Published in final edited form as:

Dev Psychobiol. 2012 May ; 54(4): 383–400. doi:10.1002/dev.20597.

Focused Attention, Heart Rate Deceleration, and Cognitive Development in Preterm and Full-Term Infants

Julianne H. Petrie Thomas¹, Michael F. Whitfield^{1,2,3}, Tim F. Oberlander^{2,3}, Anne R. Synnes^{1,2,3}, and Ruth E. Grunau^{1,2,3}

Julianne H. Petrie Thomas: jpetrie@cw.bc.ca

¹Neonatal Follow-Up Program, Children's and Women's Health Centre of British Columbia, K3-188 4480 Oak Street, Vancouver, BC, Canada V6H 3V4

²Developmental Neurosciences & Child Health, Child and Family Research Institute, Vancouver, BC, Canada

³Department of Pediatrics, University of British Columbia, Vancouver, BC, Canada

Abstract

The majority of children who are born very preterm escape major impairment, yet more subtle cognitive and attention problems are very common in this population. Previous research has linked infant focused attention during exploratory play to later cognition in children born full-term and preterm. Infant focused attention can be indexed by sustained decreases in heart rate (HR). However there are no preterm studies that have jointly examined infant behavioral attention and concurrent HR response during exploratory play in relation to developing cognition. We recruited preterm infants free from neonatal conditions associated with major adverse outcomes, and further excluded infants with developmental delay (Bayley Mental Development Index [MDI < 70]) at 8 months corrected age (CA). During infant exploratory play at 8 months CA, focused attention and concurrent HR response were compared in 83 preterm infants (born 23–32 weeks gestational age [GA]) who escaped major impairment to 46 full-term infants. Focused attention and HR response were then examined in relation to Bayley MDI, after adjusting for neonatal risk. MDI did not differ by group, yet full-term infants displayed higher global focused attention ratings. Among the extremely preterm infants born <29 weeks, fewer days on mechanical ventilation, mean longest focus, and greater HR deceleration during focused attention episodes, accounted for 49% of adjusted variance in predicting concurrent MDI. There were no significant associations for later-born gestational age (29–32 weeks) or full-term infants. Among extremely preterm infants who escape major impairment, our findings suggest unique relationships between focused attention, HR deceleration, and developing cognition.

Keywords

premature; attention; heart rate; cognition; infant

INTRODUCTION

Focused Attention in Infants

A key milestone in the developing infant is acquisition of the ability to focus and sustain attention to objects and events. Between 6 and 12 months of age infants learn to allocate and increasingly control their attention to various stimuli (Colombo & Cheatham, 2006).

Focused attention requires cognitive effort, and enables the infant to resist distraction and to process information efficiently (Colombo & Cheatham, 2006; Kahneman, 1973). Due to marked increases in focused attention during this period of development, attention problems can be detected as early as 7–10 months of age (Colombo, 2001; Colombo, Harlan, & Mitchell, 1999; Lawson & Ruff, 2004b). Interestingly, it is also during this stage of development that attention associated with information processing, using measures of habituation and recognition memory, have been found to predict cognitive ability later in childhood (e.g., McCall & Carriger, 1993; Rose, Feldman, & Wallace, 1988; Rose & Orlian, 2001).

Concurrent with the increases in focused attention over the latter half of the first year, infants develop a rapid and strong response to novelty, and an intense interest in manually exploring novel objects (Graham, Anthony, & Zeigler, 1983; Ruff, McCarton, Kurtzberg, & Vaughan, 1984; Smith, Pretzel, & Landry, 2001). In infant behavioral studies, focused attention is readily identified by the infant's careful examining, fingering, or rotating the object or toy to inspect its specific properties or features (Ruff, 1986b; Ruff et al., 1984). Maturation changes in these "examining" behaviors as well as increases in focused attention during exploratory play are well established (Belsky & Most, 1981; Fenson & Kagan, 1976; McCall, 1974; Ruff, Saltarelli, Capozzoli, & Dubiner, 1992). When attention is focused, infants are increasingly able to process and recall details of stimuli (e.g., Colombo, 2001; Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001; Frick & Richards, 2001; Richards, 1997), and show longer latency to distraction to peripheral stimuli, compared to periods characterized by more casual interest (Lansink & Richards, 1997; Oakes & Tellinghuisen, 1994; Ruff, Capozzoli, & Saltarelli, 1996). Importantly, infant examining behaviors and focused attention during exploratory play have been related to concurrent and later cognition and attention from infancy through preschool age in both full-term infants (Ruff, Lawson, Parrinello, & Weissberg, 1990; Sullivan & Lewis, 1988) and preterm infants (Choudhury & Gorman, 2000; Lawson & Ruff, 2001; Lawson & Ruff, 2004b; Ruff et al., 1990).

Focused attention and active information processing can also be inferred from sustained decreases in heart rate (HR). Studies of full-term infants have been performed using joint behavioral and cardiac autonomic measures in paradigms of infant information processing, including 3-dimensional object exploration (e.g., Lansink & Richards, 1997). Typically, infants show a significant decrease in heart rate associated with orienting to external stimuli or objects of interest (Graham et al., 1983; Porges & Raskin, 1969), followed by a phase of sustained lowered heart rate that remains below pre-stimulus level with sustained focus (Richards & Casey, 1991). Healthy full-term infants exhibit increases in the organization of attention to objects across ages 6, 9, and 12 months, during phases of heart rate that are thought to reflect focused attention and information processing (i.e., sustained decreases in heart rate) (Lansink, Mintz, & Richards, 2000). In full-term infants, prolonged heart rate deceleration during object play is associated with less distraction (compared to periods of casual interest or other phases of heart rate); and temporal overlap of behavioral focus and heart rate deceleration is associated with even less infant distraction, suggesting active processing with greater neural integrity when the two coincide (Lansink & Richards, 1997). To our knowledge there are no studies that examine joint behavioral attention and heart rate change during exploratory play in infants born preterm.

Focused Attention as Related to Development and Risk

Processes involved in focused attention are sensitive to biological risk. Preterm infants are frequently less organized in their exploration, take longer to approach objects, show less manipulation, reduced behavioral focused attention, and may need additional experience for familiarization to occur (Landry & Chapieski, 1988; Ruff, 1986a, 1988; Ruff & Lawson, 1990; Ruff et al., 1984; Sigman, 1976). At school age, the high incidence of attention-related problems, learning and cognitive difficulties in children born preterm is well established (e.g., Pharoah, Stevenson, Cooke, & Stevenson, 1994; Rose & Feldman, 2000; Taylor, Klein, Minich, & Hack, 2000), with increased risk amongst the earliestborn children (e.g., Anderson & Doyle, 2003; Grunau, Whitfield, & Davis, 2002; Taylor, Hack, & Klein, 1998).

Cardiac autonomic regulation develops with neural control and has significant prognostic value. For example, maturation of prenatal heart rate variability has been shown to predict mental, motor and social outcomes to age 3 years in fetal studies (DiPietro, Bornstein, Hahn, Costigan, & Achy-Brou, 2007), and in studies of very preterm infants prior to discharge from the neonatal intensive care unit (NICU) (Doussard-Roosevelt, Porges, Scanlon, Alemi, & Scanlon, 1997; Doussard-Roosevelt, McClenny, & Porges, 2001). Studies conducted in the first year of life suggest differences in cardiac response patterns, with preterm infants showing poorer regulation of sinus cardiac rhythm (i.e., lower parasympathetic effects) in response to surprise (DiPietro, Porges, & Uhly, 1992), and during more effortful attention tasks (Stroganova, Posikera, & Pisarevskii, 2005; Stroganova, Posikera, Pisarevskii, & Tsetlin, 2006).

Risk of Prematurity in Relation to Developmental Problems

The preterm infant makes the transition to the extrauterine environment sometime during the third trimester of “fetal life,” when many of their physiological systems are immature and when their brain systems undergo rapid development and integration. The infant’s developing systems may be disrupted differentially according to the timing of the preterm birth. For infants who make the transition to the NICU environment at extremely low gestational ages, many experience significant neonatal illnesses and undergo intensive treatments during NICU care, all of which occur during a period of relative vulnerability of the preterm infant’s developing brain (e.g., Weindling, 2010). Infants with multiple neonatal risk factors including postnatal infections are at greater risk for problems in neurodevelopment; they spend significantly more days on mechanical ventilation (Stoll & Hansen, 2003), and would likely have more biologically significant events including hypoxia, acidosis and hypotension, that may contribute to increased risk for later attention and cognitive difficulties (Stevenson et al., 1998). The routine postnatal NICU care that is necessary for preterm infants, at a time when their systems are immature for extra-uterine life, has been suggested to alter the development of infant regulatory systems, particularly for higher-risk preterm infants (Als, Lester, Tronick, & Brazelton, 1982; Graven et al., 1992; Grunau, 2002). More specifically, the adaptive challenges placed on the extremely preterm infant, may result in subtle or marked changes in neurobehavioral response and altered development in systems of arousal and regulation (e.g., Grunau, 2003). The importance of regulating state and arousal underlies the development of control processes such as attention regulation (Rothbart, 1989). The functional integrity of attention processes is mediated by multiple brain regions, networks, and circuitry, therefore ineffective signaling at any level can lead to poor regulation of attention (Casey, 2007; Mesulam, 1981; Posner & Petersen, 1990).

The nature and development of attention problems in children born very preterm need to be more clearly understood. Attention problems found in preschool and older children born preterm are frequently described as attention deficit hyperactivity disorder (Bhutta, Cleves,

Casey, Craddock, & Anand, 2002; Mick, Biederman, Prince, Fischer, & Faraone, 2002; Stjernqvist & Svenningsen, 1995; Szatmari, Saigal, Rosenbaum, Campbell, & King, 1990). However some propose that the attention problems in children born preterm may be more clearly understood as problems of self-regulation (Grunau, 2003; Robson & Cline, 1998; Robson & Pederson, 1997) or of adaptive functioning (Schothorst & van Engeland, 1996). Consistent with this concept, many very preterm children have difficulty self-regulating in structured situations, need ongoing adult support and feedback in learning or evaluation settings, and show significantly more “backing off” behaviors during cognitive assessment (Grunau, 2003; Whitfield, Grunau, & Holsti, 1997).

Considering the extent of cognitive and attention-related problems in children born very preterm, there is a comparatively scant literature on the early development of attention regulation, using ecologically appropriate methods such as infant exploratory play, that examine behavioral attention together with related cardiac autonomic response. Behavioral attention and integrity of physiological response both reflect the function of the developing nervous system, and both can be viewed as indirect measures of the generalized state of brain arousal-activation during infant attention (Richards, 2001, 2003). In the present study, we investigated behavioral focused attention and concurrent heart rate (HR) response in preterm and full-term infants during exploratory play, at 8 months corrected age (CA). We hypothesized that: (1) Preterm infants, compared to full-term infants will show: (a) poorer focused attention behaviors, including lower ratings of global focused attention and shorter duration of focused attention; (b) patterns of HR that reflect higher arousal (higher mean HR prior to, and during toy exploration) and, at a more detailed level of analysis, less HR deceleration during behaviorally coded focused attention; (2) In the preterm infants, after adjusting for neonatal risk factors (illness severity on Day 1 after birth [SNAP-II], GA, days of mechanical ventilation), better focused attention and greater HR response (deceleration) during behaviorally defined focused attention will be associated with higher cognitive functioning.

METHODS

Participants

Participants comprised 83 preterm infants (44 boys, 39 girls), and 46 full-term controls (23 boys, 23 girls), all seen at 8 months corrected age (CA), following strict exclusion criteria. Preterm infants, 32 weeks gestation or less, were recruited between 2001 and 2004 from the major tertiary neonatal intensive care unit (NICU) unit in BC, Canada, and healthy full-term infants were born at the same center and recruited through their pediatricians, and were part of a larger longitudinal program of research on early pain-related stress and neurodevelopment of preterm infants (e.g., Grunau et al., 2007, 2009). Recruitment in the NICU targeted 108 preterm infants without major congenital anomaly, severe brain injury on neonatal ultrasound (no intraventricular hemorrhage grade III or IV and/or cystic periventricular leukomalacia), or mother's report of illicit drug use (e.g., cocaine, heroin) during pregnancy, to minimize risk of major neurosensory, motor or cognitive impairment. Additionally, infants who were not born with birth weight appropriate for gestational age (AGA) were excluded. At the time of the 8-month assessment, from the sample of 108 preterm [55 boys and 53 girls] and 61 full-term [31 boys and 30 girls] infants eligible for the present study, 25 preterm infants (8 boys, 17 girls) and 15 full-term infants (8 boys, 7 girls) were excluded. Reasons for exclusion at the time of the 8-month assessment included: excessively fussy/crying/gross movement artifact (14 preterm infants [5 boys, 9 girls], 8 full-terms [3 boys, 5 girls]); technical problems including poor HR signal or problems with video recording (4 preterm infants [1 boy, 3 girls], 5 full-terms [4 boys, 1 girl]). Of the 25 preterm and 15 full-term infants excluded at the time of the 8-month assessment, 4 (2%) preterm (1 boy, 3 girls) and 2 (3%) full-term (1 boy, 1 girl) infants did not complete the

Bayley Mental Scale due to stranger anxiety, sickness, parental time-constraint or fatigue. From assessment on the Bayley-II at 8-month CA, a total of 4 (4%) preterm infants (2 boys and 2 girls) obtained a Bayley MDI Index score <70. Of these infants, 1 preterm boy, with MDI <70, was excluded due to excessive fussiness throughout toy exploration, and 3 infants (2 girls, 1 boy) were excluded solely on the basis of low MDI. The final sample comprised 83 unimpaired preterm infants (44 boys, 39 girls), and 46 full-term controls (23 boys, 23 girls).

Procedure

The study was approved by the University of British Columbia Clinical Research Ethics Board, and parent written consent was obtained. All infants underwent the same procedures in the same order. The infant and parent were brought to a quiet testing room equipped with an unobtrusive ceiling-mounted camera to record infant behavior. Three disposable Ag-AgCl electrodes were placed in a triangular pattern on the infant's anterior chest for recording of cardiac electrical activity. The infant was seated in a high-chair equipped with a tray upon which they could explore toy stimuli. The parent was seated next to, but out of direct view of the infant and asked to refrain from engaging the infant. Four novel toys were presented sequentially (90 s each), according to methods described in previous studies (e.g., Ruff, 1986b); heart rate and video recordings were acquired continuously. Cardiac signal acquisition was computer-synchronized with the video recordings of behavior. Following the infant's exploration of toys, the leads were removed from the infant's chest and the Bayley Scales of Infant Development-2nd Edition (BSID-II) were administered according to standard methods by an occupational therapist or physical therapist.

Measures

Neonatal, Infant, and Family Characteristics—Prospective infant medical and nursing chart review was carried out by a neonatal research nurse, including but not limited to birth weight, gestational age, days of mechanical ventilation, and early illness severity using the Score for Neonatal Acute Physiology (SNAP-II) (Richardson, Corcoran, Escobar, & Lee, 2001). Demographic family information was obtained by questionnaire.

Focused Attention—Infant focused attention was coded second-by-second throughout the infant's exploration of four novel toys (each 90 s) using Noldus Observer software (version 5.0), from videotape by two trained independent raters, according to established methods (Ruff, 1986a; Ruff & Lawson, 1990; Ruff et al., 1984). Raters were blinded to all the infant and family information. Only periods of focused attention ≥ 2 s were coded, due to problems of using focused episodes <2 s (Lansink & Richards, 1997), and defined as “looking that occurs simultaneously with a deliberate manipulation of the object and serious facial expression,” and a “general decrease in extraneous body movements” (see Fig. 1) (e.g., Ruff, 1986b; Ruff & Lawson, 1990). Inter-rater reliability was established on a random selected 20% of the sample, for the four toys with intra-class coefficient .83 for total duration of focused attention, and .72 for second-by-second coding. Duration of focused attention for each of the 90 s toy exposures and across all four toys was obtained so that comparisons could be made to other studies. From the timed focused attention data, as a primary measure, the longest period of focused attention for each of the four toys was determined and averaged to reflect the mean longest focus for four toys (Longest FA).

Separately, global focused attention (Global FA) was rated for each of the four toy sequences from video by two separate coders, using guidelines for a 5-point scale with ratings of 1 (relatively little engagement, no signs of concentration) to 5 (an exceptionally high level of object engagement, with clear and prolonged periods of absorption to the object) (Lawson & Ruff, 2001). The global ratings for each of the toys, summarized in a

single score, incorporate multiple cues including facial expression, steadiness of gaze, affect, and proximity of toys relative to eyes, are reliable, and are correlated with timed measures of focused attention (Lawson & Ruff, 2001). According to Lawson and Ruff's procedures, initial ratings based on a forced choice, using only whole numbers from 1 to 5, were accepted if exact and re-rated if they differed between the two coders. If re-rated scores differed by 1 point, a mid-point score was used. If the scores from the two raters differed by more than 1 point, a third trained coder settled the difference (four toys for 129 infants = 516 trials each rated by 2 coders: 68% perfect agreement, 31% of trials re-rated, <1% more than 1 point). A global rating for an individual toy could therefore consist only of whole or mid-point numbers between 1 and 5.

Thus each infant was timed for their longest focus during the four 90 s toy exploration sequences and further, each infant also had global ratings of focused attention for the four toys, both of which were then averaged (Global FA and Longest FA). Because Global FA resulted from averaging scores between 1 and 5 with some mid-point scores, ratings could result in a whole number from 1 to 5, or numbers ending in .5, or .75. Both Global FA and Longest FA were included in the main analyses in the present study, as they represent different constructs (average global quality vs. average longest time (s) of focused attention while examining toys), and are important at different levels of analyses. Finally, the distributions of the 5-point global ratings were determined to compare our results to those of Lawson and Ruff (2001) for very low birth weight 7-month infants. This method considers the distributions of scores, therefore ratings consisted of whole numbers from 1 to 5, or mid-point numbers (all four toys: 1 or 1.5; at least one rating of 2 and no rating >2.5; at least one rating of 3 and no rating >3.5; at least one rating of 4 and no rating >4.5; at least one rating of 5). The four novel toys (see Fig. 2) were unique to this study and of sufficient complexity to elicit interest, but not so interesting that they failed to differentiate more attentive from less attentive infants (H. A. Ruff, personal communication, March 2001).

Infant State and Activity—Infant state during toy exploration (calm to very fussy/crying), and infant activity (not active to very active) were rated from videotape using 3-point scales, by coders blinded to all infant information.

Infant Heart Rate (HR)—HR was recorded continuously online and processed using custom software (Boston Medical Technologies, 1996). There are reports of elevated heart rate in preterm infants compared at term-equivalent to full-term infants, prior to discharge from neonatal intensive care (Field, 1979; Krafchuk, Tronick, & Clifton, 1983; Rose, Schmidt, & Bridger, 1976), and some evidence that differences may persist beyond the newborn period (Henslee, Schechtman, Lee, & Harper, 1997). Mean HR was calculated for the 90 s period prior to the presentation of four novel toys (Pretest HR), and for each of the four 90 s toy exploration sequences (Mean HR Toy 1; Mean HR Toy 2; Mean HR Toy 3; and Mean HR Toy 4).

Separately, in order to link HR response to behaviorally defined focused attention episodes, custom software (Giles & Thomas, 2007) was used to measure HR on a second-by-second basis, in relation to each specific behaviorally-coded episode of focused attention ≥ 2 s. HR response during focused attention was defined as the response in beats per minute (bpm) from a 2.5 s baseline starting 5 s before each behaviorally identified focused episode, to mean HR *during* focused attention. These HR responses calculated for each of the infant's focused attention episodes were averaged (HR Response FA). The timing of heart rate response from the 2.5 s baseline starting 5 s prior to each focused attention episode, not only provided a proximal baseline preceding the onset of focused attention, but also effectively removed stimulus orientation time from the measure, which often begins during more casual forms of attention that precede focused attention (Lansink et al., 2000). This allowed us to

ascertain HR response as a function of focused attention without the confound of an orienting response. Figure 3 provides an example of HR bpm synchronized with an infant's behaviorally defined focused attention episodes during a 90 s toy exploration sequence. Figure 4 shows the 2.5 s baseline prior to onset of focused attention. Since HR Response FA was calculated specifically relative to the behavioral focused attention episodes, HR Response FA could not be calculated for those infants who did not show any focused attention episodes ≥ 2 s.

Cognitive Development—Development was assessed by an occupational therapist or physical therapist using the Bayley Scales of Infant Development (BSID II) Mental Development Index (MDI) (Bayley, 1993). All examiners were blinded to the infant attention ratings, and the large majority of infants were seen in our research setting, blinded to all medical background. A small subset of infants born <800 g birthweight were administered the Bayley in the hospital Neonatal Follow-up Program at the same site, by clinical staff blinded to attention ratings and detailed medical information, but aware of preterm status.

Statistical Analysis

First, mean HR during the 90 s Pretest and each of the four 90 s exploratory Toy Sequences was examined in a 3-way repeated measures ANOVA (Group [Preterm, Full-term] by Gender [Boys, Girls] with Toy Sequence [Pretest, Toys 1–4]) as a repeated measure. Data were examined for sphericity, and when present, Greenhouse-Geisser values were used to determine significance. Univariate ANOVAs by Group (Pre-term, Full-term) and Gender were conducted for attention behaviors (duration of focused attention for individual toys and across all toys, mean rating of global focused attention [Global FA] during the infant's exploration of the four novel toys, mean longest focus of attention [Longest FA]), and for mean HR response during focused attention episodes (HR Response FA). Pearson correlations were used to examine associations between (1) behavioral focused attention indices (Global FA, Longest FA) and HR Response FA, separately by Group, and (2) between neonatal risk factors and behavioral and HR indices, for the Preterm infants only. Hierarchical linear regressions were conducted for the Preterm infants only, to examine the contribution of HR Response FA and focused attention (Longest FA, Global FA) over and above neonatal factors of early illness severity [SNAP-II], days of mechanical ventilation and GA, in predicting Bayley MDI. The Full-term group did not have neonatal risk; therefore Pearson correlations were used to examine relationships only between focused attention behaviors, HR indices and Bayley MDI. A significance level of $p < .05$ was used for all statistical tests.

RESULTS

Preliminary Analyses

Infant and Family Characteristics—Table 1 shows the expected differences between Preterm/Full-term infants in birth weight and gestation. Bayley MDI did not differ in Preterm compared to Full-term infants. As seen in Table 1, in this Canadian sample, parents in both groups had relatively high education levels, despite a statistically significant difference. There were no significant correlations between maternal education ($p > .25$), or paternal education ($p > .15$), and behavioral focused attention (Global FA or Longest FA), HR Response FA, or Bayley MDI in either the Preterm Full-term groups, and therefore parent education was not considered further.

Infant Activity—On 3-point ratings of calm to very active, there were no significant mean differences for activity level over the infant's exploration of the four toys between Preterm ($M = 1.6$, $SD = .48$) and Term-born infants ($M = 1.4$, $SD = .44$), $t(127) = 1.4$, $p = .16$.

Duration of Focused Attention—Across the 6-min exploration of exploring all four toys (90 s each), the Preterm Group focused attention for total duration of 56.3 s (45.3), while the Full-term Group showed a total of 64.3 s (44.3), which did not differ significantly ($F[1,128] = .81$, $p = .37$). Further, there were no significant Preterm/Full-term Group differences in duration of focused attention for each of the individual four toys explored ($p > .1$ for each of the 4 toy stimuli). In the Preterm Group mean duration of focused attention for individual toy stimuli was 7.4 s (8.7), 17.7 s (15.1), 13.4 s (13.2), and 17.8 s (18.8) for Toys 1–4 respectively and for the Full-term Group 7.8 s (8.9), 21.7 s (17.2), 17.7 s (14.8), 17.1 s (14.3) respectively. Both the Preterm and Full-term groups both spent more time exploring Toys 2, 3, 4 compared to Toy 1, which may reflect complexity of the toy, level of attractiveness, or order of presentation. There were no Gender differences in total duration of focused attention ($F[1,128] = 3.2$, $p = .08$), and no Group by Gender interaction ($F[1,128] = 2.0$, $p = .16$).

Infants With No Timed Focused Attention Episodes ≥ 2 s—Of the 83 Preterm and 46 Full-term infants, $n = 4$ Preterm infants (2 girls, 24 and 29 weeks GA; 2 boys, 29 and 32 weeks GA) did not show any focused attention episodes (i.e., duration ≥ 2 s) during their exploration of the four novel toys. For these infants Longest FA was coded as 0 s. These infants were included in all analyses (i.e., $n = 83$ Preterm infants were compared to $n = 46$ Full-term infants), except analyses using HR Response FA that were based on $n = 79$ Preterm versus $n = 46$ Full-term infants.

Distributions of 5-Point Ratings of Focused Attention (Lawson et al., 2001)—The distribution of global ratings across all 4 toys according to Lawson and Ruff (all ratings of 1 or 1.5; at least one rating of 2 and no rating > 2.5 ; at least one rating of 3 and no rating > 3.5 ; at least one rating of 4 and no rating > 4.5 ; at least one rating of 5) did not differ significantly between the Preterm (2%, 19%, 49%, 24%, 5%) and Full-term (0%, 11%, 44%, 28%, 17%) infants respectively ($F[4,129] = 7.84$, $p = .10$). These groupings of ratings were not used in further analyses, but allowed for direct comparison with ratings of 7-month-old very low birth weight infants in an earlier study (Lawson & Ruff, 2001), and provide new data on distributions of the 5-point ratings for full-term controls at 8 months of age, not previously reported.

Mean HR (Pretest and Toy 1–4 Sequences [90 s Each])—The pattern of mean HR for the 90 s pretest, and during each of the four 90 s toy exploration sequences, was examined in a 3-way repeated measures ANOVA (Group [Preterm, Full-term] by Gender [Boys, Girls], with Toy Sequence [Pretest, Toys 1–4]) as a repeated measure. There was a significant effect of Toy Sequence ($F[4,323] = 37.95$, $p < .0001$); post hoc comparisons showed a significant decrease in mean HR from the Pretest to Toy 1 ($p < .0001$). HR increased slightly over the three subsequent Toys ($p < .0001$). Changes in mean HR from Pretest across the four Toys are shown in Figure 5. Mean HR did not differ significantly by Group ($F[2,125] = 1.01$, $p = .32$), or Gender ($F[1,125] = 1.80$, $p = .18$), and there were no significant interactions ($p > .5$). In summary, the pattern of mean HR measured across five 90 s periods (total 7.5 min) was consistent across Group and Gender. There was a significant mean HR change, from the Pretest to mean HR during the infant's first exploration sequence (Toy 1), followed by a slight increase in mean HR over the infant's subsequent exploration of the remaining three toys. This data provides information about the mean HR pattern and was not used in further analyses; see Figure 5.

Main Analyses

Behavioral Focused Attention

Mean global ratings of focused attention (Global FA): Full term infants were rated significantly higher than Preterm infants on mean global focused attention (Global FA) ($F[1,125] = 5.94, p = .016$). As noted in Table 2 the mean Global FA was 2.57 (.71) for the Preterm infants and 2.9 (.80) for the Full-term infants. There was a main effect of Gender; Global FA was higher for girls ($F[1,125] = 4.13, p = .044$), but no Group by Gender interaction ($p > .10$).

Mean longest focused attention: There were no Preterm/Full-term Group differences on mean longest focused attention (Longest FA) ($F[1,125] = .50, p = .48$); see Table 2. Gender effects for Longest FA were not statistically significant; Longest FA ($F[1,125] = 3.18, p = .08$) and no Group by Gender interaction ($p > .50$).

Heart Rate Response During Focused Attention Episodes

HR Response FA: When examining detailed HR response (i.e., HR from a 2.5 s baseline starting 5 s prior to focused attention, to mean HR *during* the infant's behaviorally defined focused attention), for HR response averaged across each of the infant's focused attention episodes (HR Response FA), there was no significant Preterm/Full-term Group difference ($F[2,121] = .00, p = .99$). Girls showed a trend for more consistent HR deceleration (HR Response FA) ($F[1,125] = 3.18, p = .08$). There was no Group by Gender interaction effect ($p > .10$).

HR deceleration versus no HR deceleration/or acceleration: There was no significant Preterm/Full-term Group difference in the proportion of infants who showed HR deceleration (versus no deceleration/or acceleration) for HR Response FA (Preterm 60%; Term 63%; $\chi^2(1, N = 125) = .15, p = .70$), mean longest focus (Longest FA), (Preterm 66%; Term 52%; $\chi^2(1, N = 125) = 2.2, p = .13$), or the single longest focus (Preterm 89%; Term 80%; $\chi^2(1, N = 125) = 1.6, p = .21$).

Associations Between Focused Attention, HR Response FA, and MDI—Global FA was significantly correlated with Longest FA for the Preterm and Full-term infants ($r = .64, p < .0001$; $r = .68, p < .0001$ respectively). Global FA and Longest FA were correlated with HR Response FA for the Full-term infants ($r = -.30, p = .046$; $r = -.31, p = .04$, respectively), but not for the Preterm infants ($p > .5$). Longest FA was correlated with Bayley MDI ($r = .27, p = .012$) for Preterm, but not Full-term infants; see Table 3.

Associations Between Neonatal Risk Factors and Focused Attention, HR Response, MDI—For the Preterm infants, none of the neonatal risk factors (GA, early illness severity [SNAP II], days on mechanical ventilation) were significantly correlated with Global FA ($r = -.01, p = .96$; $r = .13, p = .24$; $r = -.02, p = .88$ respectively), nor were GA, SNAP II, or days on mechanical ventilation correlated with Longest FA ($r = .02, p = .83$; $r = .10, p = .35$; $r = -.09, p = .40$ respectively), or Bayley MDI ($r = .11, p = .31$; $r = -.02, p = .83$; $r = -.14, p = .22$ respectively). However, higher early illness severity (SNAP II, Day 1 scores) and duration of mechanical ventilation were significantly correlated with greater HR deceleration (HR Response FA $r = -.26, p = .019$; $r = -.43, p = .0001$ respectively). Higher GA (later gestational age at birth) was related to less HR Response FA reflecting less deceleration ($r = .25, p = .025$).

Predicting Cognitive Development (Bayley MDI) at 8 Months—To address the second hypothesis, hierarchical linear regressions were conducted to determine whether

Average HR Response during focused attention (HR Response FA), Global Focused Attention (Global FA) or Longest Focus (Longest FA), contributed to predicting concurrent cognitive development (Bayley-II MDI), over and above neonatal factors of illness severity (SNAP-II Day 1) and Days of Mechanical Ventilation. The two neonatal risk factors were entered in Block 1, followed by mean HR response during focused attention (HR Response FA) in Block 2, and either Global FA or Longest FA in Block 3. Since Global FA and Longest FA were highly correlated ($r = .64, p < .0001$), the regressions were carried out with only one of these variables in Block 3.

Prior to hierarchical regression analysis to predict MDI, relationships among the neonatal factors were examined to check for multicollinearity. Days on mechanical ventilation was significantly correlated with GA ($r = -.76, p < .0001$), and SNAP-II ($r = .49, p < .0001$); GA and SNAP-II were also significantly correlated ($r = -.56, p < .0001$). Given this overlap, and in order to evaluate effects of degree of prematurity (GA) and days on mechanical ventilation, regressions were carried out separately for $n = 33$ extremely low gestational age (24–28 weeks [ELGA]) and the $n = 46$ very low gestational age (29–32 weeks [VLGA]) infants.

A summary of comparisons of predictor variables and MDI between the two preterm subgroups (ELGA; VLGA) is provided in Table 4. As expected a greater proportion of ELGA infants underwent mechanical ventilation (ELGA 91%, range 0–98 days; VLGA 35%, range 0–15 days). Additionally, GA was highly correlated to days ventilated in the ELGA subgroup ($r = -.76, p < .0001$), but not in the VLGA subgroup ($r = -.12, p = .40$). Therefore in the prediction model, days of mechanical ventilation is independent of GA in the VLGA group, but not ELGA group. As seen in Table 4 there were no significant ELGA/VLGA subgroup differences in Global FA, Longest FA, or MDI. However there were significant differences in HR Response FA with ELGA infants showing greater and more consistent HR deceleration during focused attention episodes. Figure 4 illustrates the averaged HR response by gestational age group, preceding, and over a 5 s period following the onset of focused attention. It should be noted that Figure 4 represents only a general pattern of HR response concurrent with focused episodes, reflecting the majority of focused attention episodes (i.e., focused attention may have been shorter or exceeded 5 s for individual episodes). Further, in comparing the ELGA and VLGA infants, the mean 3-point ratings of activity level (calm to very active) for the infant's exploration of the four toys did not differ (ELGA: $M = 1.6, SD = .43$; VLGA: $M = 1.6, SD = .51$) [$t(77) = -.002, p = .99$].

In the linear regression on the ELGA infants, in the first block SNAP II and Days Ventilated did not predict MDI ($p > .5$). However, when HR Response FA was added in the second block, both Days Ventilated and HR Response FA contributed significantly in predicting MDI (F Change [1,29] = 15.49, $p < .0001$), with the overall model in this 2nd block accounting for 30% of the variance (Total Adjusted $R^2 = .30$). Further, when Global FA was in the third block, the final overall model remained significant ($F[4,28] = 5.40, p = .002$), however the variance in predicting MDI increased only marginally by about 5% (Total Adjusted $R^2 = .35$). When regressions were re-run with the same factors in Blocks 1, 2, and Longest FA (rather than Global FA) in the final Block 3, Longest FA accounted for an additional 19% of the variance (after Average HR Response; (F Change [1,29] = 11.628, $p = .002$), resulting in a significant overall final model in predicting MDI; ($F[4,28] = 8.674, p < .0001$); Total Adjusted $R^2 = .49$). In the linear regression conducted on the VLGA infants none of models were significant ($p > .50$) (Fig. 6).

While hierarchical regressions examining neonatal factors were only relevant for the Preterm infants, correlations were conducted in the Full-term group to examine relationships

between behavioral and HR indices and MDI (see Tab. 3), showing that Longest FA, Global FA, and HR Response FA were not significantly associated with MDI ($p > .1$).

In summary, for preterm infants born ELGA and who escape major impairment, fewer days of mechanical ventilation ($p = .005$), greater HR response (deceleration) during focused attention ($p < .0001$) and longest focused attention ($p = .002$), were significant predictors of Bayley MDI, (predicting a total of 49% of the adjusted variance). Given the limited number of infants in the ELGA subgroup ($n = 33$), and the overlap of neonatal risk factors, results must be viewed very cautiously. In particular, days of mechanical ventilation for the ELGA group, cannot be clearly separated from other medical risk factors associated with an extremely preterm birth. Nevertheless, the amount of adjusted variance in predicting MDI as explained by mean heart rate response and mean longest focus for the ELGA infants is striking.

DISCUSSION

This is the first study, to our knowledge, to examine focused attention and HR response in preterm and full-term infants, during exploratory play, in relation to developing cognition, while considering neonatal risk factors associated with preterm birth. An important strength of the present study was the strict exclusion criteria, to address relationships between focused attention, HR response and cognition in very preterm infants who escaped major impairment, yet who remain at risk for cognitive and attention problems. In many studies of attention in preterm infants, samples are heterogeneous including infants growth-restricted in utero and/or with major neonatal brain injuries, thereby introducing multiple confounds.

The hypothesis that very preterm infants would display poorer focused attention behaviors compared to full-term infants was only partially confirmed. There were no significant preterm/full-term differences in the duration of focused attention for individual toys, across the four toys, or for mean longest focus. With regards to the quality of focused attention, preterm infants were rated significantly lower on mean global focused attention (average of global ratings for all four toys). However, there were no significant preterm/full-term differences using the 5-point global ratings distributions developed by Lawson and Ruff (2001) (i.e., all four toys: 1 or 1.5; at least one rating of 2 and no rating >2.5 ; at least one rating of 3 and no rating >3.5 ; at least one rating of 4 and no rating >4.5 ; at least one rating of 5). To our knowledge, this is the first study comparing preterm infants to a full-term control group, using the 5-point global ratings developed for use in the clinical setting by Lawson and Ruff (2001). In our sample of 83 unimpaired 8-month preterm infants, the distribution of the global ratings varied considerably in relation to those previously reported for 71 preterm infants (24–36 weeks gestation, 525–1,470 g) at 7 months of age (Lawson & Ruff, 2001). For example, 72% of the 7-month preterm infants from the Lawson and Ruff study fell in the two lowest ranges of the five distributions, compared to 21% of our preterm sample at 8 months CA. The disparity between the two studies was not likely due to coding differences, as the same training tapes and careful rating methods were used, with similar reports of inter-rater reliability (Lawson & Ruff, 2001). Rather, the samples differed in age, and in terms of risk factors. One would expect 8-month-old infants to display higher global focused attention than 7-month-old infants, given the significant increases in focused attention during this period of development (Colombo, 2001). However, of more critical importance was that the two samples differed in terms of the risk factors associated with premature birth. Lawson and Ruff (2001) included subjects with a birth weight of $<1,500$ g who were preterm (up to 36 weeks GA). According to population-based statistics, birth weights of 1,500 g for boys and 1,400 g for girls fall at the 50th percentile for 30 weeks of completed gestation (Kramer, 2001), thus their sample included a significant proportion of infants with intrauterine growth restriction, who are at greater risk for childhood attention

difficulties (e.g., Robson & Cline, 1998). Additionally, the Lawson and Ruff (2001) sample of 7-month preterm infants was recruited from clinical follow-up, without excluding infants with developmental delay, significant intraventricular hemorrhage (IVH grade III or IV) and/or periventricular leukomalacia (PVL). Moreover, in the present study, excessively fussy/crying infants were excluded. Negative emotionality at 1 and 2 years of age, together with low attentiveness, has been linked to poorer cognitive outcome at preschool age (Lawson & Ruff, 2004a). Based on our strict exclusion, the sample in the present study represents infants born very preterm who escape major impairment, and likely represent a greater proportion of higher functioning infants, who as a group would be more likely to adapt to novel situations, such as exploring three-dimensional toys in the research setting.

The hypothesis that preterm infants would show higher arousal as indicated by higher mean HR for the 90 s pretest period prior to the presentation of four novel toys, or by mean HR for each of the infant's four 90 s toy sequences, was not confirmed. There was a consistent pattern with a decrease in mean HR from the 90 s pretest to the first toy, followed by slight mean HR increases over the three subsequent 90 s toy sequences, for both preterm and full-term infants and across gender. The significant decrease in mean HR from the 90 s pretest period to exploration of the first toy likely reflects appropriate engagement.

At a more detailed level of HR analyses, we hypothesized that preterm infants would show less HR deceleration during behaviorally coded focused attention. Comparing the entire preterm group to the full-term infants, there was no differences in HR response during focused attention episodes. However, among the full-term (but not preterm) group, both global focused attention and longest focus were modestly correlated with HR response (about $r = .30$), suggesting normally some coherence between focused attention and HR deceleration (see Tab. 3). Amongst the entire preterm group, and in the full-term group, some infants showed no HR deceleration, or showed acceleration, during focused attention (see Tab. 2).

For the entire group of preterm infants, neonatal risk factors were examined in relation to focused attention, HR response and Bayley MDI. Greater illness severity at birth (higher SNAP II scores on Day 1 of life), and longer duration of mechanical ventilation were associated with greater mean HR deceleration across all of the infants' focused attention episodes. Conversely, for this sample of 83 preterm infants who escaped major impairment, none of the neonatal risk factors (GA, SNAP II, days ventilated) were related to the behavioral focused attention indices (i.e., global ratings or longest focused attention). This is inconsistent with a study of 22 preterm infants by DiPietro et al. (1992), reporting an association between longer respiratory support (ranging between 0 and 10 days postpartum only) and less sophisticated exploratory play.

Our second hypothesis was that better focused attention and greater HR deceleration would be associated with higher concurrent cognition in preterm infants, after adjusting for illness severity at birth (SNAP II, Day 1 score), and days of mechanical ventilation, which reflects intensive treatment and related illness over the course of the NICU stay. To examine the relative contribution of these neonatal risk factors, while considering physiological and brain maturity at birth according to timing of birth (GA), these relationships were examined using gestational age groups as defined in the medical literature and the National Institute of Child Health and Human Development (NICHD) Neonatal Research Network, reflecting physiological and brain maturity at delivery (e.g., Stoll et al., 2010; Synnes et al., 1994). Specifically, in this study infants born less than 29 weeks gestation were classified as extremely low gestational age [ELGA], and infants born between 29 and 32 weeks as very low gestational age [VLGA]. Our hypothesis that both behavioral and HR indices of focused attention would be related to cognitive development, over and above neonatal risk factors,

was strongly supported in ELGA, but not VLGA infants. Among the ELGA infants, after adjusting for illness severity at birth (SNAP II, Day 1), duration of mechanical ventilation and HR deceleration during the infant's focused attention episodes accounted for 30% of the variance in concurrent cognition. The mean longest focused attention accounted for an additional 19% of the variance, with a total of 49% of the adjusted variance explained. Thus the extent to which ELGA infants showed decreased HR during focused attention, and sustained focus in response to novel objects, appears to be strongly linked to cognitive development. By contrast, there were no such associations between behavioral focused attention or HR response and Bayley MDI for either the later-born VLGA, or full-term infants. For the ELGA subgroup the effects of mechanical ventilation in predicting cognition must be interpreted very cautiously; days on mechanical ventilation provides some indication of intensity of treatment during the NICU stay, but is also related to multiple medical risk factors associated with an extremely premature birth, from which the effects of duration of mechanical ventilation cannot be separated.

The critical difference between ELGA and VLGA infants is the timing of birth, which occurs at different points of physiological maturity and brain development. In a longitudinal study of heart rate and heart rate variability, DiPietro et al. (2007) found that individual differences in autonomic control originate during the fetal period. Preterm infants transition to the extra-uterine NICU environment during the third trimester of "fetal life," during a period of rapid brain development and maturation of cardiovascular systems, which may be disrupted differentially according to timing of birth. Based on other studies that found differences between preterm and full-term infants in heart rate and heart rate variability into the first year of life, it has been proposed that premature birth, complications associated with prematurity, as well as stress of adapting to repeated procedures, may have long term effects on central and peripheral mechanisms that control cardiovascular activity (e.g., Eiselt et al., 1993; Grunau et al., 2001; Henslee et al., 1997). Developmentally, mean heart rate increases from birth, and then decreases from about 3 to 9 months of age, with further decreases across infancy and early childhood (Bar-Haim, Marshall, & Fox, 2000; Davignon et al., 1980; Rijnbeek, Witsenburg, Schrama, Hess, & Kors, 2001), reflecting the neural maturation of parasympathetic restraint (Bar-Haim et al., 2000; Hofer, 1984). Developmentally, between 3 and 12 months of age, there is also greater magnitude of sustained heart rate deceleration particularly in response to more complex and dynamic stimuli (Courage, Reynolds, & Richards, 2006). As heart rate and cardiac autonomic regulation are dependent on post-natal age as well as chronological age, it has been difficult to interpret whether findings in studies of preterm infants reflect "acceleration" of the maturational course or alternatively, whether extra-uterine life delays maturation or alters autonomic regulation (Eiselt et al., 1993). While, the effects of a later transition are generally regarded as posing fewer risks, there is a need for careful studies of the differential effects of timing of birth, and intensive care treatment and interventions on attention and cardiac regulation. For example, Feldman and Eidelman (2003) showed that maturation of cardiac vagal tone between 32 and 37 weeks GA was shifted (positively) in preterm infants who received skin-to-skin (kangaroo care).

Based on an arousal model, preterm infants have been characterized as hypo- or hyper-responsive to a variety of stimuli (e.g., Gardner & Karmel, 1983; Krafchuk et al., 1983; Rose et al., 1976). Though we did not find any overall preterm/full-term differences in mean heart rate from baseline through the infant's exploration of four toys, there were intriguing differences in HR response during focused attention episodes according to preterm gestational age subgroup status. ELGA infants showed greater mean HR deceleration during focused attention than VLGA infants (see Fig. 4). Moreover, of the ELGA infants, 82% and 100%, compared to 54% and 80% of the VLGA infants showed HR deceleration for the mean and the single longest focus respectively (see Tab. 4). Early studies of the NICU

environment found that premature infants were exposed to an inappropriate pattern of persistent yet disassociated stimulation (Lawson, Daum, & Trukewitz, 1977), which have possible effects on preterm infant's intersensory function (Lawson, Ruff, McCarton, Kurtzberg, & Vaughan, 1984). Duffy, Als, and McAnulty (1990) proposed that the high degree of stimulation in the NICU for extremely preterm infants with immature brain development may lead to cortical disturbances related to later outcome difficulties. In a recent review, which examined the effects of NICU noise on the cardiovascular, respiratory, auditory and nervous systems, direct evidence linking noise to neonatal pathology was not clear, however loud transient noise was found to have negative short-term effects on the cardiovascular and respiratory systems of preterm infants (Wachman & Lahav, 2011).

It is also possible that the relationship of HR deceleration to developing cognition and the greater and more consistent HR deceleration that we found in the ELGA infants, may reflect differences in effort, or recruitment of attentional resources. In a controlled study of children with attention deficit, all children performed similarly using behavioral measures, yet children with attention deficit showed greater HR deceleration during the task (Dykman, Ackerman, & Oglesby, 1992; Jennings, vanderMolen, Pelham, Debski, & Hoza, 1997). In other studies of full-term infants (Setliff, Earl, Murphy, & Courage, 2007; Setliff, Murphy, & Courage, 2008), greater HR deceleration during focused attention to toys was apparent in the presence of potentially distracting stimuli, such as when background television was on, or when the television programming was child-oriented. Thus, it is possible that the pattern of greater and more consistent HR deceleration in the ELGA infants may reflect increased effort, or "peripheral narrowing" of focus, to avoid distraction, while exploring the novel toys. In full-term infants, heart rate deceleration during initial learning, and magnitude of heart rate deceleration have been associated with improved visual recognition memory (Linneymeyer & Porges, 1986; Richards, 1997).

The findings in the present study suggest that the nature and development of attention problems in children who were born very preterm needs to be more clearly specified. Children born extremely premature are at higher risk for childhood cognitive, learning and attention problems (e.g., Anderson & Doyle, 2003; Grunau et al., 2002; Taylor, Klein, & Hack, 2000; Taylor et al., 2000; Taylor et al., 1998), however many of these vulnerable children escape significant deficits. It is possible that relatively positive outcomes seen at later ages may be mediated by the infant's ability to regulate his or her attention and related cardiac response, which serves as a protective factor against the risks associated with prematurity. For inattentive infants or those who show little HR response to stimuli, poorer regulatory responses may be considered risk factors that increase the vulnerability of the adverse effects associated with an extremely premature birth. The ability to focus attention and regulate heart rate can be measured in the clinical follow-up of very preterm infants, and potentially used as early markers of risk, not for the diagnostic label of attention problems per se, but to guide early intervention. Based on these findings and the wider literature on focused attention and heart rate, length of sustained (longest) focused attention shows promise, both as a clinical and research measure. In our study, it was related to cognition for the ELGA infants, and as a measure of persistence, longest sustained focus can reveal whether the infant can maintain his or her interest, resist distraction and fully explore many features of a novel object. Global ratings may help identify children outside the norm. Furthermore, using both behavioral and HR indices is recommended, as each may underlie or index different developmental processes (e.g., regulatory and attention behaviors, cognition). Rothbart, Posner, and Rosicky (1994) suggest that the development of attention processes are involved in early plasticity of brain development and that the focusing of attention can be a means for changes in organization and function, resulting in long-term changes. Importantly, the development of infant attention, particularly focused attention involving "effortful control" in the latter half of the first year of life may lay the foundation

for more complex processing including executive functions (Colombo, 2001; Rothbart et al., 1994).

FUTURE DIRECTIONS AND CONCLUDING COMMENTS

Recent studies have linked focused attention to cognition in the preschool years (Lawson & Ruff, 2004a,b). Thus, an important direction for research is to examine the relationship between heart rate regulation in infancy and later attention, cognitive and executive functions in children born very preterm. Further, it is important to replicate these findings, and test whether extremely preterm show unique patterns of HR response during attention tasks using other established methodologies such as latency to distraction during focused attention and/or HR deceleration (e.g., Lansink & Richards, 1997), or infant focus when background television is on versus off (Setliff et al., 2008). Further work is also needed to examine contexts that may contribute to differences in infant regulation. The negative impact of adverse or social risk environments on the behavioral and developmental trajectories of preterm infants are well known (Hack et al., 1992; Robson & Pederson, 1997; Robson & Cline, 1998). In preterm infants, caregiver and home context have been shown to moderate continuity between infant attention and later cognition (e.g., Sigman, Cohen, & Beckwith, 1997). Importantly, Feldman (2007) has emphasized the ecological significance of physiological synchrony in parent–infant interactions, as the basis for the organization and development of relational behaviors and response patterns.

In conclusion, in very preterm infants who escape major impairment, we found associations between gestational age at delivery, illness severity at birth, neonatal intensive care treatment (days on mechanical ventilation) and patterns of infant cardiac response during infant focused attention at 8 months corrected age. These associations may shed light on disruptive factors related to a very preterm birth and possible adaptive mechanisms. Among the earliest-born infants, who undergo extensive and intensive neonatal treatment, our findings also suggest unique relationships between focused attention, heart rate response during focused episodes and developing cognition. Given the central role of attention in neurodevelopment, attention and cardiac autonomic regulation in infants and children born extremely preterm, warrant further study.

Acknowledgments

We extend sincere thanks to participating families and staff of the Children's and Women's Health Centre of BC and the Child and Family Research Institute. This study was supported by grants from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (RO1 HD39783 to REG). JPT was supported by graduate fellowship awards from CIHR, Michael Smith Research Foundation and HELP. REG was supported by a Senior Scientist award from the Child & Family Research Institute.

REFERENCES

- Als, H.; Lester, BM.; Tronick, EZ.; Brazelton, TB. Toward a research instrument for the assessment of preterm infants' behavior (APIB). In: Fitzgerald, HM.; Lester, BM.; Yogman, MW., editors. *Theory and research in behavioral pediatrics*. New York: Plenum Press; 1982. p. 35-132.
- Anderson P, Doyle LW. Neurobehavioral outcomes of school-age children born extremely low birth weight or very preterm in the 1990s. *Journal of the American Medical Association*. 2003; 289:3264–3272. [PubMed: 12824207]
- Bar-Haim Y, Marshall PJ, Fox NA. Developmental changes in heart period and high-frequency heart period variability from 4 months to 4 years of age. *Developmental Psychobiology*. 2000; 37:44–56. [PubMed: 10937660]
- Bayley, N. *Bayley Scales of Infant Development (BSID-II)*. 2nd ed.. San Antonio: Psychological Corporation; 1993.

- Belsky J, Most R. From exploration to play: A cross-sectional study of infant free-play behavior. *Developmental Psychology*. 1981; 17:630–639.
- Bhutta AT, Cleves MA, Casey PH, Cradock MM, Anand KJ. Cognitive and behavioral outcomes of school-aged children who were born preterm: A meta-analysis. *Journal of the American Medical Association*. 2002; 288:728–737. [PubMed: 12169077]
- Boston Medical Technologies. HR View Software (Version 2.0) [Computer software]. Boston, MA: Boston Medical Technologies; 1996.
- Casey, BJ. Colloquium Series, UBC Institute of Mental Health. Vancouver, BC: 2007 March 8. A theoretical model of ADHD: Behavioral, imaging and genetic support. 2007
- Choudhury N, Gorman KS. The relationship between sustained attention and cognitive performance in 17–24-month old toddlers. *Infant and Child Development*. 2000; 9:127–146.
- Colombo J. The development of visual attention in infancy. *Annual Review of Psychology*. 2001; 52:337–367.
- Colombo J, Cheatham CL. The emergence and basis of endogenous attention in infancy and early childhood. *Advances in Child Development and Behavior*. 2006; 34:283–322. [PubMed: 17120808]
- Colombo, J.; Harlan, JE.; Mitchell, DW. Look duration in infancy: Evidence for a triphasic developmental course. Poster presented at the biennial meeting of the Society for Research in Child Development; April, 1999; Albuquerque, NM. 1999.
- Colombo J, Richman WA, Shaddy DJ, Greenhoot AF, Maikranz JM. Heart rate-defined phases of attention, look duration, and infant performance in the paired-comparison paradigm. *Child Development*. 2001; 72:1605–1616. [PubMed: 11768135]
- Courage ML, Reynolds GD, Richards JE. Infants' attention to patterned stimuli: Developmental change from 3 to 12 months of age. *Child Development*. 2006; 77:680–695. [PubMed: 16686795]
- Davignon A, Rautaharju P, Boisselle E, Soumis F, Megelas M, Choquette A. Normal ECG standards for infants and children. *Pediatric Cardiology*. 1980; 1:123–131.
- DiPietro JA, Bornstein MH, Hahn CS, Costigan K, Achy-Brou A. Fetal heart rate and variability: Stability and prediction to developmental outcomes in early childhood. *Child Development*. 2007; 78:1788–1798. [PubMed: 17988321]
- DiPietro JA, Porges SW, Uhly B. Reactivity and developmental competence in preterm and full-term infants. *Developmental Psychology*. 1992; 28:831–841.
- Doussard-Roosevelt JA, McClenny BD, Porges SW. Neonatal cardiac vagal tone and school-age developmental outcome in very low birth weight infants. *Developmental Psychobiology*. 2001; 38:56–66. [PubMed: 11150061]
- Doussard-Roosevelt JA, Porges SW, Scanlon JW, Alemi B, Scanlon KB. Vagal regulation of heart rate in the prediction of developmental outcome for very low birth weight preterm infants. *Child Development*. 1997; 68:173–186. [PubMed: 9179997]
- Duffy FH, Als H, McAnulty GB. Behavioral and electrophysiological evidence for gestational age effects in healthy preterm and fullterm infants studied two weeks after expected due date. *Child Development*. 1990; 61:271–286. [PubMed: 2209195]
- Dykman RA, Ackerman PT, Oglesby DM. Heart rate reactivity in attention deficit disorder subgroups. *Integrative Physiological and Behavioral Science*. 1992; 27:245.
- Eiselt M, Curzi-Dascalova L, Clairambault J, Kauffmann F, Medigue C, Peirano P. Heart-rate variability in low-risk prematurely born infants reaching normal term: A comparison with full-term newborns. *Early Human Development*. 1993; 32:183–195. [PubMed: 8486120]
- Feldman R. Parent-infant synchrony and the construction of shared timing; physiological precursors, developmental outcomes, and risk conditions. *Journal of Child Psychology and Psychiatry and Allied Disciplines*. 2007; 48:329–354.
- Feldman R, Eidelman AI. Skin-to-skin contact (Kangaroo Care) accelerates autonomic and neurobehavioural maturation in preterm infants. *Developmental Medicine and Child Neurology*. 2003; 45:274–281. [PubMed: 12647930]
- Fenson L, Kagan J. The developmental progression of manipulative play in the first two years. *Child Development*. 1976; 47:232–236.

- Field TM. Visual and cardiac responses to animate and inanimate faces by young term and preterm infants. *Child Development*. 1979; 50:188–194. [PubMed: 446203]
- Frick JE, Richards JE. Individual differences in infant's recognition of briefly presented visual stimuli. *Infancy*. 2001; 2:331–352.
- Gardner, JM.; Karmel, BZ. Attention and arousal in preterm and full-term infants. In: Field, T.; Sostek, A., editors. *Infants born at risk: Physiological, perceptual, and cognitive processes*. New York: Grune & Stratton; 1983. p. 69-98.
- Giles, G.; Thomas, RM. HR change analyses software for behavioural data (Version 1.0) [Computer software]. Vancouver, BC: Giles & Associates; 2007.
- Graham, FK.; Anthony, BJ.; Zeigler, BL. The orienting response and developmental processes. In: Siddie, D., editor. *Orienting and habituation: Perspectives in human research*. New York: Wiley; 1983. p. 371-430.
- Graven SN, Bowen FW Jr, Brooten D, Eaton A, Graven MN, Hack M, Sommers J. The high-risk infant environment. Part 1. The role of the neonatal intensive care unit in the outcome of high-risk infants. *Journal of Perinatology*. 1992; 12:164–172. [PubMed: 1522437]
- Grunau RE. Early pain in preterm infants: A model of long term effects. *Clinics in Perinatology*. 2002; 29:373–394. [PubMed: 12380464]
- Grunau, RE. Self-regulation and behavior in preterm children: Effects of early pain. In: McGrath, PJ.; Finley, GA., editors. *Pediatric pain: Biological and social context*. Seattle: IASP Press; 2003. p. 23-55.
- runau RE, Haley DW, Whitfield MF, Weinberg J, Yu W, Thiessen P. Altered basal cortisol levels at 3(6), 8 and 18 months in infants born at extremely low gestational age. *Journal of Pediatrics*. 2007; 150:151–156. [PubMed: 17236892]
- Grunau RE, Oberlander TF, Whitfield MF, Fitzgerald C, Morison SJ, Saul JP. Pain reactivity in former extremely low birth weight infants at corrected age 8 months compared with term born controls. *Infant Behavior & Development*. 2001; 24:41–55.
- Grunau RE, Whitfield MF, Davis C. Pattern of learning disabilities in children with extremely low birth weight and broadly average intelligence. *Archives of Pediatric and Adolescent Medicine*. 2002; 156:615–620.
- Grunau RE, Whitfield MF, Petrie-Thomas J, Synnes AR, Cepeda IL, Keidar A, Johannesen D. Neonatal pain, parenting stress and interaction, in relation to cognitive and motor development at 8 and 18 months in preterm infants. *Pain*. 2009; 143:138–146. [PubMed: 19307058]
- Hack M, Breslau N, Aram D, Weissman B, Klein N, Borawski-Clark E. The effect of very low birth weight and social risk on neurocognitive abilities at school age. *Journal of Developmental and Behavioral Pediatrics*. 1992; 13:412–420. [PubMed: 1469109]
- Henslee JA, Schechtman VL, Lee MY, Harper RM. Developmental patterns of heart rate and variability in prematurely-born infants with apnea of prematurity. *Early Human Development*. 1997; 47:35–50. [PubMed: 9118827]
- Hofer MA. Early stages in the organization of cardiovascular control. *Proceedings of the Society for Experimental Biology and Medicine*. 1984; 175:147–157. [PubMed: 6694973]
- Jennings JR, vanderMolen MW, Pelham W, Debski KB, Hoza B. Inhibition in boys with attention deficit hyperactivity disorder as indexed by heart rate change. *Developmental Psychology*. 1997; 33:308–318. [PubMed: 9147839]
- Kahneman, D. *Attention and effort*. Engelwood Cliffs, NJ: Prentice-Hall; 1973.
- Krafchuk, EE.; Tronick, EZ.; Clifton, RK. Behavioral and cardiac responses to sound in preterm neonates varying in risk status: A hypothesis of their paradoxical reactivity . In: Field, T.; Sostek, A., editors. *Infants born at risk: Physiological, perceptual and cognitive processes*. New York: Grune & Stratton; 1983. p. 99-128.
- Kramer MS. A new and improved population-based Canadian reference for birth weight for gestational age. *Pediatrics*, electronic version [On-line]. 2001 Available: www.pediatrics.org/cgi/content/full/108/2/e35.
- Landry SH, Chapieski ML. Visual attention during toy exploration in preterm infants: Effects of medical risk and maternal interactions. *Infant Behavior & Development*. 1988; 11:187–204.

- Lansink JM, Mintz S, Richards JE. The distribution of infant attention during object examination. *Developmental Science*. 2000; 3:163–170.
- Lansink JM, Richards JE. Heart rate and behavioral measures of attention in six-, nine-, and twelve-month-old infants during object exploration. *Child Development*. 1997; 68:610–620. [PubMed: 9306641]
- Lawson KR, Daum C, Trukewitz G. Environmental characteristics of a neonatal intensive-care unit. *Child Development*. 1977; 48:1633–1639. [PubMed: 608372]
- Lawson, KR.; Ruff, HA. Focused attention. In: Singer, LT.; Zeskind, PS., editors. *Biobehavioral assessment of the infant*. New York: Guilford Press; 2001. p. 293-311.
- Lawson KR, Ruff HA. Early attention and negative emotionality predict later cognitive and behavioural function. *International Journal of Behavioral Development*. 2004a; 28:157–165.
- Lawson KR, Ruff HA. Early focused attention predicts outcome for children born prematurely. *Journal of Developmental and Behavioral Pediatrics*. 2004b; 25:399–406. [PubMed: 15613988]
- Lawson KR, Ruff HA, McCarton CM, Kurtzberg D, Vaughan HG. Auditory-visual responsiveness in full-term and preterm infants. *Developmental Psychology*. 1984; 20:120–127.
- Linnemeyer SA, Porges SW. Recognition memory and cardiac vagal tone in 6-month infants. *Infant Behavior & Development*. 1986; 9:43–56.
- McCall RB. Exploratory manipulation and play in the human infant. *Monographs of the Society for Research in Child Development*. 1974; 39:1–87. [PubMed: 4444723]
- McCall RB, Carriger MS. A meta-analysis of infant habituation and recognition memory performance as predictors of later IQ. *Child Development*. 1993; 64:57–79. [PubMed: 8436038]
- Mesulam MM. A cortical network for directed attention and unilateral neglect. *Annals of Neurology*. 1981; 10:309–325. [PubMed: 7032417]
- Mick E, Biederman J, Prince J, Fischer MJ, Faraone SV. Impact of low birth weight on attention-deficit hyperactivity disorder. *Journal of Developmental and Behavioral Pediatrics*. 2002; 23:16–22. [PubMed: 11889347]
- Oakes LM, Tellinghuisen DJ. Examining in infancy: Does it reflect active processing. *Developmental Psychology*. 1994; 30:748–756.
- Pharoah PO, Stevenson CJ, Cooke RW, Stevenson RC. Prevalence of behaviour disorders in low birthweight infants. *Archives of Disease in Childhood*. 1994; 70:271–274. [PubMed: 8185358]
- Porges SW, Raskin DC. Respiration and heart rate in attention. *Experimental Psychology*. 1969; 81:497–503.
- Posner MI, Petersen SE. The attention system of the human brain. *Annual Review of Neuroscience*. 1990; 13:25–42.
- Richards JE. Effects of attention on infants' preference for briefly exposed visual stimuli in the paired-comparison recognition-memory paradigm. *Developmental Psychology*. 1997; 33:22–31. [PubMed: 9050387]
- Richards, JE. Attention in young infants: A developmental psychophysiological perspective. In: Nelson, CA.; Luciana, M., editors. *Handbook of developmental cognitive neuroscience*. Cambridge, MA: MIT Press; 2001. p. 321-338.
- Richards, JE. The development of visual attention and the brain. In: DeHaan, M.; Johnson, MH., editors. *The cognitive neuroscience of development*. East Sussex, UK: Psychology Press; 2003. p. 73-98.
- Richards JE, Casey BJ. Heart rate variability during attention phases in young infants. *Psychophysiology*. 1991; 28:43–53. [PubMed: 1886963]
- Richardson DK, Corcoran JD, Escobar GJ, Lee SK. SNAP-II and SNAPPE-II: Simplified newborn illness severity and mortality risk scores. *Journal of Pediatrics*. 2001; 138:92–100. [PubMed: 11148519]
- Rijnbeek PR, Witsenburg M, Schrama E, Hess J, Kors JA. New normal limits for the paediatric electrocardiogram. *European Heart Journal*. 2001; 22:702–711. [PubMed: 11286528]
- Robson A, Cline B. Developmental consequences of intrauterine growth retardation. *Infant Behavior & Development*. 1998; 21:331–344.

- Robson AL, Pederson DR. Predictors of individual differences in attention among low birth weight children. *Journal of Developmental and Behavioral Pediatrics*. 1997; 18:13–21. [PubMed: 9055145]
- Rose, SA.; Feldman, JF. The relation of very low birthweight to basic cognitive skills in infancy and childhood. In: Nelson, CA., editor. *The effects of early adversity on neurobehavioral development*. Mahwah, NJ: Lawrence Erlbaum; 2000. p. 31-59.
- Rose SA, Feldman JF, Wallace IF. Individual differences in infants' information processing: Reliability, stability, and prediction. *Child Development*. 1988; 59:1177–1197. [PubMed: 3168635]
- Rose, SA.; Orlian, EK. Visual information processing. In: Singer, LT.; Zeskind, PS., editors. *Biobehavioral assessment of the infant*. New York: Guilford Press; p. 274-292.
- Rose SA, Schmidt K, Bridger WH. Cardiac and behavioral responsivity to tactile stimulation in premature and full-term infants. *Developmental Psychology*. 1976; 12:311–320.
- Rothbart, MK. Temperament in childhood: A framework. In: Bates, JE.; Rothbart, MK., editors. *Temperament in childhood*. New York: Wiley; 1989. p. 59-73.
- Rothbart MK, Posner MI, Rosicky J. Orienting in normal and pathological development. *Development and Psychopathology*. 1994; 6:635–652.
- Ruff HA. Attention and organization of behavior in high-risk infants. *Journal of Developmental and Behavioral Pediatrics*. 1986a; 7:298–301. [PubMed: 3771805]
- Ruff HA. Components of attention during infants' manipulative exploration. *Child Development*. 1986b; 57:105–114. [PubMed: 3948587]
- Ruff, HA. The measurement of attention in high risk infants. In: Vietze, PM.; Vaughan, HG., editors. *Early identification of infants with developmental disabilities*. Philadelphia: Grune & Stratton; 1988. p. 282-296.
- Ruff HA, Capozzoli M, Saltarelli LM. Focused visual attention and distractibility in 10-month-old infants. *Infant Behavior & Development*. 1996; 19:281–293.
- Ruff HA, Lawson KR. Development of sustained, focused attention in young children during free play. *Developmental Psychology*. 1990; 26:85–93.
- Ruff HA, Lawson KR, Parrinello R, Weissberg R. Long-term stability of individual differences in sustained attention in the early years. *Child Development*. 1990; 61:60–75. [PubMed: 2307047]
- Ruff HA, McCarton CM, Kurtzberg D, Vaughan HG. Preterm infant's manipulative exploration of objects. *Child Development*. 1984; 55:1166–1173. [PubMed: 6488951]
- Ruff HA, Saltarelli LM, Capozzoli M, Dubiner K. The differentiation of activity in infants' exploration of objects. *Developmental Psychology*. 1992; 28:851–861.
- Schothorst PF, van Engeland H. Long-term behavioral sequelae of prematurity. *Journal of the American Academy of Child & Adolescent Psychiatry*. 1996; 35:175–183. [PubMed: 8720627]
- Setliff, AE.; Earl, AAS.; Murphy, AN.; Courage, ML. TV, toys, or parent: Infants' attention during free play with toys. Poster presented at the biennial meeting of the Society for Research in Child Development; April, 2007; Boston, MA. 2007.
- Setliff, AE.; Murphy, AN.; Courage, ML. Does background television distract infants from toy play and parent interaction. Poster presented at the biennial meeting of the International Society on Infant Studies; April, 2008; Vancouver, BC. 2008.
- Sigman M. Early development of preterm and fullterm infants: Exploratory behavior in 8-month-olds. *Child Development*. 1976; 47:606–612.
- Sigman M, Cohen SE, Beckwith L. Why does infant attention predict adolescent intelligence. *Infant Behavior & Development*. 1997; 20:133–140.
- Smith, T.; Pretzel, RC.; Landry, K. Infant assessment. In: Simeonsson, RJ.; Rosenthal, SL., editors. *Psychological and developmental assessment*. New York: Guilford; 2001. p. 176-204.
- Stevenson DK, Wright LL, Lemons JA, Oh W, Korones SB, Papile LA, Verter J. Very low birth weight outcomes of the National Institute of Child Health and Human Development Neonatal Research Network, January 1993 through December 1994. *American Journal of Obstetrics and Gynecology*. 1998; 179:1632–1639. [PubMed: 9855609]

- Stjernqvist K, Svenningsen NW. Extremely low-birth-weight infants less than 901g: Development and behaviour after 4 years of life. *Acta Paediatrica*. 1995; 84:500–506. [PubMed: 7633143]
- Stoll BJ, Hansen N. Infections in VLBW infants: Studies from the NICHD Neonatal Research Network. *Seminars in Perinatology*. 2003; 27:293–301. [PubMed: 14510320]
- Stoll BJ, Hansen NI, Bell EF, Shankaran S, Laptook AR, Walsh MC, Higgins RD. Neonatal outcomes of extremely preterm infants from the NICHD Neonatal Research Network. *Pediatrics*. 2010; 126:443–456. [PubMed: 20732945]
- Stroganova TA, Posikera IN, Pisarevskii MV. Endogenous attention in 5-month-old full-term and premature infants. *Human Physiology*. 2005; 31:262–268.
- Stroganova TA, Posikera IN, Pisarevskii MV, Tsetlin MM. Regulation of sinus cardiac rhythm during different states of attention in full-term and preterm 5-month infants. *Human Physiology*. 2006; 32:161–168.
- Sullivan MW, Lewis M. Facial expressions during learning in 1-year old infants. *Infant Behavior & Development*. 1988; 11:369–373.
- Synnes AR, Ling EW, Whitfield MF, Mackinnon M, Lopes L, Wong G, Effer SB. Perinatal outcomes of a large cohort of extremely low gestational age infants (twenty-three to twenty-eight completed weeks of gestation). *Journal of Pediatrics*. 1994:952–960. [PubMed: 7996370]
- Szatmari P, Saigal S, Rosenbaum P, Campbell D, King S. Psychiatric disorders at five years among children with birthweights less than 1000 g: A regional perspective. *Developmental Medicine and Child Neurology*. 1990; 32:954–962. [PubMed: 2269404]
- Taylor HG, Hack M, Klein NK. Attention deficits in children with <750 gm birth weight. *Child Neuropsychology*. 1998; 4:21–34.
- Taylor HG, Klein N, Hack M. School-age consequences of birth weight less than 750 g: A review and update. *Developmental Neuropsychology*. 2000; 17:289–321. [PubMed: 11056846]
- Taylor HG, Klein N, Minich NM, Hack M. Middle-school-age outcomes in children with very low birthweight. *Child Development*. 2000; 71:1495–1511. [PubMed: 11194251]
- Wachman EM, Lahav A. The effects of noise on preterm infants in the NICU. *Archives of Diseases in Childhood: Fetal and Neonatal Edition*. 2011; 96:F305–F309. [PubMed: 20547580]
- Weindling, M. Clinical aspects of brain injury in the preterm infant. In: Lagercrantz, H.; Hanson, MA.; Ment, LR.; Peebles, DM., editors. *The newborn brain*. 2nd ed.. New York: Cambridge University Press; 2010. p. 301-327.
- Whitfield MF, Grunau RV, Holsti L. Extremely premature (<or=800 g) schoolchildren: Multiple areas of hidden disability. *Archives of Disease in Childhood: Fetal Neonatal Edition*. 1997; 77:F85–F90.

FIGURE 1.
Infant's focused attention while exploring toys.

FIGURE 2.
Novel toys for infant exploration (90 s each).

FIGURE 3.

Example of HR synchronized with behaviorally defined focused attention during a 90 s toy exploration sequence. In this example, the infant showed four separate episodes of focused attention >2 s, identified by the short horizontal lines.

FIGURE 4. Continuous HR response over a 5 s period following onset of focused attention by Gestational Age Group mean (ELGA/VLGA/Full-term).

FIGURE 5.
Mean HR during 90 s Pretest and four 90 s toy exploration sequences.

FIGURE 6.

Scatterplot: Bayley MDI at 8 months CA in extremely low gestational age (ELGA) infants as a function of days of mechanical ventilation, 8-month focused attention, and HR response during focused attention (after controlling for early illness severity).

Table 1

Infant and Family Characteristics for Preterm and Full-Term Infants

Infant or Family Characteristic	Preterm 23–32 Weeks GA (<i>n</i> = 83)	Full-Term 37–41 Weeks GA (<i>n</i> = 46)	<i>p</i>
Gender (number of boys/girls)	44/39	23/23	.745
Gestational age (weeks) mean (SD)	29.2 (2.7)	39.9 (1.1)	<.0001
Birth weight (g) mean (SD)	1,322 (461.0)	3,493.4 (367.4)	<.0001
Score for Neonatal Acute Physiology (SNAP-II, Day 1) mean (SD), range	13 (12), 0–50	—	
Mechanical ventilation (days) mean (SD)	13.3 (23)	—	
Proportion of infants ventilated (%)	58		
First born (%)	54	48	.48
Twins (%)	19	4	.02
Corrected age at visit (months) mean (SD)	8.1 (.28)	8.0 (.32)	.26
MDI Bayley (mean: 100, SD: 15)	96 (8.6)	97.4 (5.9)	.20
Mother age (years) mean (SD)	33.0 (5.5)	33.8 (4.7)	.25
Mother education (years) mean (SD)	15.0 (2.6)	16.9 (3.0)	<.0001
Father age (years) mean (SD)	34.0 (5.5)	36.5 (4.3)	.011
Father education (years) mean (SD)	15.1 (3.8)	16.8 (3.1)	.01
Marital status (percent married/common law)	95	95	.96
Mother ethnicity (percent Caucasian)	70	80	.19
Father ethnicity (percent Caucasian)	70	78	.31
Dominant home language (percent English)	85	89	.55

Table 2

Focused Attention and Heart Rate Response (Preterm/Full-Term)

	Preterm, 23–32 Weeks GA (<i>n</i> = 83)	Full-Term, 37–41 Weeks GA (<i>n</i> = 46)	<i>p</i>
Duration of focused attention (s) mean (SD)			
Total duration (4 toys)	56.3 (45.3)	64.4 (44.3)	.33
Global focused attention (Global FA) (ratings 1–5) mean (SD)			
Mean Global FA	2.6 (.71)	2.9 (.80)	.019*
Mean longest focused attention (Longest FA) (s) mean (SD)	7.7 (4.6)	9.2 (4.9)	.48
Mean HR Response FA (beats/min) mean (SD)	−.80 (3.6) ^a	−.76 (3.4)	.99
HR deceleration vs. none/acceleration (% infants)			
All focused episodes	62 ^a	65	.70
Mean longest focus	66 ^a	52	.13
Single longest focus	87 ^a	80	.21

*
p < .05.

^a HR response during focused attention (HR Response FA) was based on a sample of 79 infants (i.e., HR Response FA was not calculated for four preterm infants who failed to show focused attention of at least 2 s in duration).

Table 3
Pearson Correlations of Focused Attention, HR Response, and MDI (Preterm/Full-Term Infants)

	Mean Longest Focused Attention (Longest FA)		HR Response During Focused Attention (HR Response FA)		Bayley MDI	
	Preterm	Full-Term	Preterm	Full-Term	Preterm	Full-Term
Global ratings focused attention (Global FA)	.64**	.68**	-.05 ^a	-.30*	.20	.23
Mean longest focused attention (Longest FA)			.05 ^a	-.31*	.27*	-.03
HR response during (HR Response FA)					-.15 ^a	-.08

* $p < .05$.

** $p < .01$.

^a HR response during focused attention (HR Response FA) was based on a sample of 79 infants (i.e., HR Response FA was not calculated for four preterm infants who failed to show focused attention of at least 2 s in duration).

Table 4

Comparison of Predictor Variables and MDI (ELGA/VLGA Infants)

Predictor Variables and Bayley MDI	ELGA, 23–28 Weeks (<i>n</i> = 33)	VLGA, 29–32 Weeks (<i>n</i> = 46)	<i>p</i>
SNAP II (Day 1) mean (SD)	20.5 (12.2)	7.6 (9.1)	<.0001
Ventilation (days) mean (SD)	29.8 (28.2)	1.3 (2.6)	<.0001
Infant ventilated (%)	91	35	
Global focused attention (Global FA) mean (SD)	2.7 (.69)	2.6 (.69)	.50
Longest focused attention (Longest FA) mean (SD)	9.1 (5.3)	8.9 (5.3)	.88
Mean HR response for focused attention (HR Response FA) mean (SD)	−1.8 (3.7)	−.06 (3.4)	.02*
HR deceleration vs. none/acceleration (%)			
All focused episodes	67	54	.27
Mean longest focus	82	54	.01**
Single longest focus	100	80	.007**
Gender (% boys)	58	50	.52
Bayley MDI mean (SD)	94.7 (10.2)	96.3 (7.2)	.43

The results in this table suggest that extreme prematurity has an effect on HR response (deceleration) during focused attention; the ELGA group showed significantly more deceleration during focused attention (HR Response FA), and a greater proportion of ELGA infants showed deceleration versus no deceleration/acceleration during focused attention.

*
 $p < .05$.

**
 $p < .01$.