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To Stroop or Not to Stroop: Sex-Related Differences in Brain-Behavior Associations During Early Childhood

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Abstract

Executive functions (EFs) are linked with optimal cognitive and social-emotional development. Despite behavioral evidence of sex differences in early childhood EF, little is known about potential sex differences in corresponding brain-behavior associations. The present study examined changes in 4-year-olds' 6–9 Hz EEG power in response to increased executive processing demands (i.e., “Stroop-like” vs. “non-Stroop” day-night tasks). Although there were no sex differences in task performance, an examination of multiple scalp electrode sites revealed that boys exhibited more widespread changes in EEG power as compared to girls. Further, multiple regression analyses controlling for maternal education and non-EF performance indicated that individual differences in boys' and girls' EF performance were associated with different frontal neural correlates (i.e., different frontal scalp sites and different measures of EEG power). These data reveal valuable information concerning sex differences in the neural systems underlying executive processing during early childhood.

Keywords

children; executive function; sex differences; EEG; inhibitory control

To Stroop or Not to Stroop: Sex-Related Differences in Brain-Behavior Associations During Early Childhood

One of the biggest challenges during early childhood is being able to withhold a prepotent response in order to perform a subdominant response. Inhibitory control (IC) along with working memory and cognitive flexibility are considered “core” executive functions (EFs)—higher order cognitive and self-regulatory processes that underlie goal-directed behavior (Diamond, 2013). Well-regulated behavior and cognition are particularly important during early childhood, as EFs are associated with optimal developmental outcomes, such as school

readiness and academic success (Bierman, Torres, Domitrovich, Welsh, & Gest, 2009; Blair & Razza, 2007). Although initial evidence of EFs is seen during infancy (e.g., Cuevas & Bell, 2010), these processes continue to develop throughout adolescence and early adulthood (Huizinga, Dolan, & van der Molen, 2006). This protracted development is considered to be intricately linked to the extended maturation of the frontal cortex, with frontal networks being recruited during executive processing (see Diamond, 2013 for review).

There is a large body of literature focusing on behavioral measures of EF during early childhood, but comparatively few have examined underlying brain-behavior associations (see Bell & Cuevas, in press, for review). Despite some behavioral evidence of sex differences in EF during early childhood (e.g., Wiebe, Espy, & Charak, 2008), little (*if anything*) is known about potential sex differences in corresponding brain-behavior associations. In the present study, we examined changes in 4-year-olds' electroencephalogram (EEG) power (6–9 Hz, child “alpha”) during a task that requires executive processing¹, especially working memory and IC (i.e., day-night task). By comparing EEG during both a “non-Stroop” and “Stroop-like” version of the task, our design controls for the potential influence of extraneous factors (e.g., variations in visual stimuli, verbal responses); thus, enhancing our ability to examine changes in EEG primarily linked to executive processing. In the following paragraphs, we briefly review (a) the sex differences in executive processing-related brain-behavior association literature; (b) work on early childhood EF and corresponding brain-behavior associations; and (c) what is known about sex differences in early brain development.

Sex Differences in EF: Brain-Behavior Associations

Evidence of sex differences in neural activity and brain-behavior associations has emerged across multiple domains of psychology (e.g., Gasbarri et al., 2007). When completing the same task, males and females often (a) recruit different neural systems; and/or (b) exhibit different levels of activation in the same brain regions. The majority of the EF investigations on this topic have used functional magnetic resonance imaging (fMRI). In adults, evidence of sex differences in brain activity despite equivalent behavioral performance has been noted for working memory (Bell, Willson, Wilman, Dave, & Siverstone, 2006; Goldstein et al., 2005) and IC tasks (Li, Huang, Constable, & Sinha, 2006; Li et al., 2009; Liu, Zubieta, & Heitzeg 2012). In the context of a stop signal task, for instance, men recruited a larger number of brain regions and showed greater activation (e.g., bilateral medial frontal and cingulate cortices, thalamus, parahippocampal gyrus) than women to achieve similar levels of performance (Li et al., 2006). Downward extension of this work to adolescence using measures of cognitive flexibility (switch task) and IC (Simon task) has also revealed sexual differentiation in neural activity in the absence of performance differences with adolescent females exhibiting a more mature pattern of prefrontal brain activation than adolescent males (Christakou et al., 2009). Further, this work with adults and adolescents has also

¹In this manuscript, we refer to child EF as opposed to only focusing on IC for two reasons. First, in line with previous work (e.g., Cuevas et al., 2012; Wolfe & Bell, 2004), we conceptualize that during early childhood, the “Stroop-like” version of the day-night task requires both working memory [in line with Engle’s conceptualization of working memory (e.g., Engle, Kane, & Tuholski, 1999); maintaining task rules and focusing attention] and IC. Further, there is also evidence via factor analyses that a unitary model of EF best accounts for the early childhood data (even when sex is taken into consideration) as compared to the multiple, separable factor structure found in adults and older children (Wiebe et al., 2008, 2011).

revealed that individual differences in males' and females' EF performance are associated with activity in different brain regions (Christakou et al., 2009; Li et al., 2006). An important caveat, however, is that findings are mixed regarding the particular neural correlates of executive processing in males and females, which is likely related to the multifaceted nature of EF (e.g., Miyake et al., 2000).

EF During Early Childhood

Children exhibit substantial improvements in EF between 3 and 5 years of age (Carlson, 2005). During early childhood, there is evidence of sex differences in some measures of EF, with girls typically outperforming boys in the context of IC and delay of gratification (e.g., Kochanska, Murray, & Harlan, 2000; Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996; Silverman, 2003). On other tasks, such as the day-night task, sex differences are not apparent (e.g., Diamond, Kirkham, & Amso, 2002; Gerstadt, Hong, & Diamond, 1994). In the present study, we chose a task in which sex differences were not typically demonstrated to examine whether boys and girls exhibit different patterns of neural activity (i.e., EEG power) in the absence of performance differences.

As compared to fMRI, EEG is ideal for use with young children; it is well tolerated by most children, is noninvasive, and is relatively resistant to motor artifacts (Casey & de Haan, 2002). A growing body of EF research suggests that EEG is an informative measure of brain-behavior associations during early childhood (see Bell & Cuevas, in press, for review). Similar to EEG research with adult participants, child EEG is context related, with rapid shifts in brain functioning immediately reflected in the EEG signal. This temporal resolution allows for the testing of hypotheses about brain processes. For example, EEG methodology has confirmed frontal functioning during EF tasks throughout early childhood. At 4.5 years of age, children exhibited baseline-to-task increases in 6–9 Hz frontal EEG power during executive processing (i.e., day-night and yes-no tasks; Bell & Wolfe, 2007). Likewise, 3.5- to 4.5-year-olds' executive performance was accounted for by corresponding 6–9 Hz task-related frontal EEG power (Wolfe & Bell, 2004, 2007a, 2007b). Recent event-related potential (ERP) research with preschoolers has revealed that the amplitude of the N2 component at fronto-central sites is related to individual differences in conflict detection within the context of the Dimensional Change Card Sort task (Espineta, Anderson, & Zelazo, 2012, 2013). To our knowledge, the current study will be the first examination of sex differences in executive processing-related EEG during early childhood.

Sex Differences in Brain Development

Although fMRI work indicates that sex differences are present in brain-behavior associations underlying executive processing by adolescence, it is unknown when these differences emerge. The frontal lobes exhibit consistent increases in volume during childhood and adolescence, reflecting increases in neurons, synaptic density, and myelination of frontal axons (Huttenlocher & Dabholkar, 1997; Kanemura, Aihara, Aoki, Araki, & Nakazawa, 2003). The limited research on sex differences in early brain development indicates that, similar to adults, boys have larger total brain volume than girls (Reiss, Abrams, Singer, Ross, & Denckla, 1996; Sanchez, Richards, & Almli, 2012). Further, the maturation of white matter is likely sexually dimorphic during early childhood,

as evidenced from work with children 5 years and older (Schmithorst, Holland, & Dardzinski, 2008). Thus, one potential mechanism by which sex could affect brain-behavior associations is via early sexual dimorphisms in brain development (i.e., sex differences in structural development influencing sex differences in functional development).

Fetal measures—The origins of these early sex differences in brain development can be traced to the fetal period, where interactions between the intrauterine environment and fetal sex can be complex. Observations of fetal behavioral changes can be used to assess potential sex differences in fetal brain functioning (Buss et al., 2009; Hepper, 1995). For example, fetal heart rate response to vibroacoustic stimulation is mature in girl fetuses by 31 weeks gestational age, but continues to develop in boy fetuses until 37 weeks (Buss et al., 2009). There is evidence that the synchrony or coupling between fetal heart rate and motor activity predicts newborn neurological maturation assessed using the brain stem auditory response. Moderate levels of maternal prenatal stress differentially affect the newborn brain stem auditory response of boys and girls, with boys showing less neurological maturation with greater maternal prenatal stress (DiPietro et al., 2010).

Measures of maternal hypothalamic-pituitary-adrenal (HPA) function can be used to document the level of prenatal stress, although cortisol levels present a complicated view of the prenatal environment. Relative to women with girl fetuses, women with boy fetuses exhibit higher cortisol levels from 24 to 30 weeks gestation. The pattern switches at 30 weeks and continues until birth (DiPietro et al., 2011). Higher cortisol in early pregnancy is associated with poorer neurological maturation at birth for boys, whereas higher cortisol in later pregnancy is associated with better neurological maturation for girls (Ellman et al., 2008). Thus, there may be endocrine mechanisms that influence sex differences in fetal brain development, suggesting that sex differences in brain development have prenatal origins.

EEG measures—There are also reports of sex differences in EEG activity. In older children, boys exhibit greater alpha power than girls (Clark, Barry, McCarthy, & Selikowitz, 2001; Matsuura et al., 1985) and by adolescence, girls exhibit higher frequency in resting EEG than boys (Henry, 1944; Matoušek & Petersen, 1973). Other work, however, has failed to find evidence of sex differences in the EEG recordings of school age children and adolescents (Gasser, Verleger, Bacher, & Sroka, 1988). One report notes that preschool age girls exhibit higher resting EEG frequencies than preschool age boys, suggesting earlier brain maturation in girls than boys (Petersen & Eeg-Olofsson, 1971). Evidence of sex differences in the EEG of children has been interpreted as being relatively minor compared to age-related differences in EEG development (Matsuura et al., 1985; Matousek & Petersen, 1973). Thus, examinations of sex differences in the EEG of preschool children are not common and are typically not the focus of this period of development.

The Current Study

The goal of the present study is to determine whether children exhibit sex differences in EF brain-behavior associations by 4 years of age. Our focus on EF-related EEG at age 4 was strategic. As noted above, performance on EF tasks improves substantially between the ages

of 3 and 5 years, with some stability in performance by 4 years of age (Alloway, Gathercole, & Pickering, 2006). Furthermore, EF in preschool children is related to early mathematics and reading achievement (e.g., Blair & Razza, 2007; Espy et al., 2004), with girls exhibiting higher performance in elementary school (for a review see Halpern, 2000). To this end, we examined whether boys and girls exhibited significant changes in EEG power when engaged in executive processing, and whether these changes occurred at overlapping scalp electrode sites. Next, based on previous evidence of frontal EEG activity being linked with EF performance during early childhood (Wolfe & Bell, 2004, 2007a, 2007b), we examined whether the same frontal sites accounted for variance in boys' and girls' EF performance.

Method

Participants

Our final sample consisted of 144 typically developing 4-year-olds (68 boys, 76 girls; 9 Hispanic, 135 Non-Hispanic; 114 Caucasian, 21 African American, 4 Other Race; 3 Multi-Racial, 2 Not Reported) who participated in the "Stroop-like" and "non-Stroop" day-night tasks as part of a longitudinal investigation of cognition and emotion development. Participants were recruited during infancy by two research locations (Blacksburg, Virginia, and Greensboro, North Carolina) via commercial mailing lists, newspaper birth announcements, and word of mouth. Although each location recruited half of the total longitudinal sample, the tasks of interest were not administered during the first wave of testing in Blacksburg; thus, approximately 2/3 of this sample was recruited from Greensboro. Children were seen between 3 years 11.93 months and 4 years 3.63 months of age ($M = 4$ years 25 days; $SD = 23$ days). All children were born within 4 weeks of their expected due dates, weighed at least 5lb 8 oz, and had no diagnosed neurological problems or developmental delays. For parents who reported educational information (139 mothers, 136 fathers), 97.8% completed a high school education (7.2% and 8.8% technical degree; 46.8% and 33.1% bachelor's degree; 22.3% and 22.8% graduate degree; respectively). Average maternal and paternal age at birth was 30.0 and 32.0 years ($SD = 6.1$ and 7.0), respectively. Children were given a small gift and parents received an honorarium for each laboratory visit.

Data were collected in both research locations using identical protocols. Research assistants from both locations were trained together by Martha Ann Bell on protocol administration, as well as on behavioral and psychophysiological coding. To ensure that identical protocol administration was maintained between the labs, the Blacksburg team periodically viewed DVD recordings and psychophysiological files collected by the Greensboro lab. To ensure that identical coding criteria were maintained between labs, the Blacksburg lab provided reliability for the data and verification of artifact screening for psychophysiology data collected and coded by the Greensboro lab.

Procedures

EEG recording—EEG recordings were made from 16 left and right scalp sites: frontal pole (Fp1, Fp2), medial frontal (F3, F4), lateral frontal (F7, F8), central (C3, C4), temporal (T7, T8), lateral parietal (P7, P8), medial parietal (P3, P4), and occipital (O1, O2). All

electrode sites were referenced to Cz during recording. EEG was recorded using a stretch cap (Electro-Cap, Inc.; Eaton, OH; E1-series cap) with tin electrodes in the 10/20 system pattern. After the cap was placed on the head, a small amount of abrasive gel was placed into each recording site and the scalp gently rubbed. Conductive gel was then added to the recording sites. Electrode impedances were measured and accepted if they were below 20 k Ω .

The electrical activity from each lead was amplified using separate James Long Company Bioamps (James Long Company; Caroga Lake, NY). During data collection, the high pass filter was a single pole RC filter with a 0.1 Hz cut-off (3 dB or half-power point) and 6 dB per octave roll-off. The low pass filter was a two-pole Butterworth type with a 100 Hz cut-off (3 dB or half-power point) and 12 dB octave roll-off. Activity for each lead was displayed on the monitor of the acquisition computer. The EEG was digitized on-line at 512 samples per second for each channel to eliminate the effects of aliasing. The acquisition software was Snapshot-Snapstream (HEM Data Corp.; Southfield, MI) and the raw data were stored for later analyses. Prior to the recording of each subject a 10 Hz, 50 μ V peak-to-peak sine wave was input through each amplifier. This calibration signal was digitized for 30 s and stored for subsequent analysis.

EEG analysis—Spectral analysis of the calibration signal and computation of power at the 9 to 11 Hz frequency band was accomplished. The power figures were used to calibrate the power derived from the subsequent spectral analysis of the EEG. Next, EEG data were examined and analyzed using EEG Analysis software developed by James Long Company. Data were re-referenced via software to an average reference configuration.

The average reference EEG data were artifact scored for eye movements using a peak-to-peak criterion of 100 μ V or greater. Artifact associated with gross motor movements over 200 μ V peak-to-peak was also scored. These artifact-scored epochs were eliminated from all subsequent analyses. No artifact correction procedures were used. The data then were analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. Across children, the mean number of artifact-free DFT windows during “Stroop-like” and “non-Stroop” versions of the day-night task was 45.78 ($SD = 19.32$) and 42.92 ($SD = 16.93$), respectively.

Power was computed for the 6 to 9 Hz frequency band. The 6- to 9-Hz frequency band was selected for analysis because young children show a dominant peak in EEG rhythms within this frequency range from infancy (Bell & Fox, 1994) into childhood (Marshall, Bar-Haim, & Fox, 2002). In previous biobehavioral investigations of cognitive development the 6- to 9-Hz band was shown to discriminate successful and unsuccessful overall cognitive performance (Bell, 2001, 2012; Wolfe & Bell, 2004) on working memory and inhibitory control tasks for infants and preschool-age children. Power was expressed as mean square microvolts, and data were transformed using the natural log ($\ln$) to normalize the distribution.

Data available for analysis—To be included in our final sample, it was necessary for children to provide behavioral and psychophysiological data for both tasks. Although 190 participants returned to the laboratory at 4 years of age, behavioral data were available for

157 children (task refusal/non-compliance: $n = 17$; failure to pass practice trials: $n = 9$; parental interference: $n = 3$; “non-Stroop” version not in protocol: $n = 3$; experimenter error: $n = 1$). EEG electrodes were accepted by 150 children; psychophysiological data were available for 147 participants (equipment failure $n = 3$); and sufficient artifact-free EEG (10 DFT windows per task) data were available for 144 four-year-olds.

Day-night tasks—The same set of laminated cards (10 cm × 15 cm) was used for both versions of the day-night task. All children were presented with the “non-Stroop” version followed by the “Stroop-like” version, ensuring equivalent prior practice of the prepotent response. For the “non-Stroop” day-night task, children were instructed to say “night” when shown a moon card and to say “day” when shown a sun card. For the “Stroop-like” day-night task (Gerstadt et al., 1994), children were instructed to say “night” when shown a sun card and “day” when shown a moon card. Each version began with two practice trials for each card and responses were praised or corrected. If necessary, practice trials were re-administered. Next, 16 test trials (half for each type) were administered in a fixed pseudorandom order. No feedback was given during test trials. For each version, administration time was approximately 3 min. The percentage of correct trials was calculated. Interrater reliability was calculated for 23% of the sample and the resulting Intraclass Correlation Coefficients were .92 (“non-Stroop”) and .99 (“Stroop-like”).

Statistical analyses—Our analyses examined sex differences in behavioral performance, EEG power, and brain-behavior associations. Our first set of psychophysiological analyses consisted of repeated measures multivariate analyses of variance (MANOVAs) with region, hemisphere, and condition as within-subjects factors and sex as a between-subjects factor. Of major interest for the specific analyses associated with each question were the main effect and the interactions involving condition (i.e., “Stroop-like” vs. “non-Stroop”) and sex. For ease in examining any interactions involving these variables, follow-up MANOVAs were performed. A multivariate approach for assessing multivariate interaction effects has been suggested by Keselman (1998). Next, we completed multiple regression analyses to examine brain-behavior associations. Because this is the first examination of sex differences cognitive processing-related EEG during early childhood, marginally significant results are provided for informational purposes.

Results

Performance

A repeated measures MANOVA with performance on each version of the day-night task as the within-subjects factor and sex as the between-subjects factor revealed a significant effect of task version, $F(1, 42) = 12.39, p = .001, \eta_p^2 = .08$. As expected, children performed better on the “non-Stroop” ($M = .92, SD = .07$) than “Stroop-like” ($M = .75, SD = .18$) version of the day-night task. There were no sex differences in performance (i.e., non-significant main effect and interaction involving sex, $F_s < 1$). Performance on the “Stroop-like” and “non-Stroop” versions of the day-night task was correlated, $r(142) = .31, p < .001$. Separate analyses for boys and girls revealed that performance across versions of the day-night task was correlated for girls, $r(74) = .37, p = .001$, but not for boys, $r(66) = .19, p = .13$.

“Stroop-like” versus “non-Stroop” EEG

Usable EEG—Prior to examination of sex differences in ln EEG power values, it was important to verify that the two groups had equal amounts of artifact-free EEG (Pivik et al., 1993). The amount of artifact-free data (i.e., number of DFT windows) for boys and girls was not significantly different for the “Stroop-like”, $t(142) = 1.66, p = .11$, or “non-Stroop”, $t(142) < 1, p = .79$, versions of the day-night task.

EEG power—A repeated-measures MANOVA was completed on the ln 6- to 9-Hz EEG power values. The within-subjects factors were condition (i.e., “Stroop-like” or “non-Stroop”), region (i.e., frontal pole, medial frontal, lateral frontal, central, temporal, lateral parietal, medial parietal, or occipital), and hemisphere (i.e., left or right), and the between-subjects factor was sex (i.e., boy or girl). For this overall MANOVA, there were main effects for condition, $F(1, 138) = 13.45, p < .001, \eta_p^2 = .09$; region, $F(7, 132) = 105.82, p < .001, \eta_p^2 = .85$; hemisphere, $F(1, 138) = 14.26, p < .001, \eta_p^2 = .09$; and sex, $F(1, 138) = 8.28, p = .005, \eta_p^2 = .06$. There were also interactions of Condition $\times$ Sex, $F(1, 138) = 3.95, p = .049, \eta_p^2 = .03$; Hemisphere $\times$ Sex, $F(1, 138) = 3.97, p = .048, \eta_p^2 = .03$; Region $\times$ Condition, $F(7, 132) = 2.77, p = .01, \eta_p^2 = .13$; and Region $\times$ Hemisphere, $F(7, 132) = 4.40, p < .001, \eta_p^2 = .19$. Finally, there was a marginally significant Region $\times$ Condition $\times$ Sex interaction, $F(7, 132) = 2.00, p = .06, \eta_p^2 = .10$.

To examine the aforementioned interactions, we performed separate MANOVAs (within-subjects factors: condition, hemisphere; between-subjects factor: sex) on the power values for each region. The results of regional MANOVAs are displayed in Table 1. Only main effects and interactions involving sex and condition are highlighted. There was a main effect of sex for all regions with females exhibiting higher power values than males (see Figure 1). Further, for medial frontal, lateral frontal, temporal, medial parietal, and lateral parietal regions there was a main effect of condition. As seen in Figure 1, children exhibited higher power values during the “Stroop-like” day-night task as compared to the “non-Stroop” version.

There was a Condition $\times$ Sex interaction for medial parietal and occipital regions. Post hoc analyses ($ps < .05$) revealed that only boys exhibited a main effect of condition, with higher power values during the “Stroop-like” as compared to “non-Stroop” day-night task (see Figure 1). Likewise, there was a Hemisphere $\times$ Sex interaction for frontal pole and central regions. Post hoc analyses revealed that only boys exhibited a main effect of hemisphere, with higher right hemisphere than left hemisphere power values. Finally, there was a Condition $\times$ Hemisphere interaction for medial frontal sites. Post hoc analyses revealed that the main effect of condition was only significant for the left hemisphere, with higher power values during the “Stroop-like” day-night task as compared to the “non-Stroop” version.

Brain-Behavior Associations

“Stroop-like” frontal EEG power—The EF literature indicates that different neural correlates are associated with individual differences in performance for men and women. To examine potential sex differences in EF-related brain activity during early childhood, we completed multiple regression analyses predicting boys’ and girls’ performance on the

“Stroop-like” day-night task. Previous work with 4-year-olds has indicated that power at frontal sites is associated with EF performance (e.g., Wolfe & Bell, 2004). We averaged EEG power values across hemispheres for the three frontal regions of interest: frontal pole, medial frontal, and lateral frontal. We also controlled for maternal education (i.e., a correlate of socioeconomic status and verbal intelligence) and children’s performance on the “non-Stroop” day-night task. Regression analyses included 137 participants (i.e., five participants did not have maternal education data and two participants had F7/F8 removed due to electrical failure or high signal impedance).

The results of the multiple regression analyses for girls and boys can be found in Table 2. Frontal EEG power, “non-Stroop” task performance, and maternal education accounted for 25% of variance in girls’ “Stroop-like” day-night task performance. An examination of the regression weights revealed that frontal pole EEG power and “non-Stroop” task performance accounted for unique variance in girls’ EF performance (Table 2). In contrast, the multiple regression analysis for boys revealed that frontal EEG power, “non-Stroop” task performance, and maternal education did not account for significant variance in EF performance, $F(5, 58) = 1.07, p = .39$ (Table 2).

Frontal EEG power change scores—To determine if a different measure of neural activity may potentially reveal brain-behavior associations in boys (Liu, Xiao, & Shi, 2013), we calculated EEG power change scores by subtracting the “non-Stroop” power value from the “Stroop-like” power value (i.e., “Stroop-like” – “non-Stroop”) and averaging across hemisphere for the three frontal regions of interest. Frontal baseline-to-task change scores have been linked with individual differences in EF performance during early childhood (e.g., Cuevas, Hubble, & Bell, 2012; Watson & Bell, 2013).

The results from a multiple regression analysis for girls and boys are displayed in Table 3. Frontal EEG power change scores, “non-Stroop” task performance, and maternal education accounted for 24% of variance in girls’ “Stroop-like” day-night task performance. An examination of the regression weights revealed that only “non-Stroop” task performance accounted for unique variance in girls’ EF performance; although there was a marginally significant trend for frontal pole EEG change scores (Table 3). Frontal EEG power change scores, “non-Stroop” task performance, and maternal education accounted for 18% of variance in boys’ EF performance. An examination of the regression weights revealed that lateral frontal EEG power change scores accounted for unique variance in boys’ “Stroop-like” day-night task performance (Table 3).

Effect of not considering sex differences—Finally, to explicitly examine the effect of not considering sex differences in brain-behavior associations, we combined groups and computed multiple regression analyses for the entire sample. Both the “Stroop-like frontal EEG power” model and the “frontal EEG power change score” model accounted for 15% in children’s “Stroop-like” day-night task performance (see Tables 2 and 3, respectively). Although an examination of the regression weights revealed that “non-Stroop” task performance accounted for unique variance in EF performance in both models, the only EEG measure to account for unique variance was medial frontal EEG power change scores (Tables 2 and 3).

Discussion

By 4 years of age, children exhibit sex differences in executive processing-related changes in 6–9 Hz EEG power in the absence of performance differences. Further, brain-behavior analyses indicate that different frontal EEG measures are linked with boys' and girls' EF performance. To our knowledge, this is the earliest evidence of sex differences in brain-behavior associations underlying executive processing to date. These findings have important implications for our understanding of the underlying neural systems of EF during early childhood, and highlight the importance of taking sex into consideration even when children exhibit similar levels of EF behaviorally.

“Stroop-like” versus “non-Stroop” EEG

We found that 4-year-olds exhibit increases in 6–9 Hz EEG power in response to added executive processing demands (i.e., “Stroop-like” vs. “non-Stroop” day-night tasks). Our work expands upon previous developmental EEG work examining baseline-to-task changes in executive processing (e.g., Bell & Wolfe, 2007). Our comparison condition (“non-Stroop” day-night task) was ideal because the visual stimuli and verbal responses were identical across conditions with only task demands (i.e., IC to say “day” to the night card and vice versa) differing across conditions. Thus, our stringent design ensured that changes in EEG were directly related to executive processing as opposed to extraneous factors unrelated to EF.

An examination of the scalp distribution of EF-related changes in 6–9 Hz power indicates more widespread changes in boys than girls. Specifically, although both sexes exhibited significant changes for lateral and medial frontal, temporal, and lateral parietal regions, boys also exhibited changes for medial parietal and occipital regions. One way that these data might be interpreted is in line with a neural efficiency hypothesis (e.g., Grabner, Fink, Stipacek, Neuper, & Neubauer, 2004), where intellectual competence is associated with less cortical activation (i.e., more efficient recruitment of neural resources) during cognitive processing. In fact, EF research with adults has found evidence of sex differences in neural efficiency within the alpha band (often considered the adult analog of the 6–9 Hz child band; Grabner et al., 2004). In the present study, the more localized changes in EEG power in girls, as compared to boys, may be indicative of more neurally efficient brain functioning to reach the same level of cognitive performance.

The developmental EEG literature has also provided evidence of increased neural efficiency during executive processing as a function of age (Espinete et al., 2012; Lamm, Zelazo, & Lewis, 2006). Longitudinal EF work indicates that 6–9 Hz EEG measures (power and coherence) exhibit more widespread changes during infancy and become more localized during early childhood (Bell & Wolfe, 2007). Thus, when our findings are considered in the context of the longitudinal executive processing literature, it appears that girls are potentially exhibiting a more mature pattern of functional brain development than boys.

Although there were no differences in EF performance in the present study, girls often exhibit higher levels of EF than boys in other settings (e.g., Kochanska et al., 1996, 2000; Wiebe et al., 2008), which could potentially be related to more mature patterns of executive

processing-related brain activity. In the present study, girls also exhibited higher overall levels of 6–9 Hz EEG power than boys. There are age-related increases in EEG power in the 6–9 Hz and higher bands, such as the adult 8–13 Hz alpha band. It is plausible that higher overall 6–9 Hz EEG power in girls is another indication of greater brain maturation as compared to boys (Bell, 1998; but see Limitations section).

Differences in the cerebral organization in boys and girls could also potentially underlie dissociations in behavioral and EEG measures of executive processing (Dunst, Benedek, Bergner, Athenstaedt, & Neubauer, 2013). The origins of these early sex differences in brain development can be traced to the fetal period, including differential maturation of brain stem auditory responses (DiPietro et al., 2010) and heart rate reactivity (Buss et al., 2009). These differences likely arise from complex interactions involving the intrauterine environment and fetal sex. Investigations of maternal HPA function (i.e., cortisol measures) indicate that there may be endocrine mechanisms that influence sex differences in fetal brain development (DiPietro et al., 2010, 2011; Ellman et al., 2008). Thus, sex differences in children's brain development by 4 years of age, likely have prenatal origins.

Beyond the prenatal period, boys have larger total brain volume than girls (Reiss et al., 1996; Sanchez et al., 2012), and by adulthood females have greater gyrification (i.e., more cortical surface area) than males in frontal and parietal regions (Luders et al., 2004). It has been posited that greater cortical complexity in females is a sexual dimorphism in brain structure that contributes to females' enhanced performance in certain cognitive domains (Luders et al., 2004). If sexual dimorphism in cortical complexity of frontal and parietal regions emerges during early childhood, then it could potentially contribute to early sex differences in executive-related brain activity and brain-behavior associations. Clearly, developmental analyses of sex differences in early cortical complexity are critical to our understanding of the potential underlying mechanisms of early sex differences in EF brain-behavior associations.

Further, our findings of sex differences in the scalp distribution of executive processing-related EEG changes at 4 years of age are parallel to evidence from fMRI work with adults using an IC task (Li et al., 2006). Men recruited a larger number of brain regions and showed greater activation than women to achieve similar levels of performance. Likewise, during adolescence, age modulation analyses suggest that females exhibit a more mature pattern of prefrontal brain activation than males with early functional maturation of the prefrontal cortex potentially underlying different cognitive strategies (Christakou et al., 2009). Thus, it appears that our hypotheses about girls' functional neural maturation during executive processing are in line evidence from later development.

Brain-Behavior Associations

The present study also revealed that by 4 years of age, individual differences in boys' and girls' EF performance is associated with different frontal neural correlates. When controlling for "non-Stroop" task performance and maternal education, 6–9 Hz EEG power at frontal pole sites during executive processing accounted for unique variance in girls' "Stroop-like" day-night performance. For boys, on the other hand, only lateral frontal EEG changes scores ("Stroop-like" minus "non-Stroop" power) accounted for unique variance in EF task

performance. Although previous research has examined frontal baseline-to-task change scores and EF performance (Cuevas et al., 2012; Watson & Bell, 2013), this is our first analysis of change scores between a non-executive and executive task using the same stimuli. Future work with a variety of EF measures is necessary to more precisely characterize the validity of this measure throughout early childhood.

ERP and fMRI work has also found evidence that neural correlates of EF differ as a function of sex (e.g., Christakou et al., 2009; Liu et al., 2012, 2013). In adults, males with higher levels of IC exhibited more activation in a variety of frontal and temporal regions as compared to males with lower levels of IC (Li et al., 2006). On the other hand, females with higher levels of IC exhibited more activation in some regions (i.e., caudate tail and parahippocampal) and less activation in frontal regions (i.e., middle frontal and anterior cingulate) as compared to females with lower levels of IC. Likewise, an ERP investigation with 5-year-olds found sex differences in links between neural activity during preattentive processing in the context of an oddball task and response inhibition on a separate no/no-go task (Liu et al., 2013). Neural activity at different electrode sites (central: boys; frontal: girls) was related to different behavioral measures of IC for boys (correct hit rates) and girls (commission error rates). It was posited that girls' preattentive processing potentially contributes to their superior IC performance. Thus, at a slightly later point in development than examined in the present study, we continue to see that different measures and different electrode sites are linked with individual differences in IC performance for boys and girls. Together, these findings highlight the need for not only the considerations of sex differences when examining brain-behavior associations during early development, but also the use of multiple behavioral and neural measures of EF.

An important challenge to forming an integrated explanation of sex differences in neural systems underlying EF is that there is not a consistent pattern of findings. Some work has failed to find sex differences, including an fMRI study of 8- to 25-year-olds' brain activity related to rule-switching (Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006). Even when sex differences are present in EF-related brain activity, the specific regions that exhibit greater activation for one sex or the other often varies between studies (e.g., Christakou et al., 2009). Thus, patterns of sex difference likely vary as a function of task, specific cognitive aspect of EF assessed, measure of neural activity, and age. Although we offer a potential explanation of our sex difference findings, additional work focusing on early childhood is essential to elucidating potential underlying mechanisms as well as determining the robustness and replicability of these findings.

Implications

Despite the critical role that EFs play in optimal outcomes during early childhood and beyond (see Diamond, 2013, for review), there remain significant gaps in our understanding of the etiology of individual differences in EF. As demonstrated in the current investigation, sex differences in the underlying neural networks of EF development are present by 4 years of age even when boys and girls exhibit similar levels of behavioral performance. The few studies that have examined the neural underpinnings of EF during early childhood have not considered sex differences (e.g., Watson & Bell, 2013). This is often justified by the absence

of main effects of sex in behavior or neural measures, but a growing body of literature indicates that sex can moderate potential brain-behavior associations.

What are the potential ramifications of not including sex in brain-behavior analyses of early childhood EF?—One potential outcome would be null results. In the

current study, collapsing across sex for individual differences analyses resulted in no evidence that frontal EEG power during executive processing was related to individual differences in EF. This null effect for “Stroop-like” day-night frontal EEG power emerged because this measure only accounted for unique variance in girls’ performance. Another, quite different, potential outcome of not including sex in brain-behavior analyses is finding a pattern of brain-behavior associations that in reality is only present for one (or neither!) sex. When we collapsed across sex, EEG power changes scores from medial frontal sites was related to corresponding EF, when in fact this association was not present for either boys or girls. Furthermore, evidence of more widespread changes increases in EEG power for boys than girls is only revealed when considering sex by condition interactions. In the present study, we had a relatively large sample size; however, sample size can be an influential factor, affecting between-study comparisons. Collapsing samples across sex will be most detrimental to studies with smaller sample sizes and likely contributes to inconsistency across studies as they fluctuate in sample composition. In sum, sex is an important factor, prior to the onset of puberty for analysis of brain-behavior associations.

A challenge in determining potential underlying mechanisms of sex differences in early childhood EF neural activity is that little is known about sexual dimorphisms in specific brain regions and specific areas of white matter development. There is consistent evidence of differences in total brain volume (Reiss et al., 1996; Sanchez et al., 2012), but sexual dimorphism in total brain volume itself does not appear to be related to EF development. Although it is hypothesized that sex differences in brain volume is potentially linked with sex differences in cortical complexity (Luders et al., 2004), developmental analysis of potential sexual dimorphisms are needed. In the last 20 years, we have started to get more detailed analysis of brain development (e.g., Sanchez et al., 2012); however, the sample sizes of these studies are typically too small for analysis of sex differences (e.g., Gogtay et al., 2004). Clearly, this is an important part of the puzzle.

There is much interest in EF training programs as an early intervention for children “at risk” for EF deficits (Diamond, Barnett, Thomas, & Munro, 2007; Thorell, Linqvist, Nutley, Bohlin, & Klinberg, 2009). When determining which measures are most effective, behavioral outcomes are typically considered, although there is increasing interest in also finding corresponding neural indicators (e.g., Espinet et al., 2013). Likewise, research on attention deficit-hyperactivity disorder, autism spectrum disorder, and other clinical disorders associated with EF deficits often focus on neural indicators (Liotti et al., 2007). In light of current evidence that sex can moderate links between EF and neural activity in the absence of performance differences, sex is an important factor to consider even during early childhood. First, an EF training program could lead to more efficient neural activity, in the absence of behavioral outcomes. Further, neural indicators also potentially vary as a function of sex, and diagnoses can be biased by unequal sex distribution (e.g., more boys

than girls); thus, having a single neural indicator for both males and females can result in inappropriate neural diagnostic criteria for the less represented sex.

Additional considerations for characterizing sex differences during early childhood

In the present study, we used parent report to classify children's biological sex. However, this does not account for differences in gender role behavior—the expression of feminine and masculine traits—that are evident during early childhood (Golombok & Rust, 1993; Hines et al., 2002). Work with older children (7 years +) and adolescents suggests that gender role behavior is associated with differences in brain morphology and social cognition (Belfi, Conrad, Dawson, & Nopoulos, 2014; Wood, Murphy, & Nopoulos, 2008). These findings support assertions that, “gender roles may be a more fine grained measure of sex; looking at both biological sex and psychological gender role behaviors can provide a more accurate picture of a person's gendered self” (Belfi, et al., 2014, p. 35). Thus, gender role measures are potentially informative for the broader sex differences literature, and there is at least some evidence of adult gender role identity being associated with individual differences in EF (Norvilitis & Reid, 2002).

Limitations

Strengths of the present study include its relatively large sample size, its stringent comparison condition, as well as its consideration of sex differences in the neural correlates of early childhood EF. The majority of the work on sex differences in EF has used fMRI, providing information about localized changes in neural activity. Because fMRI is not the optimal method for analysis of brain activity while young children are engaged in cognitive activity, we used EEG. Although EEG has precise temporal resolution, it cannot provide precise spatial resolution (i.e., areas other than the cortical region directly underneath each scalp electrode contribute to changes in EEG activity). Thus, we are unable to determine the subcortical and exact cortical regions that are differentially active during executive processing at 4 years of age. Future work with near-infrared spectroscopy can potentially overcome these barriers. We limited our examination of the EEG to the 6–9 Hz child alpha frequency band. There are valid reasons for doing so, as this frequency band is the dominant frequency band at age 4 (Marshall et al, 2002) and is associated with preschoolers' performance on EF tasks (e.g., Wolfe & Bell, 2004). Yet, including other child-specific EEG frequency bands would allow for a more in-depth examination of potential sex differences in the EEG during EF task performance. In addition, although we controlled for maternal education, this sample represents a rather homogenous sample, and future work is essential to determining whether similar patterns of sex differences are found across a range of socioeconomic status and culture.

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References

- Alloway TP, Gathercole SE, Pickering SJ. Verbal and visuospatial short-term and working memory in children: Are they separable? *Child Development*. 2006; 77:1698–1716. [PubMed: 17107455]
- Belfi AM, Conrad AL, Dawson J, Nopoulos P. Masculinity/femininity predicts brain volumes in normal healthy children. *Developmental Neuropsychology*. 2014; 39:25–36. [PubMed: 24405182]
- Bell, MA. The ontogeny of the EEG during infancy and childhood: Implications for cognitive development. In: Garreau, B., editor. *Neuroimaging in child neuropsychiatric disorders*. Berlin: Springer-Verlag; 1998. p. 97–111.
- Bell MA. Brain electrical activity associated with cognitive processing during a looking version of the A-not-B task. *Infancy*. 2001; 2:311–330.
- Bell MA. A psychobiological perspective of working memory performance at 8 months of age. *Child Development*. 2012; 83:251–265. [PubMed: 22103396]
- Bell, MA.; Cuevas, K. Psychobiology of executive function in early development. In: Griffin, JA.; Freund, LS.; McCardle, P., editors. *Executive function in preschool age children: Integrating measurement, neurodevelopment and translational research*. Washington, D.C: APA Press; (in press)
- Bell, MA.; Fox, NA. Brain development over the first year of life: Relations between electroencephalographic frequency and coherence and cognitive and affective behaviors. In: Dawson, G.; Fischer, KW., editors. *Human behavior and the developing brain*. New York: Guilford; 1994. p. 314–345.
- Bell MA, Wolfe CD. Changes in brain functioning from infancy to early childhood: Evidence from EEG power and coherence during working memory tasks. *Developmental Neuropsychology*. 2007; 31:21–38. [PubMed: 17305436]
- Bell EC, Willson MC, Wilman AH, Dave S, Silverstone PH. Males and females differ in brain activation during cognitive tasks. *NeuroImage*. 2006; 30:529–538. [PubMed: 16260156]
- Bierman KL, Torres MM, Domitrovich CE, Welsh JA, Gest S. Behavioral and cognitive readiness for school: Cross-domain associations for children attending Head Start. *Social Development*. 2009; 18:305–323.
- Blair C, Razza RP. Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*. 2007; 78:647–663. [PubMed: 17381795]
- Buss C, Davis EP, Class QA, Gierczak M, Pattillo C, Glynn LM, Sandman CA. Maturation of the human fetal startle response: Evidence for sex-specific maturation of the human fetus. *Early Human Development*. 2009; 85:633–638. [PubMed: 19726143]
- Carlson SM. Developmental sensitive measures of executive function in preschool children. *Developmental Neuropsychology*. 2005; 28:595–616. [PubMed: 16144429]
- Casey BJ, de Haan M. Introduction: new methods in developmental science. *Developmental Science*. 2002; 5:265–267.
- Christakou A, Halari R, Smith AB, Ifkovits E, Brammer M, Rubia K. Sex-dependent age modulation of frontostriatal and temporo-parietal activation during cognitive control. *NeuroImage*. 2009; 48:223–236. [PubMed: 19580877]
- Clarke AR, Barry RJ, McCarthy R, Selikowitz M. Age and sex effects in the EEG: Development of the normal child. *Clinical Neurophysiology*. 2001; 112:806–814. [PubMed: 11336896]
- Crone EA, Donohue SE, Honomichl R, Wendelken C, Bunge SA. Brain regions mediating flexible rule use during development. *The Journal of Neuroscience*. 2006; 26:11239–11247. [PubMed: 17065463]
- Cuevas K, Bell MA. Developmental progression of looking and reaching performance of the A-not-B task. *Developmental Psychology*. 2010; 46:1363–1371. [PubMed: 20822245]
- Cuevas K, Hubble M, Bell MA. Early childhood predictors of post-kindergarten executive function: Behavior, parent-report, and psychophysiology. *Early Education and Development*. 2012; 23:59–73. [PubMed: 22711983]
- Diamond A. Executive functions. *Annual Review of Psychology*. 2013; 64:135–168.

- Diamond A, Barnett WS, Thomas J, Munro S. Preschool program improves cognitive control. *Science*. 2007; 318:1387–1388. [PubMed: 18048670]
- Diamond A, Kirkham N, Amso D. Conditions under which young children can hold two rules in mind and inhibit a prepotent response. *Developmental Psychology*. 2002; 38:352–362. [PubMed: 12005379]
- DiPietro JA, Costigan KA, Kivlighan KT, Chen P, Laudenslager ML. Maternal salivary cortisol differs by fetal sex during the second half of pregnancy. *Psychoneuroendocrinology*. 2011; 36:588–591. [PubMed: 20940089]
- DiPietro JA, Kivlighan KT, Costigan KA, Rubin SE, Shiffler DE, Henderson JL, Pillion JP. Prenatal antecedents of newborn neurological maturation. *Child Development*. 2010; 81:115–130. [PubMed: 20331657]
- Dunst B, Benedek N, Bergner S, Athenstaedt U, Neubauer AC. Sex differences in neural efficiency: Are they due to stereotype threat effect? *Personality and Individual Differences*. 2013; 55:744–749. [PubMed: 24092950]
- Engle, RW.; Kane, MJ.; Tuholski, SW. Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In: Miyake, A.; Shah, P., editors. *Models of working memory: Mechanisms of active maintenance and executive control*. New York: Cambridge University Press; 1999. p. 102-134.
- Espinete SD, Anderson JE, Zelazo PD. N2 amplitude as a neural marker of executive function in your children: An ERP study of children who switch versus perseverate on the Dimensional Change Card Sort. *Developmental Cognitive Neuroscience*. 2012; 2S:S49–S58. [PubMed: 22682910]
- Espinete SD, Anderson JE, Zelazo PD. Reflection training improves executive function in preschool-age children: Behavioral and neural effects. *Developmental Cognitive Neuroscience*. 2013; 4:3–15. [PubMed: 23280362]
- Espy KA, McDiarmid MM, Cwik MF, Stalets MM, Hamby A, Senn TE. The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental Neuropsychology*. 2004; 26:465–486. [PubMed: 15276905]
- Gasbarri A, Arnone B, Pompili A, Pacitti F, Pacitti C, Cahill L. Sex-related hemispheric lateralization of electrical potentials evoked by arousing negative stimuli. *Brain Research*. 2007; 1138:178–186. [PubMed: 17274960]
- Gasser T, Verleger R, Bacher P, Sroka L. Development of the EEG of school-age children and adolescents: I. Analysis of band power. *Electroencephalography and Clinical Neurophysiology*. 1988; 69:91–99. [PubMed: 2446839]
- Gerstadt CL, Hong YJ, Diamond A. The relationship between cognition and action performance of children 3 ½–7 years old on a Stroop-like day-night test. *Cognition*. 1994; 53:129–153. [PubMed: 7805351]
- Grabner RH, Fink A, Stipacek A, Neuper C, Neubauer AC. Intelligence and working memory systems: evidence of neural efficiency in alpha band ERD. *Cognitive Brain Research*. 2004; 20:212–225. [PubMed: 15183393]
- Goldstein JM, Jerram M, Poldrack R, Anagnoson R, Breiter HC, Makris N, ...Seidman LJ. Sex differences in prefrontal cortical brain activity during fMRI of auditory verbal working memory. *Neuropsychology*. 2005; 19:509–519. [PubMed: 16060826]
- Golombok S, Rust J. The measurement of gender role behavior in pre-school behavior. A research note. *Journal of Child Psychology and Psychiatry*. 1993; 34:805–811. [PubMed: 8340446]
- Gogtay N, Giedd JN, Lusk L, Hayashi KM, Greenstein D, Vaituzis C, Thompson PM. Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Science*. 2004; 101:8174–8179.
- Halpern, DF. Sex differences and cognitive abilities. Mahwah, NJ: Erlbaum; 2000.
- Henry JR. Electroencephalograms of normal children. *Monographs of the Society for Research in Child Development*. 1944; 9 (3, Serial No. 39).
- Hepper, PG. The behavior of the fetus as an indicator of neural functioning. In: Lecanuet, JP.; Fifer, WP.; Krasnegor, NA.; Smotherman, WP., editors. *Fetal development: A psychobiological perspective*. Hillsdale, NJ: Earlbaum; 1995. p. 405-417.

- Hines M, Golombok S, Rust J, Johnston KJ, Golding J. the Avon Longitudinal Study of Parents and Children Study Team (ALSPAC). Testosterone during pregnancy and gender role behavior of preschool children: A longitudinal, population study. *Child Development*. 2002; 73:1678–1687. [PubMed: 12487486]
- Huizinga M, Dolan CV, van der Molen MW. Age-related changes in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia*. 2006; 44:2017–2036. [PubMed: 16527316]
- Huttenlocher PR, Dabholkar AS. Regional differences in synaptogenesis in human cerebral cortex. *The Journal of Comparative Neurology*. 1997; 387:167–178. [PubMed: 9336221]
- Kanemura H, Aihara M, Aoki S, Araki T, Nakazawa S. Development of the prefrontal lobe in infants and children: a three-dimensional magnetic resonance volumetric study. *Brain & Development*. 2003; 25:195–199. [PubMed: 12689699]
- Keselman HJ. Testing treatment effects in repeated measures designs: An update for psychophysiological researchers. *Psychophysiology*. 1998; 35:470–478. [PubMed: 9643062]
- Kochanska G, Murray KT, Harlan ET. Effortful control in early childhood: Continuity and change, antecedents, and implications for social development. *Developmental Psychology*. 2000; 36:220–232. [PubMed: 10749079]
- Kochanska G, Murray K, Jacques TY, Koenig AL, Vandegeest KA. Inhibitory control in young children and its role in emerging internalization. *Child Development*. 1996; 67:490–507. [PubMed: 8625724]
- Lamm C, Zelazo PD, Lewis MD. Neural correlates of cognitive control in childhood and adolescence: Disentangling the contributions of age and executive function. *Neuropsychologia*. 2006; 44:2139–2148. [PubMed: 16310813]
- Li, C-s. R; Huang, C.; Constable, RT.; Sinha, R. Gender differences in the neural correlates of response inhibition during a stop signal task. *NeuroImage*. 2006; 32:1918–1929. [PubMed: 16806976]
- Li, C-s. R; Zhang, S.; Duann, J-R.; Yan, P.; Sinha, R.; Mazure, CM. Gender differences in cognitive control: an extended investigation of the stop signal task. *Brain Imaging and Behavior*. 2009; 3:262–276. [PubMed: 19701485]
- Liu J, Zubieta J-K, Heitzeg M. Sex differences in anterior cingulate cortex activation during impulse inhibition and behavioral correlates. *Psychiatry Research: Neuroimaging*. 2012; 201:54–62.
- Liu T, Xiao T, Shi J. Response inhibition, preattentive processing, and sex difference in young children: an event-related potential study. *NeuroReport*. 2013; 24:126–130. [PubMed: 23262505]
- Marshall PJ, Bar-Haim Y, Fox NA. Development of the EEG from 5 months to 4 years of age. *Clinical Neurophysiology*. 2002; 113:1199–1208. [PubMed: 12139998]
- Matousek, M.; Petersen, I. Frequency analysis of the EEG in normal children and adolescents. In: Kellaway, P.; Petersen, I., editors. *Automation of clinical electroencephalography*. New York: Raven Press; 1973. p. 75-102.
- Matsuura M, Yamamoto K, Fukuzawa Y, Okubo H, Uesugi M, Moriwa T, Shimazono Y. Age development and sex differences of various EEG elements in healthy children and adults: Quantification by computerized wave form recognition method. *Electroencephalography and Clinical Neurophysiology*. 1985; 60:394–406. [PubMed: 2580690]
- Miyake A, Friedman NP, Emerson MJ, Witzki AH, Jowrter A, Wager TD. The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis. *Cognitive Psychology*. 2000; 41:49–100. [PubMed: 10945922]
- Norvilitis JM, Reid HM. Evidence for an association between gender-role identity and a measure of executive function. *Psychological Reports*. 2002; 90:35–45. [PubMed: 11899009]
- Petersen I, Eeg-Olofsson O. The development of the electroencephalogram in normal children from the age of 1 through 15 years. *Neuropadiatrie*. 1971; 2:247–302. [PubMed: 5171359]
- Pivik RT, Broughton RJ, Coppola R, Davidson RJ, Fox NA, Nuwer MR. Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts. *Psychophysiology*. 1993; 30:547–558. [PubMed: 8248447]
- Reiss AL, Abrams MT, Singer HS, Ross JL, Denckla MB. Brain development, gender, and IQ in children: A volumetric imaging study. *Brain*. 1996; 119:1763–1774. [PubMed: 8931596]

- Sanchez CE, Richards JE, Almli CR. Neurodevelopmental MRI brain templates for children from 2 weeks to 4 years of age. *Developmental Psychobiology*. 2012; 54:77–91. [PubMed: 21688258]
- Schmithorst VJ, Holland SK, Dardzinski BJ. Developmental differences in white matter architecture between boys and girls. *Human Brain Mapping*. 2008; 29:696–710. [PubMed: 17598163]
- Silverman IW. Gender differences in delay of gratification: A meta-analysis. *Sex Roles*. 2003; 49:451–463.
- Thorell LB, Linqvist S, Nutley SB, Bohlin G, Klinberg T. Training and transfer effects of executive functions in preschool children. *Developmental Science*. 2009; 12:106–113. [PubMed: 19120418]
- Watson AJ, Bell MA. Individual difference in inhibitory control skills at three years of age. *Developmental Neuropsychology*. 2013; 38:1–21. [PubMed: 23311312]
- Wiebe SA, Espy KA, Charak D. Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*. 2008; 44:575–587. [PubMed: 18331145]
- Wiebe SA, Sheffield T, Nelson JM, Clark CAC, Chevalier N, Espy KA. The structure of executive function in 3-year-olds. *Journal of Experimental Child Psychology*. 2011; 108:436–452. [PubMed: 20884004]
- Wolfe CD, Bell MA. Working memory and inhibitory control in early childhood: Contributions from physiology, temperament, and language. *Developmental Psychobiology*. 2004; 44:68–83. [PubMed: 14704991]
- Wolfe CD, Bell MA. Source variability in working memory during early childhood: A consideration of age, temperament, language, and brain electrical activity. *Cognitive Development*. 2007a; 22:431–455.
- Wolfe CD, Bell MA. The integration of cognition and emotion during infancy and early childhood: Regulatory processes associated with the development of working memory. *Brain and Cognition*. 2007b; 65:3–13. [PubMed: 17630061]
- Wood JL, Murphy V, Nopoulos P. Ventral frontal cortex in children: morphology, social cognition, and femininity/masculinity. *Social Cognitive and Affective Neuroscience*. 2008; 3:168–176. [PubMed: 19015107]

Figure 1.

EEG power values for “non-Stroop” and “Stroop-like” versions of the day-night task in 4-year-old boys and girls. Main effects of condition are highlighted for particular scalp electrodes via brackets labeled “C”. The unlabeled brackets represent significant post hoc analyses (i.e., a main effect of condition for boys) following significant Condition $\times$ Sex interactions at corresponding scalp electrodes. Although not highlighted with brackets, significant main effects of sex at all scalp electrodes are evident by comparing the light and dark gray bars (boys) with the yellow and black bars (girls). *** $p < .001$; ** $p < .01$; * $p < .05$.

Table 1

Summary of regional multivariate analyses F values for “Stroop-like” vs. “non-Stroop” day-night comparisons as a function of sex and hemisphere.

	Condition	Hemi	Sex	C x H	C x S	H x S	C x H x S
Fp1/Fp2		9.81** (.06)	8.00** (.05)		3.54+ (.02)	4.34* (.03)	
F3/F4	7.95** (.05)		5.58* (.04)	4.37* (.03)			
F7/F8	10.30** (.07)	4.71* (.03)	4.13* (.03)				
C3/C4		8.66** (.06)	5.72* (.04)			4.82* (.03)	
T7/T8	9.64** (.06)		4.15* (.03)				
P3/P4	6.38* (.04)	6.20* (.04)	6.33* (.04)		5.96* (.04)		
P7/P8	24.83*** (.15)	7.37** (.05)	4.10* (.03)				
O1/O2		13.79*** (.09)	11.13*** (.07)		8.06** (.05)		

Note.

*** p .001;

** p .01;

* p .05;

+ p .065.

Effect sizes (ηp^2) are in parentheses.

Table 2

Results of multiple regression analyses predicting “Stroop-like” day-night performance (as a function of sex) from maternal education, “non-Stroop” day-night performance, and frontal EEG power during the “Stroop-like” task.

	Girls			Boys			Combined		
	β	t	sr^2	β	t	sr^2	β	t	sr^2
<i>Dependent variable: Stroop-like task performance</i>									
Maternal education	.07	0.61		.10	0.74		.09	1.13	
Non-Stroop task performance	.34	3.10**	.11	.19	1.47	.03	.30	3.71***	.09
<i>Frontal EEG power during Stroop-like task</i>									
Fp1/Fp2	.57	2.49*	.07	-.01	-0.03		.30	1.84	.02
F3/F4	-.15	-0.74		-.26	-1.11	.02	-.25	-1.68	.02
F7/F8	-.23	-0.92		.27	1.14	.02	.05	0.31	
R^2	.25			.08			.15		
F	4.55***			1.07			4.76***		
n	73			64			137		

Note:

*** p .001;

** p .01;

* p .05.

Only sr^2 values > .01 are reported.

Table 3

Results of multiple regression analyses predicting “Stroop-like” day-night performance (as a function of sex) from maternal education, “non-Stroop” day-night performance, and frontal EEG power change scores.

	Girls			Boys			Combined		
	β	t	sr^2	β	t	sr^2	β	t	sr^2
<i>Dependent variable: Stroop-like task performance</i>									
Maternal education	.04	0.34		.13	1.06	.02	.09	1.05	
Non-Stroop task performance	.45	4.03***	.18	.18	1.44	.03	.32	3.81***	.09
<i>Frontal EEG power change scores ("Stroop-like" minus "non-Stroop")</i>									
Fp1/Fp2	.25	1.95+	.04	-.08	-0.46		.14	1.30	.01
F3/F4	-.17	-1.30	.02	-.16	-1.06	.02	-.21	-2.12*	.03
F7/F8	-.23	-1.75	.03	.41	2.82**	.11	.06	0.60	
R^2	.24			.18			.15		
F	4.26**			2.57*			4.52***		
n	73			64			137		

Note:

 p .001;

**
 p .01;

*
 p .05;

+
 p .06.

Only sr^2 values > .01 are reported.