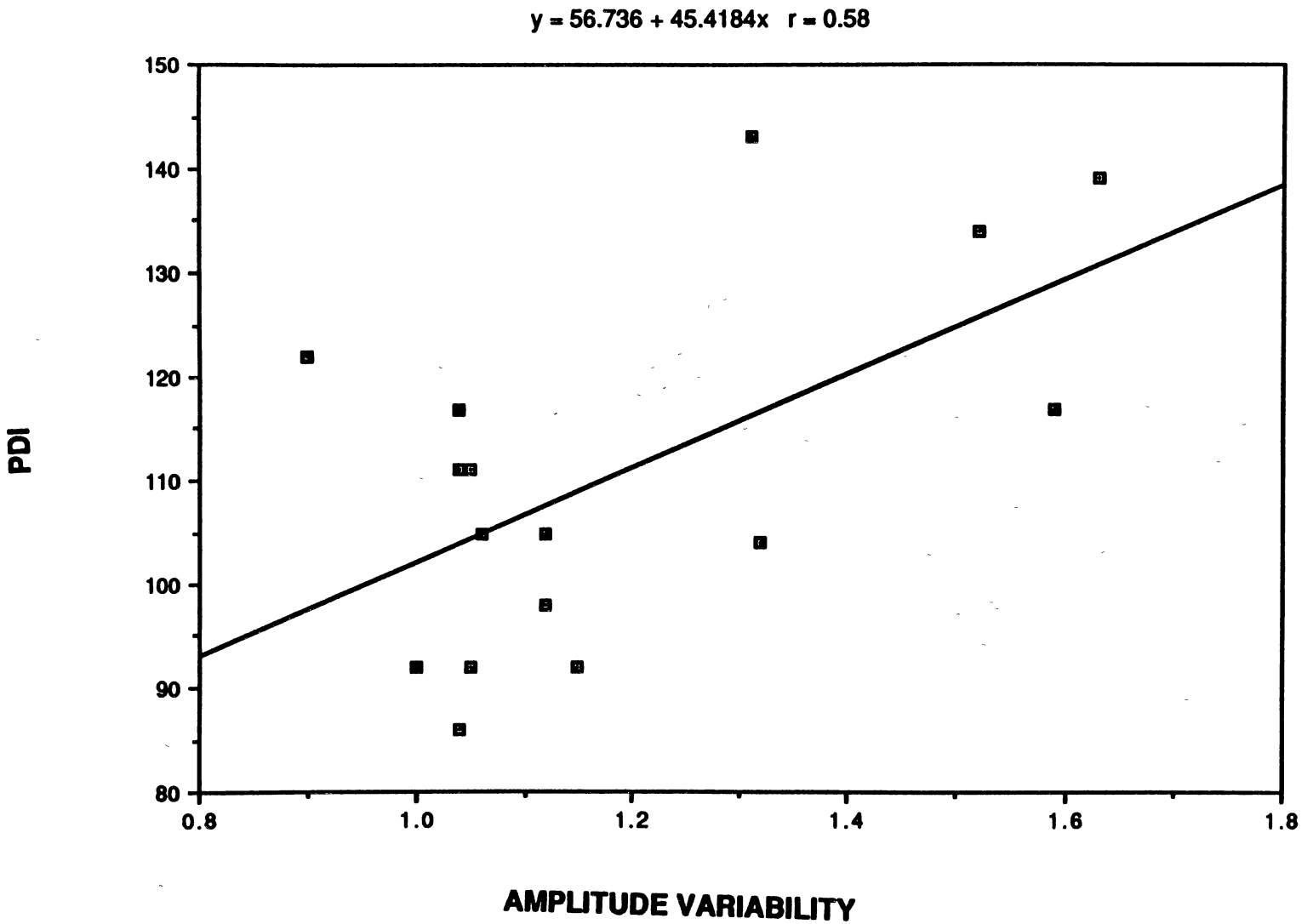

10.0
6.00
2.00
-2.00
-6.00
μv
P2
N1
P3
N2
-400.
.000
400.
800.
1200
ms

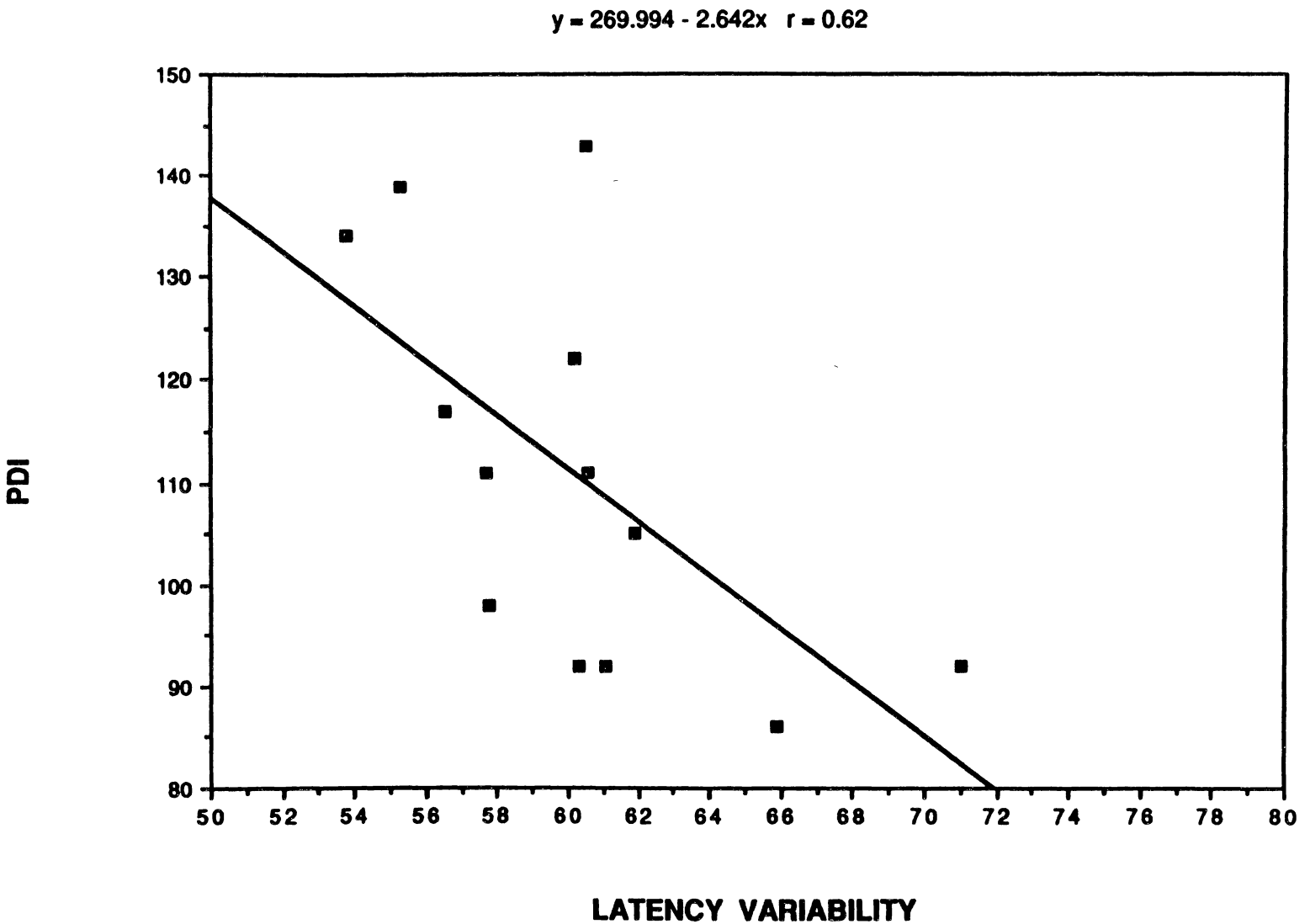

y = 106.2713 + 8.8372x r = 0.57
PDI
150
140
130
120
110
100
90
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
RATIO OF CHANGE IN AMPLITUDE


y = 107.9539 + 16.7406x r = 0.54
140
130
120
110
100
90
MDI
-1.0
-0.5
0.0
0.5
1.0
RATIO OF CHANGE IN LATENCY


y = 43.7326 + 52.4437x r = 0.55
150
140
130
120
110
100
90
80
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
PDI
AMPLITUDE VARIABILITY


y = 36.3731 + 58.5694x r = 0.58
150
140
130
120
110
100
90
80
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
PDI
AMPLITUDE VARIABILITY


y = 56.736 + 45.4184x r = 0.58
150
140
130
120
110
100
90
80
0.8
1.0
1.2
1.4
1.6
1.8
PDI
AMPLITUDE VARIABILITY


y = 269.994 - 2.642x r = 0.62
PDI
150
140
130
120
110
100
90
80
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
LATENCY VARIABILITY

APPENDIX

FAMILIES OF UNIVARIATE CORRELATIONS BASED ON DATA REDUCTION METHODOLOGY

Amplitude

Family 1: N1 at Cz and Fz collected at 16 weeks of age and percentage change between ages correlated with MDI and PDI

Family 2: P2 at Cz and Fz collected at 16 weeks of age and percentage canges between ages correlated with MDI and PDI

Family 3: N2 at Cz and Fz collected at 16 weeks of age correlated with MDI and PDI

Latency

Family 1: N2 percentage change in latency from 4 to 16 weeks of age recorded at Cz and Fz correlated with MDI and PDI

Family 2: P3 percentage change in latency from 4 to 16 weeks of age recorded at Cz and Fz correlated with MDI and PDI

Amplitude Variability

Family 1: Ratio of first time window to prestimulus time window for Cz and Fz at 4 weeks, 16 weeks and variability change between ages correlated with MDI and PDI

Family 2: Ratio of second time window to prestimulus time window for Cz and Fz at 4 weeks, 16 weeks and variability change between ages correlated with MDI and PDI

Latency Variability

Family 1: Standard deviation of trial-to-trial variability of P2 by Cz and Fz at 4 weeks, 16 weeks, and the change between ages correlated with MDI and PDI

VITA

C. Donel Crow

Candidate for the degree of

Doctor of Philosophy

Thesis: THE RELATIONSHIP OF AUDITORY EVENT-RELATED POTENTIALS IN FULL-TERM INFANTS TO THE BAYLEY SCALES OF INFANT DEVELOPEMNT

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Member: American Psychological Association 1985-present; Southwest Psychological Association, 1987-1988; Association of Women in Psychology, 1985-present.