4 Correlates of Language Development: Electrophysiological and Behavioral Measures

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Since the 1970s, researchers and practitioners have been interested in the development of assessment tools for neonates that are predictive of cognitive status in later infancy and early childhood. The ideal measures would permit the assessment of abilities at birth, when virtually total populations of infants are readily accessible in hospitals, and would be easily administered, cost effective, and accurate in identifying those infants who are at risk for developmental delays. However, the ideal measures that satisfy all of these criteria have been difficult to identify. Most typical approaches to assessment have involved the use of a wide variety of newborn measures as predictors and a variety of performance measures as the criterion scores. The newborn and early infancy measures used as predictors have included measures of perinatal complications (e.g., the Obstetrical Complications Scale, Littman & Parmelee, 1978), neurological and behavioral assessments (e.g., the Brazelton Neonatal Assessment Scale, Brazelton, 1973; Prechtl Neurological Examination, Prechtl, 1968), electrophysiological measures of brain functioning (e.g., brainstem-auditory evoked responses, evoked brain potentials), and measures reflecting attention and tactile abilities. Criterion measures have included scores on scales such as the Bayley Scales of Infant Development (Bayley, 1969), the Denver Developmental Screening Test (Dunn, 1965), the Stanford-Binet Intelligence Scale (Thorndike, Hagen, & Sattler, 1986), and the McCarthy Scales of Children's Abilities (McCarthy, 1972).

In the majority of studies that have been published, the amount of variance accounted for by the predictor variables, alone or in combination, is low. Since 1990, there has been an increase in the variance accounted for and an increase in the number of studies reporting predictive relationships between neonatal measures and scores in later childhood. Still, the amount of variance accounted for is less than 60%. It appears that the variables studied thus far still do not accurately predict later abilities in reliable and meaningful ways. Findings from our laboratory over the past decade have shown that evoked potential response (AER) techniques can be used to provide dramatic improvements in the prediction of language and cognitive performance. Findings obtained in our laboratory document a strong relationship between AERs to speech-relevant stimuli recorded soon after birth and measures of later language and cognitive development. In our earliest reported study (D. L. Molfese & V. J. Molfese, 1985), 78% of the variance was accounted by five AER components in predicting McCarthy verbal scores of 3-year-olds ($F = 6.90, p < .005$), and 69% of the variance was accounted for in predicting Peabody vocabulary scores of 3-year-olds ($F = 4.43, p < .02$). Subsequent findings from our laboratory have verified and extended these initial results.

The review that follows divides the traditional studies into four groups: (a) prediction of childhood cognitive and language scores from perinatal measures (e.g., measures obtained before, during, or within a few days after birth), (b) predictions from measures obtained in later infancy, (c) predictions from auditory brainstem responses (ABER), and (d) predictions from AERs. The review concludes with a discussion of a longitudinal study currently underway in our laboratory, exploring changes in predictivity of language and cognitive outcome measures from birth to 5 years.

PREDICTIONS BASED ON PERINATAL MEASURES

Past studies have evaluated the relative values of perinatal and neonatal characteristics, postnatal status, scores on behavioral and neurological assessment scales, and social/demographic characteristics as predictors of general mental development in infancy. These studies generally show that infants with more neonatal risk conditions (e.g., prematurity, respiratory and neurological problems) do not perform as well as infants without complications (see Table 4.1). Efforts to predict outcomes throughout infancy from these neonatal measures generally account for 43% or less of the total variance. For example, V. J. Molfese and Thomson (1985) used a variety of perinatal risk scales with full-term infants to determine whether any could predict infant mental development and temperament scores. The best performance was produced by the Brazie perinatal scale, which was able to account for 11% of the variance of Bayley Mental Development Index scores at 6 months. Fox and Porges (1985) used heart rate measures and perinatal and postnatal measures with healthy and sick full-term and preterm infants and accounted for 13% of Bayley mental scores at 8 and 12 months. Ross (1985) reported that perinatal conditions for preterm and full-term infants accounted for 26% of the variance in Bayley mental scores at 12 months. Similar results in which perinatal and neonatal status measures accounted for 17% of the variance in visual information processing scores were found by Rose (1983) with full-term and preterm infants in a longitudinal study.

Other researchers have obtained somewhat greater success by combining perinatal, environmental, and social/demographic variables as predictors (see Table 4.1). For example, Pederson and colleagues (Pederson, Evans, Bento, Chance, & Fox, 1987; Pederson, Evans, Chance, Bento, & Fox, 1986) studied preterm infants and accounted for 17% of the Bayley mental score variance at 7 months when Minde Morbidity Scale scores, home environment, and socioeconomic status (SES) scores were combined. In a longitudinal study, Crisafi, Driscoll, Rey, and Adler (1987) combined measures of perinatal illness, SES, and infant sex in infants with very low birthweights and accounted for 32% of the Bayley mental score variance at 2 years and 21% of the variance in McCarthy perceptual scores. Vohr, Coll, and Oh (1988) found that gestational age, SES, and neurological scores accounted for up to 42% of the variance of 2-year-olds (representing premature and full-term samples) on receptive/expressive language tests. Hack and Breslau (1986) combined neonatal risks, newborn physical measures, neurological assessment, race, and SES in very low birthweight infants and accounted for 43% of the variance on the Stanford–Binet at 3 years. Yet, despite the encouraging signs that perinatal measures, especially when combined with social/demographic measures, can be used to predict cognitive and language measures obtained in later infancy and early childhood, many researchers (e.g., Cohen & Beckwith, 1979; Cohen & Parmelee, 1983; Reich, Holmes, Slaymaker, & Lauesen, 1984; Silva, McGee, & Williams, 1984) have found little or no predictive power in perinatal measures.

One possible reason for the low predictive power found when perinatal risk measures are used is that the measures used are summaries of risk points rather than individual risk items (V. J. Molfese, 1989). Most researchers use a standard perinatal risk assessment scale (e.g., Hobel, Hyvarinen, Okada, & Oh, 1973; Littman & Parmelee, 1978; Prechtl, 1968) that permits individual risk conditions to be assessed. These risk conditions reflect various complications that can arise in the prenatal, intrapartum, or postpartum periods. The individual risk conditions are then assigned a score representing either a "present" or an "absent" system or a specific risk value thought to represent how serious one risk condition is believed to be in affecting infant outcome compared to other risk conditions on the scale. Thus, point values of either one point per risk condition or up to 35 points

TABLE 4.1

Summary of Selected Studies Using Neonatal and Environmental Measures to Predict Early Cognitive Development

Author(s)	*Sample*	*Predictors*	*Criteria*	*Results*
Cohen & Beckwith (1979)	50 PT (< 38 weeks, < 2500g)	OCS, PNCS, BWT, GA, Hospitalization length, HOME	2-year Gesell, MDI, Receptive Language	Perinatal risks not predictive; Caretaking predictive of all criteria (R^2 = .33 to .54)
Cohen & Parmelee (1983)	126 PT (< 38 weeks, < 2501g)	BWT, GA, Hospitalization length, OCS, PNCS, Neurological Exam, Sensory Tests, 9-month Gesell, Ma Ed, Birth Order	2-year Gesell, MDI, Receptive Language, 5-year Stanford–Binet	Perinatal risks not predictive; Caregiving, Ma Ed correlated with Gesell scores; Ma Ed, visual attention, 9-month Gesell, and manipulation (R^2 = .31)
Crisafi, Driscoll, Rey, & Adler (1987)	144 VLBS (< 1500g)	BWT, GA, 1- & 5-min. Apgar, Sex, Asphyxia, SES, Race	2-year MDI, 3-year Merrill–Palmer, S–B at 4, 5, 6 years, WPPSI at 4, 5, 6 year, McCarthy 4, 5, 6 year	SES predicted 3–6 outcomes (R^2 = .20 to .27); Asphyxia, SES, Sex predicted MDI (R^2 = .32); Perinatal Risk and SES predicted McCarthy Percep. (R^2 = .21)
Fox & Porges (1985)	80 healthy and sick FT and PT	Heart Measures, GA, OCS, PNCS, RDS, Asphyxia, Ma Age	8- and 12-month MDI	Heart measures, GA, OCS, PNCS predicted 8- and 12-month MDI (R^2 = .13)
Hack & Breslau (1986)	139 VLBW (< 1500g)	BWT, Length, Head Circumference, Hobel Risk Scores, SES, Race, Neurological Scores	3-year S–B, Neurological Scores at 20 & 33 mo	Hobel Risk, BWT, Head Circumference, Neurological Scores, race, SES predicted 3-year S–B (R^2 = .43)
Kopp & Vaughn (1982)	76 PT	GA, SES, Ethnicity, 9-month Gesell, Attention Scores	2-year Gesell, MDI, Sensorimotor, Language Scores	Ethnicity, 9-month Gesell, Attention Scores predicted 2-year Gesell (R^2 = .42)
V. J. Molfese & Thomson (1985)	103 infants	5 Perinatal Risk Scales	6-month PCS, MDI, Carey Scores	Brazie scale predicted MDI (R^2 = .11)
O'Connor, Cohen, & Parmelee (1984)	9 FT and 19 PT (< 38 weeks < 2500g)	GA, BWT, SES, Ethnicity, Ma Ed	18-month MDI, 5-year S–B	MDI predicted S–B (R^2 = .52)

Pederson, Evans, Bento, et al. (1987)	50 PT (< 38 weeks)	Minde, GA, Apgar, BWT, SES, HOME, Parent Measures	7-month Denver, 12-month MDI and PDI	Minde, GA, Denver predicted MDI (R^2 = .37)
Pederson, Evans, Chance, et al. (1986)	135 LBW (< 2500g)	GA, BWT, Apgar, Medical Complications, Hospitalization, SES, Maternal Measures	6-month MDI	Quality of Mothering (R^2 = .14) and intervention (R^2 = .18) predicted MDI
Reich et al. (1984)	17 PT (< 37 weeks), 36 healthy and sick FT	GA, OCS, PNCS, Brazelton Scores, Infant Sex	3-year S–B	Perinatal risk not predictive
Rose (1983)	40 FT and 40 PT	BWT, GA, OCS, PNCS	Visual Info. Process at 6- and 12-months	BWT and GA correlates of 6- and 12-month performance
Rose, Feldman, McCarton, & Wolfson (1988)	50 PT and 43 FT	BWT, GA, Length, OCS, PNCS, Apgar Scores, Hospitalizations, Respirator	7-month Info Processing Scores	GA and OCS predicted General Recognition scores (R^2 = .17)
Ross (1985)	46 PT (< 1501g), 46 FT	Apgar Scores, GA, BWT, Sepsis, Ventilation, Specific Physiological Measures, SES	12-month MDI and PDI	Apgar Scores, ICH, Hypoglyc., GA, Sepsis, BWT, PH and NEC predicted MDI (R^2 = .26)
Sostek et al. (1987)	113 PT (< 34 weeks)	IVH, BWT, SES	1-year & 2-year MDI, PDI, Neurological Scores	1-year, Neurological Scores, 1-year MDI predicted 2-year MDI (R^2 = .62)
Silva et al. (1984)	1037 tested 3, 5, and 7 year	Perinatal Risks, GA, BWT, Apgar, Delivery, Neonatal Comp., SES	3-year Language Measures, 5-year S-B and Language Measures, 7-year ITPA & WISC	Perinatal Risks predicted outcomes at 3, 5, & 7 year (R^2 = 3, 2, 1, respectively)
Vohr et al. (1988)	50 LBW (< 1500g) 18 FT	BWT, GA, SGA vs AGA, Perinatal Risks, 8-months Neurological Status, SES, Ma Age	2-year MDI, 2-year Language Measures	GA, SES, Neurological Scores predicted language (R^2 = .42)

Note: Abbreviations: PT – preterm, FT – fullterm, BWT – birthweight, LBW – low birthweight, VLBW – very low birthweight, GA – gestational age, AGA – appropriate for gestational age, SGA – small for gestational age, OSC – Obstetric Complications Scale, PNCS – Postnatal Complications Scale, PCS – Pediatric Complications Scale, RDS – respiratory distress syndrome, IVH – intraventricular hemorrhage, MDI – Mental Development Index, PDI – Psychomotor Development Index, S-B – Stanford-Binet, Ma Ed – maternal education, Ma Age – maternal age.

per risk condition can be given. The individual risk points are then summed for a total risk score. These total risk scores are commonly used as predictors. However, Siegel (1982a, 1982b) showed that the use of individual risk items results in greater predictive power. Siegel's risk index contains perinatal complications and SES characteristics, and separate scales have been developed for preterm and full-term infants. Siegel reported accounting for up to 42% of the variance in predicting scores on the Stanford-Binet, Reynell Language Scales, and the McCarthy scales in a longitudinal study of preschool children using her risk index. Because the use of individual perinatal risk items results in a large number of variables being used to predict outcomes, and this has the potential of violating the cases to measures ratios recommended for reliability in statistical analyses, it makes sense that certain perinatal risk conditions would have greater influence in infant outcomes when considered individually than when diluted with other variables. The use of individual perinatal risk measures rather than summed perinatal risk scores has been found to produce improved results in predictive studies (V. J. Molfese, DiLalla, & Lovelace, 1995).

PREDICTIONS BASED ON INFANT MEASURES

In considering the predictive value of neonatal measures, some researchers have argued that these early measures may be too unstable to use as long-term predictors and measures obtained in later infancy might be better, possibly more stable predictors. Several researchers have examined the relationship between measures obtained in the infancy period and cognitive and language scores in late infancy and the early preschool period. However, the predictive power obtained in these studies, although stronger than those obtained in the studies reported previously, still leaves 40% or more of the variance unaccounted for (see Table 4.1). For example, Kopp and Vaughn (1982) studied preterm infants and found that 42% of the variance in the scores of male children on the Gesell at 2 years could be accounted for by a combination of gestational age, 9-month Gesell scores, attention measures, and ethnicity. Sostek, Smith, Katz, and Grant (1987) found with a sample of preterm infants that 1-year Bayley mental and physical (Physical Development Index) scores and neurological assessment scores accounted for 62% of the Bayley mental scores at 2 years. Cohen and Parmelee (1983) found 31% of the variance on Stanford-Binet scores could be accounted for from a combination of education, visual and manipulative schema scores, and 9-month Gesell scores in a preterm sample. O'Connor, Cohen, and Parmelee (1984) found that the Bayley mental scores at 18 months alone accounted for 52% of the variance on the Stanford–Binet at 5 years in a sample of preterm and full-term children.

Especially encouraging results have been found when individual perinatal risk items, SES, HOME environment measures, and first-year mental status scores have been used to predict outcomes. Siegel (1982b) and Smith, Flick, Ferriss, and Sellmann (1972) compared classification accuracy obtained with 6- and 7-year-old children when perinatal measures and social measures were used as predictors and when first-year Bayley scores were added to the equations. Siegel found that classification accuracy improved from 71% to 89% when the first-year measures were added in predicting performance on the McCarthy General Cognitive Index in a preterm, very low birthweight sample. Smith et al. found that classification accuracy improved from 89% and 77% to 94% and 93% for normal and risk groups, respectively, when 8-month Bayley scores were added to the equation along with individual perinatal risk items, demographic variables, and maternal IQ. A confirmation of these findings was reported by V. J. Molfese et al. (1993) in a study with high- and low-risk 3- and 4-year-old children. In this study, classification accuracy was improved by up to 9% (with classification accuracy reaching 83%) when 12-month Bayley mental scores were added to the equation along with individual perinatal risk items, SES, and HOME (Caldwell & Bradley, 1978) scores. Interestingly, all three of these studies found greater improvements in the low-risk groups than in the high-risk group.

A growing number of studies reported in recent years are longitudinal. Longitudinal studies optimally provide ideal conditions for observing changes in the influence of variables on developmental outcomes over time. Some of these studies have supported the Transactional Model (Sameroff & Chandler, 1975), which postulates an interrelationship between the infant and its environment. A variation in the model (proposed by V. J. Molfese, Holcomb, & Helwig, 1994) postulates that perinatal variables influence the infant during the neonatal and early infancy periods more strongly than environmental variables. After infancy, social/demographic and environmental variables begin to exert stronger influences on development, eventually outweighing many perinatal variables. Recent studies reporting outcomes during the preschool years provide support for this view of the Transactional Model. Wilson (1985) found that the influence of perinatal risk measures stabilized by 18 months, with correlations in the low .20s thereafter. The influence of maternal education and SES increased after 18 months, with correlations in the .40s. Yeates, MacPhee, Campbell, and Ramey (1983) reported on the increasing influence of HOME scores from 2 to 4 years and the increasing ability of HOME scores and maternal IQ to predict Stanford–Binet scores from 2 to 4 years. The amount of variance accounted for by these variables rose from 11% to 29%. Rose and Wallace

(1985a, 1985b) reported on the early influence of perinatal risk measures, which account for 9% of the Bayley mental scores variance at 2 years. Parental education, which shows its strongest influence at 3 and 4 years, accounted for up to 66% of the variance at those ages. Visual novelty scores remained relatively constant, accounting for about 25% of the variance. A recent study by V. J. Molfese et al. (1994) used path analysis to examine the influence of perinatal risk, pediatric health, which was assumed to reflect lingering effects of perinatal risks, and SES on measures of cognitive development at 1 and 2 years and on cognitive and language measures at 3 years. The results showed that total perinatal risk scores were related only to cognitive measures obtained in the first year, but pediatric health was a weak correlate at 2 and 3 years. In contrast, SES was a weak correlate at 1 year but a stronger correlate at 2 and 3 years. These results appear to support that notion that perinatal risk (and pediatric health) conditions are predictive of outcomes in early infancy but weaken as correlates at later ages, with SES becoming a stronger correlate with age.

PREDICTIONS USING AUDITORY BRAINSTEM EVOKED RESPONSE MEASURE

Some researchers have examined the use of brainstem evoked responses (BSER) to predict developmental outcomes. In general, the results have not appeared promising as indicated by the brief review provided later. BSERs show little success in predicting long-term developmental outcomes.

The BSER consists of seven peaks that occur during the first 10 to 15 ms of the brain's response to an auditory or visual stimulus (e.g., a click or a photic flash). Each peak lasts for approximately 1 ms and the maximum amplitude is approximately $\frac{1}{2}$ microvolt. Barden and Peltzman (1980) used this technique with newborn infants, including 12 with no risk factors and 15 with 3 or more perinatal risk factors. No significant difference in the latency of Wave V, where the difference was expected, was found among subjects when grouped according to birthweight and according to 5-min Apgar scores. Correlations of Wave V with other perinatal risks were also not significant. Cox, Hack, and Metz (1984) studied a population of 50 very low birthweight infants. BSER indicated that 9 infants had abnormal responses at birth, but only 1 of the 9 was still abnormal at 4 months. BSER results were found to be correlated with individual perinatal risk conditions. Murray, Dolby, Nation, and Thomas (1981) studied 60 high-risk and 28 low-risk neonates. The latency difference between Waves I and V were found to be correlated with specific perinatal events and with postnatal assessment on the Brazelton scale. Murray (1988) later studied 65 high-risk and 28 low-risk infants at birth and 9 months. The accuracy rate overall was 45% (5 of 11 correctly identified at birth) when newborn BSER abnormalities were used to predict the presence of varying levels of neurobehavioral handicaps at 9 months. When used to provide information on neuromaturational delay, the accuracy rate overall was 12% (2 of 16 correctly identified at birth). Eldredge and Salamy (1988) used BSER to study 15 neonates at risk for neurological problems and 15 normal infants. Although a neurological screening test was able to distinguish between the two subject groups, the BSER test could not. Also there were no significant correlations between BSER and the number of perinatal risk factors.

Given the number of false positives and negatives and the inconsistencies in the abilities of BSER to distinguish between risk and no risk subjects, the BSER procedure does not appear to be effective when used as a general assessment tool for screening neonates.

PREDICTIONS USING EVOKED POTENTIAL BRAIN RESPONSES

The auditory evoked response (AER) has been used extensively to study language and cognitive processes (see D. L. Molfese, 1983, for a review of this literature). The AER is a synchronized portion of the ongoing EEG pattern that is detectable at the scalp and occurs immediately in response to some stimulus (Callaway, Tueting, & Koslow, 1978; Rockstroh, Elbert, Birbaumer, & Lutzenberger, 1982). The AER has been demonstrated to reflect both general and specific aspects of the evoking stimulus and the person's perceptions and decisions regarding it (D. L. Molfese, 1983; D. L. Molfese & Betz, 1988; D. L. Molfese & V. J. Molfese, 1979a, 1979b, 1980, 1985; Nelson & Salapatek, 1986; Ruchkin, Sutton, Munson, & Macar, 1981).

Studies conducted since the 1970s to predict later development based on neonatal evoked potential (EP) measures have varied in their effectiveness. In general, studies with restricted analyses to a single early peak or peak latency (usually the N1 component) have achieved some success in short-term prediction but failed to reveal a long-term relationship. Other studies of additional portions of the waveform have shown that AERs have long-term predictive value in assessing later language skills. Butler and Engel (1969) reported the first success in noting correlations between the neonatal evoked potential latencies and later measures related to intelligence. They recorded visual evoked potentials from 433 newborn infants in response to a series of photic flashes. Although the correlations were significant between motor behaviors and photic latency, the effects were small and accounted for little of the variance (Mental: $r = .33$, $p < .01$;

Fine Motor: $r = .24, p < .01$; Gross Motor: $r = .23, p < .01$). Jensen and Engel (1971) also reported correlations between neonatal photic latencies and later motor skills when they divided the photic latency response into three regions. Engel and Fay (1972) found that infants with faster visual evoked response N1 latencies (less than 146 ms) performed better at 3 years on an initial and final consonant articulation task than slow reactors, although no differences were noted on the Stanford–Binet at 4 years. In subsequent studies with older populations of children, Engel and Henderson (1973) and Henderson and Engel (1974) failed to find a relationship between neonatal visual evoked responses and a variety of later IQ and achievement scores. However, different electrode sites were used in their study than in those employed by earlier investigators (Ertl, 1969). Henderson and Engel (1974) assessed whether the neonatal visual evoked responses could predict total IQ and subtest scores, sensorimotor, perceptual–motor, and achievement test scores at 7 years. The photic latency data from 809 infants did not correlate 7 years later with their performance on a variety of IQ tests and subtests.

Thus, several studies have reported some early relationships between one component of the visual evoked response, usually the latency or length of the interval between stimulus onset and the N1 peak, and subsequent motor, cognitive–motor, or language-related abilities up to 3 years. However, further research that compared early neonatal evoked responses with later intelligence score measures failed to demonstrate a relationship. Although such conclusions may appear discouraging, more recent studies suggest that relationships might in fact exist (D. L. Molfese, 1989; D. L. Molfese & V. J. Molfese, 1985, 1986; D. L. Molfese & Searock, 1986). The differences in success among such studies may reflect a number of differences in both methodology and experimental design:

1. Molfese and his associates analyzed the entire evoked potential waveform, and Ertl and others confined their analysis to a single initial peak. Analysis of all data collected instead of only a subset should increase the likelihood of finding a relationship between early brain responses and later development, if such relationships do in fact exist.
2. The frequency range of the evoked potential studied by Molfese includes a lower range of frequencies (below 2 Hz) than those employed by earlier investigators. Given that the brain wave frequencies characterizing the evoked potentials of young infants are concentrated in the frequency range below 3 Hz, such a strategy should utilize more of the neonate's brain wave activity.
3. The studies reported by Molfese employ language-related, speech sounds as stimuli. Since predictors of successful performance are generally better if they measure predicted skills, the inclusion of more language-

relevant stimuli should increase the likelihood for predicting later language performance.

EVOKED POTENTIAL STUDIES USING CHANGES IN THE ENTIRE WAVEFORM TO PREDICT LATER DEVELOPMENT

Molfese and Molfese, in addition to investigating changes in developmental patterns of lateralization across the life span, have isolated and identified electrophysiological correlates of various speech perception cues across and within a number of developmental periods (D. L. Molfese & V. J. Molfese, 1979a, 1985, 1988). The implications of these lateralized patterns of response for later language development is an important issue. Are these patterns of responses related to later language development for individual children, or do they reflect some basic pattern of auditory processing in the brain that has little relation to language development? Given Lenneberg's (1967) notion that lateralization is a biological sign of language, could such early patterns of lateralized discrimination of speech sounds predict later language outcomes? Theoreticians have speculated that the absence of hemispheric differences in a child indicates that the child is at risk for certain cognitive or language disabilities (Travis, 1931). Although the data generally have not supported such a position, predictions concerning later performance could be enhanced when hemispheric differences are considered in light of specific processing capacities.

In this regard, D. L. Molfese and V. J. Molfese (1985, 1986) attempted to establish the predictive validity for a variety of factors in predicting long-term outcomes in language development from measures taken shortly after birth and during the first year of life. In their first study (D. L. Molfese and V. J. Molfese, 1985), 16 infants were studied longitudinally from birth through 3 years. Information was collected on gender, birthweight, length, gestational age, and scores on the Obstetric Complications Scale (Littman & Parmelee, 1978), the Brazelton Neonatal Assessment Scale (Als, Tronick, Lester, & Brazelton, 1977; Brazelton, 1973), the Bayley Scales of Infant Development (Bayley, 1969), the Peabody Picture Vocabulary Test (Dunn, 1965), and the McCarthy Scales of Children's Abilities (McCarthy, 1972). Parental ages, incomes, educational levels, and occupations were also obtained. In addition, AERs were recorded in response to speech stimuli from the left and right temporal areas (T3 and T4) at birth and again at 6-month intervals until the child's third birthday. The speech stimuli were chosen because they produced reliable general hemispheric difference effects as well as bilateral and lateralized discrimination effects. Eight other stimulus tokens were added to facilitate tests of generalizeability across different consonant and vowel contrasts. Such stimuli appeared to be ideally suited for determining whether general hemispheric differences per se or specific lateralized discrimination abilities were the best predictors of later language skills.

Analyses of the AER data indicated that electrophysiological measures recorded at birth could identify children who performed better or worse on language tasks 3 years later. One component of the auditory AER that occurred between 88 and 240 ms reliably discriminated among children whose McCarthy Verbal Index scores were above 50 (the High group) and those who scored lower (the Low group). Only AERs recorded over the left hemisphere of the High group systematically discriminated among the different consonant speech sounds. The right-hemisphere responses of this group, in contrast, discriminated among the different nonspeech stimuli. However, the Low group displayed no such lateralized discrimination for either the speech or the nonspeech sounds. A second portion of the AER with a late peak latency of 664 ms also discriminated between the High and Low groups. Unlike the earlier peak, however, this component occurred over both hemispheres and, consequently, reflected bilateral activity. This second component did not behave in exactly the same manner as the first. Although the second component discriminated among speech and nonspeech stimuli, discrimination between consonant sounds depended on which vowel followed the consonant. A third component of the AER (peak latency = 450 ms) that varied only across hemispheres failed to discriminate between the two groups.

Thus, hemispheric differences per se could not discriminate at birth among infants who would have better or poorer language skills 3 years later. Furthermore, given that the AER components that discriminated between the two groups were sensitive to certain speech and nonspeech contrasts but not to others, the AERs appear to reflect the infant's sensitivity to specific language-related cues rather than overall readiness of the brain to respond to any general stimulus in its environment.

A stepwise multiple regression model of these data was developed using the Peabody and McCarthy Verbal Index scores as the dependent variables and the AER components obtained at birth that best discriminated the different consonant sounds as the independent variables. This model accounted for 78% of the total variance in predicting McCarthy scores from the brain responses and 69% of the variance in predicting Peabody scores (D. L. Molfese & V. J. Molfese, 1988). Clearly, early AER discrimination of speech-related stimuli is strongly related to later language skills.

D. L. Molfese and Searock (1986) later noted that this relationship between early AER activity and later language skills also exists at 1 year. AERs were recorded from 16 infants within 2 weeks of their first birthday. A series of three vowel sounds with speech formant structure and three nonspeech tokens containing 1 Hz-wide formants that matched the mean frequencies of the speech sounds were presented to these infants, and their AERs were recorded in response to each sound. Two regions of the AERs, one centered between 300 and 400 ms and another centered around 200 ms following stimulus onset, discriminated among the 1-year-old infants who 2 years later would perform better or worse on the McCarthy language tasks. Infants who were able to discriminate among more vowel sounds performed better on the language tasks at 3 years.

Subsequently, D. L. Molfese (1989) recorded the AERs at birth from scalp electrodes placed over frontal, temporal, and parietal scalp areas over the left and right hemispheres. The speech and nonspeech sounds that served as stimuli were a subset of those employed by D. L. Molfese and V. J. Molfese (1985) and consisted of the speech syllables (bi, gi) and the nonspeech analogues for these two consonant-vowel sounds. These four sounds had been found to be the best predictors in the earlier study. This sample of 30 infants had McCarthy verbal scores at 3 years that ranged from 32 to 69 (mean = 53, *SD* = 9.41). The mean for the infants who scored 50 or below on the McCarthy test was 45 (*SD* = 4.97, range = 32–50), and the mean for the infants who scored above 50 was 61 (*SD* = 4.95, range = 54–69). Overall, both groups of children possessed largely average language scores. A discriminant function procedure was applied. The time points of the averaged AERs were used to discriminate the language scores obtained when the children were 3 years. The stepwise analysis, with an F-to-enter of 3.0, selected 17 points in order of their effectiveness in classifying each of the 720 original averaged AERs into one of the two groups. These points clustered in four regions of the AER—the first between 20 and 140 ms, the second between 230 and 270 ms, the third between 410 and 490 ms, and the fourth between 600 and 700 ms. The likelihood of correctly classifying a brain response as belonging to a Low or High language performance child was 50%, but the actual classification accuracy was significantly higher than chance. For the Low and High groups, respectively, the classification was accurate 69.7% and 68.6% of the time. A z-test of proportions indicated that the actual classification was significantly better than chance for each group (z = 9.98, 10.57, $p < .001$). Applying a rule that at least 54% of an individual's AERs must be classified into the Low group before that infant would be classified as having a lower-than-average language performance, Molfese noted that, out of 30 infants, only 1 infant from the Low group and 1 from the High group would be misclassified.

One region of the AER waveforms that distinguish among the brain waves of infants who will later develop differently in language skills is illustrated in Fig. 4.1. The top two figures are from the data published by D. L. Molfese and V. J. Molfese (1985). The waveform on the left is the averaged AER for the 8 neonates who at 3 years obtained a verbal subtest

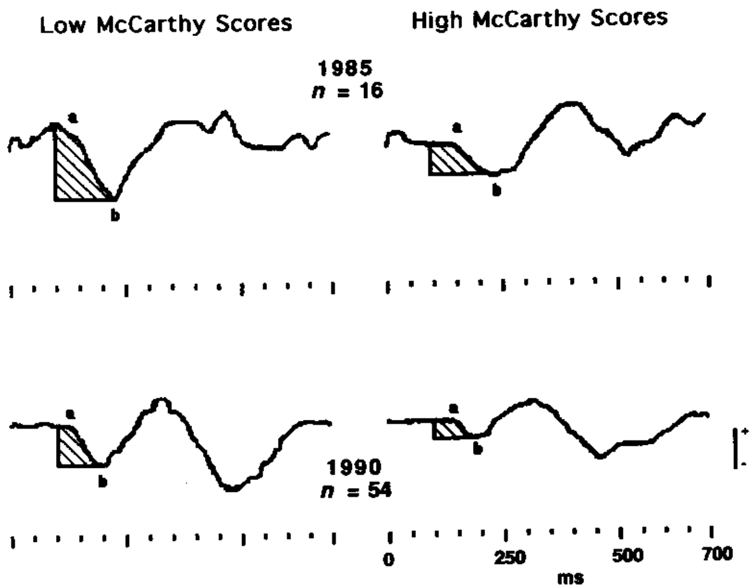

FIG. 4.1. Newborn auditory evoked responses to high and low language performing children.

score on the McCarthy of 20.5 (SD = 12.6) and that on the right is the average waveform for the 8 infants who obtained an average score of 77.25 (SD = 15.5). The amplitude of the region responsible for this discrimination is between the positive peak labeled *a* and the leading edge of the following negative wave labeled *b*, which occurred between 88 and 240 ms. The group differences were marked. The amplitude or vertical distance between a and b for the positive peak is larger for the Low than the High group.

One interpretation of these results is that early discrimination abilities relate directly to later language development. The children who performed better on language tasks at age 3 discriminated better at birth among consonant sounds alone and consonant sounds in combination with different vowel sounds (D. L. Molfese, 1989; D. L. Molfese & V. J. Molfese, 1985). Such a pattern of responding suggests that more linguistically advanced children are already at an advantage at birth because their nervous systems can make finer discriminations along a variety of dimensions. As D. L. Molfese (1989) suggested: "Perhaps the earlier an infant can discriminate between speech sounds in its environment, the more likely that infant will be able to use such information to discriminate word sound differences" (p. 55). Such early discrimination abilities may later play a major role in the infant's early word learning as it attempts to relate one sound pattern to a specific object and a different sound pattern to a second object.

These data provide further support for the position that early physiological indices are predictive of long-term developmental trends. One especially striking aspect of these data concerns the range of language abilities that are differentiated 3 years after the newborn brain responses were recorded. Although the language skills in the D. L. Molfese and V. J. Molfese (1988) study ranged from relatively poor receptive and productive skills to well above average skills, the amount of variance was not as large as has been reported in other studies that have included children with significant perinatal risk conditions. In spite of this degree of relative similarity across children, the brain responses are able to distinguish children who perform differently on the language tasks.

LONGITUDINAL STUDY OF ELECTROPHYSIOLOGICAL CORRELATES OF LANGUAGE DEVELOPMENT

Currently underway in our laboratory is a second longitudinal study designed to determine whether the results of our previous longitudinal study can be replicated and extended using a larger sample of normal and at-risk children. The longitudinal study began with the testing of 387 newborn infants using AER procedures and the abstracting of medical information needed to quantify a battery of 290 perinatal risk variables. Risk variables from the battery were used to explore different predictive models involving various configurations of these variables. Subsequently, 196 infants were tested at their first birthdate and 186 in Year 2, 3, and 4. Testing of 5-year-old children is in progress with 147 tested to date and 39 more to be tested. The highest attrition rate (49%) occurred in Year 1 because families moved, were unreachable after repeated attempts, or lost interest. The remaining participant population was stable with only the loss of 10 additional children after Year 1. Within the sample are 60 infants considered at risk because of perinatal and early neonatal complications. Participant data are shown in Table 4.2.

Testing of the children has occurred yearly, with evoked potential testing and behavioral assessments occurring at each age. Shown in Table 4.3 are the assessments used at each age.

Four independent analysis procedures were used: (a) the principal components analysis of the digitized time points from averaged AERs followed by an analysis of variance of factor scores from the principal components analysis as the dependent measures; (b) a discriminant function analysis using the jackknife procedure in which the dependent variables were the digitized time points of the averaged AERs obtained in the present

TABLE 4.2
Descriptive Statistics in Children in Longitudinal Study

	Normal Participants		*At-Risk Participants*	
	M	*SD*	*M*	*SD*
Birthweight	3415.38	690.88	2649.30	1030.72
Gestational Age	39.39	2.38	36.48	4.23
One-Min Apgar	7.47	1.75	6.0	2.5
Five-Min Apgar	8.75	1.02	7.7	1.89
Postnatal Complications Score	54	1.57	3.07	2.31
Perinatal Risks	6.18	3.39	10.33	4.19
Maternal Age	27.71	5.25	26.32	5.35
Maternal Employment	Yes = 87	No = 41		
Paternal Employment	Yes = 110	No = 8		

Full Sample

	M	*SD*		*M*	*SD*
PSC - One Year	1.67	1.41			
PSC - Two Years	1.62	1.35			
PCS - Three Years	1.51	1.23			
HOME Total	45.54	4.39	HOME–Academic Stimulation	4.22	.83
HOME Learning Materials	8.76	1.72	HOME–Modeling	3.38	1.18
HOME Communicative Competence	6.24	.81	HOME–Variety in Experience	7.01	1.04
HOME Environment	6.69	.78	HOME–Acceptance of Child	3.61	.96
HOME-Nurturance	5.75	1.15			
Bayley - 1	115.37	17.21	Bayley - 2	109.16	19.31
Stanford–Binet - 2	103.81	7.49	Stanford–Binet - 3	104.62	10.09
Stanford–Binet - 4	105.55	11.71	Stanford–Binet - 5	101.87	9.69
McCarthy Verbal - 3	53.66	9.02	Peabody - Three	100.02	16.09

study; (c) a control analysis that utilized a Monte-Carlo like procedure in which the input order of the AERs to the principal components analysis was randomized (this step provides additional information concerning the likelihood of Type I error); and (d) a regression analysis that used language performance scores noted at 3 years as the dependent variables and the various measures of the AERs recorded at birth (e.g., factor scores, amplitude, latency, area), perinatal variables, HOME, and demographic measures as the independent variables. To date, the results of the current longitudinal study are comparable to the results of the initial longitudinal study. We have briefly outlined some of our findings to date concerning the principal components analysis/analysis of variance procedures and the discriminant function procedures that we have employed to isolate and identify neonatal AER components that predict long-term outcomes.

TABLE 4.3
Behavioral Assessments Administered in Longitudinal Study

Age 4
Stanford-Binet Intelligence Scale (4th Edition)
McCarthy Scales of Children's Abilities (VSI only)
Parent Demographic Information Sheet
Pediatric Complications Scale
Ages 5 and 6
Stanford-Binet Intelligence Scale (4th Edition)
Parent Demographic Information Sheet
Pediatric Complications Scale
School Achievement Test results
Age 7
Weschler Intelligence Scale for Children-III
50 Utterance Language Sample
Parent Demographic Information Sheet
Pediatric Complications Scale
School Achievement Test results
Age 7
Weschler Intelligence Scale for Children-III
Wide-Range Achievement Test
Word Attack
Parent Demographic Information Sheet
Pediatric Complications Scale
School Achievement Test results

PCA/ANOVA

Initial Findings. Principal components analysis procedures were used with AER time points as the variables and AER averages as the cases. Seven factors, accounting for 79.93% of variance, were retained using the Cattell Scree Test criterion. The seven factors characterized the different regions of the averaged AERs that varied most across the entire set of brain responses. The factor scores from one portion of the AERs between 88 and 240 ms as reflected by Factor 3 were included as dependent variables in an ANOVA that included a single between-participants measure based on a median split separating the brain responses of newborn infants who later scored above 50 (High MCVSI) on the McCarthy verbal scale index at 3 years from those scoring below 50 (Low MCVSI). Repeated measures characterized the remaining variables: two consonant sounds (/b/, /g/), the two formant structures (speech, nonspeech), the three vowel sounds (/i, æ, ɔ/), and the two electrode positions (left- and right-hemisphere temporal sites). The factor scores for Factor 3 varied systematically as a function of group membership as reflected by a Group × Formant × Hemisphere interaction, $F(1, 14) = 8.65$, $p < .01$. Scheffe tests indicated that for children in the High MCVSI group, the AER region between 88 and 240 ms discriminated between the /b/ and /g/ speech stimuli only at the left hemisphere site, $F(1, 14) = 8.95$, $p < .01$. The right hemisphere AER for the High MCVSI children discriminated the nonspeech /b/ and /g/ consonants, $F(1, 14) = 4.40$, $p < .04$. No comparable effects were found for Low MCVSI children.

Present Findings. Analyses conducted to date for a set of 54 children also identified an early portion of the AER recorded over the left hemisphere of newborn infants that discriminates among children who 3 years later differ in their language performance. As before, this region discriminates among consonant sounds. Scheffe tests of a Group × Consonant × Hemisphere interaction, $F(1, 52) = 12.12$, $p < .001$, indicated that AERs recorded from the left hemisphere differed in response to the /b/ and /g/ consonant sounds, $F(1, 52) = 8.37$, $p < .0057$, for only the High language performance group. An analysis just completed with 120 children and modeled after D. L. Molfese and V. J. Molfese (1985) also revealed a Group × Consonant × Hemisphere interaction, $F(1, 118) = 6.00$, $p < .0158$ at this same latency in the brainwave. As before, Scheffe tests indicated that for children in the High MCVSI group, the AER region up to 230 ms discriminated between the /b/ and /g/ speech stimuli only at the left hemisphere site, $F(1, 118) = 7.11$, $p < .009$. No comparable effect was found for the Low MCVSI children. This effect overlaps both temporally and functionally with the original effects reported by D. L. Molfese and V. J. Molfese (1985). Once all the 3-year data are obtained for our entire sample, these analyses will be repeated with the full sample of 186 children. However, given that these results have held up across different subsamples of this population with up to 120 children and the important fact that the region of the AER waveform that discriminates between the two groups is identical to that reported in the original study (D. L. Molfese & V. J. Molfese, 1985), we anticipate that comparable findings will be obtained with the entire population. One additional point is that the current population of children have a somewhat narrower range of language and cognitive scores than the original population. In spite of this difference, the analyses of newborn AERs continue to indicate strong differences between the Low and High language performers 3 years later.

Discriminant Function

Initial Findings. Linear discriminant function procedures were developed for the averaged AERs based on the digitized time points for each waveform. This step used the amplitude values of the averaged AERs as the input data to discriminate participant groups and conditions. Results were cross-validated using the jackknifed procedure. There were 16 classes to be discriminated—the 2 participant groups, the 2 consonant sounds, the 2 formant bandwidths, and the 2 electrode sites. The stepwise discriminant function analysis selected two points (96 ms, U-statistic = .90, $p < .01$ and 224 ms, U-statistic = .82, $p < .01$) based on effectiveness in classifying each original averaged AERs into 16 conditions. Chance classification was 6.25%. For High MCVSI children, classification was successful for the left-hemisphere site for normal formant /b/ (62.5%, $z = 64.4$, $p < .01$) and normal formant /g/ (29.2% correct, $z = 26.3$, $p < .01$). The right-hemisphere site correctly classified AERs for sinewave formant /b/ (29.2% correct, $z = 26.3$, $p < .01$) and sinewave formant /g/ (20.8% correct, $z = 16.7$, $p < .01$). Significant levels of classification for Low MCVSI children occurred for only normal formant /g/ AERs recorded from the right temporal site (16.7% correct, $z = 12.0$, $p < .010$). When jackknifed classification was used, the classification accuracy for the High MCVSI was 58.3%, 29.2%, 29.2%, and 26.7%, respectively (all at $p < .01$). Classification accuracy for the Low MCVSI dropped to chance levels. The discriminant function analysis correctly classified the same stimuli and participant groups found to be important for the PCA/ANOVA analyses. In addition, data points selected by discriminant function analysis were within the region dominated by the factor identified in the PCA. This level of high agreement across the two procedures was interpreted as a further indicator of the reliability of the effects.

Present Findings. These discriminant analyses procedures are continuing. Preliminary indications are that when AERs from 79 neonates are classified by their actual electrode site of origin, the evoking stimulus, and the language performance group from which they were recorded, classification accuracies of 100% can be reached. For example, in one analysis of the 79 infants, the verbal performance score on the Stanford–Binet intelligence test at 3 years was used to identify and separate three groups of scores—those one standard deviation (117) above the mean of 105.4, those one standard deviation (94) below the mean, and the intermediate group with scores between these two groups. These groups included 22, 19, and 38 infants, respectively. The AERs from this sample of 79 neonates included those obtained in response to nine different auditory stimuli recorded over 6 scalp electrode sites. As in the D. L. Molfese and V. J. Molfese (1985) study, the AERs were recorded at 10 ms intervals over a 700 ms period following the onset of the acoustic stimuli. Electrodes were placed at left and right temporal sites, T_3 and T_4 (Jasper, 1958), as well as at left and right frontal (F_l, F_r) and parietal (P_l, P_r) locations midway between the external meatus and F_z and P_z, respectively. The electrodes were referred to linked ear references. These 4,266 AERs were normalized using a z-score transformation and then input to a principal components analysis procedure that employed a varimax rotation. Six factors accounting for 85.5% of the total variance were then selected and rotated. The resulting factor scores for each electrode site and stimulus event were then used as variables in a discriminant function procedure to distinguish the three language performance groups at 3 years. As indicated in Table 4.4, all seventy-nine 3-year-old children were correctly assigned to their language performance group based on their newborn AERs ($x^2 = 127.3, p < .0001$).

SUMMARY AND IMPLICATIONS

The studies described in this chapter illustrate a number of research issues of importance to the task of developing a predictive assessment tool for use with neonates and young infants. First, the perinatal variables have been shown to have some use in prediction of cognitive and language scores, particularly early in infancy. The simple correlations, multiple correlations, and attempts to classify subjects have shown that perinatal measures used alone have some power. Yet the amount of variance accounted for by perinatal measures alone is at best 43% and is not high enough to make confident predictions of the implications that these early measures have for later functioning. When perinatal risk measures are combined with social and demographic measures or used as individual predictors, the picture improves somewhat in that more studies report multiple correlations over 40%, yet the total amount of variance accounted for does not improve much beyond 60%. We have argued, and continue to argue here, that the problem is less one of little predictability for measures obtained in the neonatal period than one of selecting more sensitive measures. AER measures of neonatal participants have yielded high correlations with language scores in the preschool period. The discriminant function data reported previously that demonstrate 100% classification accuracy serve to reinforce this point.

TABLE 4.4
Classification Results

			Predicted Group Membership		
	Actual Group	*No. of Cases*	*1*	*2*	*3*
Group	1	22	22 100%	0 0%	0 0%
Group	2	38	0 0%	38 100%	0 0%
Group	3	19	0 0%	0 0%	19 100%

Note: Percentage of "grouped" cases correctly classified: 100%.

Second, although many studies are cross sectional, some issues such as the prediction of long-term development for individuals need to be addressed in longitudinal studies. Unfortunately, reports from longitudinal studies frequently do not contain information on the influence over time of the same variables on the measures under study. Further, many studies are focused on discriminating between groups (e.g., premature/low birthweight vs. full-term) rather than using analyses that permit assessment of predictivity. A few studies, described previously do provide information on the influence of variables over time. These studies, plus the current research reported from our laboratory, offer unique opportunities to observe and document the relative roles that perinatal, physiological, social/demographic, and environmental variables play in influencing development over the infancy and preschool years.

Third, advantages of a longitudinal approach to the study of cognitive and language abilities can be realized only if the measures are appropriate across the age range covered. Unlike some measures, which depend on the maturity of the infant's behavioral response, AER methods can be used with infants, children, and adults to provide measures of brain processing of stimuli from many modalities. Further, the AER methods have shown promise as providing a basis by which accurate predictions of language and cognitive status can be made even when the scales used for status assessments must change as the children mature.

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