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Executive Attention at Eight Years: Concurrent and Longitudinal Predictors and Individual Differences

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Abstract

Executive attention, the attention necessary to reconcile conflict among simultaneous attentional demands, is vital to children's daily lives. This attention develops rapidly as the anterior cingulate cortex and prefrontal areas mature during early and middle childhood. However, the developmental course of executive attention is not uniform amongst children. Therefore, the purpose of this investigation was to examine the role of individual differences in the development of executive attention by exploring the concurrent and longitudinal contributions to its development at 8 years of age. Executive attention was predicted by concurrent measures of frontal electroencephalography, lab-based performance on a conflict task, and parent report of attention. Longitudinally, 8-year-old executive attention, was significantly predicted by a combination of 4-year old frontal activity, conflict task performance, and parent report of attention focusing, but not with an analogous equation replacing attention focusing with attention shifting. Together, data demonstrate individual differences in executive attention.

Keywords

Executive attention; temperament; electrophysiology; development

Executive attention (EA), one of Posner's three components of attention, involves the central processing that occurs when handling two tasks simultaneously (Posner & Boies, 1971; Posner & Peterson, 1990). EA resolves conflict among thoughts, feelings, and responses, and it relates to childhood skills such as bilingual communication, reading comprehension, self-regulation, and the control of mind-wandering (McVay & Kane, 2012; Rueda, Posner, &

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Rothbart, 2005; Yang, Yang, & Lust, 2011). Despite its importance, relatively little research has explored individual differences in EA among typically-developing children. Following, we examine these differences by focusing on EA-related task performance, frontal electrical activity, and temperament.

EA is associated with brain mechanisms of the Executive Attention System (EAS), encompassing the anterior cingulate cortex and areas of the prefrontal cortex (Posner, Rothbart, Sheese, & Voelker, 2012). Posner's conceptualization of the EAS is measured using attention tasks associated with resolving conflicts among response tendencies (Posner et al., 2012). Therefore, EA is often studied using tasks that involve conflict, such as Stroop or Flanker tasks, which both require individuals to focus on a target while ignoring irrelevant information (Bush, Luu, & Posner, 2000; Chajut, Schupak, & Algom, 2009). Each taxes EA by requiring the EAS to detect, monitor, and resolve the conflict between two competing sources. The Attention Network task (ANT), specifically, provides scores for all three attention networks in Posner's model, including EA (Fan, McCandliss, Fossella, Flombaum, & Posner, 2002; Posner & Rothbart, 2007). The task, which has become a definitive, though certainly not the only, measure of EA, measures reaction time differences between trials in which congruent and incongruent cues are given about upcoming stimuli, thus pinpointing the time necessary to resolve conflict between competing sources of attention (Posner & Rothbart, 2007).

With development, EA helps to control mind wandering and is related to improved metacognition, socioemotional adjustment, and academic achievement (Fernandez-Duque, Baird, & Posner, 2000; McVay & Kane, 2012). Because of this, it is important to measure EA during childhood in order to understand the origins of these potential benefits. Developmentally, there is evidence that infants as young as six months are capable of rudimentary EA (Sheese, Rothbart, Posner, White, & Fraundorf, 2008). It is not until early childhood, however, that development of the frontal lobes allows for more advanced EA (Astle & Scerif, 2009). There are a number of cross-sectional studies examining early EA task performance (see Jones, Rothbart, & Posner, 2003; Rothbart, Ellis, Rueda, & Posner, 2003; Rueda, Checa, & Rothbart, 2010; Rueda, Fan, et al., 2004). Similarly, many other studies have shown how infant focused attention, infant short vs. long looker behavior, toddler inhibitory control, and more predict later EA (Holmboe, Pasco, Csibra, Tucker, & Johnson, 2008; Rose, Feldman, & Jankowski, 2012; Ruff & Lawson, 1990). However, we focused our longitudinal research on a very specific time point surrounding rapid neurological changes underlying EA development in childhood.

Specifically, there is evidence of considerable EA, and frontal lobe, development between 3 and 7 years of age (Rueda, Fan, Halparin, Gruber, Lercari, McCandliss, & Posner, 2004; Rueda, Posner, & Rothbart, 2004). Therefore, we examined EA at 8 years, immediately following this period of rapid development. We also explored its precursors in 4-year-old children, who are on the cusp of this rapid development. By examining aspects of EA at the beginning and end of this period of rapid development, we hoped to capture those early childhood EA characteristics that were most beneficial to middle childhood EA. To the best of our knowledge, ours is the first to examine EA longitudinally during this particular time period.

Because EA development is tied to frontal lobe development, we examined the electrophysiological correlates of EA performance at ages 4 and 8 years. Specifically, childhood performance on various EA tasks is related to prefrontal and fronto-parietal activity, as measured by event related potential and concurrent oscillatory activity (Rueda, Checa, & Combita, 2011; Rueda, Posner, Rothbarth, & Davis-Sover, 2004; Sauseng, Klimesch, Freunberger, Percherstorfer, Hanslmayr, & Doppelmayr, 2006). Much of the previous research on attention and brain activity in children has relied on event-related potentials (e.g., Rueda et al., 2011; Rueda et al., 2004) or functional magnetic resonance imaging (e.g., Casey, Thomas, Davidson, Kunz, & Franzen, 2002; Daamen et al., 2015). Research using continuously-collected electroencephalographic (EEG) data can provide a precise temporal resolution in analyses of brain activity, while also allowing children to move more freely while completing research tasks. Thus, continuous EEG can provide information about underlying early brain development, as it relates to EA concurrently and developmentally, that may not be so readily accessible using other techniques.

Children's EA is also associated with their temperament. Associations between attention-related aspects of temperament and performance of tasks taxing EA has been amply examined in the past (see Rothbart & Rueda, 2005; Rueda, 2012 for a review; Checa, Rodriguez-Bailon, & Rueda, 2008; Rueda et al., 2005). Laboratory measures of attention are positively associated with parent-reported effortful control, the self-regulation aspect of temperament that includes EA (i.e., Chang & Burns, 2005; Checa & Rueda, 2011; Gonzalez, Fuentes, Carraza, & Estevez, 2001; Rothbart et al., 2003). Because of the associations between temperament and EA, it is essential to examine how individual differences in attention-related aspects of temperament are linked to EA task performance, concurrently and longitudinally.

Commonly, research on individual differences in EA is done in atypical samples. EA relates to anxiety, depression, aggression, and attention deficit hyperactivity disorder (Johnson et al., 2007; Johnson et al., 2008; Muris, Meesters, & Rompleberg, 2007; Urbanek et al., 2009). Furthermore, most research examines concurrent associations between EA and its correlates (i.e., Chang & Burns, 2005; Gonzalez et al., 2001), and those studies that examine it longitudinally are, again, conducted in specialized populations (i.e., Konrad, Neufang, Fink, & Herpertz-Dahlmann, 2007; Mezzacappa, 2004). To the best of our knowledge, our study is the first to describe individual differences in EA in typically-developing children concurrently and longitudinally across early and middle childhood.

As noted previously, the ANT has become a definitive, although certainly not the only, measure of EA. For our longitudinal study of individual differences in the development of EA, we examined EA performance on the ANT at 8 years of age as our outcome measure. Because there are other methods for assessing EA, we focused on three other measures of EA at age 8 in the statistical prediction of EA performance on the ANT. Those were brain electrical activity during an EA task, behavioral performance on a non-ANT conflict EA task, and maternal report of EA using a temperament questionnaire. Additionally, we focused on three similar measures of EA at age 4 in the statistical prediction of EA on the ANT at age 8 to examine EA early childhood precursors of performance on the ANT. We hypothesized that age 8 EA, as assessed by the ANT, would be predicted by concurrent and longitudinal measures of EA-related temperament, conflict task performance, and EEG.

Method

Participants

Twenty-five children, originally recruited as infants through newspaper advertisements, visited the laboratory when they were approximately 4.5 years old (Blinded for review) and then all were seen again at approximately 8.25 years old. Use of a modest sample size is typical for electrophysiological work with young children (Molfese et al., 2013; Wolfe & Bell, 2004). Forty-four percent of participants were female, and 96% were Caucasian. At the time of their child's birth, mothers were 30.9 (*SD* = 4.27) years old, and fathers were 32.4 (*SD* = 5.26) years old. The majority of parents, 72% of mothers and 76% of fathers, were college educated.

One child refused the EA conflict task at age 4, and the same child refused the EEG cap at age 8. This child was above the group mean, but did not have the most extreme scores, in language and shyness. Because the ANT EEG was used in each regression analysis, this child was dropped from all analyses. The final sample size was 24. Because 4 children did not provide usable EEG data during the Day-Night task at age 4, analyses using that data are further limited to 20 participants.

Procedures

For both visits, we greeted children and their parents, described procedures, obtained parent consent and child verbal (age 4) or written (age 8) assent, applied EEG and electrodes, and then administered a battery of EA tasks. Parental report of temperament was completed shortly before the laboratory appointment. For this investigation, we consider 4- and 8-year-old measures of temperament, EEG, conflict task performance, and ANT task performance, to be measures of EA.

Age 4 Visit

Full details of the age 4 laboratory visit are described in (Blinded for review). In this report, we focus on three measures from this visit.

EEG recordings—Full details of the recording are available in earlier reports of this data (Blinded for review). Briefly, we computed power for the 6–9 Hz frequency band, which includes frequencies of both the theta (4–7 Hz) and alpha (8–13 Hz) bands. Theta is positively correlated with attention and EF tasks in adults (Finnigan & Robertson, 2011) and slower alpha frequencies reflect greater task attentional demands (Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998). It could be argued that theta and alpha activity relate to different attentional processes, and, therefore, should be analyzed separately from one another. For example, activity in theta has been associated with conflict, whereas activity in alpha has been associated with attention shifting and focusing (Sauseng, et al., 2006). However, as we are conceptualizing this band as a broad measure of attention, both alpha and theta activity are appropriate here. Therefore, we selected this band for continuity with our infant and early childhood EEG work with this sample (Blinded for review). Higher task-related EEG power values, demonstrated by changes from baseline to task, are correlated with better cognitive control performance (e.g., Wolfe & Bell, 2004, 2007).

Conflict task—The Day-Night task (Diamond & Taylor, 1996) is a Stroop-like task used to assess resolution of conflict. For this task, each child was instructed to say "day" when shown a picture of moon and stars and to say "night" when shown a picture of the sun. Day-Night scores were each calculated based on the proportion of trials during which children correctly responded. Higher scores reflect more efficient performance.

Parent-report of attention—The Child Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001) was used to examine parental perceptions of aspects of child temperament associated with EA. It was designed for use with 3- to 7-year-old children (Rothbart, et al., 2001). The questionnaire was mailed to parents about one week in advance and collected at the laboratory visit. For our analyses, the attention focusing and attention shifting were of interest, because of their potential to draw on the need to resolve conflict in attention.

Age 8 Visit

EEG recordings—EA and EF tasks were administered during EEG data collection. Task-related frontal EEG is the focus of this study. EEG data were collected and analyzed in the same way as they were when the children were 4 years old.

Attention Network Test—The child version of the ANT assessed Posner's brain-based attention networks (Rueda, Fan, et al., 2004). The test requires the child to indicate whether a central target (arrow) points right or left. The child is instructed to look at the fixation point, above or below which the target will appear. The target may appear with or without flankers, which may be congruent or incongruent. The ANT is divided into 3 blocks of roughly 5 minutes each, with a brief rest period between blocks. EA was assessed through the conflict network score, which is obtained by subtracting congruent from incongruent reaction times. Lower scores reflect more efficient EA performance.

Conflict task—The color-word Stroop task is a conflict task sometimes used to assess EA. The Stroop task has many variations (see MacLeod, 1991, for review). We used the Golden Stroop version (Golden, 1976) of the color-word Stroop task (Adleman, Menon, Blasey, White, Warsofsky, Glover, & Reiss, 2002; Archibald & Kerns, 1999), which follows previous developmental work with children. For each subtest, each child was told he/she had 45 seconds to read/name items. First, each child read color words printed in black ink, then named the color of ink in which sets of XXXX's were printed, and, finally, named the ink color of color words printed in incongruent ink colors. Raw word, raw color, and raw color-word scores were recorded as the raw number of items completed for each subtest (word, color, color-word). A Stroop interference score was calculated as the difference between the raw color-word score and the predicted performance on the color-word task [calculated as (raw word score * raw color score)/(raw word score + raw color score); Adleman, et al., 2002)]. Lower scores reflect more efficient Stroop performance.

Parent report of attention—The parent form of the Early Adolescent Temperament Questionnaire - Revised (EATQ-R; Ellis & Rothbart, 2001) was used to examine parental perceptions of child temperament associated with EA. Parents completed the EATQ-R Parent Report during their children's laboratory visit. For our analyses, the attention scale, which captures aspects of attention shifting and attention focusing, was of particular interest. The EATQ-R has successfully been used with children as young as 7 (McKeen & Campbell, 2001).

Results

Descriptive statistics and correlations

Descriptive statistics and correlations among the EA measures are displayed in Table 1.

Concurrent analysis

Results from the age 8 multiple regression analysis are displayed in Table 2. Together, concurrent age 8 measures of EA (EEG during ANT, Stroop interference score, EATQ attention) accounted for 56% of the variance in ANT EA network score. An examination of the regression weights revealed that all three age 8 predictors accounted for unique variance in age 8 ANT EA score (Table 2).

Longitudinal analyses

Next, to determine the early childhood predictors of age 8 ANT EA network score, we focused on longitudinal regression analyses, which are displayed in Table 3. We began with CBQ parent-report of attention focusing and repeated the analysis with attention shifting. The equation with EEG, Day-Night task performance, and attention focusing was able to describe 39% of the variance in age 8 ANT EA. The analogous equation with attention shifting was not significant.

Discussion

We have shown that there are important individual differences in ANT EA in 8-year-old children, and that we can predict large amounts of variance in these differences through other measures of EA, specifically frontal electrophysiology, conflict task performance, and temperament, both concurrently and longitudinally from 4 years of age.

Individual differences in EA are apparent from the large standard deviations in Table 1. Despite these individual differences, the correlations between measures of EA are often statistically significant, implying that various measures of EA, administered across early and middle childhood, tap into the same underlying construct. This matches previous research that found that improvements in ANT EA and conflict task performance are associated with frontal lobe development (i.e., Posner et al., 2012).

Concurrent measures of age 8 EA (EEG during ANT, Stroop interference score, EATQ attention) accounted for more than half of the variance in EA, with each predictor accounting for unique variance in EA. However, analogous longitudinal analyses did not always produce similarly significant effects. Though EA is readily observable at 4 years, via conflict task performance, parent report of attention, and frontal EEG, it is not always a good predictor of later EA. For instance, attention shifting was not a significant predictor of later EA, nor were EEG data during a conflict task at 4 years. Given that EA drastically improves from 3- to 7 years (Rueda, Fan et al., 2004; Rueda, Posner et al., 2004), this underdeveloped early EA may be too sporadic to reliably observe continuity with later EA, and other variables may more significantly impact later EA.

Specifically, it was interesting that attention focusing, but not attention shifting, at 4 years of age was a predictor of ANT EA at 8 years of age. Though the EATQ contains a single parent-reported EA scale, the CBQ contains both attention focusing and shifting scales, which both have potential to draw upon the ability to resolve conflict in attention. Yet, only attention focusing longitudinally predicted later ANT EA. Attention shifting and focusing are negatively correlated with one another in 3- and 4-year-old children, but fall underneath the same factor in 6- and 7-year-old children, which suggests that the two become unified under a larger attentional construct as children age (Jones et al., 2003, Rothbart, Ahadi, & Hersey, 1994). It is possible, then, that, because attention shifting and focusing are in conflict with one another at our younger time-point, only one of them could predict later EA. However, it is unclear why, of the two, attention focusing emerged as this predictor.

This is in contrast to previous work in two-year-old children that showed that both attention shifting and focusing were predictive of concurrent performance on a spatial conflict task (Derryberry & Reed, 1998). What's more, in our study, neither attention focusing nor shifting at 4 years were correlated with concurrent conflict task performance (i.e., Day-Night task), nor did parent report of attention at 8 years of age correlate with concurrent ANT EA. This suggests that there is something unique about the parent report of attention at 4 and 8 years of age, as they relate to EA task performance, perhaps because 4-year-olds and 8-year-olds are, respectively, at the very beginning and end stages of a period of rapid development in EA. More research is needed to clarify the ways that these three temperament-based attentional variables change in their associations with one another and with EA task performance with age.

Importantly, frontal EEG during an EA task contributed variance in concurrent ANT EA at 8 years of age. In fact, each of our EA variables of interest—EEG, Color-Word Stroop interference score (i.e., conflict task), and parent report of attention—contributed significant variance in concurrent ANT EA score. This confirms previous research connecting EA with the neural networks of the EAS (e.g., Posner et al., 2012), while also giving insight into the magnitude of associations that can be expected with EA when controlling for this crucial electrophysiological predictor. The three variables, together, predicted 56% of the variance in concurrent ANT EA score.

The analogous longitudinal analyses predicting 8-year-old ANT EA from 4-year-old EEG, conflict task performance, and parent report of attention, though, described a more modest amount of variance in ANT EA. In fact, the equation including attention shifting was not significant, again implying that early childhood attention focusing may be a better predictor of later EA. EEG gathered during the Day-Night conflict task at age 4 was not a significant predictor of age 8 ANT EA, which suggests that the dramatic development in the areas of the brain associated with the EAS in early childhood may not allow for clean prediction of later EA from early EEG. Still, both Day-Night conflict task performance and CBQ attention focusing longitudinally predicted later EA scores. This means that both concurrently and longitudinally, EA aspects of temperament and EA conflict task performance predicted ANT EA

Another important feature of this research is that it appears that we have found support of the Day-Night task as a measure of early EA. The Day-Night task is traditionally used as a measure of executive function in early childhood (Carlson, 2005; Diamond & Taylor, 1996), but we would argue that it also taxes children's EA abilities. As a Stroop-like task, the task required children to resolve conflict between a prepotent response and a conflicting response which they had been instructed to give. Indeed, those who succeeded on the task did so by inhibiting a response while following the instructions given to them. Thus, the task may have rewarded those with the strongest EA.

In conclusion, our investigation contributes to the developmental literature by exploring, concurrently and longitudinally, individual differences in EA. We found that large proportions of variance in ANT EA at age 8 are described by measures of brain electrophysiology, conflict task performance, and temperament. Importantly, the current study has limitations that can be addressed by future research. First, future research should further explore why some early indicators of attention may not be good predictors of later EA, perhaps by determining if 4-year-old attention-related aspects of temperament are predictive of concurrent ANT performance. Given that EA may be apparent in infancy (Sheese et al., 2008), future longitudinal research examining the infant predictors of early and middle childhood attention would also benefit the research literature. Still, the current study is valuable, as we have shown that it is possible to predict, concurrently and longitudinally, variance in 8-year-old ANT EA performance through frontal electrophysiology, conflict task performance, and temperament. These findings emphasize the importance of implementing a variety of tasks to capture variance in EA and they highlight the need for future research to continue to examine the complex associations between attentional variables over time.

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Table 1

Descriptive Statistics and Bivariate Correlations

Task	1	2	3	4	5	6	7	8
AGE 8 SCORES								
1. Executive Attention (ANT)	--							
2. ANT Frontal EEG	−.34+	--						
3. Color Word Stroop Interference	.51**	.03	--					
4. EATQ Attention	−.33	−.31	−.11	--				
AGE 4 SCORES								
5. Day-Night	−.13	.13	.16	.18	--			
6. CBQ Attention Focus	−.48*	.37*	−.10	.28	−.29	--		
7. CBQ Attention Shifting	−.15	−.15	−.15	.40*	.16	.11	--	
8. Day-Night Frontal EEG	.06	.41+	−.03	−.37	−.27	.03	−.22	--
n	25	24	25	25	24	25	25	20
M	109.20	2.70	33.70	3.20	72.84	4.70	3.64	3.16
SD	76.25	.26	11.70	.71	12.17	.77	.71	.41

Note. Lower scores on the ANT represent more efficient executive attention.

+ $p \leq .10$,

* $p \leq .05$,

** $p \leq .01$,

*** $p < .001$.

Table 2

Results of Multiple Regression Analysis Predicting Age 8 ANT Executive Attention Score from Concurrent Executive Attention Measures

	R	R^2	*F*	β	*T*	*p*
Dependent variable: Age 8 ANT executive attention score						
ANT frontal EEG	.75	.56	8.05	−.53	−3.37	.003
Color-word Stroop interference score				.47	3.19	.005
Parent-report of attention				−.45	−2.87	.009

Note. Lower scores on the ANT represent more efficient executive attention.

Table 3

Results of Longitudinal Multiple Regression Analyses Predicting Age 8 ANT Executive Attention Score from Age 4 Executive Attention Measures

	R	R^2	*F*	β	*T*	*p*
Dependent variable: Age 8 ANT executive attention score						
Day-Night frontal EEG	.63	.39*	3.54	−.06	−0.30	.77
Day-Night task				−.48	−2.36	.03
CBQ attention focusing				−.45	−2.32	.03
Dependent variable: Age 8 ANT executive attention score						
Day-Night frontal EEG	.44	.20	1.31	−.06	−0.27	.79
Day-Night task				−.46	−1.95	.07
CBQ attentional shifting				−.02	0.10	.92

Note.

* $p < .05$.

Lower ANT scores represent more efficient executive attention.