Cardiac Responsivity to Speech in Normal and At-Risk Infants: Implications for Clinical Assessment

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Currently there are no definitive neurologic or intellectual test protocols for identifying at-risk infants and even existing protocols have limited diagnostic and prognostic value as they are most effective primarily in identifying obviously neurologically impaired infants (e.g., Gallagher & Bradley, 1972; Honzik, 1983). Identification of milder forms of central nervous system (CNS) dysfunction or developmental delay, therefore, often go undetected until they are manifested later within the framework of a more complex behavioral repertoire (e.g., Parmelee, Kopp, & Sigman, 1976). The development of more sensitive measures may illuminate more precisely the complex interaction between pre- and perinatal events, and current and later neurologic and developmental status, as well as facilitate earlier diagnosis of mild or subtle deficits thus ensuring continued monitoring and, where indicated, the provision of clinical intervention (Porges, 1983).

Many researchers studying early assessment suggest that earlier and more accurate diagnosis of at-risk infants, as well as prediction of later developmental outcome, could be achieved if contemporary assessment protocols adopted an information-processing model, similar to that underlining standardized psychometric tests of childhood cognition (Caron & Caron, 1981; Fagan & McGrath, 1981; Fagan & Singer, 1983). Employing methodologies and paradigms presently used in the study of early perception and cognition, the major thrust of this research effort has focused on the assessment of infants' pattern of visual attention and visual-recognition memory abilities (e.g., Caron & Caron, 1981; Cohen, 1981; Fagan & Singer, 1983; Miller et al., 1977; Miranda & Fantz, 1973, 1974). The results provide preliminary support for the diagnostic and prognostic value of these protocols in assessing ability to process visual information. Less research has been conducted regarding specific methods to assess early neurologic and/or perceptual-cognitive integrity in the auditory domain (e.g., Berkson, Wasserman, & Behrman, 1974; Dillon & Emory, 1984; Eisenberg, Coursin, & Rupp, 1966; Fox & Lewis, 1980, 1983; Fox, in press; Krafchuk, Tronick & Clifton, 1983; Kurtzberg et al., 1984); O'Connor, 1980; Schulman, 1969; Swoboda et al., 1978). The need for further research is of particular importance given that one of the characteristic long-term sequelae of high-risk infants is a deficit in language.

Furthermore, given the relatively early anatomic and neurophysiologic maturation of the mammalian auditory system, early deviant patterns of responsivity to auditory input may readily reflect subtle deficits in CNS function.

One well established measure of early attention to auditory input has been the infant's pattern of cardiac response (see Berg & Berg, 1979 for review). The presence and subsequent recovery of cardiac orienting (OR) [deceleration of heart rate (HR)] during stimulus presentation and its reoccurrence to presentation of a novel stimulus has been interpreted by many researchers as a reliable index of individual differences in attention and information processing. The corollary of this inference has led others to see it as a potential index of current neurologic and/or perceptual-cognitive functioning (e.g., Lewis & Brooks-Gunn, 1981; Porges, 1983). For example, Eisenberg et al. (1966) found that at-risk infants and those suspected of a neurological deficit took significantly longer to process auditory stimuli (i.e., habituate or show response decrement) compared to normal full-term infants. Eisenberg et al. interpreted this as evidence of disrupted brainstem organization.

More recently, Krafchuk et al. (1983), in comparing low- and high-risk preterm infants, found that the high-risk preterm infants were most compromised in their cardiac and behavioral responsivity to auditory stimuli, suggesting differences in information processing as a function, in part, of severity of neurological dysfunction secondary to perinatal history. Similarily, Fox & Lewis (1983) found that, when compared to healthy preterm infants, preterm infants diagnosed as having Respiratory Distress syndrome (RDS) in the postnatal period, demonstrated relatively inefficient information processing ability as evidenced by an absence of significant habituation of cardiac OR to speech stimuli. The RDS infants, unlike the relatively more healthy preterms, also did not discriminate between speech sounds. Fox & Lewis concluded that the RDS preterms presented with a com-

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promised pattern of attention, as evidenced by their cardiac response to the speech stimuli. Finally, O'Connor and her colleagues (O'Connor, 1980; O'Connor, Cohen & Parmelee, 1984) found that, for both full-term and preterm infants, their pattern of attention (cardiac OR) to auditory input significantly predicted standard cognitive test performance at 1½ and 5 years of age.

The preliminary results suggest that the use of a psychophysiologic measure like the cardiac OR may provide an early index of infants' attention to and processing of auditory input and as such it may provide an additional clinical tool in detecting at-risk infants. The need for further study of the relationship between attention, particularly to auditory input, and both concurrent and subsequent developmental status seems warranted. In particular, study of early attention patterns with at-risk infants, rated according to specific perinatal trauma (e.g., prematurity vs. RDS plus prematurity; asphyxia vs. prematurity plus asphyxia), may prove to be particularly informative.

This study was designed to compare various groups of at-risk and normal full-term infants in regard to their attention to and processing of speech stimuli by examining evidence of differential responsivity to various temporal parameters of speech stimuli. Although several measures of attention are being used (i.e., visual attention to source of sound, general bodily movement, startle responses, cardiac OR), to date only the pattern of cardiac OR has been computed and is the only measure of attention presented in this paper. It was hypothesized that, in contrast to healthy full-term infants, a subset of at-risk infants will present with a less mature response manifested in either an accelerated cardiac response to stimulus onset or a deceleratory cardiac OR whose recovery will take longer, possibly reflecting a slower rate of information processing. Finally, unlike many studies of this nature, we are retesting the same infants within their first year of life to determine whether attention (cardiac responsivity) patterns are specific to one age.

METHOD

Subjects

To date, 42 normal healthy full-term, six preterm, and five asphyxiated full-term infants have been tested at 3 months (± 1 wk) of age (corrected age for preterms) (see Table 1). The criteria for inclusion in the study were as follows:

Moderate asphyxia: a 1-min Apgar score of 4 to 6; less than 1 min of positive pressure breathing; heart rate less than 100 BPM; irregular and slow respiration; depressed tone with presence of minimal limb flexion; and blood pH of 7.0-7.1.

Severe asphyxia: 1-min Apgar score less than or equal to 3; less than 1 min of positive pressure breathing; heart rate less than 100 BPM: depressed tone with limp, flaccid limbs; pale skin colour; and blood pH of 6.8-6.9.

Table 1

3 Month Olds

Normal Full-term (n=42)

	Age (Days)		Gestational Age (GA)	Birth Weight (Bwt)
M	93.83		39.79	3633.69
SD	6.61		1.30	526.32

Premature (n=6)

	Corrected	Uncorrected		
M	98.33	126.33	35.17	2521.67
SD	9.89	16.07	1.60	357.23

Asphyxiated (n=5)

M	94.40		40.20	3654.00
SD	4.83		1.92	609.90

For both categories of asphyxia the infants were otherwise normal having experienced no other pre- or perinatal trauma.

Prematurity: less than 37 weeks gestational age (GA) and birth weight appropriate for their GA (AGA). They were otherwise normal infants having experienced no other significant form of birth trauma.

Full-term: greater than or equal to 37 weeks GA, experienced no form of birth trauma and had a birth weight appropriate for GA.

Table 2

6 Month Olds

Normal Full-term (n=17)

	Age (Days)		Gestational Age (GA)	Birth Weight (Bwt)
M	189.12		39.47	3581.18
SD	6.98		.94	393.30

Premature (n=4)

	Corrected	Uncorrected		
M	188.25	219.75	35.75	2502.5
SD	4.86	9.18	.5	313.30

Asphyxiated (n=3)

M	191.00		40.67	3796.67
SD	6.24		2.52	595.01

Of these 53 infants a small number of them have been, to date, retested at 6 months (± 1 week) of age (see Table 2). These ages were chosen as they mark major milestones or transition points in early neurologic and cognitive development and, therefore, were expected to more readily highlight possible discrepancies in pattern of cardiac response. The cardiac OR is considered to be more reliably elicited beginning at approximately 3 months of age (e.g., Gerber, 1979; Graham & Clifton, 1966; Graham & Jackson, 1970). The 6-month retest was conducted to determine whether a deviant cardiac OR at 3 months of age was transient and specific to that age or if it was a persistent pattern still evident at the more neurologically mature age of 6 months.

Stimulus

The stimulus was a computer synthesized version of the diphthong /ai/. Each vowel was 500 ms in duration and connected by a 500 ms linear transition (total duration 1500 ms). A full description of these stimuli (e.g., fundamental frequency, bandwidths for each format) can be found in Miller & Byrne (1983). The stimulus was presented in a pulsed fashion with a 500 ms inter-stimulus interval (ISI). A pulsed stimulus format was chosen as it has been consistently shown to be particularly powerful in eliciting a cardiac OR (Berg & Berg, 1979). It was reasoned that the absence of cardiac OR or presence of a deviant pattern of cardiac response will more likely reflect CNS involvement than specific stimulus features. The stimulus tape was prepared so as to include a 30 sec pre-stimulus baseline (no stimulation), a 60 ec period of stimulation, and a 60 sec post-stimulation period. On the second channel of the stimulus tape a 1 ms 1000 Hz square wave was recorded coincident with stimulus onset and offset to facilitate subsequent data transformation and computation.

Apparatus

The 70 dBA stimulus was presented via a speaker mounted directly in front of the infant (at eye level) at a distance of approximately 65-70 cm. The HR was monitored via miniature electrodes and the raw EKG data were output from the polygraph and recorded online to a computer interfaced with the polygraph. The infant was seated in a specialy equipped infant seat designed to detect magnitude to general bodily movement.

During testing, the infants behavior and behavioral state were monitored via a video camera connected to a video cassette recorder and a video monitor, to ensure that behavioral state fluctuation did not confound the recorded EKG pattern.

General Procedure and Design

The infant was prepared with HR electrodes affixed to the chest in a modifed Lead II configuration and then seated in the infant seat which was situated in the center of an IAC sound-attenuated chamber. Testing began when the infant was judged to be in a stable alert behavioral state. One research assistant was in the chamber, positioned behind the infant and out of his/her sight throughout the session. A second research assistant monitored EKG and behavioral state from outside the chamber. Each testing session consisted of a 30 sec pre-stimulus baseline, a 60 sec period of stimulation, and a 60 sec post-stimulation period.

Data Reduction: Heart Rate

The computer computed and stored the duration (in ms) of successive EKG interbeat (R-R) intervals for the entire session, and then converted the R-R data to beats-per-minute (BPM) for each second of the session. Difference scores were then computed by subtracting the BPM for each of the 30 stimulus seconds from that of the last pre-stimulus second. More frequently, no more than 15 sec of the cardiac response are examined; however, for illustrative purposes these preliminary data represent a lengthier period, allowing an examination of a more complete form of the cardiac response.

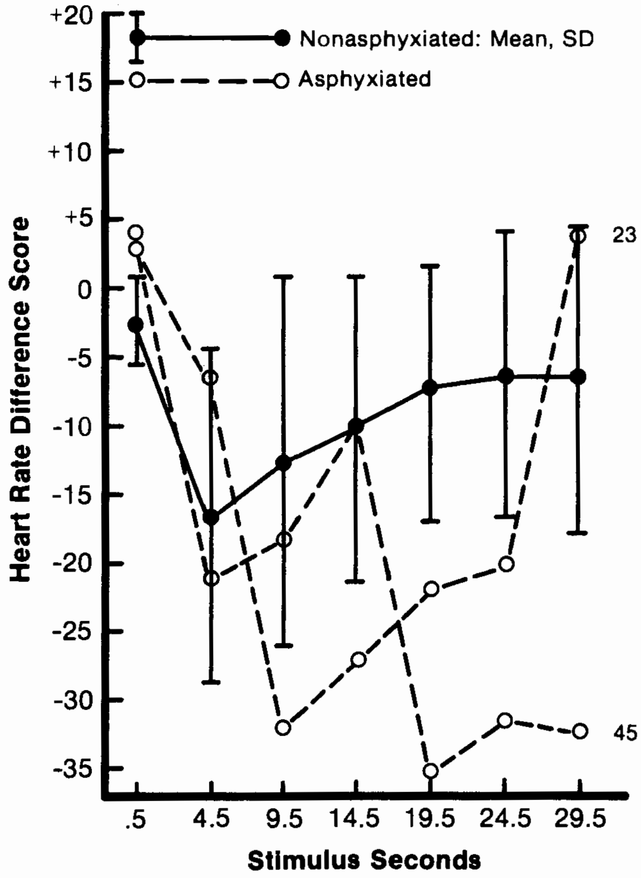

Figure 1: Heart rate (HR) difference scores (in BPM) for first 30 stimulus seconds plotted separately for 6-month-old infants with moderate (23) or severe (45) neonatal asphyxia. Mean and SD HR difference scores of nonasphyxiated infants are plotted.

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*By convention, each stimulus second is represented by a one-half second notation (e.g., 10 sec = 9.5 sec) so as to reflect the fact that the BPM represents the entire 1-second period.

Results

The data of at-risk infants are presented in case format for comparison with the normal full-term data which are presented with the mean and SD of Heart Rate (HR) difference scores at each second. The presentation of indiviudal cases may be of greater clinical value than the presentation of group data.

Asphyxia

3 Months. For illustrative purposes, Figure 1 shows the cardiac response of two of the asphyxiated infants seen at 3 months of age. Relative to the normal (nonasphyxiated) infants, Subject 23 demonstrated a cardiac OR with a greater latency of peak response (i.e., greatest magnitude of change in BPM); it occurred at 10* sec rather than at 5 sec, as was the case for the full-term infants. In addition, a lengthier exposure to the stimulus was necessary before appreciable habituation or decrement of the cardiac OR was evident. Subject 45, consistent with normal full-term infants, reached an apparent peak response at 5 sec; however, his trend of cardiac OR did not habituate. At 20 sec a second "peak" occurred and it was generally maintained throughout the 30 sec period.

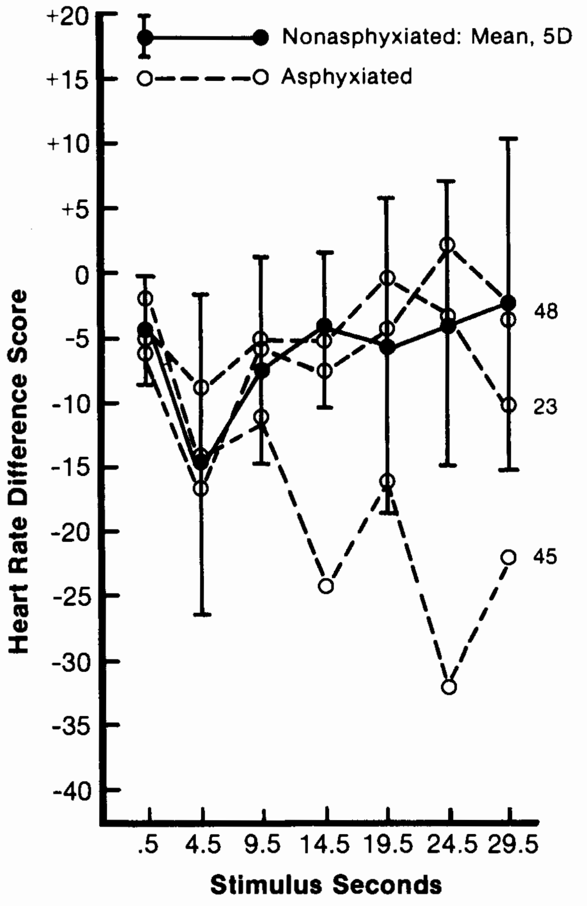

Figure 2: Heart rate (HR) difference scores (in BPM) for first 30 stimulus seconds plotted separately for 6-month-old infants with moderate (23, 48) or severe (45) neonatal asphyxia. Mean and SD HR difference scores of nonasphyxiated infants are plotted.

6 Months. One of the reasons for retesting infants at 6 months of age was to determine whether an unusual cardiac response at 3 months was transitory in nature, reflecting only a short-term consequence of perinatal history or whether it was still present at 6 months of age, suggesting more long-term effect. Both (asphyxiated) Subjects 23 and 45 were seen again at 6 months (see Figure 2). Subject 23 now presented with a cardiac OR very similar to the normal full-term infants, possibly suggesting that, although a relatively immature cardiac response was evident at 3 months, sufficient maturation of the nervous system may have occurred within the 3-mont test-retest interval, as evident by a more mature 6-month cardiac OR. Subject 45, however, continued to present a pattern of cardiac OR which was unlike that of the normal full-term infants. The peak response did not occur until 25 sec and it did not show appreciable decrement throughout the 30 sec period. Of interest is the fact that Subject 45 is the only infant seen to date who experienced severe asphyxia, as opposed to moderate asphyxia. Subject 48, not shown in Figure 3 but also seen at both 3 and 6 months of age, continues to present with a cardiac OR characteristic of the full-term infants, despite experiencing moderate perinatal asphyxia.

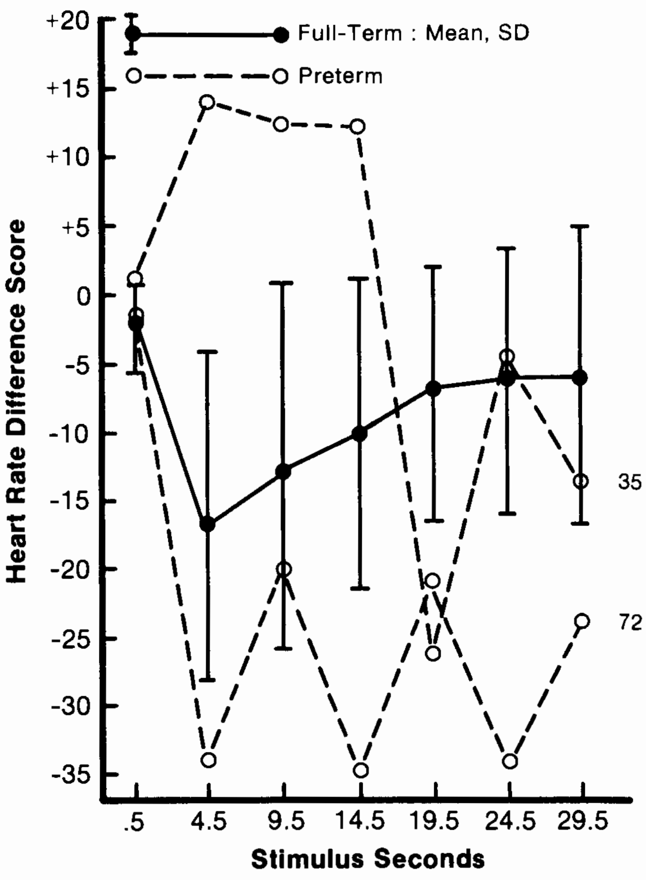

Figure 3: Heart rate (HR) difference scores (in BPM) for first 30 stimulus seconds plotted separately for 3-month-old (35, 72) premature infants. Mean and SD HR difference scores of full-term infants are plotted.

Prematurity

3 Months. In figure 3, two preterm infants are presented for comparison with the full-term infants. As is evident, Subject 35 did not demonstrate a cardiac OR but rather an accelatory response to stimulus onset. This accelatory response continued until 20 sec when a decrease in BPM was observed followed by response decrement. Although variability in response pattern is expected, generally the cardiac OR can be elicited by 3 months of age using pulsed stimuli. Subject 72 also presents with an unusual response pattern. Although he shows a peak response at 5 sec the cardiac OR is rather unstable and never does recover appreciably even by 30 sec of stimulation.

6 Months. In Figure 4, only Subject 72, who was shown in Figure 3 at 3 months of age, is now shown at 6 months. Unlike his unusual cardiac OR at 3 months, Subject 72 now presents with a pattern characteristic of the normal 6-month-old full-term infant, again suggesting that, although a relatively immature cardiac OR was evident at 3 months of age, Subject 72's 6-month response may reflect maturation of the nervous system over the 3-month interval. Subject 59, although not plotted in Figure 3 at 3 months of age, showed a 6-month cardiac OR characteristic of the full-term infants, while Subject 109's pattern at 6 months is globally in the range of the full-term infants, although it is somewhat variable over the 30-second period.

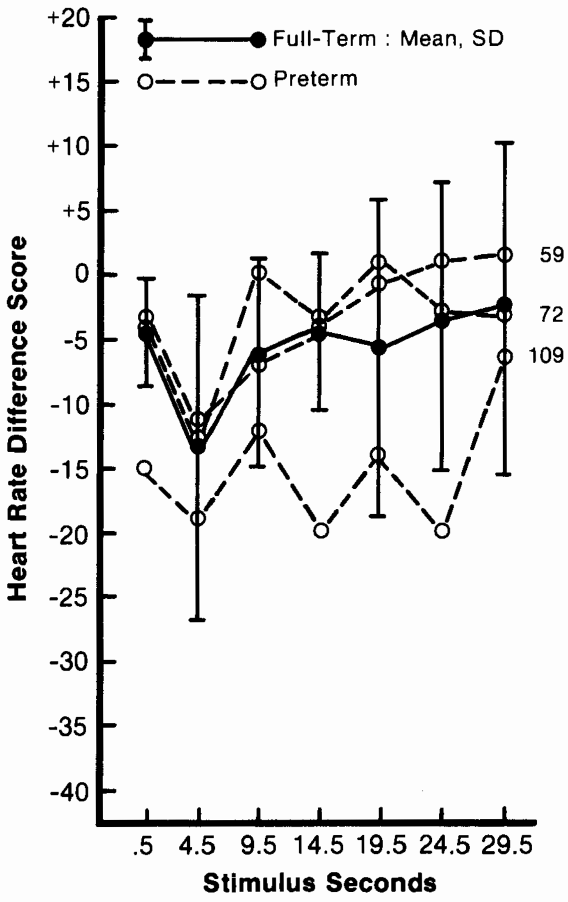

Figure 4: Heart rate (HR) difference scores (in BPM) for first 30 stimulus seconds plotted separately for 6-month-old preterm infants (59, 72, 109). Mean and SD HR difference scores of full-term infants are plotted.

Asphyxiated and Premature

Data for all of the asphyxiated and preterm infants seen at 3 months are plotted in Figure 5a and 5b, respectively, to present a more global picture to show the variability of individual attention to and processing of the speech stimuli, despite experiencing similar perinatal histories. In comparing the individual trends of the cardiac response of the asphyxiated and preterm infants, relative to the full-term infants, the more salient feature is that the asphyxiated infants generally have a pattern of cardiac OR quite similar to that of the full-term (nonasphyxiated) infant. In contrast, many of the preterm infants show more diversity in their individual response patterns; the individual cardiac responses are more scattered. One possible interpretations that the preterms have a less mature ability to attend to and process the speech stimuli. The preterms' relatively more immature cardiac response is rather interesting considering that they have been age-corrected for length of prematurity and, therefore, they are chronologically older than their full-term counterparts. Nevertheless, individual preterm infants displayed a pattern of cardiac response that was more scattered and possibly less mature at 3 months of age despite the fact that they share a similar perinatal history. The asphyxiated infants were born full-term and the only perinatal trauma is that of moderate, and in one case severe, perinatal asphyxia. Because the asphyxiated infants are full-term, their CNS maturity may more closely parallel that of the normal full-term infants, relative to preterms, and therefore they attend and process the speech stimuli in a more mature and efficient manner. Since the asphyxiated infants experienced their trauma after a normal gestational period, we can assume they experienced a prenatal develpmental course similar to the full-term. In contrast, preterm developmental course was interrupted. Therefore, the observed differences may reflect, in part, the different CNS status at ime of birth.

Discussion

Several observations may be made based on these preliminary data. First, as early as 3 months of age, individual at-risk infants responded to the presentation of a speech stimulus in a manner that may reflect delayed CNS maturation secondary to specific perinatal trauma. Such response patterns may be interpreted, in part, as differences in attention and information processing ability. Second, despite the presence of a deviant response pattern at 3 months of age, retesting at 6 months of age suggested that some of these individuals now presented with an age-appropriate response, possibly suggesting CNS maturation within the 3-month test-retest interval

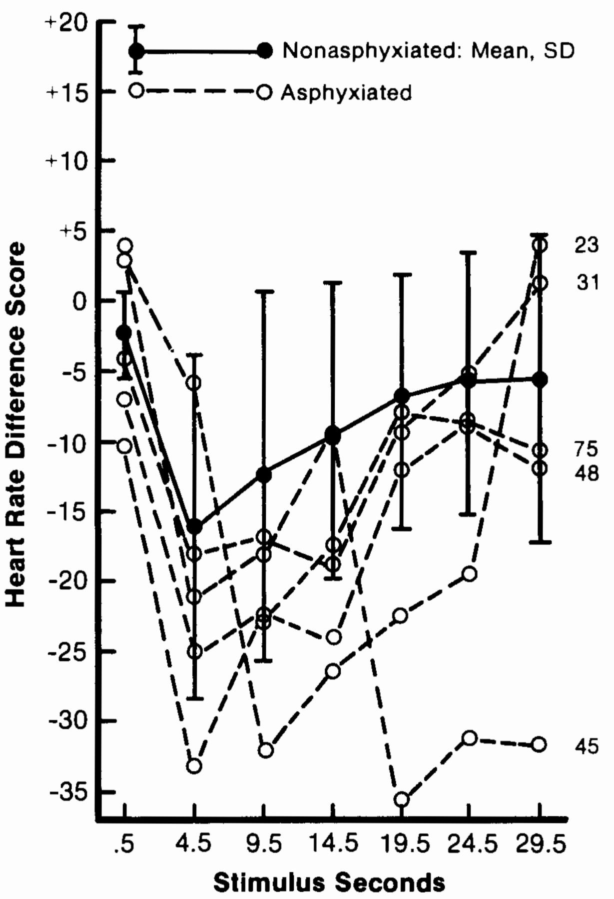

Figure 5a: Heart rate (HR) difference scores (in BPM) for first 30 stimulus seconds plotted separately for 3-month-old infants with moderate (23, 31, 48, 75) or severe (45) perinatal asphyxia. Mean and SD HR difference scores for nonasphyxiated infants are plotted.

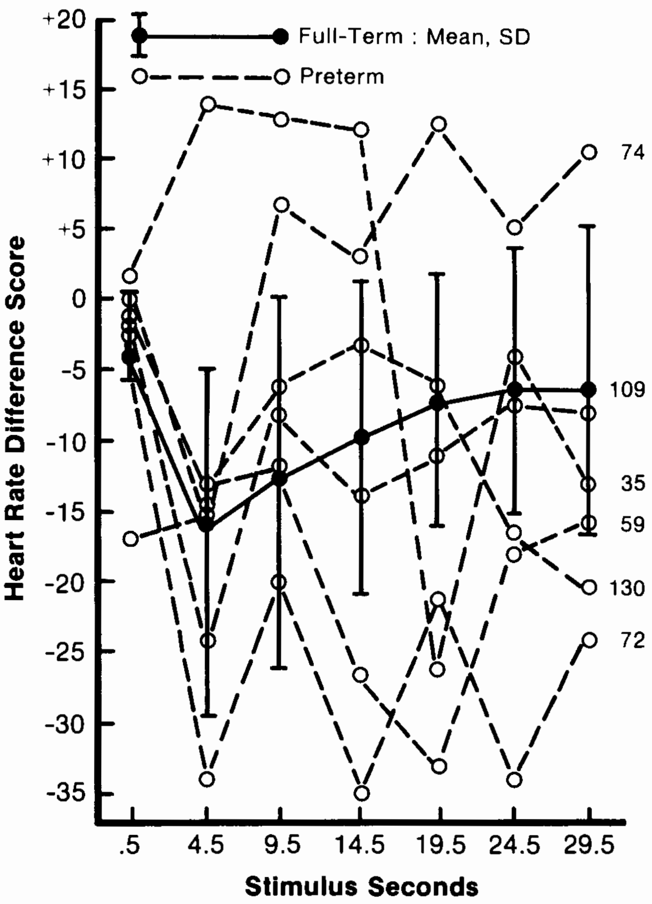

Figure 5b: Heart rate (HR) difference scores (in BPM) for first 30 stimulus seconds plotted separately for 3-month-old preterm infants (35, 59, 72, 74, 109, 130). Mean and SD HR difference scores for full-term infants are plotted.

and/or the transitory nature of the periantal experiences under study. The converse may be true, however, for those infants who continued to present with an unusual response pattern at 6 months. The persistence of a deviant response may be clinically significant and suggestive of the need for continued monitoring. These data underscore the need for repeated testing at different ages. Third, the observed differences in pattern of cardiac responsivity are of interest on two levels. The sensitivity of the cardiac response in reflecting current CNS maturity may be reflected in the comparison made between the asphyxiated and preterm 3-month-old infants with the normal full-term infants. For the asphyxiated full-term infants generally the form of their cardiac response was very similar to that of the nonasphyxiated full-terms. In contrast, the preterms displayed a much more scattered response form. Because the asphyxiated infants were also born full-term, their CNS maturity may more closely parallel that of the normal full-terms, relative to the preterm infants.

On an individual level of analysis, it is noteworthy that the preterms responded to the onset of the speech stimulus in an individual fashion despite the fact that they shared a similar perinatal history with little variability in gestational age or birth weight. These data may provide preliminary support for the important, although not always acknowledged, issue of individual adaptation to specific perinatal events. Prematurity and other remarkable perinatal events cannot be expected to have the same effect on all infants who experience them. The impact of such trauma is a function of the individual ability to recover from it.

If further study confirms the observation that cardiac responsivity is a relatively sensitive index of CNS integrity and, as such, an index of early attention and information processing abilities, what, if any, are the implications for early language acquisition? Certainly, the language to which young infants are exposed in their environments is obviously far more complex than the speech stimulus used in the present study. Many would rightly argue that generalization from these data concerning early acquisition for the at-risk infant is rather tenuous. However, generalizations may be warranted. Cardiac responsivity has been suggested to reflect CNS maturity and by inference attention and information processing abilities. If one considers the relative simplicity of the stimulus used in the present study, and yet the obviously deviant individual cardiac responses to its presentation, it is reasonable to question the ability of these at-risk infants to attend to and process the far more complex language stimuli experienced in their environments. Further study of this issue clearly would be informative.

One of the more important issues made salient by these data concerns the issue of individual vs group data. With the addition of more at-risk infants later group data analysis will be possible. However, is such an approach clinically valuable? When presenting data for normal healthy full-term infants, a general trend is expected with low to moderate variability within the data set. This was the case in our full-term group data. However, it is expected that at-risk infants as a group will have less conformity and therefore yield a higher level of variability in response pattern. For example, even the category of prematurity does not represent a homogeneous entity of perinatal experience and, more importantly, it does not allow one to estimate the specific level or form of impact on current or later developmental outcome for a particular infant, Indeed the data presented here confirm that, although several individuals experienced a similar perinatal history, their response patterns were quite individual and as such may reflect individual level of CNS maturity. It is clear from these data that we cannot continue to look *only* at group data to determine the possible adverse impact of perinatal history. Obviously, what will be of particular interest will be the developmental outcome of these infants at 12 and 24 months of age. These data are in the process of being collected.

Our data suggests an immature response pattern at one age does not necessarily persist at an older age, but for some children this is indeed the case and, for them, continued monitoring would appear to be important. A test protocol at different ages might incorporate a set of stimuli representing a broad spectrum of complexity. Also, studies designed to investigate individual discrimination of various parameters of speech stimuli may provide additional information allowing discrimination of individual CNS integrity, attentional, and information-processing abilities. Some of the recent research (e.g., Fox & Lewis, 1983; O'Connor, 1980; O'Connor et al., 1984) seems to suggest that tests of speech discrimination may in fact provide important information in this regard.

In summation, contemporary infant assessment protocols have generally low diagnostic and prognostic validity. Therefore, the need to develop alternative assessment strategies is warranted. The use of already existing measures of attention and information-processing of auditory input may be but one index to assist in early identification of at-risk infants.

References

Berg, W.K., Berg, K.M. (1979). Psychophysiological development in infancy: State, sensory function and attention. In J. Osofsky (Ed.), *Handbook of infant development*. New York: Wiley.

Berkson, G., Wasserman, G., & Behrman, R. (1974). Heart rate response to an auditory stimulus in preterm infants. *Psychophysiology, 11*, 244-246.

Caron, A.J. & Caron, R.F. (1981). Processing of relational information as an index of infant risk. In S.L. Friedman & M. Sidman (Eds.), *Preterm birth and psychological development*. New York: Academic Press.

Cohen, L.B. (1981). Examination of habituation as a measure of aberrant infant development. In S.L. Friedman & E.M. Sigman (Eds.), *Preterm birth and psychological development*. New York: Academic Press.

Dillon, D.J. & Emory, E.K. (1984). *Influences of perinatal risk on brainstem auditory evoked potentials of human neonates.* Paper presented at the biannual meeting of the International Conference on Infant Studies, New York.

Eisenberg, R.B., Coursin, D.B., & Rupp, N.R. (1966). Habituation to an acoustic pattern as an index of differences among human neonates. *Journal of Auditory Research, 6*, 239-248.

Fagan, J.F. & McGrath, S.K. (1981). Infant recognition memory and later intelligence. *Intelligence, 5*, 121-130.

Fagan, J.F. & Singer, L.T. (1983). Infant recognition memory as an index of intelligence. In L.P. Lipsitt (Ed.), *Advances in infancy research*. Vol. 2. New Jersey: Ablex.

Fox, N. (in press). Maturation of autonomic activity in preterm infants. *Developmental Psychology*.

Fox, N. & Lewis, M. (1980). Maturation and experience in preterm infants. In J. Gallagher (Ed.), New directions for exceptional children. Vol. 3. New York: Jossey Bass.

Fox, N. & Lewis, M. (1983). Cardiac response to speech sounds in preterm infants: Effects of postnatal illness at three months. *Psychophysiology, 20*, 481-488.

Gallagher, J.J. & Bradley, R.H. (1972). Early identification of developmental difficulties. In I.J. Gordon (Ed.), *Early childhood education*. Chicago: University of Chicago Press.

Gerber, S.E. (1979). Cardiovascular response to acoustic stimuli in one- two- and three-month-old infants. *Journal of the American Auditory Society, 5*, 123-129.

Graham, F.K. & Clifton, R.K. (1966). Heart rate change as a component of the orienting response. *Psychological Bulletin, 65*, 305-320.

Graham, F.K. & Jackson, J.C. (1970). Arousal systems and infant heart rate responses. In L.P. Lipsitt and H.W. Reese (Eds.), *Advances in child development and behavior*. Vol. 5. New York: Academic Press.

Honzik, M. (1983). Measuring mental abilities in infancy: The value and limitations. In M. Lewis (Ed.), *Origins of intelligence: Infancy and childhood*, (2 ed.). New York: Plenum.

Krafchuk, E.E., Tronick, E.F. & Clifton, R.K. (1983). Behavioral and cardiac response to sound in preterm neonates varying in risk status and a hypothesis of their paradoxical activity. In T.M. Field & A.M. Sostek (Eds.). *Infants born at-risk: Psychological and perceptual process*. New York: Grune & Statton.

Kurtzberg, W., Hilpert, P.L., Kreuzer, J.A., & Vaughan, H.G. (1984). Differential maturation of cortical auditory evoked potentials to speech sounds in normal full-term and very low birthweight infants. *Developmental Medicine and Child Neuropsychology, 26,* 466-475.

Lewis, M. & Brooks-Gunn, J. (1981). Visual attention at three months as a predictor of cognitive functioning at two years of age. *Intelligence, 5,* 131-140.

Miller, C.L. & Byrne, J.M. (1983). Psychophysiologic and behavioral response to auditory stimuli in the newborn. *Infant Behavior and Development, 6,* 369-389.

Miller, D.J., Ryan, E.B., Short, E.J., Reis, P.G., McGuire, M.D. & Culler, M.P. (1977). Relationships between early habituation and later cognitive performance in infancy. *Child Development, 48,* 658-661.

Miranda, S.B. & Frantz, R.C. (1973). Visual preference of Down's syndrome and normal infants. *Child Development, 44, 555-561.*

Miranda, S.B. & Frantz, R.C. (1974). Recognition memory in Down's syndrome and normal infants. Child Development, 44, 555-561.

O'Connor, M.J. (1980). A comparison of preterm and full-term infants on auditory discrimination at four months and on Bayley Scales of Infant Development at eighteen months. *Child Development, 51,* 81-88.

O'Connor, M.J., Cohen, S., & Parmelee, A.H. (1984). Infant auditory discrimination in preterm and full-term infants as a predictor of 5-year intelligence. *Child Development, 55,* 159-165.

Parmelee, A.H., Kopp, C.B., & Sigman, M. (1976). Selection of developmental assessment techniques for infants at risk. *Merrill-Palmer Quarterly, 22,* 177-199.

Porges, S.W. (1983). Heart rate patterns in neonates: A potential diagnostic window to the brain. In T. Field & A. Sostek (Eds.), *Infants born at risk: Physiological perceptual and cognitive processes.* New York: Grune & Stratton.

Schulman, C. (1969). Effects of auditory stimulation on heart rate in premature infants as a function of level of arousal, probability of CNS damage, and conceptional age. *Developmental Psychobiology, 2,* 172-183.

Swoboda, P.J., Kass, J., Morse, C.A., & Leavitt, K.A. (1978). Memory factor in vowel discrimination of normal and at risk infants. *Child Development, 49,* 332-339.