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Brain Electrical Activity of Shy and Non-Shy Preschool-Aged Children during Executive Function Tasks

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Abstract

Psychophysiological and cognitive performance differences exist between shy and non-shy individuals. Neuroimaging studies have shown identifiable differences in task-related cortical functioning between adults with and without sensitivity to social events. The current study compared baseline and task measures of EEG power (6–9 Hz) for 125 shy and non-shy children between the ages of 41–55 months who differed in core executive function (EF) skills. Results indicated an increase in medial frontal EEG power from baseline-to-task for high EF performers (shy and non-shy). Shy/low EF performers also demonstrated this increase, but the non-shy/low EF group did not. For the medial parietal region, only the shy children (high and low EF performers) showed an increase in power from baseline-to-task; and for the shy/high EF group, left hemisphere power was greater than the right during baseline and task. This study is believed to be the first continuous-recording EEG comparison between children who are shy and non-shy in the context of an EF assessment. These findings highlight differences in medial frontal and medial parietal power for children who differ in shyness and EF skills. They also suggest the value of future research examining strong EF skills as protective and regulatory for shy children.

Differences in brain electrical activity between children who are shy or inhibited and those who are less so are well-documented (e.g., Davidson, 1992; Fox, Schmidt, Calkins, Rubin, & Coplan, 1996; Fox & Reeb-Sutherland, 2010; Kagan, Snidman, Kahn, & Towsley, 2007; Miskovic & Schmidt, 2012). In general, greater relative left frontal electroencephalogram (EEG) activation is associated with positive emotions and approach motivation, whereas greater relative right frontal EEG activation is related to negative emotions, withdrawal motivation, and tendencies toward behavioral inhibition and shyness. Additionally, greater overall activation at frontal scalp locations and greater relative right activation in the parietal areas have been considered indices of emotional intensity and have been associated with increased arousal and anxiety, as well as with distinguishing among subtypes of shyness (Dawson, 1994; Engels et al., 2007; Heller, 1993; Schmidt, 1999; Schmidt & Fox, 1994). These studies include EEG activity during resting baseline and/or emotion-based contexts.

Many labels have been used to reference shy behavior (e.g., behavioral inhibition, social wariness, social reticence, introversion, etc.). Although, these terms represent distinct constructs and research traditions, they share a common element, namely sensitivity to social events. We focus on the construct of shyness defined as wariness during novel social events and/or the display of self-conscious behavior in situations where there is a perception of being socially evaluated (Coplan & Rubin, 2010). This latter definition of shyness has implications for cognitive processing and, thus, implications for brain activity during cognition.

The purpose of our study was to examine associations between EEG activity and shyness in a non-emotion context. We wanted to know if shy and non-shy children exhibited differences in frontal and parietal EEG when performing difficult age-appropriate cognitive tasks in front of a stranger. We build our rationale for examining EEG during cognition by briefly reviewing literature on shyness and cognition, as well as cognition and EEG, and then offer the hypotheses that guided our work.

Shyness and Cognition

Temperamentally shy children and adults who are introverted or socially anxious tend to be at a disadvantage on various measures of cognitive ability compared to individuals who are less socially sensitive (e.g., Asendorpf, 1994; Blankson, O'Brien, Leerkes, Marcovitch, & Calkins, 2011; Crozier & Hostettler, 2003; Eysenck & Calvo, 1992; Gray & Braver, 2002; Hughes & Coplan, 2010; Lieberman, 2000; Ludwig & Lazarus, 1983). Much of this research focuses on the core cognitive skills that comprise executive function (EF; working memory, inhibitory control, attentional flexibility; Roberts & Pennington, 1996). For example, Ludwig and Lazarus (1983) compared performance differences for shy and non-shy children, ages 8 to 11 years, on the classic Stroop color-word task. They found that shy children were at a disadvantage on this cognitive control task, with slower reading rates, and concluded that individual differences in temperament are directly related to the flexibility of one's cognitive control system. Using a child version of the Stroop (i.e., the Day-Night Stroop; Diamond, Prevor, Callender, & Druin, 1997), Blankson et al. (2011) reported this negative relation between shyness and EF as early as 3½-years of age.

Other than an inflexible cognitive system, explanations for EF performance differences include cognitive interference resulting from shy individuals' preoccupation with social evaluation and cognitive "busyness" (i.e., intrusive, task-irrelevant, and self-conscious thoughts), inefficient processing related to inefficient resource allocation or working memory capacity, and differential functioning of certain brain regions (e.g., Eysenck & Calvo, 1992; Gray & Braver, 2002; Kagan 1994; Lieberman, 2000; Owens, Stevenson, Norgate, & Hadwin, 2008; Sarason, 1984). For example, EF relies on the dorsolateral prefrontal cortex (DLPFC; see Diamond, 2013, for review); and this cortical area has been hypothesized as differentially functional in introverts and extraverts (Lieberman, 2000). Similarly, the anterior cingulate cortex (ACC) with subdivisions for emotion (rostral region, specifically the subgenual area) and cognitive (caudal region) processing has been associated with the executive control of cognitive and emotion-related behaviors (Bush, Luu, & Posner, 2000). fMRI work with adults has shown that higher scores on an extraversion-

related measure were associated with better performance on a challenging working memory task and lower task-related activation in the caudal ACC (Gray & Braver, 2002). These findings suggest that more extraverted individuals performed the task more effectively and their brains worked more efficiently (Eysenck & Calvo, 1992) than those less extraverted individuals. Thus, psychophysiological and neuroimaging studies have shown differences in brain functioning for socially sensitive individuals. Further, studies done in the context of cognitive processing have focused on adults. We are unaware of any comparable psychophysiological comparisons between children who are shy and non-shy in the context of a cognitive assessment.

Cognition and EEG

Research on EEG power and EF performance in young children has shown task-related increases in 6–9 Hz power for high EF performers. For example, Wolfe and Bell (2004) demonstrated a baseline-to-task increase in 6–9 Hz EEG power at the medial frontal scalp locations for preschool-aged children who performed well on tasks of working memory and inhibitory control. This frontally focused, baseline-to-EF task increase for the 6–9 Hz frequency band has been replicated in other studies with young children (e.g., Bell & Wolfe, 2007; Cuevas, Hubble, & Bell, 2012; Watson & Bell, 2013; Wolfe & Bell, 2007a, 2007b).

These task-related EEG power changes at 6–9 Hz during cognitive processing in childhood are similar to reports of adults demonstrating positive correlations between task-related changes in theta band EEG (4–7 Hz) and EF performance (Klimesch, 1999; Fernández et al., 1995; see Bell & Cuevas, 2012; Bell & Fox, 1994; Pivik et al., 1993, for discussions of developmental differences between child and adult EEG). Additionally, EEG power at 6–8 Hz (encompassing upper theta and lower alpha bands) is sensitive to arousal levels in adults, with power values at parietal-occipital scalp locations higher during personal rumination than during nominal rumination or baseline counting (Andersen, Moore, Venables, & Corr, 2009). Increases in power during personal rumination were interpreted as indicative of increased vigilance and arousal.

This is an intriguing paradox because task-related increases in EEG at frontal locations (children and adults) during EF tasks are associated with better performance and presumably cortical efficiency. However, task-related increases in EEG at parietal-occipital locations during personal rumination may be associated with increased vigilance, arousal, and anxiety and, thus, cortical inefficiency in adults (Heller, 1993). Given these findings, we formulated the following research question: Are task-related increases in EEG power for children with high EF performance, but who were also rated by parents as shy, associated with a pattern of EEG typically associated with cortical efficiency (e.g., Wolfe & Bell, 2007b) and also potentially associated with a pattern of EEG associated with arousal due to the social performance aspects of laboratory tasks (i.e., done one-on-one with a researcher)?

Our examination of this research question focused on a community sample of young children performing two typical preschool EF tasks. Our focus on preschool-aged children was influenced by the early identification of the EF-shyness relation in 3½-year-olds (i.e., Blankson et al., 2011), this time period's association with the development of the social self

(Theall-Honey & Schmidt, 2006), and the emerging developmental stability of EF skills around 4 years of age (Alloway, Gathercole, & Pickering, 2006; Alloway, Gathercole, & Willis, 2004).

Hypotheses

We examined potential differences between baseline and EF task-related EEG for shy and non-shy preschool-aged children. Based on previous research (e.g., Wolfe & Bell, 2004), we hypothesized that high EF performers (both shy and non-shy) would demonstrate baseline-to-task increases in 6–9 Hz EEG power at medial frontal scalp locations. We were curious to see if the shy children in the high EF performance group would demonstrate a different pattern of task-related EEG power due to their cognitive busyness, although we did not predict the direction of these effects. We anticipated these differences to be most prominent at frontal scalp locations due to the involvement of the DLPFC and the ACC in studies of cognition and emotion (Bell & Deater-Deckard, 2007; Gray & Braver, 2002; Lieberman, 2000). We also examined baseline and task EEG for the children at parietal scalp locations, given associations with arousal, anxiety, and shyness in adults (e.g., Andersen et al., 2009; Heller, 1993; Schmidt & Fox, 1994). However, due to the lack of parietal findings reported with infants and young children (e.g., Davidson & Fox, 1989; Dawson, Panagiotides, Hill, & Spieker, 1992; Jones, Field, & Davalos, 2000), we had no specific hypotheses about the activity of this region with our preschool-aged children.

Method

Participants

One hundred twenty-five children (65 male, 60 female) between the ages of 41–55 months ($M=4.07$ years, $SD = .26$) and their parents were recruited for participation. All children were born to parents with at least a high school diploma, with the majority (66.5%) earning a college degree. Participating children and their parents represented two cohorts, Cohort A ($n = 61$; blinded for review) and Cohort B ($n = 64$; blinded for review), recruited for separate studies investigating associations between cognition, emotion, and psychophysiology. As the studies included some of the same cognitive tasks and identical temperament and physiological protocols, these two datasets were combined for the current analyses. Most of the children in the two cohorts were European Caucasian (89%). All of the children were born after uncomplicated, full-term pregnancies and all children had experienced healthy development.

Procedure

Upon arrival to the lab, procedures were described, written consent was obtained from the parents, and verbal assent was obtained from the children. The accompanying parent remained with the child throughout the visit.

Shyness Assessment—Parents completed the Children's Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001) before the laboratory visit to assess caregiver perceptions of temperament. Parents were to rate how true or untrue a statement was about their child's behavior within the last 6-months. Our analyses focus on the *shyness*

scale, defined as slow or inhibited approach in situations involving novelty or uncertainty. All items that comprised the shyness scale ($\alpha = .93$ for our entire sample) included a social component (e.g., “Sometimes seems nervous when talking to adults s/he has just met”).

Executive Function Tasks—A series of age-appropriate tasks was administered to the children that required them to pay attention to a given set of rules, remember the rules throughout the task, and to inhibit a dominant response tendency. Two of the tasks, the day-night Stroop-like task (Diamond et al., 1997) and the yes-no task (Wolfe & Bell, 2004), were accomplished during the collection of EEG measures as they required little gross motor movement from the child. The day-night Stroop-like task is hypothesized to involve the functioning of DLPFC (Diamond et al., 1997), and performance on both tasks has been associated with increased 6–9 Hz EEG power at frontal scalp locations (Wolfe & Bell, 2004, 2007a, 2007b).

For the *day-night Stroop-like task*, Children were instructed to say “day” when shown a card with a picture of the moon and stars and to say “night” when shown a card with a picture of the sun. The children were given two learning trials during which they were praised or corrected, and then 16 test trials were administered, eight with the sun card and eight with the moon card arranged in a pseudorandom order. The percentage correct was calculated. The percentage of agreement between two coders coding individual trials for 20% of the sample was 95%.

Modeled after the day-night testing procedure, in the *yes-no task*, the child was instructed to say “no” when the experimenter nodded her head and to say “yes” when the experimenter shook her head. Again, the children were given two learning trials, during which they were praised or corrected, and then 16 test trials were administered, with eight head nods and eight head shakes arranged in a pseudorandom order. The percentage correct was calculated. The percentage of agreement between two coders coding individual trials for 20% of the sample was 97%.

Psychophysiological Recording—EEG measures were accomplished during a 2-minute baseline period while children watched an animated video-clip and during the two aforementioned EF tasks. EEG data were collected using an Electro-Cap from 16 left and right scalp locations: frontal pole (Fp1/Fp2), medial frontal (F3/F4), lateral frontal (F7/F8), central (C3/C4), temporal (T7/T8), medial parietal (P3/P4), lateral parietal (P7/P8), and occipital (O1/O2), with Cz reference. We focused on power at the medial frontal (F3/F4) and the medial parietal (P3/P4) scalp locations, in line with past research investigating brain activity associated with early childhood EF (e.g., Wolfe & Bell, 2004) and temperament-related characteristics (Davidson & Fox, 1989; Dawson et al., 1992; Jones et al., 2000; Schmidt & Trainor, 2001). NuPrep and EEG Gel conductor were inserted into each recording site and the scalp lightly rubbed. Electrode impedances were measured and were accepted if they were below 10 k Ω . The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps (San Diego, CA), band passed from 1 Hz to 100 Hz, and digitized online at 512 Hz. EEG data were examined and analyzed using software developed by James Long Company (Caroga Lake, NY). Data were rereferenced via software to an average reference configuration and then artifact scored for eye blinks 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. The artifact-free data were analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. Power was computed for the 6–9 Hz frequency band, the dominant frequency for preschool-aged children (Marshall, Bar-Haim, & Fox, 2002) and a bandwidth that has shown associations with individual differences in cognitive processing with this age population (Cuevas et al., 2012; Wolfe & Bell, 2004, 2007a, 2007b). The power was expressed as mean square microvolts, and the data transformed using the natural log (ln) to normalize the distribution. The EEG power values for the two tasks were strongly correlated (all r 's $> .80$ and all p 's $< .001$) and were combined (weighting the power values by the amount of EEG data collected for each task). The amount of task-related artifact-free EEG data was not related to the shyness measure ($r = -.17, p = .09$), nor was it related to performance on the EF assessment ($r = .04, p = .67$).

Results

The percentage of correct responses for each EF task was averaged to yield a composite EF score for each child. Seven children participated in one or the other of the tasks; for these children, the EF composite score was the score on the one completed task. The average EF composite score for the children in this study was 64.78% correct ($SD = 25.94$). High ($n = 69$) and low ($n = 56$) EF groups were formed based the child's EF score relative to the mean (low EF $< 64.78\%$ $<$ high EF). There was no difference in EF task performance between the two cohorts of children in this study, $t(123) = -.60, p = .55$.

Three children contributed no shyness data (due to parents not returning the CBQ) and were omitted from the remaining analyses. The average shyness score on a 7-point scale for the 122 children with CBQ data was 3.43 ($SD = 1.24$). Shy ($n = 59$) and non-shy ($n = 63$) categories were created based on the child's shyness score relative to the mean (non-shy $< 3.43 <$ shy). There was no difference in shyness ratings between the two cohorts of children in this study, $t(120) = .96, p = .34$, nor was there a difference in EF task performance for the two shyness groups, $t(120) = .82, p = .41$.

One hundred and one children contributed complete EEG data, including all 4 channels of interest for baseline and task, and an additional 7 children contributed baseline EEG data but not task. No EEG data were available for 17 children (16 children refused cap application, and one child's recording had excessive artifact and was not usable). Twelve of these children were classified in the low EF group, and five of these children were in the high EF group.

EEG Power Analyses

To examine differences in EEG power between the medial frontal and medial parietal regions as a function of condition, shyness, or cognitive task performance, a repeated measures MANOVA was conducted on the ln EEG power values (6–9 Hz) for these regions. The within subjects factors were condition (baseline, task), region (medial frontal, medial parietal), and hemisphere (left, right). The between-subjects factors were EF performance

group (low, high) and shyness group (shy, non-shy). Multiple main effects and interactions were found, but these were superseded by a significant 5-way interaction between Condition, Region, Hemisphere, Shyness group, and EF group, $F(1,97)=5.22$, $p=.03$, $\eta^2 P=.05$. To aid in interpretation of this interaction and to address our hypotheses related to specific cortical areas, follow-up analyses were conducted separately for each region.

Medial Frontal Region (F3/F4)

We hypothesized that children in the high EF group would demonstrate baseline-to-task increases in EEG power for the medial frontal scalp locations based on previous research (e.g., Wolfe & Bell, 2004). We also thought that the shy children in the high EF group might exhibit different patterns of EEG power in this region due to their cognitive busyness. To test these hypotheses, a repeated measures MANOVA was conducted on the ln EEG power values (6–9 Hz) for the medial frontal region (F3/F4). The within-subjects factors were condition (baseline, task) and hemisphere (left, right). The between-subjects factors were EF performance group (low, high) and shyness group (shy, nonshy). The results of this analysis showed a main effect for Condition, $F(1,97)=25.79$, $p<.001$, $\eta^2 P=.21$. This was superseded by Condition $\times$ Shyness group $\times$ EF group, $F(1,97)=3.92$, $p=.05$, $\eta^2 P=.04$, and Condition $\times$ Hemisphere, $F(1,97)=4.31$, $p=.04$, $\eta^2 P=.04$, interactions. A Hemisphere $\times$ EF group interaction also was found, $F(1,97)=6.75$, $p=.01$, $\eta^2 P=.07$.

Because our hypotheses focused on EF performance for the medial frontal region and the identified three-way interaction included EF group, follow-up analyses were performed separately for each EF performance group. These analyses revealed most of the effects were for the low EF group; for this group, a main effect was found for Condition, $F(1,37)=7.79$, $p=.008$, $\eta^2 P=.17$, and this was superseded by a Condition $\times$ Shyness group interaction, $F(1,37)=4.04$, $p=.05$, $\eta^2 P=.10$. Follow-up analyses show an increase in baseline-to-task power for the shy children, $t(16)=-4.29$, $p=.001$, but not for the non-shy children, $t(21)=-.51$, $p=.62$, in the low EF group. A Hemisphere effect also was seen for the low EF group, $F(1,37)=10.87$, $p=.002$, $\eta^2 P=.23$, with increased right hemisphere power relative to the left for both shy and non-shy children.

For the high EF group, a main effect for Condition was seen, $F(1,60)=21.38$, $p<.001$, $\eta^2 P=.26$, with higher power values evident during task compared to baseline. Incidentally, the task power values for the shy children in the high EF performance group were not different than the non-shy children in this group, $t(60)=-.93$, $p=.34$ (see Figure 1).

Medial Parietal Region (P3/P4)

A repeated measures MANOVA was conducted on the ln EEG power values (6–9 Hz) for the medial parietal region comparable to the medial frontal analysis described above. A main effect for Condition was found, $F(1,97)=18.23$, $p<.001$, $\eta^2 P=.16$. This effect was superseded by Condition $\times$ Shyness group, $F(1,97)=13.76$, $p<.001$, $\eta^2 P=.12$, and Condition $\times$ Shyness group $\times$ Hemisphere, $F(1,97)=4.64$, $p=.03$, $\eta^2 P=.05$, interactions. Interactions also were found for Condition $\times$ EF group, $F(1,97)=4.84$, $p=.03$, $\eta^2 P=.05$, and for Hemisphere $\times$ EF group, $F(1,97)=9.41$, $p=.003$, $\eta^2 P=.09$.

Because of the three-way interaction including shyness, follow-up analyses were conducted separately for each shyness group and revealed most of the effects were for the shy group. Specifically, for the shy children, an effect for Condition, $F(1,43)=26.70$, $p<.001$, $\eta^2 P=.38$, was found, and this was superseded by Condition $\times$ EF group, $F(1,43)=6.42$, $p=.02$, $\eta^2 P=.13$, and Condition $\times$ Hemisphere, $F(1,43)=5.40$, $p=.03$, $\eta^2 P=.11$, interactions. A Hemisphere $\times$ EF group interaction was seen also, $F(1,43)=6.29$, $p=.02$, $\eta^2 P=.13$. Analyses further examining the interactions for the shy group, revealed a Condition $\times$ Hemisphere interaction, $F(1,16)=4.61$, $p=.05$, $\eta^2 P=.22$, for the low EF performers. For the shy, low EF children, task-related power was greater than baseline for both hemispheres combined, $t(16)= -4.62$, $p<.001$ (2-tailed); further, the right hemisphere exhibited marginally higher task-related power relative to the left, $t(16)= -1.76$, $p=.09$ (2-tailed).

For the high EF group of shy children, main effects for Condition, $F(1,27)=4.93$, $p=.04$, $\eta^2 P=.15$, and Hemisphere, $F(1,27)=4.64$, $p=.04$, $\eta^2 P=.15$, were seen. Specifically, shy children in the high EF group displayed greater task-related EEG power compared to baseline, and increased left hemisphere power relative to the right during both baseline and task in the medial parietal region.

No medial parietal effects were found for the non-shy children, all F 's < 3.04 , all p 's $> .09$ (see Figure 2).

Discussion

The purpose of our study was to examine associations between EEG and shyness in the context of a cognitive assessment. We found EEG power differences at frontal and parietal scalp locations between shy and non-shy children who differed in EF skills.

Children in the high EF groups (shy and non-shy) exhibited an increase in medial frontal EEG power from baseline-to-task. This was consistent with the current study's hypothesis and previous work including 4½-year-old children (e.g., Bell & Wolfe, 2007; Wolfe & Bell, 2004). Thus, shy children with strong EF skills were indistinguishable from their non-shy counterparts with regard to medial frontal EEG power, the region reliably associated with EF task performance. Perhaps the more interesting effects were seen for the low EF group. Specifically, like the high EF group, the shy/low EF children exhibited a baseline-to-task increase in power. This change was interesting as their task performance was not high, and their non-shy/low EF counterparts did not exhibit this increase in frontal EEG power. Perhaps this increase for the shy/low EF children was reflective of their "cognitive busyness" or their equally focused and narrow, yet self-conscious and task-irrelevant, thinking that was detrimental to their cognitive performance. This interpretation is supported by the fact that non-shy/low EF children exhibited no change in EEG power from baseline to task, perhaps reflecting their lack of focused attention to or disengagement with the task situation or their lack of intrusive, anxious thoughts related to the social testing situation. This interpretation may add to the discussion surrounding what a task-related increase in medial frontal 6–9 Hz EEG power is capturing in children: For some children (low performance, high shyness), it may be capturing cognitive busyness and inefficiency rather than competent cognitive processing related to correct task performance.

The task-related increase in medial frontal power for the shy/low EF children also might be related in some way to their emotional arousal in the social testing situation. If so, we might have expected the task-related EEG power values for the shy/high EF children to be significantly higher than their non-shy/high EF counterparts, and they are not. Perhaps, those shy children with stronger EF skills were able to effectively regulate their anxious-arousal in this situation. Previous research has demonstrated the moderating effects of strong core EF skills on the association between potentially disadvantageous temperaments (i.e., negative emotionality, shyness) and positive developmental outcomes, such as social competence and vocabulary development (e.g., Belsky, Friedman, & Hsieh, 2001; Blankson et al., 2011). For the current study, perhaps the moderating effects of strong EF skills were detectable through a comparison of task EEG power for shy children in the low and high EF groups.

These findings also showed an EF performance-based hemispheric asymmetry for the medial frontal region. Specifically, for the low EF groups (shy and non-shy), the EEG power values in the right hemisphere were greater than those in the left during baseline and task. Similar research with 4½-year-old children has not demonstrated this performance-related asymmetry but instead showed greater right medial frontal power compared to the left for all children, including both high and low cognitive performance groups (Wolfe & Bell, 2004), whereas other studies have shown no hemispheric differences in frontal EEG power (Wolfe & Bell, 2007b). We were not expecting the low EF children to show this asymmetry and because it included both shy and non-shy groups, it is difficult to have an arousal-based interpretation for this finding. More research, possibly including a comparison of EF tasks using emotion-based and non-emotion stimuli may help determine if this was a unique finding.

Unlike the medial frontal EEG data, the medial parietal baseline-to-task increases in EEG power were unrelated to EF performance. They, however, may have been related to the experience of being in the stressful context of a socially-based, cognitive assessment. That is, only the shy children demonstrated a task-related increase in power (regardless of EF group). The non-shy children demonstrated no change in power across conditions. This finding suggests that this brain area may be differentially involved for shy and non-shy children during a stressful cognitive task or social situation. Bremner et al. (1999) noted a relation with parietal functioning (among other areas) during the provocation of anxiety. Citing Vogt, Finch, and Olsen (1992), the authors concluded that these cortical areas are involved in the mediation of cognitive processes that are necessary for coping with situations that are stressful.

Although all shy children demonstrated a task-related increase in EEG power for the medial parietal region, there were hemispheric asymmetries associated with EF group. Specifically, the shy/high EF group demonstrated greater left hemisphere power relative to right during baseline and task. Notably, the non-shy/high EF children did not demonstrate this asymmetry. These findings for the shy/high EF children are consistent with existing adult work showing parietal asymmetry as an index of emotional arousal or anxiety (Davidson, Marshall, Tomarken, & Henriques, 2000; Engels et al., 2007; Heller, 1993; Schmidt & Fox, 1994). It is intriguing that only the shy children in the high EF group mirrored the adult work. In fact, the shy children in the low EF group had a marginally significant effect for the

opposite trend (i.e., increased right hemisphere power during task). Perhaps, the shy children with strong EF skills also were more effective with their cognitive appraisal and processing of their current state and situation, and thus, displayed the parietal asymmetry seen with socially sensitive adults. More research is needed to test this hypothesis linking EF and cognitive appraisal skills.

Two limitations of this study should be considered when considering these findings. First, the effect sizes for our study were small. However, unlike many studies of shyness and behavioral inhibition (e.g., Kagan et al., 2007), the shy and non-shy participants in the current study were not selected for extreme scores on a shyness measure. Their scores represent the full continuum of shyness and were grouped for comparison via a mean-split. We expect that effect sizes would be larger in a selected sample. Second, the temperament measures used to classify children as shy or non-shy were exclusively maternal report. Many studies of shyness include an observational measure or non-parental report; however, parent-report measures have been praised for their consideration of the child's behavior in multiple contexts and time periods allowing for strong ecological validity (Rothbart & Bates, 2006).

In conclusion, this research contributes to our knowledge regarding differences between shy and non-shy children and does so from a perspective that considers EEG measures during a cognitive assessment. These findings suggest differential involvement of the medial frontal and medial parietal cortical regions for shy children during EF tasks. These findings also suggest the value of designing future research to test the hypothesis that strong cognitive skills may enable shy children to regulate their reactivity and arousal in a socially-based testing situation. Shy children with high EF performance were indistinguishable from their non-shy counterparts in medial frontal EEG power (reliably associated with EF task performance) while they demonstrated the same medial parietal asymmetry of anxious adults. Thus, one strategy to optimize shy children's experiences and developmental outcomes may be to train and enhance their core EF skills. Future studies should replicate these findings and explore additional psychophysiological (e.g., heart rate, heart-rate variability, cortisol, etc.) differences between shy and non-shy children within the context of a cognitive assessment.

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Figure 1.

Baseline-to-task increases in EEG power were seen for all groups of children, except the non-shy, low EF group. For the low EF groups (non-shy and shy), power values in the right hemisphere were greater than those in the left. *Note:* L = left hemisphere; R = right hemisphere; Low EF = low executive function; High EF = high executive function.

Figure 2.

Baseline-to-task increases in EEG power were seen only for the shyness groups (low EF and high EF). For the shy, high EF group left hemisphere power was greater than the right for baseline and task combined. *Note:* L = left hemisphere; R = right hemisphere; Low EF = low executive function; High EF = high executive function.