

ORIGINAL CONTRIBUTION

Infant Attention and Age 3 Executive Function

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Executive function (EF) abilities refer to higher order cognitive processes necessary to consciously and deliberately persist in a task and are associated with a variety of important developmental outcomes. Attention is believed to support the development and deployment of EF. Although preschool EF and attentional abilities are concurrently linked, much less is known about the longitudinal association between infant attentional abilities and preschool EF. The current study investigated the impact of infant attention orienting behavior on preschool EF. Maternal report and laboratory measures of infant attention were gathered on 114 infants who were 5 months old; performance on four different EF tasks was measured when these same children were 3 years old. Infant attention skills were significantly related to preschool EF, even after controlling for age 3 verbal intelligence. These findings indicate that infant attention may indeed serve as an early marker of later EF. Given the significant developmental outcomes associated with EF, understanding the foundational factors associated with EF is necessary for both theoretical and practical purposes.

INTRODUCTION

The sophisticated cognitive abilities necessary to consciously persist in a task despite challenges from competing information emerge in early childhood and are collectively known as executive functions (EF). EFs are typically divided into three components: updating (working memory), inhibitory control, and cognitive flexibility (attention shifting) [1]. Developmental studies indicate

lack of differentiation among the three component processes during early childhood [2,3], with a two-factor structure emerging during middle childhood and continuing through early to mid-adolescence [4]. By mid to late adolescence, there is differentiation into the three-factor structure that is prominent in the adult cognitive literature [5]. Thus, not only does performance on EF tasks develop throughout childhood, the structure of EF appears to develop as well. It has been suggested that EF assessed

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†Abbreviations: EF, executive function; CFA, confirmatory factor analysis; IBQ-r, Infant Behavioral Questionnaire-revised; DCCS, Dimensional Change Card Sort; ICC, intraclass correlations; IQ, intelligence quotient; PPVT, Peabody Picture Vocabulary Test; FIML, Full Information Maximum Likelihood; MCAR, Little's Missing Completely at Random; CFI, Comparative Fit Index; RMSEA, Root Mean Square Error of Approximation; SRMR, Standardized Root Mean Square Residual.

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during early childhood may be simpler in form than EF in older children and adults [2].

Although they are brain-based, EFs do appear to be malleable, and several interventions for children at risk of developing suboptimal EF abilities have shown promising results [6]. EF deficits are linked with a variety of less than optimal outcomes, among them clinical-level ADHD symptomatology [7], emotion regulation difficulties [8], and lower levels of academic success [9]. One study indicates that EF deficits may *precede* problem behaviors [10], making a thorough understanding of the nature of early executive functioning and its antecedents especially crucial.

The ability to focus attention, particularly in the face of distraction, is a vital component of goal-directed behavior [11]. Indeed, infant attention may be an early marker of later EF abilities. Studies report a relationship between infant attention and infant regulatory skills [12], as well as later measures of cognitive development [13,14]. The association between infant attention and preschool EF, however, is an underexplored area [15] and may have practical implications for the early identification of children who may be particularly vulnerable to later executive control difficulties. Infant attention emerges early in the first year of life and is relatively easy to measure, whereas EF does not begin to emerge until late into the first year [16] and is notoriously challenging to measure in very young children. The goal of this study was therefore to investigate the impact of infant attentional skills on subsequent EF using multiple measures of infant attention and early childhood EF.

Posner and Rothbart [17] propose that attention is an “organ system,” or a brain-based ability reliant on separate but related brain networks. The alerting and orienting networks develop early in the first year of life and govern reactive attentional processes, such as detection of novelty, duration of looking, and perceptual processing. Behavioral and neurological data support the role of orienting as a primary means of attentional control by 7 months of age [17]. Infant attention has been examined through a variety of different means, including look duration [e.g., 18], the use of a single behavioral variable such as susceptibility to distraction [e.g., 19], and physiological measures such as heart rate [e.g., 20]. Infant attention has also been assessed using observer report [e.g., 21] and composite variables consisting of measures like shifting and look duration [e.g., 13,22].

Importantly, infant orienting behavior has been linked with later cognitive measures. Look duration during infancy is commonly used as an index of attention and infants who are classified as “short lookers” (*i.e.*, more efficient information processors) score higher on subsequent intelligence quotient (IQ) measures in childhood than do “long lookers” [see 23 for a review]. Much

of the early research linking infant attention to later IQ, however, relied on correlational analyses [see 24 for a review]. The ability of basic statistical methods to address sophisticated phenomena is limited; early attention is more complex than simple look duration and later cognition is more encompassing than an IQ score. Given the dynamic nature of development, particularly concerning inter- and intra-individual differences, structural equation modeling is a logical approach to examining the structure and organization of attention and complex cognitive processes such as EF. The measurement part of structural equation modeling is confirmatory factor analysis (CFA), a theory-driven technique that allows *a priori* hypothesis testing of complex relationships between sets of observed and latent variables. Observed variables refer to those variables that the researcher can measure, such as performance on a particular task; their common variance is extracted to form latent variables. Unlike statistical analyses that focus solely on observed variables, CFA additionally models error terms so that observed variables are depicted as being the result of both the true score and measurement error.

Garon, Bryson, and Smith [25] refer to attentional abilities as the foundation of the EF system and argue that studies exploring attentional mechanisms and their relation to EF are needed to develop a comprehensive theory of EF development and change. Although studies implicate orienting behavior in infancy with concurrent regulatory skills [26,27] and later measures of cognitive development [14], the association between infant attentional abilities and preschool EF is an underexplored area. The few studies that have explored this association indicate that infant attention may indeed contribute to the development of preschool EF. Kochanska, Murray, and Harlan [8] report that attention at 9 months predicts EF at 22 months, and Johansson and colleagues report that 12-month attention is correlated with EF at 24 months [21] and at 36 months [28].

Previously we reported that infant look duration, a commonly-used measure of infant attention) is related to preschool EF [15]. We divided infants into short lookers (more sophisticated information processors) and long lookers (less sophisticated information processors) based on look duration [18] and then examined group differences in EF at ages 2, 3, and 4 years. There were group differences at each age, with short lookers having better performance on EF. This looking variable, however, focused solely on the length of a single longest look to a stimulus, one simple observed variable that fails to address the issue of measurement error. Thus, just as CFA is critical for modeling the EF latent factor, it is also critical for modeling the infant attention factor and provides a more comprehensive assessment of infant attention than any one measure by itself could provide.

The goal of the current study was to investigate the impact of infant attention on subsequent levels of EF using a latent factor analysis framework. We hypothesized that behavioral and parental report indices of infant attention would demonstrate cohesion by loading significantly on a common latent factor. Although adult EF is characterized by both concordant and discordant components [1], research indicates that childhood EF is best characterized as a cohesive, unitary construct [29]; therefore, we hypothesized that preschool EF would load significantly on a single latent factor. Given the role that attention appears to play in supporting and enabling EF abilities [25,30], we hypothesized that infant attention would relate to EF at age 3. We focused on EF at age 3 for two reasons. First, age 3 is the age at which CFA studies have found that a single factor model best explains performance on a battery of EF [3,29]. Second, EF emerges during the first year [30] and then develops rapidly during the preschool years [31]. Three-year-old children show great variability on a variety of EF tasks, with some stability in individual differences by 4 years of age [32,33]. Because 3-year-olds are at the beginning of rapid developmental changes in EF [34,35], we chose that age group for our study of infant attention and preschool EF.

MATERIALS AND METHODS

Participants

One hundred and fourteen full-term, healthy infants were recruited using birth announcements and commercial mailing lists of new parent names as part of an ongoing longitudinal investigation of cognition and emotion development (58 girls; 6 Hispanic, 108 Non-Hispanic; 102 Caucasian, 12 Multi-Racial). All children participated at 5 months ($M = 162.47$ days, $SD = 10.76$) and at 3 years ($M = 3.12$ years; $SD = 28.03$ days). Eighty two percent of mothers had college degrees, as did 71 percent of fathers. Average maternal and paternal age at the child's birth was 30.55 and 33.74 years ($SD = 4.68$ and 6.53, respectively).

Upon arrival at the research laboratory for each visit, written parental consent was obtained and all research procedures were explained. Families were paid at each assessment for their participation and children were given a small gift. Procedures were approved by the Institutional Review Board.

5 Month Attention Assessment Measures

Look Duration and Shift Rate. Look duration and shift rate were both assessed while infants watched 45 sec of a *Sesame Street* video (*Cecile - Up Down, In Out, Over and Under*). Within developmental literature, both measures are commonly used jointly as indices of

attention [e.g., 13,14,22,36]; shorter looking durations are associated with more efficient information processing [18], and higher shift rates typically represent better attention [36]. Infants' single longest continuous look and the number of shifts of gaze at the video during its entirety were recorded; while each infant had one single longest look recorded, they potentially had multiple shifts of gaze. Interrater reliabilities for behavioral coding were calculated for 20% of the sample and interrater reliability using intraclass correlations (ICC) exceeded .90.

Orienting. The Infant Behavioral Questionnaire-revised Short Form (IBQ-r SF) is a parental-report questionnaire composed of 14 subscales loading onto three factors that measure general patterns of infant behavior [37,38]. Designed for infants between 3 and 12 months of age, the IBQ-r SF has good reliability and validity across several different populations (Cronbach's Alpha range from 0.64-0.86) [38]. The orienting factor was of particular interest in the current study. Orienting provides a global measure of infants' daily attentional and regulatory behavior in their regular environments, thus capturing behavior that may not emerge in a laboratory setting. It has been significantly related to laboratory measures of infant attention [39].

3 Year Measures

All EF measures selected are developmentally appropriate, used widely within the literature, and have varying non-executive demands. For all tasks listed, individual interrater reliabilities for behavioral coding were calculated for at least 20 percent of the sample and percent agreement exceeded 95 percent in all cases.

Tongue task. The Tongue task [3] requires children to place a goldfish cracker on their tongue and inhibit chewing for increasing intervals of time (*i.e.*, three trials with delays of 10, 20, and 30 s). Final scores were based on the number of successful trials.

Dimensional Change Card Sort. The Dimensional Change Card Sort (DCCS) has been used in the developmental literature to assess EF and rule use in young children [40,41]. One set of laminated cards (11 cm×7 cm) was used. There were two target cards (*i.e.*, a blue car and a red flower) to be matched to a series of 14 test cards that displayed the same shape but colors opposite of the target cards (*i.e.*, red cars and blue flowers). The children were first instructed to sort seven test cards by color (pre-switch condition) and then were instructed to switch and to sort the remaining seven test cards by shape (post-switch condition). The dimension (*i.e.*, color or shape) that was relevant during the pre-switch phase was counterbalanced across participants within each age group. In the post-switch condition, the child was reminded of the rule after each trial. However, the child was not told whether or not she sorted the cards correctly;

Table 1. Descriptive statistics for all variables in the study.

| Variable | N | Range | M | SD |
|----------------------------------|-----|-------------|-------|-------|
| <i>5 months¹</i> | | | | |
| Shift rate | 110 | 1.00-17.00 | 8.44 | 3.73 |
| Look duration | 110 | 2.04-47.28 | 16.59 | 10.94 |
| IBQ-r SF orienting | 111 | 1.55-6.45 | 3.97 | 1.00 |
| <i>3 years²</i> | | | | |
| Tongue task | 101 | 0.00-3.00 | 2.11 | 1.11 |
| Day/Night task | 102 | 0.00-8.00 | 3.31 | 2.51 |
| Pig/Bull task | 97 | 0.00-4.00 | 1.34 | 1.78 |
| DCCS task | 107 | 0.00-6.00 | 3.34 | 2.75 |
| Verbal intelligence ³ | 108 | 9.00-102.00 | 52.22 | 17.85 |

Note: IBQ-r = Infant Behavior Questionnaire-revised. DCCS = Dimensional Change Card Sort.

¹Infant attention values represent raw data prior to linear transformations.

²Age 3 values represent number of correct trials.

³Peabody Picture Vocabulary Test.

the experimenter simply said, “okay,” and began the next trial. Children received six pre-switch trials and six post-switch trials. The number of correct post-switch sorts was used in these analyses.

Pig/Bull. The Pig Bull task closely followed the Bear-Dragon procedure described by Carlson and Moses [42; adapted from 43] and requires children to follow the instructions given by one puppet and ignore the instructions given by another puppet. The experimenter showed the child the pig puppet, told him or her that this was a nice puppet, and instructed the child to do as the pig said. The experimenter then showed the child the bull puppet, told him or her that this was a very grumpy puppet, and instructed the child to not do as the bull said. The bull trials were the trials of particular interest in this study. Children received two practice trials and then eight test trials (four bull trials and four pig trials). Final scores were calculated as the number of correct bull trials.

Day/Night. In the Day/Night task [30], children were instructed to say “sun” when they saw a picture of the moon and “moon” when they saw a picture of the sun. Thus, children were measured on their ability to inhibit and override the tendency to correctly label a picture and instead perform an opposite action. Children received two practice trials with feedback about their performance and sixteen test trials, with eight day cards and eight night cards presented in a pseudorandom order. Children did not receive performance feedback during the test trials. Final scores were calculated as the number of correct trials.

Verbal Intelligence. Infant attention is related to language during early childhood [e.g., 44] and language is concurrently related to measures of EF in young children [e.g., 45]. The Peabody Picture Vocabulary Test (PPVT-

III) [46], a nationally standardized assessment of receptive vocabulary and verbal comprehension, was used to measure verbal intelligence.

Participants’ raw scores were used in these analyses.

RESULTS

Descriptive statistics for all variables are listed in Table 1. Correlations between infant attention measures and age 3 EF performance are listed in Table 2. Because three out of the four EF tasks (Tongue task, Pig/Bull, and DCCS) were significantly correlated or marginally correlated with PPVT scores, verbal intelligence was covaried out of these tasks in subsequent analyses. Child gender and maternal education were examined as potential covariates but were uncorrelated with performance on any of the EF tasks and consequently were not included in further analyses.

Variables were screened for nonnormality and all fell within the acceptable levels of skew and kurtosis suggested by Kline [47]. No values on any of the variables fell above or below 3 standard deviations from the mean. Full Information Maximum Likelihood (FIML) estimation was used in analyses; the FIML approach uses all available data and thus maximizes statistical power and estimation accuracy. Little’s Missing Completely at Random (MCAR) test [48] was used to assess if data was missing completely at random; the non-significant finding indicated that the data did fit an MCAR pattern, ($\chi^2(138) = 119.81, p = .87$).

Three separate CFAs were conducted using *MPlus* (Version 7) [49] to assess the fit of the infant attention model, the age 3 EF model, and finally the longitudinal relationship between infant attention and age 3 EF. The

Table 2. Correlations among all study variables.

| Variable | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
|------------------------|--------|-------------------|-------|------------------|------------------|-------|------|------|------|
| <i>5 months</i> | | | | | | | | | |
| 1. Shift rate | — | | | | | | | | |
| 2. Look duration | -.76** | — | | | | | | | |
| 3. IBQ-r SF orienting | .23* | -.14 | — | | | | | | |
| <i>3 years</i> | | | | | | | | | |
| 4. Tongue task | -.06 | .09 | -.07 | — | | | | | |
| 5. Day/Night task | .14 | -.17 ^t | -.16 | .17 ^t | — | | | | |
| 6. Pig/Bull task | .12 | -.05 | -.06 | .14 | .34** | — | | | |
| 7. DCCS | .09 | -.18 ^t | -.07 | .13 | .22* | .29** | — | | |
| 8. Verbal intelligence | -.06 | .13 | -.14 | .20* | .10 | .24* | .37* | — | |
| 9. Gender | .14 | -.03 | .04 | .11 | .10 | .06 | .15 | .19* | — |
| 10. Maternal edu | -.13 | .18 ^t | -.22* | -.01 | .19 ^t | .16 | .02 | .06 | -.02 |

Note: IBQ-r SF = Infant Behavior Questionnaire-revised, Short Form. DCCS = Dimensional Change Card Sort.
^t $p < .05$. ** $p < .01$. ^t $p < .10$.

chi-square statistic, the comparative fit index (CFI), the root mean square error of approximation (RMSEA), and the standardized root mean square residual (SRMR) were all used to evaluate model fit. Within structural equation modeling literature, these four measures are widely considered the minimal set of fit indexes to be reported [e.g., 47,50,51]. The chi-square statistic indexes the discrepancy between the hypothesized covariance matrix and the true covariance matrix; as the chi-square increases, model fit worsens. For this reason, it is sometimes referred to as a “badness of fit” statistic; a non-significant value indicates that the hypothesized model is supported by the sample matrix. The CFI indicates the extent to which the proposed model fits the data compared to the baseline/population model. Values range from 0.00 to 1.00, and values of .95 or above are generally considered to indicate good fit [52]. The RMSEA [53] also measures how well the hypothesized model fits the data. Like the chi-square statistic, the RMSEA is also sometimes called a “badness of fit” statistic, as higher values correspond with worse fit. Values at or below .05 are considered to indicate good fit and values at or below .08 indicate acceptable fit [54]. The standardized root mean square residual, or SRMR, computes the correlation matrices of both the hypothesized and the sample model and indexes the mean absolute correlation residual. Values below .10 are considered to indicate good fit.

Data were first analyzed with a unidimensional CFA with all three manifest variables (IBQ-r SF orienting subscale, shifting, and looking duration) loading on the latent Infant Attention factor. Variables were linearly transformed (by dividing each value by 10) and multiplied by -1 (if necessary) to ensure that they were on a

similar scale and that their correlations were in the same direction. The model was a good fit for the data ($\chi^2(1) = 0.42$, $p = .52$; CFI = 1.00; RMSEA = .00; SRMR = .01), all factor loadings were significant and in the expected direction.

Data for the age 3 EF variables were likewise analyzed with a unidimensional CFA and the number of variables permitted testing of model fit. The model was a good fit for the data ($\chi^2(2) = 0.32$, $p = .85$; CFI = 1.00; RMSEA = .00; SRMR = .01). Three of the four tasks had significant factor loadings; but because the Tongue Task failed to load significantly on the latent EF variable ($\beta = .26$, $SE = .14$, $p = .07$), it was dropped from further analyses. Dropping the Tongue Task did not significantly affect the EF CFA model fit or the overall longitudinal attention-EF relationship.

Next, the relation between attention in infancy and EF at age 3 was assessed by regressing age 3 EF onto 5-month attention. The full model was a good fit for the data ($\chi^2(9) = 10.30$, $p = .33$; CFI = .99; RMSEA = .04; SRMR = .05; see Table 3 for standardized parameter estimates). The results indicated that higher 5 month attention was significantly related to higher age 3 EF ($\beta = .26$, $SE = .13$, $p = .05$). All the factor loadings were significant and in the expected direction.

DISCUSSION

Our study is unique in combining structural equation modeling with a longitudinal approach to investigate the degree to which attention in infancy relates to preschool EF. Infant attention was measured with both laboratory and maternal-report measures. Although the number of

Table 3. Standardized parameter estimates of the longitudinal pathways between infant attention and age 3 EF, controlling for verbal intelligence.

| Parameter | Estimate | SE | <i>p</i> |
|--|----------|-----|----------|
| 5 Month Infant Attention Factor Loadings | | | |
| Shift rate | .94 | .15 | .00 |
| Look duration | .76 | .04 | .00 |
| IBQ-r SF orienting | .24 | .09 | .01 |
| Age 3 EF Factor Loadings | | | |
| Day/Night | .56 | .16 | .00 |
| Pig/Bull | .57 | .15 | .00 |
| DCCS | .40 | .13 | .00 |
| Age 3 EF on 5 mo Infant Attention | .26 | .13 | .05 |
| Residual Variances | | | |
| Shift rate | .96 | .06 | .00 |
| Look duration | .43 | .06 | .00 |
| IBQ-r SF orienting | .94 | .04 | .00 |
| Day/Night | .69 | .17 | .00 |
| Pig/Bull | .67 | .18 | .00 |
| DCCS | .84 | .11 | .00 |
| Age 3 EF | .93 | .07 | .00 |
| R-square | | | |
| Shift rate | .04 | .06 | .47 |
| Look duration | .57 | .06 | .00 |
| IBQ-r SF orienting | .06 | .04 | .20 |
| Day/Night | .31 | .17 | .07 |
| Pig/Bull | .33 | .18 | .06 |
| DCCS | .16 | .11 | .12 |
| Age 3 EF | .07 | .07 | .32 |

Note: IBQ-r SF = Infant Behavior Questionnaire-revised, Short Form. DCCS = Dimensional Change Card Sort.

tasks precluded testing for model fit, all three infant variables loaded significantly on the latent factor, indicating the cohesiveness of infant attention. Preschool EF tasks, which varied in terms of requirements and format, loaded significantly on one common latent factor of age 3 EF, supporting recent findings of the unitary nature of EF in early childhood [e.g., 2,55].

Based on theoretical [e.g., 25,56] and some empirical support [e.g., 15,28] for the role of infant attention in later EF, and given the rapid development of brain-based attentional and EF networks during infancy and early childhood [e.g., 17,57], infant orienting attention was hypothesized to relate to age 3 EF. Indeed, 5-month attention was significantly related to later executive skills, even after controlling for age 3 verbal intelligence, supporting the idea that infant attention may serve as an early marker of later EF.

Using data from these same infants, we [15] recently reported that infants who demonstrated more efficient information processing skills (as indexed by dichotomizing look duration into short lookers and long lookers during a puppet task) [18]) had higher EF in early childhood. Our current study extends this finding in several ways. We used three different measures of infant attention (look duration and shifting rate during a video task, as well as parental report as measured by the IBQ-r SF orienting factor) instead of simply dichotomizing look duration during a puppet task. The use of continuous variables, rather than dichotomizing into a short looker vs. long looker split, takes advantage of the full range of variance present in infant attention and allows for a better examination of individual differences than does the use of a simple dichotomy. Further, indexing infant attention using both behavioral and parent report measures is likely

to offer a more robust, reliable assessment. Examining the association between infant attention and subsequent EF skills through a latent factor analysis framework additionally provides a more accurate reflection of “true” regulatory abilities, as it extracts only the common variance among tasks with different nonexecutive requirements. Because the nonexecutive demands relied upon by EF tasks (such as language comprehension) can vary widely in early childhood, separating their effects from genuine EF performance is particularly important during this age.

Age 3 is a pivotal developmental period. It represents the beginning of a major shift in self-regulatory abilities as children become increasingly more proficient at appropriately coordinating their own goals and actions with situational demands [e.g., 57]. These emerging abilities rely heavily on neural mechanisms, but evidence nevertheless exists that they are shaped by experience, as comprehensive EF training substantially improves performance on novel tasks [e.g., 6]. Much remains unknown about the degree to which EF abilities are malleable over the lifespan. Given the brain-based changes occurring during this time, however, the preschool period may represent a time during which EF abilities are particularly susceptible to environmental influences. Indeed, two of the curricula empirically demonstrated to improve EF functioning in preschoolers, Tools of the Mind, and the Chicago School Readiness Project, are designed to start at age 3 [6,58], making this a particularly crucial age to study.

The ability to deploy EF in a variety of situations poses a significant challenge for many young children. This is particularly true among children from lower income families, as lower socioeconomic status is associated with lower EF [59,60]. Parenting behaviors are associated with childhood EF [e.g., 61,62], and research indicates that behaviors that contribute to the development of EF – parental warmth and scaffolding, for example – are less likely to occur in lower SES households [e.g., 63], thus providing children in such homes with less opportunities to practice strengthening their regulatory skills. All the mothers in the current study had at least a high school diploma, and a quarter had advanced degrees, making the lack of educational diversity among participants a significant limitation. Further research on more socioeconomically diverse samples is needed to assess the extent to which demographic variables such as SES may affect the relationship between infant attention and preschool EF.

Although general information processing abilities in infancy have been linked with later cognition, this study was the first to specifically examine orienting attention in infancy and preschool EF using a latent analysis framework. The tremendous impact that EF has on development, both concurrently and longitudinally, highlights the need for a thorough understanding of its development during the important shift from more external to more

internal systems of self-regulation. Given the interest in developing interventions for children at risk of lower levels of self-regulatory skills, further research investigating attention in infancy could significantly help inform our understanding of the processes and mechanisms through which executive functions develop and flourish.

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