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Children's shyness and frontal brain maturation

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ABSTRACT

Although shyness is a ubiquitous phenomenon and long viewed as a maladaptive characteristic, we know relatively little about the possible brain mechanism(s) underlying and maintaining shyness. Using a prospective longitudinal study, we examined frontal brain maturation in shy children. We collected measures of resting regional EEG spectral power approximately every six months for two years in young school-age children and characterized frontal brain maturation using a growth curve analysis of proportion of spectral power in relative faster-to-slower EEG frequencies. We found that children classified as low in shyness exhibited a significant linear *growth* in the proportion of overall frontal alpha power relative to delta power across assessments relative to children classified as high in shyness. High shy children displayed no growth in the proportion of overall frontal alpha power relative to delta power across assessments. These preliminary results indicate that high shy children exhibited delayed frontal brain maturation compared to low shy children. We interpret these findings within the context of a proximate explanation, suggesting links between delayed frontal maturation and emotion dysregulatory processes related to an approach-avoidance conflict. We also speculate on an ultimate explanation in which delayed frontal brain maturation may reflect neoteny (i.e., the prolongation and extension of childhood), which may have supported an adaptive function of shyness across human evolution.

1. Introduction

Shyness is a ubiquitous phenomenon that reflects a pre-occupation with the self in response to real or imagined social situations leading to social inhibition and anxiety (Melchior & Cheek, 1990). Shyness is presumed to emerge from an approach-avoidance conflict (Asendorpf, 1990; Coplan, Prakash, O'Neil, & Armer, 2004), resulting from an inability to regulate competing emotions of interest and fear (Schmidt, 1999; Schmidt & Buss, 2010). These emotion regulatory processes are dependent on maturation of the frontal cortex (Fox, 1994; Passler, Isaac, & Hynd, 1985; Posner & Rothbart, 2000). Previous work has suggested that delays in brain maturation, particularly in the frontal regions, may underlie a range of behavioral, emotion regulatory, and neuropsychiatric problems in children (see, e.g., Dawson & Fischer, 1994; Posner & Rothbart, 2000; Schore, 1996; Stuss & Knight, 2002, for reviews), including but not limited to attention deficit hyperactivity disorder (ADHD; McLaughlin et al., 2010), conduct disorder (Bauer & Hesselbrock, 2003), and autism (Zilbovicius et al., 1995). However, whether there are differences in frontal brain maturation associated with individual differences in temperament in typically developing children in general and between shy versus non-shy children in particular remains an empirical question.

One way to measure brain maturation is to examine the development of EEG spectral power (see Thatcher, 1991, for a review). The development of spectral power in faster frequencies is thought to reflect increased brain maturation of the cerebral cortex (Clarke, Barry, McCarthy, & Selikowitz, 2001). For example, increases in EEG power in faster frequencies in the frontal region have been linked to the development of executive and regulatory functions (Bell & Wolfe, 2007). In the less mature brains of infants and young children, there is more spectral EEG power at slower frequencies relative to faster frequencies in absolute terms; with age, delta occupies less power and alpha more in the overall power spectrum (Clarke et al., 2001; Marshall, Bar-Haim, & Fox, 2002). Accordingly, increases in an alpha/delta (A/D) ratio reflect an increase in the proportion of alpha to delta power and, ostensibly, an increase in brain maturation.

1.1. The present study

Using a prospective longitudinal design, we examined how shyness affected frontal brain maturation in typically developing children beginning at age 6 and approximately every 6 months for two years. Given that shy children exhibit problems regulating their emotions (Poole & Schmidt, 2018; Theall-Honey & Schmidt, 2006), we hypothesized that

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delays in frontal brain maturation may be one mechanism that underlies and maintains these problems. Accordingly, we predicted that, while children classified as low shy would exhibit the typical increase in the A/D ratio in the frontal region, children classified as high shy would display relatively little to no increase in the A/D ratio in the frontal regions across follow-up assessments.

We also examined sex differences in frontal brain maturation in the present study. Although sex differences in brain maturation are not well understood, there is some limited evidence for sex differences in brain maturation in children. However, most of the extant studies on sex differences in brain maturation have been done with older children than examined in the present study and/or adolescents, using cross-sectional designs, and MRI measures (see, e.g., De Bellis et al., 2001) or EEG coherence measures (Hanlon, Thatcher, & Cline, 1999). One study using EEG spectral power measures did find sex differences in EEG power in children ranging in ages from 8 to 12, with males having less theta and more alpha than females, but this study was again cross-sectional in design (Clarke et al., 2001). Given the lack of longitudinal work using EEG spectral power measures with young school age children, we made no a priori predictions for sex differences in the present study.

2. Method

2.1. Participants & overview

Thirty-seven typically developing children (16 males, 21 females) and their mothers participated in this study, examining biological and socioemotional development during the early school years. Children were enrolled in the summer prior to grade 1 [Time 1 (T1); M_{age} = 6.39 years, SD = 0.15 years], with follow up assessments occurring the second term of grade 1 [Time 2 (T2); M_{age} = 6.79 years, SD = 0.25 years], the summer prior to grade 2 [Time 3 (T3); M_{age} = 7.39 years, SD = 0.16 years], and the second term of grade 2 [Time 4 (T4); M_{age} = 7.77 years, SD = 0.20 years]. We began data collection at age 6 because previous studies have shown that this age coincides with the first evidence of a developmental peak in alpha activity (Somsen, van't Klooster, van der Molen, van Leeuwen, & Licht, 1997).

Participants were recruited from a database containing the birth records of children whose mothers were recruited upon their child's birth for future developmental research studies conducted in the Child Emotion Laboratory. The children were born either at McMaster University Medical Centre or St. Joseph's Healthcare Hamilton. All children were typically developing with no significant pre-, peri-, or post-natal health problems and were primarily Caucasian and from middle-class backgrounds.

2.2. Procedures

Upon arrival to the Child Emotion Laboratory at McMaster University, the mother and child were briefed about study procedures and consent was obtained. Mothers completed questionnaires pertaining to the child's temperament. At all assessments, mother and child were brought to a testing room where baseline EEG recordings were conducted on the child. Following the baseline EEG recording, the child was presented with four separate 1-minute video clips. The video clips contained segments selected from popular children's movies and were used to induce different emotions in the child (see Theall-Honey & Schmidt, 2006). Heart rate and subjective ratings of emotion were measured in response to the affective video clips. These measures were part of a larger study examining how shy children process emotion and are not reported below. Following the completion of watching the affective video clips, the child received a “Junior Scientist Certificate” and a toy prize as a token of appreciation for their participation. All procedures were approved by the McMaster University Research Ethics Board.

2.3. Electroencephalogram (EEG) data collection and reduction

2.3.1. EEG recording

Identical procedures were used for the EEG collection across all four assessments. Baseline electroencephalogram (EEG) recordings were obtained for 2 min (1 min with the child's eyes open, and 1 min with the child's eyes closed) while the child was seated. The child was instructed to simply relax during the baseline testing and try not to move around. Resting EEG data of two minute duration have been shown to be sufficient for deriving reliable estimates of frontal EEG power (e.g., Schmidt, 2008; Somsen et al., 1997).

EEG was recorded using a lycra stretch cap (Electro-Cap, Inc.) with electrodes positioned according to the international 10/20 Electrode Placement System. Electrode impedances below 10K Ω per site were considered acceptable. EEG was recorded from the left and right mid-frontal (F3, F4), central (C3, C4), parietal (P3, P4), occipital (O1, O2) sites. These sites represent the left and right hemispheres and anterior and posterior regions of the brain. All electrodes were referenced to the central vertex (Cz). The channels were amplified by individual SA Instrument Bioamplifiers. The filter settings for the channels were set at 0.1 Hz (high pass) and 100 Hz (low pass). The data from all channels were digitized on-line at a sampling rate of 512 Hz.

2.3.2. EEG data reduction and analysis

The EEG data were visually and manually scored for artifacts due to eyeblinks, eye movements, and other motor movements using software developed by James Long Company (EEG Analysis Program, Caroga Lake, NY). This program removes data from all channels if artifact is present on any one channel. The amount of artifact-free EEG data was examined among all participants in order to ensure that it did not systematically differ among participants. Here we examined the number of 1-second artifact-free [i.e., discrete Fourier transform (DFT)] EEG windows (i.e., the inverse of artifact-edited data) in the analysis. The total number of possible DFT windows was 239 [i.e., 120 s × 2 (50% overlapping windows) − 1]. The average number of 1-second artifact free DFT windows for each visit was as follows: T1 = 216.46; T2 = 129.41; T3 = 201.84; T4 = 206.53. We also ensured that the average number of 1-second artifact free DFT windows used in the analyses across visits was not correlated with any of the study's measures.

We examined spectral power in two EEG frequency bands: a relatively faster frequency band (6 to 8 Hz) and a slower frequency band (0 to 4 Hz) at each assessment. These two frequency bands are thought to be psychologically and functionally equivalent to adult alpha and delta frequencies in children, respectively (Marshall et al., 2002). Because EEG power was highly correlated in the eyes open and eyes closed conditions, as well as left and right frontal (alpha: rs = 0.90 to 0.98, ps < .001; delta: rs = 0.72 to 0.96, ps < .001) and parietal sites (alpha: rs = 0.92 to 0.96, ps < .001; delta: rs = 0.86 to 0.95, ps < .001) at each visit, we collapsed power across conditions and hemisphere for each region and derived overall power in the alpha and delta frequency bands separately for each region at each visit. We then computed an A/D ratio measure (i.e., alpha power/delta power) separately for the frontal and parietal regions to index increases or decreases in the proportion of overall alpha to delta EEG power in anterior and posterior brain regions at each assessment. Increases in the A/D ratio reflect an increase in the proportion of alpha to delta power and ostensibly an increase in brain maturation.

2.4. Maternal-report of child shyness

At each assessment, mothers completed the Colorado Child Temperament Inventory (CCTI) shyness subscale, a widely-used and well-validated measure of temperamental shyness (Buss & Plomin,