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Infant Attention and Early Childhood Executive Function

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Abstract

Individual differences in infant attention are theorized to reflect the speed of information processing and are related to later cognitive abilities (i.e., memory, language, intelligence). This study provides the first systematic longitudinal analysis of infant attention and early childhood executive function (EF; e.g., working memory, inhibitory control, cognitive flexibility). A group of 5-month-olds ($n = 201$) were classified as short or long lookers. At 24, 36, and 48 months of age, children completed age-appropriate EF tasks. Infant short lookers (i.e., more efficient information processors) exhibited higher EF throughout early childhood as compared to infant long lookers, even after controlling for verbal ability (a potential indicator of intelligence). These findings are discussed in relation to the emergence of executive attention.

Individual differences in infant attention are theorized to reflect the speed of information processing (for review see Colombo, Kapa, & Curtindale, 2010). Systematic research on infant short lookers (SL) and long lookers (LL) has revealed that (a) SL process information more efficiently and/or rapidly than LL; (b) SL encode the global features while LL typically encode the local features (i.e., holistic versus elemental encoding), (c) LL are likely delayed in their ability to disengage and shift visual attention, and (d) SL have better visual recognition memory than LL (Colombo, 1995; for review see Colombo et al., 2010). In fact, there is substantial evidence from different research groups that a variety of measures of infant information processing measures (e.g., habituation, visual recognition memory) are related to later cognition, such as language, memory, and intelligence (Bornstein & Sigman, 1986; Colombo, 1993; Courage, Howe, & Squires, 2004; Fagan, Holland, & Wheeler, 2007; McCall & Carriger, 1993; Tamis-LeMonda & Bornstein, 1989). The aim of the present study was to determine whether 5-month attention style would be related to emerging executive function (EF; e.g., working memory, inhibitory control, cognitive flexibility) during early childhood. In the following sections, we briefly review the development of different attentional systems as well as their corresponding neurocircuitry and how these systems are related to EF.

There are multiple visual attention systems with each network exhibiting a unique developmental trajectory and associated neurocircuitry (Colombo & Cheatham, 2006; Posner & Fan, 2008). Here, we focus on the two attention networks most relevant to the current investigation: orienting and executive. The orienting attention network, responsible for the selection of sensory inputs (i.e., disengaging fixation and voluntary shifts in visual attention), involves areas of the frontal eye fields, inferior and superior parietal lobe, and superior colliculus (Posner & Peterson, 1990) and is functionally mature between 3 and 6 months of age (Colombo, 2001; Courage, Reynolds, & Richards, 2006). The development of

this system and the ability to disengage fixation most likely underlies the aforementioned differences in SL and LL (Colombo, 1995).

The executive attention network, responsible for the resolution of conflicts among response tendencies (Posner, Rothbart, Sheese, & Voelker, 2012), involves the anterior cingulate gyrus, basal ganglia, and prefrontal cortex (Posner & Fan, 2008). This network emerges during latter half of the first year with continued development into early childhood (Berger, Tzur, & Posner, 2006; Kochanska & Knaack, 2003; Rothbart, Derryberry, & Posner, 1994). Posner and Rothbart (e.g., Posner et al., 2012) have proposed that fMRI functional connectivity (i.e., measurement of synchronization in activity from distinct areas) during a resting state is informative about the development of attention networks. This research has revealed that in neonates, parietal areas (associated with the orienting network) exhibited strong connectivity to lateral and medial frontal areas (associated with the executive network), and by 2 years of age, the anterior cingulate (associated with executive network) exhibited strong connectivity to both parietal and frontal areas (Gao et al., 2009). Thus, early in development, there appears to be overlap in the functional connectivity of the orienting and executive networks with additional synchronization between the two networks by early childhood. Given the overlap in functional connectivity between the executive and orienting networks early in development, we examined whether 5-month attention style (associated with the development of the orienting network) would be related to EF as it emerges during early childhood.

EFs are higher-order cognitive and self-regulatory processes, intricately linked to the prefrontal cortex, that underlie goal-directed behaviors. The development of both the prefrontal cortex and EF are protracted through childhood and early adulthood, with EFs exhibiting moderate stability in individual differences by 4 years of age (e.g., Kochanska & Knaack, 2003). During early childhood, EFs are linked to school readiness (Blair & Peters, 2003) as well as academic performance (St. Clair-Thompson & Gathercole, 2006), and deficits in EFs are associated with early-onset disorders (e.g., attention-deficit/hyperactivity disorder, autism spectrum disorder, phenylketonuria; Diamond, Prevor, Callender, & Druin, 1997; Semrud-Clikeman, Walkowiak, Wilkinson, & Butcher, 2010). Despite the significance of EF in both clinical and educational settings, there have been no systematic investigations of infant information processing and the emergence of EF.

Two studies have included measures of infant information processing and later EF (Rose & Feldman, 1997; Sigman, Cohen, & Beckwith, 1997). Their findings suggest that infant information processing is potentially associated with future EF. In an examination of contributors to intelligence at 11 years of age, Rose and Feldman found that 7-month visual recognition memory was associated with a latent factor at 11 years that included measures of encoding speed and working memory (which were related to 11-year intelligence). The study, however, was not designed to specifically examine associations between infant information processing and EF, and it is plausible that measures of 11-year encoding speed might mediate the association. Furthermore, both EF and infant information processing are associated with intelligence (e.g., Colombo, 1993; Friedman et al., 2006). It is unknown whether 7-month information processing would be related to future EF after controlling for intelligence. In fact, Sigman et al. found that visual attention fixation in preterm infants (assessed at term) was associated with performance on the Tower of Hanoi task (an EF measure) at 18 years, but this association was not significant when controlling for adolescent intelligence. It should be noted, however, that interpretation of Sigman et al.'s EF findings are potentially limited because of the use of a single EF measure (see below) and the inclusion of pre-term infants. In sum, although there is strong evidence that infant information processing is related to future intelligence and language, it remains to be determined whether the same can be said for EF. Furthermore, there is considerable

development in EF after 5 years of age (see Best, Miller, & Jones, 2009 for review), and it is unknown whether infant attention would be associated with EF as it emerges and exhibits stability in individual differences during early childhood.

This study provides the first systematic longitudinal analysis of infant information processing and its relation to the emergence of EF during early childhood. In order to capture the emergence of EF as well as stability in individual differences in EF, we assessed EF from 2 (i.e., approaching the youngest assessment age) to 4 years of age (i.e., when there is moderate stability in individual differences in EF). Our conceptualization of the SL-LL dichotomy was influenced by the substantial literature from Colombo (1995) and others (Courage et al., 2004; see Colombo et al., 2010 for review). To this end, we used analogous methods to classify 5-month-olds as SL or LL. At 24, 36, and 48 months of age, children completed age-appropriate EF tasks that required a variety of EF skills. Because EF task performance is also affected by non-EF demands (e.g., variance due to measurement error) we obtained multiple measures of the outcome measure, EF (Carlson, Mandell, & Williams, 2004; Rushton, Brainerd, & Pressley, 1983). We used principal component analysis to verify that EF measures at a particular age were associated, and then calculated EF composite scores. Based on the literature reviewed, we hypothesized that SL would exhibit higher EF during early childhood than LL.

During this developmental period, children also exhibit substantial improvements in language. Research with toddlers and preschoolers has found that language is associated with EF (Hughes, 1998; Kaler & Kopp, 1990). It has been hypothesized that flexible higher-order control of behavior, as expressed during executive processing, involves language (see Müller, Jacques, Brocki, & Zelazo, 2009, for review). Furthermore, there is evidence that infant attention style is related to language during early childhood (Bornstein & Sigman, 1986; Colombo, Shaddy, Richman, Maikranz & Blaga, 2004; Colombo et al., 2008). To control for the potential role of language (and intelligence) in the association between infant attention style and future EF, we controlled for child verbal ability (a measure often used as an indicator of verbal or crystallized intelligence) in a second set of analyses to ensure that our findings would not be entirely due to variance shared with verbal ability.

Method

Participants

Infants ($n=211$) were recruited as part of an ongoing longitudinal investigation of cognition and emotion development. The final sample consisted of 202 infants (five were low birth weight [$< 5\text{lb } 8\text{ oz}$]; three were premature [$> 4\text{ weeks}$]; one later exhibited developmental delays). Of the 202 infants (91 boys, 111 girls; 9 Hispanic, 193 Non-Hispanic; 180 Caucasian, 17 Multi-Racial, 2 Asian, 2 African American, 1 Other Race) in our sample, 201 participated at 5 months ($M = 162.6\text{ days}$, $SD = 9.5$; one enrolled at 10 months), 152 returned at 2 years ($M = 2.1\text{ years}$; $SD = 22\text{ days}$), 134 returned at 3 years ($M = 3.1\text{ years}$; $SD = 29\text{ days}$), and 117 returned at 4 years ($M = 4.1\text{ years}$; $SD = 32\text{ days}$). For parents who reported educational information (199 mothers, 192 fathers), 99% and 98.4%, respectively, completed a high school education (5% and 3.6% technical degree; 44.7% and 32.8% bachelor's degree; 27.6% and 32.8% graduate degree; respectively). Average maternal and paternal age at birth was 29.7 and 32.6 years ($SD = 5.0$ and 6.5), respectively. Children were given a small gift and parents received an honorarium for each laboratory visit.

Procedure

Infants participated in the attention task, as well as other self-regulation tasks not reported in this paper. [Additional publications include portions of the attention (Diaz & Bell, 2011) and

EF (Morasch & Bell, 2011) data.] Children participated in a battery of EF tasks. For all tasks, interrater reliability (Cronbach's α .90) was established for at least 20% of our entire longitudinal sample. Study procedures were approved by the institutional review board.

5-Month Attention

The puppet stimuli were red or gray glove puppets, adorned with facial features on the palms of each glove and small wooden beads or bells attached to each fingertip. Infants sat on their mothers' laps 1.1m from the edge of the testing table [90cm (L) $\times$ 60cm (W) $\times$ 75cm (H)]. Infants were presented with a glove puppet until they accrued four looks, each separated by a 3-s look away from the puppet (habituation criterion used by Diamond et al., 1997). Median peak look to the glove puppet was used to classify infants as SL or LL (Colombo, Mitchell, Coldren, & Freeseaman, 1991).

Looking data were coded offline to determine median peak look. A video camera was placed behind and above the experimenter's head and focused to maintain a close-up view of the puppet and the infant's face. A research assistant coded each infant's look duration from a videotape/DVD of the laboratory session using the Video Coding System software developed by James Long Company (Caroga Lake, NY). The stimulus median peak look to the 3-dimensional glove puppet was 9.84 s. Infants whose peak look was above 9.84 s were classified as LL, whereas those whose peak look fell below 9.84 s were classified as SL.

EF Measures

We chose age-appropriate EF tasks that were used in previous research and measured a variety of executive processes (e.g., working memory, inhibitory control).

A-not-B with invisible displacement (24 months)—The toddler A-not-B looking procedure is detailed in Morasch and Bell (2011). An attractive item was hidden under a cup (central location); the cup was shifted to one side (side A, counterbalanced left/right); and a barrier was placed in front of the cup. During the 5-s delay, the experimenter distracted the toddler (kept gaze at midline) and behind the barrier, placed a second cup (side B). The barrier was removed and toddlers were asked, "Where's the ball?" The first look toward either location was coded, and after two consecutive correct same-side searches, the hiding location was reversed (pattern AAB). Performance was the proportion of correct searches (Diamond et al., 1997).

Tongue task (24 months)—The tongue task (Kochanska, Murray, & Harlan, 2000; Wolfe & Bell, 2007) required children to hold a goldfish cracker on their tongue without chewing it (three trials with delays of 10, 20, and 30 s). Performance was the proportion of successful trials.

Day-Night (36 months)—For the day-night task (Gerstadt, Hong, & Diamond, 1994), children were instructed to say "day" when shown a moon card and to say "night" when shown a sun card. After two learning trials, children received 16 test trials (half for each type) in a pseudorandom order. Correct responses received 1 point and incorrect responses followed by self-correction received .5 point. Performance was the proportion of points earned.

Simon-says (36 and 48 months)—The Simon-says task followed the Bear/Dragon procedure (Carlson, Moses, & Breton, 2002) and is detailed in Wolfe and Bell (2007). Children were instructed to do what the nice horse (48 months: pig) "tells us" and to not do what the mean cow (48 months: bull) "tells us." Ten test trials (half for each type,

alternating order) followed practice trials of each type, and children's response on each trial was coded as either correct or incorrect (Carlson, 2005). Performance was the proportion of correct responses on inhibition (cow/bull) trials.

Dimensional Change Card Sort (DCCS: 36 and 48 months)—For this task (Zelazo, Frye, & Rapus, 1996), children were instructed to sort cards based on two dimensions (i.e., color, shape). Children first sorted six cards by one dimension (pre-switch; counterbalanced across participants) and then were instructed to switch and to sort the remaining six cards by the other dimension (post-switch). At 48 months, children who passed the post-switch condition also participated in the borders condition. During this phase, children sorted according to one dimension for cards with borders (e.g., shape) and sorted according to the other dimension for cards without borders (e.g., color; counterbalanced). (The borders condition was not initially in the protocol and 25 children failed the post-switch condition.) Performance was the proportion of correct post-switch (36 months) or borders (48 months) responses.

Visual search (48 months)—In this modified version of the NEPSY subtest (Espy & Bull, 2005; Korkman, Kirk, & Kemp, 1998), children were asked to point only to items that matched the target item (i.e., bears) on a page containing both distractors and targets. (Visual search was not initially in the protocol.) An efficiency score was calculated as the proportion of target responses.

EF composite measures (24, 36, 48 months)—When possible, it is highly preferred to form a composite score of a latent construct of correlated indicators because such composite scores are most reliable (Carlson et al., 2004; Rushton et al., 1984). The 24-month composite included tongue task and A-not-B performance, and the first principal component explained 55% of the variance ($\lambda = .74$). At 36 months, the first principal component among the three tasks (simon-says, day-night, DCCS) explained 50% of the variance ($\lambda = .66-.74$). Likewise, the first principal component among the 48-month tasks (simon-says, visual search, DCCS) explained 45% of the variance ($\lambda = .60-.77$). At each age, individual indicator scores were standardized, averaged, and standardized again to yield an EF composite z-score. (In the case of missing data, composites consisted of the remaining performance measures.) Finally, a child EF composite was formed by averaging the annual composite z-scores, and the final overall composite standardized again to yield a z-score. The first principal component explained 45% of the variance ($\lambda = .58-.73$). This is our most reliable measure of child EF because it includes multiple measures assessed at different time points.

Verbal Ability

MacArthur-Bates Communicative Development Inventory (MCDI: 24 months)

—The MCDI “Words and Sentences” form (Fenson et al., 1992) was completed by toddlers' mothers to provide a measure of toddler verbal ability. The MCDI is an inventory of common words and phrases. We used the percentile score associated with vocabulary production.

Peabody Picture Vocabulary Test (PPVT: 36 and 48 months)

—The PPVT-III (Dunn & Dunn, 1997) or PPVT-IV (Dunn & Dunn, 2007) was administered to children to determine receptive vocabulary and verbal comprehension. The PPVT-III and -IV are nationally standardized instruments, and the measure of interest was participants' percentile scores.

Results

First, we computed descriptive statistics for all measures (Table 1). To examine potential sample bias, independent groups *t*-tests were conducted for children with and without EF composite at each age. These analyses revealed no differences in 5-month attention (i.e., longest look; all *t*s = 1.50, all *p*s > .10) or earlier EF composite (for those with missing data at 36 or 48 months; all *t*s = 1.68, all *p*s > .10). Next, we created residualized EF composites with verbal ability removed. Verbal ability was correlated (one-tailed) with same-age child EF at 36 and 48 months, *r*s = .19–.32, *p*s < .016 (24 months: *r* = .04, *ns*). We hypothesized that infants classified as SL at 5 months of age would have higher early childhood EF (and residualized EF) than LL. Because of our directional hypotheses, we used one-tailed *t*-tests for our child EF measures.

Bivariate correlations (one-tailed) confirmed that our child EF composites were correlated over time, 24–36 months: $r(121) = .15, p = .054$; 36–48 months: $r(103) = .22, p = .011$. The 24–48 month EF correlation was not significant, $r(102) = .10, p = .15$. As can be seen in Table 2, both sets of *t*-tests (i.e., EF and residualized EF) revealed SL had higher EF throughout early childhood as compared to LL. Thus, even when controlling for verbal intelligence, 5-month attentional style was related to EF from 24 to 48 months of age. The child EF composite, our most reliable measure, was also higher for SL as compared to LL.

Discussion

These data provide the first systematic longitudinal analysis of infant information processing and early childhood EF. Infants were classified as either SL or LL at 5 months of age, and we hypothesized that SL (i.e., more efficient information processors) would have higher EF during early childhood as compared to LL. Our findings support our hypothesis: Infant SL exhibited higher EF at 24, 36, and 48 months of age as compared to infant LL. Furthermore, our findings were confirmed when analyzing the early childhood EF composite—our most reliable EF measure. Importantly, the associations between 5-month information processing and later EF were not entirely due to variance shared with verbal ability (a potential indicator of verbal or crystallized intelligence). Our analyses remained significant even with verbal ability partialled from our EF measures.

The present findings extend our understanding of infant information processing and its relation with future cognitive abilities (e.g., intelligence, language, memory) to include future executive abilities (i.e., higher-order cognitive and self-regulatory processes). The regulation of memory and attention processes is essential to optimal social-emotional and cognitive development (Bell & Deater-Deckard, 2007; Blair, 2002). Thus, there has been substantial interest in the development and effectiveness of EF training programs designed to improve EF during early childhood (e.g., Diamond, Barnett, Thomas, & Munro, 2007). Our data provide initial evidence that infant attention is associated with early childhood EF. Accordingly, infant attention could potentially be used as an early indicator of children at risk for EF deficits or potentially at risk for early-onset disorders.

In accordance with previous research, we interpret individual differences in attention style between SL and LL to be related to the efficiency and/or speed of information processing. These differences are most directly related to the development of the orienting network and associated neurocircuitry (i.e., parietal areas, frontal eye fields, superior colliculus), which contribute to the ability to disengage attention (Colombo, 1995). It is clear that an elemental skill, such as efficient information processing, would be important to a variety of cognitive abilities. It is also plausible that the association between 5-month attention style and EF could be partially related to the overlap in functional connectivity of the orienting and

executive networks early in development (Gao et al., 2009). Specifically, there is strong connectivity between the parietal areas (associated with the orienting network) and the lateral and medial frontal areas (associated with the executive network). The frontal cortex is critical to the development of EF and executive attention, and we question whether individual differences in attentional style at 5 months are related to differences in the maturation of the frontal cortex and/or its connectivity. If so, this would reveal an additional mechanism that would contribute to the association between 5-month attention style and future EF.

In an analysis of 5-month-olds' resting EEG activity (6–9 Hz), Diaz and Bell (2011) found that at all electrodes SL had higher power values (a measure of neural activity) than LL. This finding is potentially indicative of different levels of brain maturation (e.g., Marshall, Bar-Haim, & Fox 2002). Likewise, an event-related potential investigation of 6-month-old SL and LL found that only SL showed changes in the Nc component (associated with attention) with this effect being strongest at frontal midline electrodes (Guy, Reynolds, & Zhang, in press). Importantly, cortical source localization suggests that the cortical sources of the Nc component are likely the same frontal areas associated with attention in adults (e.g., anterior cingulate, inferior prefrontal cortex; Reynolds, Courage, & Richards, 2010; Reynolds & Richards, 2005; Richards, Reynolds, & Courage, 2010). These differences in brain electrical activity between SL and LL, particularly those related to frontal areas, are likely linked to individual differences in future EF.

Colombo and Cheatham's (2006) endogenous attention system, responsible for volitional attention-holding (inhibition of shifting attention), is also potentially related to the current findings. Colombo and Cheatham have proposed that (a) endogenous attention emerges when basic attentional processes are integrated with memory processes via maturation of frontal circuitry during the second half of the first year, and (b) endogenous attention underlies higher order cognition (e.g., EF). Accordingly, the present association between basic attentional properties and future EF is potentially mediated by endogenous attention, and these associations should be examined by future research.

Using a sequential looking task, Rothbart and colleagues failed to find an association between 6- to 7-month-olds' reactive and anticipatory looks and executive attention at 3 to 4 years of age (Posner et al, 2012; Rothbart, Sheese, Rueda, & Posner, 2011). It is unclear, however, whether the null findings were related to a small sample size ($n=19$), the use of a single measure of executive attention (as compared to an EF composite measure), or the type of infant looking task and measures. Clearly, additional research is needed to understand how different measures of infant attention are related to each other as well as future cognition.

Although our sample varied in verbal ability, almost all parents of the children in our sample graduated from high school. A test of whether this effect is consistent across the full socio-economic spectrum is essential in determining the generalization of our findings. In conclusion, our data reveal that by 5 months of age, attention style is related to EF during early childhood. It is impressive that this association is present although there are challenges in the measurement of EF as it emerges during early childhood. Our findings are particularly intriguing considering that "higher order" attention systems (that are reliant on the frontal cortex and most closely associated with EF) do not emerge until the second half of the first year, and future investigations are necessary to determine the mechanisms of this association.

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Table 1

Descriptive Statistics for Infant Attention and Child EF Measures.

Measure	Mean	Min	Max	SD	N
5 months					
Peak look duration	14.13	1.8	76.08	12.03	195
24 months					
A-not-B	0.65	0.00	1.00	0.22	143
Tongue task	0.50	0.00	1.00	0.41	118
MCDI percentile	49.37	5.00	99.00	29.01	137
EF composite	0.00	-2.17	2.11	1.00	146
36 months					
Day-Night	0.42	0.00	1.00	0.31	117
Simon-says	0.34	0.00	1.00	0.44	110
DCCS (post-switch)	0.61	0.00	1.00	0.45	117
PPVT percentile	70.41	1.00	99.90	25.09	123
EF composite	0.00	-1.82	2.09	1.00	129
48 months					
Visual search	0.88	0.38	1.00	0.14	78
Simon-says	0.80	0.00	1.00	0.37	110
DCCS (borders)	0.57	0.29	1.00	0.17	76
PPVT percentile	71.63	8.00	99.90	25.79	109
EF composite	0.00	-3.08	1.92	1.00	111
Child					
EF composite	0.00	-3.90	2.40	1.00	155

Table 2

T-test Comparisons of Child EF for 5-month Short Lookers (SL) and Long Lookers (LL).

Measure	5 months SL <i>M</i> (<i>SD</i>)	5 months LL <i>M</i> (<i>SD</i>)	<i>t</i>	<i>df</i>	Cohen's <i>d</i>
<i>EF Composite</i>					
24-month	0.14 (0.99)	-0.16 (0.99)	1.81*	144	0.30
36-month	0.24 (0.94)	-0.31 (1.00)	3.23***	127	0.57
48-month	0.17 (0.86)	-0.22 (1.13)	2.08*	109	0.39
Child	0.19 (0.68)	-0.22 (0.84)	3.30***	153	0.53
<i>Residualized EF Composite (controlling for verbal ability)</i>					
24-month	0.16 (0.97)	-0.18 (1.00)	2.03*	135	0.35
36-month	0.24 (0.92)	-0.31 (1.02)	3.15***	121	0.57
48-month	0.18 (0.83)	-0.24 (1.15)	2.25*	107	0.43
Child	0.21 (0.64)	-0.21 (0.87)	3.38***	150	0.54

Note: 1-tailed *t*-tests.*
p < .05***
p < .001.