Distinguishing shyness and sociability in children: An event-related potential study

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Abstract

Shyness and sociability are independent personality dimensions, each with distinct behavioral and psychophysiological correlates that are conserved across development, culture, and phylogeny. However, relatively little is known regarding how shyness and sociability are instantiated in the brain, particularly during childhood and during the processing of non-social stimuli. Using a three-stimulus auditory oddball task, we examined whether variations in shyness and sociability were related to the N200 and P300 event-related potential (ERP) brain responses to processing task-relevant, novel, and standard auditory tones in 53 typically developing 10-year-old children. ERP amplitudes were measured at four midline scalp sites: Fz, FCz, Cz, and Pz. We found that increases in shyness were correlated with increases in target P300 amplitudes across all four head sites, increases in standard P300 amplitudes, and decreases in target P300 latencies in anterior sites. No relations were found for sociability and P300 responses. We also found that P300 amplitude in the frontal region to standard tones mediated the relation between conflicted shyness (i.e., high shyness and high sociability) and emotional instability. These results suggest that shyness and sociability are distinguishable on neurocognitive measures and that these neurocognitive measures may be putative mechanisms in understanding risk for emotional instability and a broad range of dysregulated behavioral problems observed in individuals characterized by conflicted shyness.

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Introduction

Contrary to popular belief, people who are shy are not necessarily unsociable. Shyness and sociability have been defined as independent traits in terms of motivational behavioral differences, with shyness being related to inhibition/withdrawal–related tendencies in social situations and sociability/approach tendencies being related to a desire to be with others (Asendorpf, 1990; Cheek & Buss, 1981). A number of studies have shown that shyness and sociability are fundamental personality dimensions that are conceptually and empirically orthogonal (for a review, see Schmidt & Buss, 2010). In humans, the independence of shyness and sociability has been replicated across development, including children (Asendorpf & Meier, 1993; Coplan & Armer, 2007; Coplan, Prakash, O’Neil, & Armer, 2004), adolescents (Mounts, Valentiner, Anderson, & Boswell, 2006; Page, 1990), and adults (Eisenberg, Fabes, & Murphy, 1995; Sheeks & Birchmeier, 2007; but see Bruch, Gorsky, Collins, & Berger, 1989), across clinical populations (Goldberg & Schmidt, 2001; Jetha, Schmidt, & Goldberg, 2009), and across cultures, including German (Czeschlik & Nurk, 1995), Portuguese (Neto, 1996), and Asian (Hussein, Fathy, Mawla, Zyada, & El-Haddidy, 2011) samples. In nonhuman animals, the independence of these two basic dimensions is also captured by individual differences in timidity and boldness in overt behavior (for a review, see Reale, Reader, Sol, McDougall, & Dingemanse, 2007). The ubiquitous manifestation of distinct behavioral correlates of shyness and sociability across development, cultures, and phylogeny suggests that these two personality traits may be deeply rooted in our evolutionary history.

The potential importance of considering shyness and sociability as orthogonal is that we can examine their interaction to understand subtypes of shyness and why shy people are not all alike. For example, shy–sociable individuals characterized by an approach–avoidance conflict (i.e., mixed feelings of inhibition and desires to interact with others) display greater anxious behavior during social interactions (e.g., Asendorpf & Meier, 1993; Cheek & Buss, 1981; Coplan et al., 2004) and greater anxiety in social evaluative situations (Schmidt & Fox, 1999) relative to their shy–unsociable counterparts (i.e., individuals characterized by low approach and high avoidant tendencies) and are at greater risk for emotional instability and a range of dysregulated behavioral problems, including internalizing problems such as depression and substance use and abuse (Page, 1990; Santesso, Schmidt, & Fox, 2004; Schmidt & Fox, 1995).

Psychophysiology of shyness and sociability

Beyond identifying separate behavior and self-report correlates in shyness and sociability and subtypes within shyness, separate studies have linked multiple physiological indices to these constructs. At the peripheral psychophysiological level, shyness and sociability have been distinguished in children’s everyday environments (Asendorpf & Meier, 1993), and in young adults during the anticipation of unfamiliar social interactions (Schmidt & Fox, 1994), using measures of heart rate and heart rate variability. Shy–sociable children and adults displayed higher heart rate and lower vagal tone relative to their shy–unsociable counterparts. At the neurophysiological level, a distinct pattern of frontal electroencephalogram (EEG) asymmetry has distinguished shyness and sociability. For example, shy young adults are known to display greater relative right frontal EEG activity at rest, whereas social adults exhibit greater relative left frontal EEG activity at rest (Schmidt, 1999). Although a pattern of greater relative right frontal EEG activity at rest was associated with both shyness subtypes, the two shyness subtypes were distinguishable on the pattern of absolute EEG activity in the left frontal hemisphere; shy–sociable adults displayed higher absolute activity in the left frontal hemisphere compared with shy–unsociable adults (Schmidt, 1999). As well, other studies have shown that the pattern of greater right frontal EEG asymmetry at rest is observed across cultures in clinical samples of outpatients diagnosed with schizophrenia who were shy and social (Hussein et al., 2011; Jetha et al., 2009), suggesting a conserved mechanism underlying these brain–behavior relations regardless of cultural influences and disease state.

Although there is mounting conceptual and empirical evidence to support shyness and sociability as orthogonal dimensions, studies on the psychophysiology of shyness and sociability have primarily focused on adults during resting conditions or socioemotional stressors. Accordingly, the current study examined how these two traits are involved in sensory information processing of nonsocial.
stimuli in a group of typically developing 10-year-old children. Using a three-stimulus auditory oddball paradigm, we examined whether event-related potentials (ERPs) linked to different attention processes (i.e., N200 and P300 components) distinguished shyness and sociability in this sample.

Shyness and sensory information processing

Research has suggested that shy individuals are hypervigilant to threatening information in social stimuli and have a bias to perceive ambiguous or neutral stimuli as threatening (Miskovic & Schmidt, 2012; Muris, Merckelbach, & Damsma, 2000). A series of studies that incorporated threatening and negative facial expressions as experimental stimuli, such as anger and fear, indicate that shy individuals engage in perceptual biases in threat detection involving affect-related attentional mechanisms during the early phases of processing. This notion is supported by behavioral (e.g., Brunet, Heisz, Mondloch, Shore, & Schmidt, 2009; Matsuda, Okanoya, & Myowa-Yamakoshi, 2013), neuroimaging (e.g., Beaton et al., 2008), and ERP (e.g., Jetha, Zheng, Goldberg, Segalowitz, & Schmidt, 2013; Jetha, Zheng, Schmidt, & Segalowitz, 2012) studies. Although these studies did not include nonsocial stimuli, it is possible that these attentional mechanisms are not specific to social–emotional contexts and may extend to sensory processing of the general environment.

There is some evidence that children with a temperamental bias to shyness exhibit heightened reactivity to social and nonsocial stimuli. For example, children characterized as high on behavioral inhibition (BI), a temperamental trait related to shyness observed and measured early in infancy, show heightened behavioral (e.g., high motor and negative affective) reactions to unfamiliar contexts across both social and nonsocial domains, including objects, people, and places (Kagan, 1994). However, BI is an early appearing temperamental trait of “reactivity,” whereas shyness is a broader personality style that ranges from temperament to self-concept. Accordingly, it remains an empirical question the extent to which children who are shy process nonsocial sensory information differently from other children during middle childhood.

To understand the neurocognitive mechanisms linked to shyness, we examined cognitive stages underlying specific aspects of attention that are precisely captured by different ERP components such as the N200 and P300. The N200 is a negative peak 200 to 400 ms after onset of a stimulus that deviates from the form or context (e.g., difference in sound frequency or type) of more frequently occurring stimuli in the auditory oddball task. For example, increased amplitudes of the N200 can be observed in conditions of rare stimulus types (e.g., novel and target tones) in comparison with stimuli that occur relatively more frequently (e.g., standard tones; Hoffman, 1990; Näätänen & Picton, 1986). Unlike the passive versions of the oddball task that require no overt response from participants, the active version requires participants’ conscious attention and discrimination; thus, the N200 captures both automatic and controlled detection/discrimination of stimuli and is usually evoked before a motor response (Näätänen, Simpson, & Loveless, 1982; Ritter, Simson, Vaughan, & Friedman, 1979).

The P300 is a positive peak 300 to 500 ms after stimulus onset to low probability stimuli (e.g., novel and target tones) in a context whereby the frequency of different stimuli varies. Due to the engagement in the updating of mental representations through active comparisons between an incoming stimulus and previously encountered stimuli, the oddball P300 is hypothesized to index cognitive operations underlying attention and working memory (Donchin, Karis, Bashore, Coles, & Gratton, 1986; Polich, 2007).

In general, there is a positive correlation between the P300 and arousal levels linked to personality, with higher arousal being related to greater P300 amplitudes (Brocke, Tasche, & Beauducel, 1997; DePascalis, 2004; Ditraglia & Polich, 1991; Sternberg, 1992; Wilson & Languis, 1990), presumably because arousal levels modulate the amount of attention available for task performance (Kahneman, 1973). Because higher levels of basal arousal and vigilance are presumably a physiological component of shyness and other related constructs, such as BI and social anxiety, the P300 captures individual differences in and represents a neurocognitive marker of these constructs. For example, adolescents characterized as highly behaviorally inhibited across childhood (from 14 to 84 months), who displayed greater amplitude of the P300 to novelty, were also more likely to have been diagnosed with an anxiety disorder in their lifetime; this effect was not observed in adolescents characterized by low BI (Reeb-Sutherland et al., 2009).
In contrast to personality linked to high arousal and vigilance, increased levels of sensation seeking (a trait related to sociability and extraversion), including tendencies of disinhibition, thrill and adventure seeking, experience seeking, and boredom susceptibility, are correlated with decreased P300 amplitudes (Wang & Wang, 2001). In addition, higher levels of extraversion are associated with increased habituation of the P300 amplitude, that is, greater reduction of the P300 amplitude when the oddball stimulus repeatedly occurs (Ditraglia & Polich, 1991).

The current study

The purpose of the current study was to extend prior behavioral and electrocortical studies of shyness and sociability and their independence with adults to children. Here we addressed three goals. First, we examined whether shyness and sociability were distinguishable on electrocortical responses to nonsocial stimuli. Second, we examined whether an interaction of shyness and sociability was associated with distinct electrocortical responses to nonsocial stimuli. Third, we examined whether these electrocortical responses might serve as putative brain mechanisms that mediate the relation between the conflicted shyness subtype (i.e., high shyness and high sociability) and emotional instability given the dysregulated behaviors observed in this subtype.

We examined the N200 and P300 ERP components, which capture selective attention and conscious evaluation and discrimination cognitive functions in relation to individual differences in shyness and sociability, in a sample of typically developing 10-year-old children during the processing of an active three-stimulus auditory oddball task. Children heard three types of auditory tones. They responded to target tones but ignored two other types of tones: novel tones that occurred as frequently as targets and standard tones that occurred most frequently.

We tested four specific predictions for the P300 in relation to shyness and sociability. First, we predicted that shyness, but not sociability, would be related to increased amplitudes and decreased latencies of the P300 to both target and novel stimuli due to the associations between shyness and a fearful temperament and sensitivity to threat detection as well as a concern for positive self-presentation. Individuals who are shy are more sensitive to novelty because unfamiliarity in the environment signals threat, and this bias should be reflected in higher arousal and attention in seeking out these signals (Kagan, 1994). Shyness also has been linked to cognitive elements of performance and self-presentation and, thus, may be associated with increased attention allocation to task demands (Henderson, 2010; Schmidt, Fox, Schulkin, & Gold, 1999). However, it is possible that shyness is linked to hypervigilance in general; thus, the same hypotheses may apply to the standard P300 (e.g., in introverts, see Brocke et al., 1997). For the N200, we predicted that shyness would be related to increased N200 amplitudes but decreased N200 latencies due to the known sensitivity to detect threat and/or discrepancies.

Second, we predicted that sociability would be inversely correlated, or uncorrelated, with the P300 given its independence from shyness. The reviewed research that linked arousal levels and the P300 amplitude along the introversion–extraversion dimension supports the notion that increased arousal and greater P300 amplitudes are related to introversion that is more related to shyness, not extraversion or sociability (Sternberg, 1992).

Third, we predicted that an interaction of shyness and sociability would be associated with distinct electrocortical responses. Particularly in the performance-based target condition, increased P300 amplitudes and decreased P300 latencies should be associated with the shy–sociable subtype because this subtype is presumed to be the most apprehensive about being evaluated.

Fourth, we predicted that electrocortical responses linked to a general heightened arousal and attention expressed through increased amplitudes of the standard P300 would mediate the relation between the conflicted shyness subtype (i.e., high shyness and high sociability) and emotional instability.

Method

Participants

A total of 53 10-year-old children (M_{age} = 10.1 years, SD = 0.3; 27 male) were recruited from a large database that contained birth records of children born in the McMaster University Medical Center and
St. Joseph’s Hospital (Hamilton, Ontario, Canada). This sample of children was primarily Caucasian (92%) and right-handed with no history of head injury. Consent and assent were obtained from each child’s parents and the child. The experiment was conducted with approval from the McMaster University research ethics board. Children received a photograph of themselves wearing the EEG cap and a toy for their participation.

Modified Cheek and Buss Shyness and Sociability Scales

Children and parents completed a series of self- and parental-report questionnaires of temperament. Children’s self-report of shyness and sociability were obtained by completing a modification of the Cheek and Buss Shyness and Sociability Scales (Cheek & Buss, 1981) for child assessment. The original scale for adults has a reported alpha coefficient of .79. Similar to the original shyness and sociability scales, each construct consisted of 5 items and was scored on a 4-point scale (1 = not at all true, 4 = very true). In this modified version, the original items were converted into comprehensible language for children. An example from the original shyness scale, “I find it hard to talk to strangers,” was adjusted to “I get scared when I talk to kids I don’t know.” Likewise, an example from the original sociability scale, “I feel nervous when speaking to someone in authority,” was adjusted to “I get scared/nervous when speaking to my teacher or other grown-ups.” As expected, shyness was inversely unrelated to sociability in this sample ($r = -0.117, p = .202$), suggesting that the two dimensions were largely independent.

Junior Eysenck Personality Questionnaire–Revised

The Junior Eysenck Personality Questionnaire–Revised (JEPQR-S) (Corulla, 1990) is a short-form child version of the revised adult Eysenck Personality Questionnaire (Eysenck, Eysenck, & Barrett, 1985). This self-report measure captures four personality dimensions, each with 12 items, corresponding to extraversion, neuroticism, psychoticism, and a lie scale. Each item is scored dichotomously (0 = no, 1 = yes). Extraversion reflects sociability and stimulation-seeking tendencies (e.g., “Do you like to talk a lot?”). Neuroticism reflects negative affective states, emotional instability, and spontaneity (e.g., “Do you worry about awful things that might happen?”). Psychoticism captures aggression, apathy, divergent thinking, and antisocial tendencies (e.g., “Would you enjoy practical jokes that could sometimes really hurt people?”). The lie scale assesses a concern for social desirability, conformity, and impression management (e.g., “Do you always wash before a meal?”). Ranges of alpha coefficients for each scale in 11- and 12-year-olds are as follows: extraversion = .77 to .78, neuroticism = .70 to .80, psychoticism = .77 to .82, and lie = .70 to .76.

Auditory oddball paradigm

A three-stimulus auditory oddball task presented three different types of tones: (a) standard low tones (800 Hz), (b) target high tones (1500 Hz), and (c) novel/distracter tones (20 unique tones varying between 800 and 1500 Hz with a 300-Hz deviation above or below the frequency of the previously presented novel tone). Each tone lasted for 150 ms with a stimulus onset asynchrony of 1100 ms. There were a total of 400 trials divided into five blocks of 80 trials; standard tones were presented 80% of the time, and target and novel tones were each presented 10% of the time. Following Fabiani and Friedman (1995), tones were randomly presented with the constraints that presentation of two of the same novel tones could not occur in the same block; presentation of two novel tones, two target tones, or a target tone and a novel tone could not be presented one after another in consecutive trials; and presentation of target or novel tones could not be the first trial in each block. The same randomized order of stimuli was used for each participant. Participants were instructed to respond to every occurrence of the target tone by pressing the letter “j” on a computer keyboard with their right hand but not to do so for standard and novel tones. Participants completed a practice session prior to the actual experimental task.
EEG data collection and analyses

EEG recording

EEG was collected using a lycra EEG stretch cap (Electro-Cap International). Electrodes were positioned according to the International 10/20 Electrode System (Jasper, 1958). The experimenter gently abraded the surface of the scalp underneath the selected electrodes using a blunt-ended Q-tip with abrasive gel (Nu-Prep). Each electrode site was then filled with a small amount of electrolyte gel that served as a conduit. Electrode impedances below 10 kΩ at each site and within 500 Ω between homologous sites were considered acceptable.

During the experimental task, continuous EEG was recorded at four midline scalp locations: frontal (Fz), frontal central (FCz), central (Cz), and parietal (Pz) sites. Bipolar electro-ocular recording monitored eye movements from the supraorbital ridge and the outer canthus on the right eye. The left ear served as a reference for all sites. All channels were amplified by individual SA Instruments Bioamplifiers. The filter setting for these channels was set at 1 Hz (high pass) and 100 Hz (low pass). Data from all channels were digitized online at a sampling rate of 512 Hz.

ERP reduction and analyses

EEG epochs were stimulus-locked on each trial and averaged separately for each of the standard, target, and novel conditions for each participant. ERP waveforms were examined at Fz, FCz, Cz, and Pz midline scalp sites. All electrodes were re-referenced offline to an average of the two ears. Each trial was visually inspected for movement, and eye movement artifacts were removed by regression analysis. The amplitude of the N200 and P300 components were derived from each participant’s average waveform. Mean ERP amplitude and latency of the N200 and P300 components were extracted and quantified using ERPScore (Segalowitz, 1999), a peak analysis program. Amplitude is the difference between the mean pre-stimulus baseline voltage (of 200 ms) and the largest negative peak of the ERP waveform within 150 to 300 ms for the N200, and the largest positive peak of the ERP waveform within 250 to 650 ms for the P300, for each condition and each participant. Latency is the time from stimulus onset to the maximum point of the negative and positive amplitudes within the temporal window defined for the N200 and P300, respectively, for each condition and each participant.

Internal consistencies of the N200 and P300 amplitude and latency measurements among scalp sites were tested within each condition using Pearson’s correlations. To examine the relations between scalp sites and conditions of the N200 and P300 components, two-way repeated measures analyses of variance (ANOVAs) with three conditions (target, novel, and standard) and four scalp sites (Fz, FCz, Cz, and Pz) as within-participants factors were performed for the N200 amplitude, N200 latency, P300 amplitude, and P300 latency. Mauchly’s test of sphericity indicated whether the sphericity assumption was violated, and when violated df values were adjusted with Huynh–Feldt’s epsilon. Post hoc analyses included one-way repeated measures ANOVAs and pairwise comparisons using Tukey’s LSD (least significant difference) tests.

Data analyses

A series of partial Pearson correlations were performed to assess whether individual differences in shyness (accounting for the variance in sociability) and sociability (accounting for the variance in shyness) contributed to N200 and P300 components across four midline scalp sites (Fz, FCz, Cz, and Pz) and whether it was condition specific to novel, target, and standard stimuli. One-tailed tests were employed for our stated hypotheses regarding greater amplitudes and shorter latencies for shyness and the N200 and P300 components in target, novel, and standard conditions. One-tailed tests were also employed for sociability but in the opposite directions because sociability is inversely unrelated to shyness. All other tests in this study were assessed with a two-tailed criterion.

The product of shyness and sociability scores created an interaction term of “conflicted shyness” to capture the self-conscious/shy–sociable subtype of shyness (Cheek & Buss, 1981). On this conflicted shyness spectrum, children with low scores are characterized as low on both shyness and sociability (i.e., they have low levels of conflicting motivational tendencies and resemble introverts who are neither shy nor sociable), whereas children with high scores are characterized as high on both shyness
and sociability (i.e., they have high levels of conflicting motivational tendencies and resemble the self-conscious type of shy individuals who are both shy and sociable). To test whether the neurocognitive indices in the target condition are predictive of self-conscious shyness, because these children are motivated to perform well due to presentation anxiety, a series of simple linear regression analyses were performed regressing conflicted shyness as the dependent variable on the predictor variable, target P300 amplitude and latency at each scalp site (Fz, FCz, Cz, and Pz).

Finally, to investigate how neurocognitive indices might explain the relation between conflicted shyness as a trait and emotional instability and a broad range of dysregulated behaviors, structural equation modeling (SEM), a multivariate analysis, was performed. We built and tested a simple mediated moderation model (for methodological details, see Little, Card, Bovaird, Preacher, & Crandall, 2007), with hypothesized causal relations from the exogenous variable (the interaction term, conflicted shyness) to the endogenous outcome variable (scores of neuroticism in the JEPQR-S, a measure that captures emotional instability and a broad range of dysregulated behaviors), mediated by the endogenous mediator variable (the mean amplitude of the standard P300 at Fz and FCz). This chain of relations was established on a priori theoretical and prior empirical grounds; shy–sociable individuals have increased anxiety-related behavior (e.g., Asendorpf & Meier, 1993; Cheek & Buss, 1981; Coplan et al., 2004) and dysregulatory behavioral problems (e.g., Page, 1990; Santesso et al., 2004; Schmidt & Fox, 1995). Physiological systems involved in susceptibility to arousal, attention, and emotionality, as well as chronically heightened arousal and attention, have long been hypothesized to be linked to anxiety and introversion, respectively (Eysenck, 1967). It follows that brain function capturing arousal and attention (i.e., the P300 amplitude) is a possible mediator of anxiety. Prior to building this model, positive associations among the three variables were confirmed through simple univariate regressions; conflicted shyness predicted neuroticism ($\beta = .27$, $p = .05$) and frontal standard P300 amplitude ($\beta = .34$, $p = .023$), and in turn frontal standard P300 amplitude predicted neuroticism ($\beta = .33$, $p = .027$).1

SEM was performed in the program Amos (SmallWaters, USA), applying the maximum likelihood algorithm for estimating path coefficients. A path coefficient is a regression weight representing the strength of a pathway. Suppose that the path from conflicted shyness to neuroticism resulted in a standardized path coefficient $+x$; then on average while other relevant paths remain constant, an increase in conflicted shyness 1 SD from its mean would increase neuroticism by $+x$ SD from its own mean. Goodness of fit statistics assessing the model’s ability to reproduce the original correlation matrix included the chi-square ($\chi^2$) goodness of fit, root mean square error of approximation (RMSEA), Tucker–Lewis Index (TLI), and comparative fit index (CFI) that are recommended for smaller sample sizes (Hu & Bentler, 1998).

Missing data

Due to equipment failure, excessive motor and eye movement artifact, failure to follow instructions, or absence of clear ERP peaks, we lost data on several children. The listwise deletion of observations in the analyses produced a relatively large attrition rate in the repeated measures ANOVAs for the N200 ($n = 28$) and P300 ($n = 35$), because children with just one missing data point were excluded. The partial correlation analyses preserved a maximum number of participants because we had complete participant data for the following. In the target N200 analyses, $n = 44$; in the novelty N200, $n = 35$; and in the standard N200, $n = 44$. In the target P300 analyses, $n = 48$; in the novelty P300, $n = 39$; in the standard P300, $n = 44$. The $n$ values in the regression analyses were identical to those in the partial correlational analyses. In the SEM analysis, $n = 45$.

Results

Descriptive analyses of the N200 and P300

Fig. 1 depicts the grand average waveforms of the N200 and P300 components across four midline scalp sites in the three experimental conditions. Bivariate Pearson’s correlations demonstrated strong

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1 Relations for the target P300 amplitudes at posterior sites were also tested; however, the metric was unrelated to neuroticism and, therefore, was excluded from the model.
positive correlations for amplitudes and latencies among scalp sites within each condition for the N200 and P300 components separately, signifying high internal consistencies in ERP measurements (see Table 1).

For the N200 amplitudes, a site by condition interaction emerged, \( F(3.96,107.01) = 5.22, p = .001 \) \( [df = 0.01] \). In decomposing the interaction, smaller (less negative) N200 amplitudes were elicited relative to standard tones \( (M = 1.11, SE = 0.02); \) confidence intervals (CIs) for the difference = .005 to .085 \( (p = .03) \).^2 In addition, smaller (less negative) N200 amplitude at Pz to target tones \( (M = 1.16, SE = 0.016); \) was elicited relative to standard tones \( (M = 1.08, SE = 0.006); \) CIs for the difference = .045 to .107 \( (p < .001) \), and in comparison with novel tones \( (M = 1.11, SE = 0.015); \) CIs for the difference = .013 to .086 \( (p = .01) \). Enhanced negative peaks in the standard condition contradicted the expectation that deviant stimuli relative to standard stimuli would evoke more negative N200 peaks. This reversed pattern may be explained by the infrequent deviant stimuli calling for “go” responses, whereas the frequent standard stimuli called for “no-go” responses that are observed in cognitive control/inhibition tasks (see Folstein & Van Petten, 2008, for a review), which has been observed in response to missed targets and standard stimuli (e.g., the N2b; see review in Patel & Azzam, 2005) as inhibition, conscious control of attention, and discrimination are all implemented and confounded in the active task.

For the N200 latencies, a main effect of condition was revealed, \( F(2.54) = 7.15, p = .002 \). Relative to standard tones \( (M = 240.80 \text{ ms}, SE = 4.61); \) shorter N200 latencies were evoked to target tones \( (M = 213.10 \text{ ms}, SE = 6.72); \) p = .002, and novel tones \( (M = 229.80 \text{ ms}, SE = 4.63); \) p = .033. However, N200 latencies to target and novel tones were not significantly different, \( p = .098 \).

For the P300 amplitudes, a site by condition interaction emerged, \( F(3.28,111.56) = 11.14, p < .001 \). Greater P300 amplitudes at Fz were elicited to both target tones \( (M = 1.10, SE = 0.02); \) and novel tones \( (M = 1.12, SE = 0.015) \) relative to standard tones \( (M = 1.05, SE = 0.007); \) CIs for the difference between target and standard tones and between novel and standard tones = .009 to .088, \( p < .02 \), and .042 to .102, \( p < .001 \), respectively. This same pattern was seen across the three other scalp sites. Greater amplitudes at FCz were elicited to both target tones \( (M = 1.13, SE = 0.02); \) and novel tones \( (M = 1.15, SE = 0.018) \) relative to standard tones \( (M = 1.06, SE = 0.007); \) CIs for the difference between target and standard tones and between novel and standard tones = .027 to .113, \( p < .003 \), and .054 to .120, \( p < .001 \), respectively. Greater amplitudes at Cz were elicited to both target tones \( (M = 1.17, SE = 0.018); \) and novel tones \( (M = 1.16, SE = 0.019) \) relative to standard tones \( (M = 1.07, SE = 0.008); \) \( p < .001 \); CIs for the difference between target and standard tones and between novel and standard tones = .071 to .145, \( p < .001 \), and .064 to .130, \( p < .001 \), respectively. Greater amplitudes at Pz were elicited to both target tones \( (M = 1.23, SE = 0.016); \) and novel tones \( (M = 1.21, SE = 0.017) \) relative to standard tones \( (M = 1.08, SE = 0.006); \) CIs for the difference between target and standard tones and between novel and standard tones = .122 to .180, \( p < .001 \), and .094 to .154, \( p < .001 \), respectively. Overall, the means of the target P300 amplitudes were progressively greater in moving from frontal to parietal scalp sites, which is consistent with the literature demonstrating that target P300 amplitude is maximal at posterior scalp sites (Johnstone, Barry, Anderson, & Coyle, 1996; Polich, 2007). Moreover, there was a marginal significance of greater P300 amplitude at Pz to target tones relative to novel tones, \( p = .052 \).

For the P300 latencies, a site by condition interaction emerged, \( F(3.78,128.40) = 3.36, p = .013 \) \( [df = 0.01] \). P300 latencies at Fz in both the target condition \( (M = 342.56, SE = 13.45); \) and the novel condition \( (M = 374.19, SE = 10.07) \) were shorter than those in the standard condition \( (M = 460.39, SE = 15.95); \) CIs for the difference between target and standard conditions

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^2 Analyses of the N200 amplitude were based on log-transformed values that preserved the original data order. Because the N200 is a negative wave on the ERP graph, the transformed values are interpreted as follows: A smaller/less negative N200 amplitude represents a higher position on the graph with a higher numerical value, whereas a greater/more negative amplitude represents a lower position on the graph with a lower numerical value. This interpretation holds for all analyses for the N200 amplitude in this study.
and between novel and standard conditions = −155.25 to −80.43, \( p < .001 \), and −127.32 to −45.09, \( p < .001 \), respectively. The same pattern was observed across the three other scalp sites. Latencies at FCz in both the target condition (\( M = 337.64, SE = 14.49 \)) and the novel condition (\( M = 359.07, SE = 10.10 \)) were shorter than those in the standard condition (\( M = 456.54, SE = 16.47 \)); CIs for the difference between target and standard conditions and between novel and standard conditions = −159.00 to −78.79, \( p < .001 \), and −140.16 to −54.76, \( p < .001 \), respectively. Latencies at Cz in both the target condition (\( M = 345.12, SE = 15.46 \)) and the novel condition (\( M = 345.85, SE = 10.10 \)) were shorter than those in the standard condition (\( M = 467.20, SE = 14.62 \)); CIs for the difference between target and standard conditions and between novel and standard conditions = −159.70 to −84.45, \( p < .001 \), and −159.17 to −83.51, \( p < .001 \), respectively. Latencies at Pz in both the target condition (\( M = 345.96, SE = 14.54 \)) and the novel condition (\( M = 374.82, SE = 10.91 \)) were shorter than those in the standard condition (\( M = 443.22, SE = 15.96 \)); CIs for the difference between target and standard conditions and between novel and standard conditions = −132.36 to −62.16, \( p < .001 \), and −106.00 to −30.81, \( p = .001 \), respectively. Furthermore, shorter latency at Pz in the target condition was observed relative to the novel condition; CIs for the difference = .003 to 57.71, \( p = .05 \).

Relation among shyness, sociability, and the N200

Table 2 presents partial correlations among the N200, shyness (controlling for influences of sociability), and sociability (controlling for influences of shyness) for the target (A), novel (B), and standard (C) auditory stimuli. Correlations among the amplitude of the N200 at all four midline scalp sites in all three conditions and shyness and sociability approximated zero, with the exception that children scoring higher on sociability elicited greater N200 amplitudes to standard tones at FCz, Cz, and Pz\(^3\) (see Table 2). Latencies of the N200 to targets at Fz, FCz, and Cz were negatively correlated with shyness but not sociability, \( rs = −.35 \) to −.39, \( ps < .025 \) (see Table 2A). Children scoring higher on shyness elicited faster N200 peak responses to target tones that were distributed at frontal to central sites, indicating that the target N200 latency was a specific predictor of shyness but not sociability (see Fig. 2). However, there

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\(^3\) Interpretation of the negative correlation is reversed due to the data order of log-transformed N200 amplitude values (see note 2).
was a lack of relation between latency of the novelty and standard N200 for all of the midlines scalp sites and the two personality measures: shyness and sociability (see Table 2B and C).

**Relation among shyness, sociability, and the P300**

Table 3 presents partial correlations among the P300, shyness (controlling for influences of sociability), and sociability (controlling for influences of shyness) to target (A), novelty (B), and standard (C) stimuli. Amplitudes of the target P300 at Fz, Cz, and Pz scalp sites were positively correlated with shyness, rs = .27 to .29, p < .05, whereas this relation approached significance at FCz, r = .24, p = .053 (see Table 3A). As predicted, children scoring higher on shyness elicited larger P300 amplitudes in response to target tones across all midline scalp sites. Shyness was also positively correlated with P300 amplitudes at Fz and FCz in the standard condition, rs = .32 to .34, p < .025 (Table 3C), indicating heightened frontal cortical activation during this baseline condition in shy children. No relations were found between amplitudes of the target or standard P300 and sociability, indicating that the target and standard P300 amplitudes were specific predictors of shyness but not sociability (see Fig. 3A and B). However, there was a lack of relation between the novelty P300 amplitudes across the four midline scalp sites for either shyness or sociability, suggesting no relations with these two personality dimensions (see Table 3B).

Latencies of the target P300 at anterior sites, Fz and FCz, were negatively correlated with shyness, rs = −.30 to −.35, ps < .025, whereas no relations were found between sociability and target P300 latencies (see Table 3A and Fig. 4A). As predicted, children scoring higher on shyness had faster
P300 peak responses at frontal central scalp sites to target tones. In addition, there were significant positive correlations between the novelty P300 latency and shyness for Fz, $r = .32$, $p < .025$, and trending relations for FCz, CZ, and Pz, $r_s = .26$, $p = .06$ (see Table 3B). Again, no relations were found between novelty or standard P300 latency and sociability. Overall, children scoring higher on shyness elicited slower P300 peak responses to novel stimuli (see Fig. 4B), contrary to our prediction that children who are more shy would respond faster to novelty. Lastly, no relations were found between standard P300 latency and shyness or sociability.
Relation among shyness, sociability, and behavioral performance

Table 4 displays partial correlations for shyness (controlling for influences of sociability) and sociability (controlling for influences of shyness), the reaction time to target tones, and percentage error in the three experimental conditions. There was a lack of relation between all behavioral measures and shyness. Similarly, no relations were found for sociability with the exception that children scoring lower on sociability committed a greater percentage of errors on standard trials (i.e., more false alarms), \( r = .55, p < .025 \). To examine whether ERP amplitudes were associated with behavioral performance, additional bivariate Pearson’s correlations between error rates and N200 and P300 amplitudes in corresponding conditions were performed. No relations were revealed, suggesting that behavioral performance was unrelated to these ERP amplitudes linked to different attention processes. Alternatively, this lack of relation may be attributed to a ceiling effect because the task was relatively easy.

Shy–sociable children, electrocortical responses, and emotional instability

A series of simple linear regression analyses tested whether the P300 amplitudes and latencies to target tones at the four scalp sites were predictive of variation in conflicted shyness. As expected, higher target P300 amplitudes significantly predicted higher scores of conflicted shyness at posterior sites, Cz (\( \beta = .30, p = .04 \)) and Pz (\( \beta = .32, p = .025 \)); marginal trends were demonstrated at anterior sites, Fz (\( \beta = .28, p = .055 \)) and FCz (\( \beta = .25, p = .09 \)). Similarly, shorter target P300 latencies significantly predicted higher scores of conflicted shyness at anterior sites, Fz (\( \beta = -.30, p = .039 \)) and FCz (\( \beta = -.36, p = .013 \)) but not posterior sites, Cz (\( \beta = -.19, p = .20 \)) and Pz (\( \beta = -.24, p = .10 \)) (see Fig. 5A and B).
Fig. 3. Scatter plots displaying the P300 ERP amplitude and personality traits (shyness and sociability) for the target condition at the parietal scalp site (Pz) (A) and the standard condition at the frontal scalp site (Fz) (B). Scatter plots display zero-order correlations.

Fig. 4. Scatter plots displaying the P300 ERP latency and personality traits (shyness and sociability) for the target condition at the fronto-central scalp site (FCz) (A) and the novel condition at the frontal scalp site (Fz) (B). Scatter plots display zero-order correlations.
To further demonstrate a condition-specific effect, additional simple linear regressions were performed with conflicted shyness as the dependent variable regressed on separate predictor variables of the amplitudes and latencies of the P300 to novel and standard tones. No relations were revealed.

Table 4
Partial correlations among shyness, sociability, and behavioral performance in the auditory oddball task.

<table>
<thead>
<tr>
<th></th>
<th>Shyness</th>
<th>Sociability</th>
<th>M</th>
<th>SD</th>
<th>n</th>
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<td>Reaction time to targets (ms)</td>
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<td>Percentage error in target trials</td>
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<td>Percentage error in novel trials</td>
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<td>-.055</td>
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<td>.147</td>
<td>40</td>
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<td>Percentage error in standard trials</td>
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<td>-.546**</td>
<td>.006</td>
<td>.008</td>
<td>49</td>
</tr>
</tbody>
</table>

** p < .025.

Fig. 5. Scatter plots displaying conflicted shyness versus the target P300 ERP amplitude (A) and latency (B) and versus the standard P300 ERP amplitude (C).

To further demonstrate a condition-specific effect, additional simple linear regressions were performed with conflicted shyness as the dependent variable regressed on separate predictor variables of the amplitudes and latencies of the P300 to novel and standard tones. No relations were revealed,
With the exception that higher standard P300 amplitudes significantly predicted higher levels of conflicted shyness at anterior sites, Fz ($\beta = .34$, $p = .023$) and FCz ($\beta = .33$, $p = .029$) (see Fig. 5C).

In SEM, our hypothesized model with causal relations from conflicted shyness to neuroticism, mediated by the mean frontal standard P300 amplitude at Fz and FCz, demonstrated good overall model fit as indicated by goodness-of-fit statistics, $\chi^2(4) = 0.92$, $p > .05$, ns, RMSEA < .001, TLI and CFI = 1. Conventional thresholds indicating good model fit are RMSEA $\leq .05$, TLI and CFI $\geq .95$ (Gunzler, Chen, Wu, & Zhang, 2013). A mediation effect was supported as three empirical conditions were fulfilled (Baron & Kenny, 1986; Little et al., 2007). First, the independent variable significantly predicted the mediator; increases in conflicted shyness predicted increases in frontal standard P300 amplitude ($\beta = .32$, $b = .0003$, SE = .0001, $p = .025$). Second, the mediator significantly predicted the dependent variable; increases in frontal standard P300 amplitude predicted increases in neuroticism ($\beta = .30$, $b = 14.52$, SE = 7.36, $p = .048$). Third, accounting for the mediator, the relation from the independent variable to the dependent variable must be diminished; conflicted shyness no longer predicted neuroticism ($\beta = .10$, $b = .0043$, SE = .0063, $p = .50$, ns) (see Fig. 6). Note that this regression weight is reduced in comparison with the one obtained from a simple regression model that directly regressed neuroticism on conflicted shyness without accounting for indirect pathways ($\beta = .27$, $p < .05$).

**Discussion**

We examined whether shyness and sociability were distinguishable on electrocortical indices of attention-related processes, the N200 and P300 ERP components, during an active three-stimulus (nonsocial) auditory oddball task in typically developing children and obtained three noteworthy findings. First, in support of the independence hypothesis of the two personality dimensions, we demonstrated that there are distinct correlational patterns between shyness and a set of electrocortical measures that were unrelated to sociability; shyness was positively correlated with target and standard P300 amplitudes and was negatively correlated with target N200 and P300 latencies. However, shyness was also positively correlated with novelty P300 latencies. Second, in convergence with the anxious profiles of shy–sociable individuals, we demonstrated that a set of electrocortical measures in performance-based and baseline conditions were associated with shy–sociable children; higher target and standard P300 amplitudes and shorter target P300 latencies were predictive of higher levels of conflicted shyness. Third, to understand the role of the neurocognitive processes underlying the known developmental risk of dysregulated behavioral problems in shy–sociable individuals, we demonstrated that children with high levels of conflicted shyness also had high levels of neuroticism (i.e., emotional instability), but this relation was mediated by high levels of frontal standard P300 amplitudes.
As predicted, children who were more shy exhibited faster response latencies and larger amplitudes of the P300 to target and standard tones. However, contrary to our predictions, children who were more shy were not associated with novelty P300 amplitudes; they also exhibited slower, rather than faster, response latencies of the novelty P300. Because the P300 amplitude is thought to index ongoing attentional and working memory processes (Polich, 2007) and the degree is proportional to the allocated cognitive resources used (Van Dinteren, Arns, Jongsma, & Kessels, 2014), increased target and standard P300 amplitudes among shy children indicate greater exertion of cognitive resources and hypervigilance in the identification of target and standard tones to possibly efficiently seek out the targets during the presentation of background standard tones. That is, the increased standard P300 amplitude suggests a generalized hypervigilance to the environment to aid in seeking out motivationally salient cues. Overall, although shyness was unrelated to behavioral task performance, the increased implementation of controlled cognitive processes in shy children might have been motivated by a fear of negative social evaluation (from experimenters) and self-presentation anxiety should they have performed poorly. Moreover, these electrocortical indices were predictive of increased levels of both shyness and sociability in shy–sociable children characterized by a known anxious behavioral profile, which may stem from high conflicting approach and avoidant motivational tendencies.

It is important to emphasize that shy children displayed increased implementation of controlled cognitive processes specific to task-relevant and background stimuli but not to task-irrelevant novel stimuli that is linked to automatic attention orientation. Indeed, the target and novelty P300 instantiate different aspects of attention and originate from different sources. The target P300 is elicited in response to low-probability events that are task specific and is associated with stimulus evaluation processes (Courchesne, Hillyard, & Galambos, 1975; Cycowicz, Friedman, & Rothstein, 1996; Donchin & Coles, 1988; Grillon, Courchesne, Ameli, Elmasian, & Braff, 1990). In contrast, the novelty P300 is related to stimulus-driven involuntary attention orientation and further cognitive operations to unexpected events that occur with low probability that are task irrelevant (Courchesne et al., 1975; Knight & Scabini, 1998; Snyder & Hillyard, 1976; Squires, Squires, & Hillyard, 1975). Scalp distribution of the target and novelty P300 are also different in that the production of the P300 is parietally distributed in response to targets but is frontally distributed to novel tones in adults (Fabiani & Friedman, 1995; Kazmerski & Friedman, 1995). But across development, from early childhood to adulthood, maximal P300 amplitudes to both target and novel tones have been observed at parietal sites (Cycowicz et al., 1996), which was consistent with our findings (see Table 2A and B). The controlled processing strategy employed by shy children is also consistent with the recruitment of frontoparietal neural connectivity underlying effortful processing to different types of social threat in shy adults (Tang et al., 2015).

The lack of relation between shyness and the novelty P300 amplitude suggests that automatic modes of attention orientation might not be linked to shyness for nonsocial novel stimuli, at least at 10 years of age. This accords with findings in a passive auditory oddball task where adolescents characterized by a history of BI throughout childhood did not display greater novelty P300 amplitudes, but these indices predicted their risk of developing anxiety disorders (Reeb-Sutherland et al., 2009), even though high BI during infancy is linked to greater positive slow wave amplitudes to infrequent deviant tones (Marshall, Reeb-Sutherland, & Fox, 2009).

Individual differences in shyness were linked to the novelty and target P300 latencies. Children scoring higher on shyness elicited faster P300 peak responses at anterior sites to targets but elicited slower P300 responses to novel stimuli. Latency of the P300 indexes brain efficiency and is proportional to the time required for stimulus detection; thus, it is hypothesized to index classification speed (for reviews, see Polich, 2007, and Van Dinteren et al., 2014). Accordingly, shyness may be linked to shorter time to make a decision regarding whether incoming target tones are indeed targets but longer time to make a decision regarding whether incoming novel tones should be categorized as targets or as a discrete set of events. This extended categorization process may be due to the relatively similar frequencies of novel and target tones as opposed to those of the standard tones. This finding further reflects the controlled cognitive component of shyness because shy children are not only more
self-conscious of their performance but also more cautious in the evaluation and/or categorization of incoming stimuli when they are discrepant from their expectation, as is the case of novel stimuli. Similar to other work that found of a lack of relation between shyness and the N200 amplitude during a flanker task in 9- to 13-year-olds (Henderson, 2010), we found no relations between shyness and the N200 amplitude in the current auditory oddball task in 10-year-olds. However, we found faster response latencies of the N200 to targets across the frontal central scalp sites in children who were more shy. This fronto-central distribution is consistent with a source of the N200 in the anterior cingulate cortex (Van Veen & Carter, 2002). Increased N200 latency is a function of task difficulty in discriminating stimuli, with longer latency reflecting more difficulty (Porjesz, Begleiter, Bihari, & Kissin, 1987; Towey, Rist, Hakerem, Ruchkin, & Sutton, 1980). This faster N200 latency associated with shyness may further reflect efficient evaluation and/or categorization of targets to set the stage for later evaluation of targets associated with the P300.

In understanding the developmental outcomes for different types of shyness, the mediated moderation model showed the association between high levels of shyness by sociability and high levels of neuroticism was mediated by high frontal standard P300 amplitudes to thereby explain the greater developmental risk for anxiety-related and dysregulated behaviors and problems in shy–sociable individuals (Miller, Schmidt, & Vaillancourt, 2008; Page, 1990; Santesso et al., 2004; Schmidt & Fox, 1995; Tang, Beaton, Schulkin, Hall, & Schmidt, 2014). These findings corroborate the risk potentiation and overgeneralized models of control (Henderson, Pine, & Fox, 2015), which posit that control strategies are amplified in the former, and overused in contexts that do not require them in the latter, to confer greater risk of emotional problems in shy–sociable children. Increased controlled processing, in terms of the frontal standard P300 amplitude (even at baseline conditions), represents increased arousal and greater exertion of attention and cognitive resources when they are not required. Perhaps this increased and overgeneralized controlled cognitive strategy sets off a cascade of secondary negative feelings that over time reinforces the motivationally conflicting approach and avoidant tendencies in these children.

Finally, it is important to note that the general absence of relations between sociability and the P300 indicated that this neurocognitive measure did not capture aspects that underlie or reinforce this personality trait, at least in the context of auditory sensory processing. This finding may be explained by the under-aroused profile in typical extraverts (Eysenck, 1967), which also sheds light on the positive correlation between sociability and the standard N200 amplitude in that this finding may reflect the sensation-seeking aspect of this personality—a need to seek out stimulation in a relatively non-stimulating baseline phase to perhaps augment arousal to optimal levels.

Limitations

There are at least three limitations that warrant discussion. First, our study used a typically developing, fairly homogeneous sample, so we do not know if our results would generalize to more heterogeneous and/or clinical child samples. Second, as is routinely observed with children’s ERP data, there is generally more noise for a variety of reasons. Some children in our sample simply did not have reliable data overall or did not have reliably defined peaks; thus, this limited our examination of some cases, reducing power in our analyses. Third, we note that our current mediated moderation model may be oversimplified but nevertheless useful in understanding how conflicted shyness contributes to emotional outcomes through neurocognitive processes. There are presumably other models that may fit the data to help us understand the transmission process, but due to mathematical and power constraints, the number of tested parameters was limited.

Conclusions and implications

The current findings demonstrated that a distinct set of neurocognitive markers linked to attention are specific to shyness but not sociability, thereby supporting the independence of these two personality dimensions. These results also suggest that information processing biases in shyness extend to nonsocial contexts in children. The neurocognitive markers can help us to understand subtypes of
shyness in terms of their developmental risk to social–emotional problems and to understand related constructs to shyness.

For example, although shyness is related to BI, the current results provide further evidence that they may differ not only on a conceptual level but also on a neurocognitive empirical level. BI is generally regarded as a temperamental style defined as cautiousness and wariness to social and nonsocial novelty. BI is more appropriately characterized as a trait of “reactivity” and “fearfulness” to novelty and unfamiliarity in the environment, which may include social situations observed early in infancy (e.g., Aron & Aron, 1997; Kagan, 1994). In contrast, shyness reflects a personality style that spans beyond temperament to include the self-concept. That is, shyness includes an aspect of temperamental fearfulness similar to behavioral inhibition but also centers on the self-concept and is largely driven by social contexts (Cheek & Buss, 1981). Cognitive and affective components of shyness are linked to a sense of self and self-conscious emotions, such as shame, embarrassment, and a fear of self-presentation, particularly a fear of being negatively evaluated (Crozier, 1999). Prerequisites to experience these social metacognitions and complex emotions include a developed sense of self, self-awareness, and accompanying perspective-taking ability to understand the standards based on which one’s behavior is evaluated and self-adoption of such standards, all of which do not develop until early to middle childhood (Flavell, 2000; Lagattuta & Thompson, 2007). For instance, the self-conscious type of shyness emerges at around 4 or 5 years of age (Buss, 1986); by 8 years, shyness should become more profound due to an increase in the accuracy and salience of social comparisons involved in self-evaluation and the self-concept (Harter, 1982; Harter, 2012). Although the two constructs are conceptually different, they are not mutually exclusive given that some behaviorally inhibited individuals may also be shy. As such, our findings emphasize the importance of considering different contexts and why they are important to fully understand individual differences in personality. Future studies would also benefit from examining the independence of shyness and sociability on other ERP components and tasks in children given their link to shyness (Henderson, 2010) and BI (Pérez-Edgar & Fox, 2003; Pérez-Edgar & Fox, 2005). Overall, these findings provide an empirical basis for examining differential predictive validity of these constructs and deriving hypotheses for future work on other neural and physiological levels.

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