SHYNESS

THE DEVELOPMENT OF SHYNESS FROM CHILDHOOD TO ADULTHOOD: SUBTYPES, BIOLOGICAL MECHANISMS, CORRELATES, AND OUTCOMES

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A Thesis Submitted to the School of Graduate Studies in Partial Fulfilment of the Requirements for the Degree Doctor of Philosophy

McMaster University Doctor of Philosophy (2017) Hamilton, Ontario (Psychology)

TITILE: The development of shyness from childhood to adulthood: Subtypes, biological mechanisms, correlates, and outcomes

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NUMBER OF PAGES: xv, 248

Lay Abstract

Shyness is a personality trait that is stable across time and situations in some individuals. Past research suggests that shy children exhibit more internalizing problems, including anxiety and depression, compared to their non-shy counterparts. However, the development of shyness has not been studied beyond adolescence, and the biological and social factors that contribute to adverse developmental pathways and outcomes related to shyness are not well understood. The goal of this thesis was to understand the mental health outcomes of shy individuals by examining different subtypes of shy individuals. To this end, this thesis first demonstrated how shyness unfolds across the first four decades of life to shape adult mental health outcomes in a cohort of individuals. Second, this thesis examined how neural responses to threatening social and non-social contexts related to the socioemotional outcomes across children, adolescents and adults with varying levels of shyness.

Abstract

Shyness is a personality trait that is stable across time and situations in some individuals. While childhood shyness is a risk factor for later mental health and emotional problems, not all shy children grow up to have these problems. This thesis examined subtypes of shyness identified based on the temporal stability of shyness and based on levels of sociability and their corresponding outcomes, as well as the roles of social and biological contextual factors. Chapters 2-4 comprise the empirical studies. In Chapter 2, I report three shyness trajectories from middle childhood to adulthood (ages 8 to 30-35). Relative to a low-stable non-shy trajectory, children with an increasing, but not a decreasing, shy trajectory were at higher risk for clinically significant social anxiety, depression, and substance use, and were hypervigilant to angry faces in adulthood. Chapters 3 and 4 then report electrocortical correlates and mechanisms during the processing of non-social auditory novelty and social exclusion across children, adolescents, and adults with varying levels of shyness and sociability. Chapter 3 established that shyness, but not sociability, was related to the P300 ERP in processing non-social auditory stimuli in both 10-year-old children and adults, in support of the notion that shyness and sociability are independent personality dimensions. Findings on subtypes of shyness also showed that children characterized by conflicted shyness (with high levels of both shyness and sociability) reported higher neuroticism, but this relation was mediated by increased P300 amplitudes to processing background stimuli. Finally, Chapter 4 reports that individuals characterized by conflicted shyness who exhibited high theta EEG spectral power to social exclusion were most fearful of negative evaluation, irrespective of age. Also, conflicted shy adolescents who showed high theta spectral power to social exclusion were most likely to engage in substance-use. These findings highlight that there is much heterogeneity in shyness, and that shyness is not directly related to adverse mental health outcomes.

Acknowledgements

I thank my supervisor, Louis Schmidt, for always being a positive role model. Your enthusiasm, openness and encouragement allowed me to push myself to be imaginative and inquisitive. Because you believed in me and gave me numerous opportunities, then I started believing in myself. I thank members in the laboratory- Ayelet Lahat, who has also been my mentor and role model, as well as undergraduate thesis students, volunteers and research assistants who have recruited participants and helped with data collection.

I thank my family and friends for their support and positive emotions, and my animal friend, who sat by my feet unassumingly while I conducted and wrote up most of my graduate work. Thank you all for your love and patience.

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List of Abbreviations and Symbols

ηp^2: Partial eta squared
b*:* beta/ slope
β: Standardized beta/ slope
χ^2: Chi-square
CI: Confidence interval
df: degrees of freedom
dl: deciliter
EEG: Electroencephalogram
ERP: Event-Related Potential
F: F-test statistic
h: hour
Hz: hertz
M: mean
min: minute
ms: millisecond
μg: microgram
μl: microliter
μV: microvolt
N: total sample size
n: sample size
nm: nanometer
p: p-value
r: Pearson correlation coefficient
SD: standard deviation
SE: standard error
t: t-test statistic
z: z-score

Declaration of Academic Achievement

This thesis consists of three studies published in scientific journals (Study 1 in Chapter 1, Studies 2 and 3 in Chapter 3), and one study that is to be submitted for publication (Study 4 in Chapter 4). The author of this thesis is the primary author, and her supervisor, Louis A. Schmidt, (McMaster University) is the final author on all four manuscripts. The contributions of each author in each study are outlined below.

Study 1 (Chapter 2) is a reprint of the following published journal article with permission from Springer:

Tang, A., Van Lieshout, R. J., Lahat, A., Duku, E., Boyle, M. H., Saigal, S., & Schmidt, L. A. (2017, in press). Shyness trajectories across the first four decades predict mental health outcomes. *Journal of Abnormal Child Psychology*.

This longitudinal study consists of data that have been collected once a decade over four decades to track the development of infants born with extremely low birth weight and a control group born with normal weight up to age 30-35. Alva Tang, the primary author conceptualized the research and experimental design, performed data analyses, and wrote the manuscript. Ryan Van Lieshout (McMaster University), the second author was responsible for research design and gave feedback on drafts of the manuscript. Ayelet Lahat (McMaster University), the third author gave feedback on data analyses and drafts of the manuscript. Eric Duku (McMaster University), the fourth author gave feedback on data analyses. Michael Boyle (McMaster University), the fifth author was responsible for research design and gave feedback on the manuscript. Saroj Saigal (McMaster University), the sixth author began the study when participants were infants and was responsible for research design and gave feedback on the manuscript. Louis Schmidt, the last author was responsible for conceptualization of the research and experimental design, and gave feedback on data analyses and drafts of the manuscript.

Study 2 and 3 (Chapter 3) are reprints of the following published journal articles with permission from Elsevier:

Tang, A., Santesso, D.L., Segalowitz, S.J., & Schmidt, L.A. (2016). Distinguishing shyness and sociability in children: An event-related potential study. *Journal of Experimental Child Psychology*, *142*, 291-311.

Tang, A., Santesso, D.L., Segalowitz, S.J., Schulkin, J., & Schmidt, L.A. (2016). Distinguishing shyness and sociability in adults: An event-related electrocortical-neuroendocrine study. *Biological Psychology, 119*, 200-209.

The two studies used the same auditory oddball task and electrocortical measures to examine how children (study 2) and adults (study 3) process non-social novelty, and thus the background literature, stimuli and EEG data analyses overlap. Study 3 also relates neuroendocrine measures to the processing of non-social novelty in adults. Alva Tang, the primary author conceptualized the research and experimental design, performed data analyses, and wrote the manuscript. Diane Santesso (University of Winnipeg), the second author, conceptualized the research and experimental design, collected data, and gave feedback on the manuscript. Sidney Segalowitz (Brock University), the third author, was responsible for research and experimental design, and gave feedback on the manuscript. Jay Schulkin (Georgetown University), the fourth author in study 3, provided expertise on neuroendocrine findings and gave feedback on the manuscript. Louis Schmidt, the final author, conceptualized the research and experimental design, and gave feedback on data analyses and drafts of the manuscript.

Study 4 (Chapter 4) examines how children, adolescents and adults process social exclusion using the Cyberball task and electrocortical measures. Alva Tang, the primary author conceptualized the research and experimental design, collected data, performed data analyses, and wrote the manuscript. Ayelet Lahat, the second author, conceptualized the research and experimental design, and gave feedback on drafts of the manuscript. Michael Crowley (Yale University), the third author designed the experimental task and gave feedback on data analyses and drafts of the manuscript. Jia Wu (Yale University), the fourth author, provided her expertise on EEG analysis plan and gave feedback on data analyses and the manuscript. Louis Schmidt, the last author, conceptualized the research and experimental design, gave feedback on data analyses and drafts of the manuscript.

Tang, A., Lahat, A., Crowley, M.J., Wu, J., & Schmidt, L.A. (In preparation). Event-related neural oscillations to social exclusion in shyness and sociability among children, adolescents, and adults: Associations with social anxiety and substance use.

CHAPTER 1

Introduction

Shyness is defined as an anxious preoccupation with the self to real or imagined social situations (Melchoir & Cheek, 1990). Shyness appears in early to middle childhood and is largely driven by social situations and involves cognitive-affective components linked to the self, such as self-awareness, self-conscious emotions (e.g., shame, embarrassment), and a fear of negative evaluation. Shy individuals also actively avoid social interactions, because social interactions involve the risk of being in the "spotlight" and being embarrassed or rejected, which are presumably hurtful to one's self or ego.

Biological Basis of Shyness

Given that shyness is highly heritable (Buss & Plomin, 1984; Eley et al., 2003; Emde et al., 1992; Smith et al., 2012), a biological basis has been assumed by researchers. Researchers have proposed associations between shyness, as well as emotionality/neuroticism (traits related to shyness), and arousability of the central and peripheral systems (e.g., Buss & Plomin, 1984; Eysenck, 1967). Others have focused on the association between shyness and attentional control for self-regulation (Rothbart, Sheese, & Posner, 2007), a cognitive component that is also linked to arousal with subcomponents, including attention shifting and response inhibition. In support of these theories, numerous behavioral and neurophysiological studies have demonstrated that shy individuals use cognitive-affective processing and regulation strategies that emphasize both vigilance and controlled monitoring during socially threatening contexts.

Studies using eye tracking techniques indicate that shy infants (Matsuda, Okanoya, & Myowa-Yamakoshi, 2013) and children (Brunet, Heisz, Mondloch, Shore, & Schmidt, 2009) initially focus on the eyes of unfamiliar faces before attending to other parts of the face. This processing strategy presumably facilitates the detection of potential threat. Also, shy adults show a lower threshold for, and increased sensitivity to, detecting fear in facial expressions (Gao, Chiesa, Maurer, & Schmidt, 2014). These findings suggest that shy children and adults show an elevated sensitivity to and vigilance, which helps them efficiently detect socially threatening information for later behavioral adaptaion. Similarly, studies using electrocortical methods by measuring event-related potentials (ERPs) to capture signal changes linked to specific cognitive stages of processing show that shy adults exhibit reduced P1 ERP amplitude in response to fearful faces versus neutral faces (Jetha, Zheng, Schmidt, & Segalowitz, 2012; Jetha, Zheng, Goldberg, Segalowitz, & Schmidt, 2013), suggesting hypervigilance in early stages of processing. Studies using neuroimaging methods to identify regional changes in brain activity during the processing unfamiliar faces show that shy adults display greater activity in the amygdala, a region that plays a role in fear and emotional salience (Beaton et al., 2008). In response to angry and neutral faces, shy adults also elicit a neural connectivity pattern that underlies greater attention allocation and cognitive control (Tang et al., 2016), suggesting the use of effortful processing strategies. Indeed, shy adults also show increased modulation of the dorsal anterior cingulate cortex, a brain region with functional roles in conflict monitoring and attention to less intense threatening facial expressions (Tatham, Schmidt, Beaton, Schulkin, & Hall, 2013). Together these neuroimaging findings suggest that shy adults recruit brain networks that play a role in attention and controlled monitoring processes that expend greater cognitive resources, as opposed to automatic modes of processing, in response to social threat.

To date, much of this literature has predominantly focused on examining the processing of negative (angry, fearful) facial expressions, as well as unfamiliar faces. Whether shy individuals use differential brain processes in non-socially threatening situations, such as novelty/unfamiliarity in non-social stimuli, and other more psychologically distressing contexts, such as social exclusion, remain to be empirically examined. As well, although group contrasts show that shy individuals engage in differential brain processes to social threats across development relative to non-shy individuals, it cannot be assumed that all shy individuals react the same way to these stimuli as there are subtypes of shyness that can be distinguished based on the temporal endurance of shyness and interpersonal styles. The following section reviews the development of shyness and related traits, with the aims to conceptually distinguish shyness from these traits and highlight their common temporal stability patterns, to thereby suggest the utility in accounting for such temporal differences.

Shyness across Development

The earliest form of shyness is rooted in a behaviorally inhibited temperament, a tendency to display fear and wariness in response to unfamiliarity or novelty during infancy. Around 15% of toddlers are classified as highly behaviorally inhibited based on laboratory observations and parent reports (Kagan, 1994). Patterns of negative emotional and high motor reactivity linked to behavioral inhibition are undifferentiated in social *and* non-social situations. Patterns of reactivity in behaviorally inhibited infants show developmental continuity. For instance, 4-month-old infants who react negatively to novelty showed greater fear-startle responses to bursts of sound (Schmidt & Fox, 1998), greater relative right frontal electroencephalographic (EEG) activity during rest (a neural correlate of social withdraw and negative affect) at 9 months of age (Calkins, Fox, & Marshall, 1996), and more inhibited behavior during novel situations at 14 months of age (Calkins et al., 1996; Kagan & Snidman, 1991). Infants who react negatively to novelty often, but do not always, grow up as shy children

(Fox et al., 2001). Indeed, the temporal stability of behavioral inhibition is only modest in early childhood (see review, Degnan & Fox, 2007).

Another trait related to shyness that can be observed in childhood is social withdrawal, reflecting a behavioral style involving a lack of engagement in social interactions and solitary behavior, such as playing alone (Rubin, Burgess, Kennedy, & Stewart, 2003). Social withdrawal also shows modest temporal correlations from early to middle childhood (Hymel, Rubin, Rowden, & LeMare, 1990; Rubin, Chen, McDougall, Bowker, & McKinnon, 1995) and from late childhood to early adolescence (Schneider, Younger, Smith, & Freeman, 1998). In adulthood, around 50% of non-shy college students report being shy in early adolescence (Bruch, Giordano, & Pearl, 1986) and 90% of the general population report being shy at some point in their lives (Zimbardo, Pilkonis, & Norwood, 1975).

The modest temporal stability of shyness and related constructs imply that while shyness is a somewhat stable trait, it can also be plastic, such that individuals can grow into or out of being shy. Also, the presence of a large adult population who considered themselves as currently shy (~40%) and some of the non-shy adult population who reported being shy in childhood (Zimbardo et al. 1975; Heiser, Turner, & Beidel, 2003) imply that there should be heterogeneity in how shy individuals behave, think, feel, and react in social situations. More critical is the question of *why* some non-shy adults "out grew" their shyness and *how* their experiences and outcomes throughout development may differ in comparison to those who have not grown out of their shyness. Given that childhood shyness confers risk for developing socioemotional problems, in particular, social anxiety disorder (Burnstein, Ameli-Grillon, & Merikangas, 2011; Cox, MacPherson, & Enns, 2004; Gazelle, Workman, & Allen, 2010) and is related to substance use in adolescence and adulthood (Page, 1990; Santesso, Schmidt, & Fox, 2004), identification of different developmental trajectories of shyness, their long-term consequences, and their mechanisms of change is an important goal.

Other Shyness Subtypes

Aside from tackling the problem of heterogeneity in shyness by examining temporal patterns of change in shyness, subtypes of shyness can also be examined based on patterns of interpersonal interactional styles, such as one's level of sociability. Following a heuristic motivational model, sociability is conceptualized as social approach tendencies or a preference to be with others rather than being alone; In contrast, shyness is related to social withdrawal-related tendencies (Asendorpf, 1990; Cheek & Buss, 1981). Shyness and sociability are conceptualized as orthogonal traits, the evidence supporting this assertion is based on the findings that each trait is correlated with different social behavioral patterns, as well as different psychophysiological patterns across development from childhood to adulthood (Asendorpf & Meier, 1993; Jetha, Schmidt, & Goldberg, 2009; Schmidt & Fox, 1994; Schmidt, 1999; Tang, Beaton, Schulkin, Hall, & Schmidt, 2014) and across cultures (German: Czeschik & Nurk, 1995; Portugese: Neto, 1996; Asian: Hussein, Fathy, Mawla, Zyada, & Hadidy, 2011). Indeed, in their seminal work to develop shyness and sociability self-report measures, Cheek and Buss (1981) factor analyzed items pertaining to shyness and sociability and found that shyness and sociability were two distinct personality dimensions, with moderate correlations (r= - .30).

Conceptualizing shyness and sociability as orthogonal dimensions also allows the interaction between these two traits and the examination of at least two subtypes of shyness: (1) socially conflicted and (2) socially avoidant shyness. Socially conflicted shy individuals are both high on shyness and sociability with conflicting inhibition and desires to interact with others. An example is children who circle around or watch play groups from afar, wanting to be part of the interaction but having trouble joining because they are too inhibited and anxious. In contrast, socially avoidant shy individuals are high on shyness but unsociable. They are characterized by their social withdrawal (Coplan, Prakash, O'Neil, & Armer, 2004). An example would be shy children who avoid social interactions altogether by escaping or removing themselves from social situations. Additionally, there is predictive utility in examining these shyness subtypes as they predict different psychological outcomes.

Compared to their socially avoidant individuals, socially conflicted individuals exhibit more anxious behavior during social interactions in childhood and adulthood (Asendorpf & Meier, 1993; Cheek & Buss, 1981; Coplan et al., 2004). Socially conflicted individuals also exhibit more anxiety and/or fear of negative evaluation (Fox et al., 1995; Nelson, 2013) and perceive that they contribute less to social interactions in adulthood (Arkin & Grove, 1990). In terms of mental health outcomes, socially conflicted individuals exhibit more internalizing and externalizing problems in early childhood (Kopala-Sibley & Klein, 2016), higher levels of neuroticism in middle childhood (Tang, Santesso, Seagalowitz, & Schmidt, 2016) and more social anxiety in adulthood (Poole, Van Lieshout, & Schmidt, 2017; Poole, Van Lieshout, & Schmidt, in press). Socially conflicted individuals also tend to engage in more substance-use and abuse in adolescence (Page, 1990) and adulthood (Santesso et al., 2004). In contrast, the socially avoidant subtype is socially isolated in childhood (Coplan et al., 2004) and has problems related to their social withdrawal. For example, socially avoidant adults report more self-harm behaviors, suicidal ideation (Nelson, 2013) and problematic uses of the internet (i.e., playing violent video games, watching pornography, and online gambling), which in turn mediate later socially withdrawn behaviors, as well as externalizing behaviors (Nelson, Coyne, Howard, &

Clifford, 2016).

Outline of Thesis

This dissertation aimed to examine two questions: (1) How does the personality of shyness unfold across the lifespan to shape the mental health outcomes of individuals? (2) Do shy individuals show different brain responses in processing threatening social and non-social contexts, and to the extent that their brain functioning is different, do these patterns of brain activity mediate and/or moderate mental health and psychiatric outcomes? In this dissertation, I used a multi-measure, multi-method lifespan approach, examining typically developing children, adolescents, and adults, as well as an integrative framework to look at both central and peripheral functioning in how shy individuals process social and non-social threatening situations. To answer the first research question, I delineated different developmental trajectories of shyness across the first four decades of life and their differential mental health outcomes and attentional biases to socially threatening faces in adulthood. To answer the second research question, I documented putative brain mechanisms that underlie the neural processing strategies in shyness and its different subtypes, in relation to different outcomes. In doing so, I demonstrate that different outcomes and neural and neuroendocrine physiology are linked to different shy individuals that are characterized by how their shyness changes across time (i.e., temporal patterns) and by their interactional preference (i.e, sociability patterns).

In Chapter 2, I used a prospective longitudinal design to examine developmental trajectories of shyness from middle childhood (age 8) to middle adulthood (age 30 - 35) and their associations with adult mental health outcomes and attentional biases to social threat, obtained through a structured psychiatric diagnostic interview and experimental task. Findings showed that there were three developmental trajectories, including a low stable non-shy trajectory, and two shyness trajectories, one that increased beginning in adolescence, and one that decreased beginning in middle childhood. Specifically, it was the increasing, but not decreasing, shy trajectory that was at risk for social anxiety, depression, and substance-use disorders, as well as higher attentional bias to angry faces compared to the low-stable non-shy trajectory.

Given the presence of diverging shy developmental pathways, it was important to understand the contexts in which they diverged. As such, in Chapter 2, I further examined the roles of peer and social relations during childhood and adolescence and found that the increasing, but not decreasing, shy trajectory reported more incidences of verbal bullying compared to the low-stable trajectory. Altogether, these findings provide initial evidence that there are individual differences in how shyness changes across the first four decades of life, and that not all shy children grow up to have emotional problems. Particularly, individuals who developed shyness with a later onset (i.e., beginning in adolescence onward to adulthood) were at risk for psychological problems later in adulthood. In contrast, children who grew out of their shyness overtime were not at risk for these problems.

In Chapters 3 and 4, I used cross-sectional designs in children, adolescents, and adults, to further focused on examining how the brain functions in different shy individuals during the processing of non-social novelty (Chapter 3) and social exclusion (Chapter 4) using electrocortical measures, such as ERPs and event-related EEG oscillations. To the extent that brain processes were different, I also examined whether they mediated or moderated the known emotional problems in different shy individuals characterized by their levels of sociability. Here it is noted that the background literature on shyness and sociability in Chapter 3 and 4 overlap.

In Chapter 3, I used ERPs to examine specific cognitive stages during the processing of non-social novelty using a three-stimulus-auditory oddball task in 10-year old children and adults. Children and adults were separately examined as there were developmental differences in the ERP waveforms that suggested differential brain functions in an ERP component (i.e., they were already qualitatively different), which rendered them unsuitable for direct group comparisons. In the first study, I examined whether shyness and sociability were distinguishable on the P300 ERP brain responses to processing task-relevant, novel, and standard auditory tones in typically developing 10-year-old children. I focused on the P300 ERP component as it has been positively related to high arousal levels linked to personality (e.g., introversion) and is linked to attentional and working memory processes, with higher amplitudes representing more attentional allocation and uses of cognitive resources (Polich, 2007). This study was the first to show that shyness, but not sociability, was related to higher P300 amplitudes to target and background tones, suggesting that shyness is not merely unsociability. Increased P300 amplitudes during baseline also mediated children's conflicted shyness and their greater emotional instability. These findings suggested that hyperarousal at baseline may be a mechanism in understanding the risk for emotional instability and dysregulated behavioral problems in individuals characterized by conflicted shyness.

In the second study of Chapter 3, I used the identical task to examine whether shyness and sociability were distinguishable on the P300 ERP brain responses in young adults. Following a multi-component approach to examine central-peripheral mechanisms, I also examined whether neuroendocrine responses (cortisol) were linked to shy adults' brain responses and negative emotionality. Unlike the pattern of relations found in shy children, shyness in adults, but not sociability, was related to *reduced* frontal novelty P300 amplitudes and to high emotionality. Results also indicated that low baseline cortisol levels mediated the relations between (a) high shyness and reduced frontal P300 amplitudes to novels tones, and (b) high shyness and high emotionality. This study was the first to suggest that changes in the neuroendocrine system in response to coping with chronic social stress in shy adults may indirectly impact attentional states to threat and novelty, as well as emotional arousal.

Chapter 4 further examined brain functioning across children (ages 10-12), adolescent (ages 14-16) and adults (ages 17-28) during the context of social exclusion using the Cyberball task, a ball-toss game in which the participants were excluded by virtual players with pre-programmed actions. Moreover, instead of examining ERPs that is limited to average phase locked EEG activity in the time domain, I examined event-related oscillatory EEG dynamics in both time and frequency domains that provide information more closely reflects the activity of underlying neuronal assemblies. Results indicated that adolescents were particularly sensitive to effects of distress caused by social exclusion, as they expressed a pattern of greater spectral power and lower phase synchrony of the theta EEG frequency band to rejection compared to children and adults. Results also indicated that individuals characterized by conflicted shyness, irrespective of age, reported higher distress to the task. In addition, high levels of theta spectral power to rejection moderated substance-use and fear of negative evaluation among conflicted shy individuals.

Altogether, the results of this thesis underscore the importance of examining differences within individuals and different contexts in understanding the outcomes associated with differential developmental pathways. Using a prospective longitudinal design with repeated assessments of shyness in the first four decades of life, I provided initial evidence that childhood shyness is not directly linked to adverse long-term mental health outcomes. Using different social and non-social contexts to examine individual differences in brain functioning, I demonstrated that processing strategies linked to increased cognitive resources and attention to generalized situations as well as brain correlates linked to distress from being socially excluded mediate or moderate socioemotional outcomes in different shyness subtypes. Using a developmental perspective, this work also indicated that adolescence is a period that is sensitive to influences of negative peer and social experiences. Overall, this thesis suggests that not all shy people are alike and holds larger implications for targeting specific contexts and biological processes that interact with shyness, in order to alter adverse developmental pathways and promote healthy development.

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CHAPTER 2

Study 1: The Development of Shyness and Long-term Consequences

Tang, A., Van Lieshout, R. J., Lahat, A., Duku, E., Boyle, M. H., Saigal, S., & Schmidt, L. A. (2017, in press). Shyness trajectories across the first four decades predict mental health outcomes. *Journal of Abnormal Child Psychology*.

Abstract

Although childhood shyness is presumed to predict mental health problems in adulthood, no prospective studies have examined these outcomes beyond emerging adulthood. As well, existing studies have been limited by retrospective and cross-sectional designs and/or have examined shyness as a dichotomous construct. The present prospective longitudinal study (*N*=160; 55 males, 105 females) examined shyness trajectories from childhood to the fourth decade of life and mental health outcomes. Shyness was assessed using parent- and self-rated measures from childhood to adulthood, once every decade at ages 8, 12-16, 22-26, and 30-35. At age 30-35, participants completed a structured psychiatric interview and an experimental task examining attentional biases to facial emotions. We found 3 trajectories of shyness, including a low-stable trajectory (59.4%), an increasing shy trajectory from adolescence to adulthood (23.1%), and a decreasing shy trajectory from childhood to adulthood (17.5%). Relative to the low-stable trajectory, the increasing, but not the decreasing, trajectory was at higher risk for clinical social anxiety, mood, and substance-use disorders and was hypervigilant to angry faces. We found that the development of emotional problems in adulthood among the increasing shy trajectory might be explained in part by adverse peer and social influences during adolescence. Our findings suggest different pathways for early and later developing shyness and that not all

shy children grow up to have psychiatric and emotional problems, nor do they all continue to be shy.

Introduction

Shyness reflects an anxious preoccupation with the self to real or imagined social situations (Melchoir & Cheek, 1990). Although this definition appears to be a unitary dimension, shyness is a broad multi-component phenomenon. In theory, shyness ranges from features of temperament to self-concept. Shyness has been proposed to include cognitive (e.g., self-consciousness, self-preoccupation in social situations), affective (e.g., social anxiety, somatic symptoms), and behavioral (e.g., social inhibition, avoidance, and reticence) components, with some individuals experiencing only one or two of the three components considered as shy (Cheek & Briggs, 1990). Because these aspects overlap with symptoms of social anxiety (Beidel & Turner, 1999), shyness can be viewed as a sub-syndromal form of social anxiety. In assessment, shyness questionnaires include items tapping cognitive, affective, and behavioral aspects that decompose into factors labeled as social avoidance/distress, social facility, and difficulties being assertive, and are correlated with measures of social anxiety, anxiety and depression, as well as personality dimensions, such as introversion and neuroticism (Hopko, Stowell, Jones, Armento, & Cheek, 2005; Jones, Briggs, & Smith, 1986).

The past several decades of scientific investigations and popular writings on childhood shyness have highlighted deleterious effects of childhood shyness on adult life course outcomes. For example, shy children tended to delay marriage, parenthood, and stable career establishment when examined in their 30s (Caspi, Elder, & Bem, 1988; also see, Dennissen, Asendorpf, & Van Aken, 2008; Kerr, Lambert, & Bem, 1996). Others found that when shy children reached emerging adulthood, they exhibited lower social competence (Grose & Coplan, 2015), and more aggression if they also lacked social support from their parents in adolescence (Hutteman, Dennissen, Asendorpf, & Van Aken, 2009) relative to their non-shy peers. While some shy compared to non-shy children face more socioemotional challenges on a daily basis (see Rubin, Coplan, & Bowker, 2009; Schmidt & Buss, 2010, for reviews), a popular belief is that childhood shyness is a problem that requires intervention as it increases the risk for developing social anxiety disorder (SAD; see Crozier, 2014; Lane, 2008). Surprisingly, no prospective studies have, however, repeatedly assessed shyness across development and beyond emerging adulthood to examine whether childhood shyness predicts mental health in adulthood.

Much of the research on the association between childhood shyness and adult mental disorders exhibits methodological weaknesses, including the use of cross-sectional designs, retrospective reports, and limited conceptualization and measurement of shyness across the lifespan. For example, in a sample of 5,877 participants aged 15-54, 26% of women and 19% of men retrospectively identified themselves as being "very shy" during childhood, but only a minority of these shy women (28%) and shy men (21%) met lifetime SAD diagnosis of the DSM-III-R (Cox, MacPherson, & Enns, 2005). Likewise, in a national sample of adolescents (ages 13-18), 47% of the sample identified themselves as shy, but only 12.4% of these shy adolescents met criteria for lifetime diagnosis of SAD of the DSM-IV (Burnstein, Ameli-Grillon, & Merikangas, 2011). Furthermore, in a cross-sectional study of 200 adults, Heiser, Turner, and Beidel (2003) found that among the 20 individuals who met DSM-IV criteria for SAD, 17 were shy, while 3 were non-shy. Notably, the distributions of shyness scores overlapped between shy adults who met criteria for SAD and shy adults who had not met criteria, suggesting that SAD is not merely extreme shyness. Also, shyness did not only predict a diagnosis of SAD, but a range of psychiatric disorders as a greater proportion of the shy group (67%) relative to the non-shy group (42%) met diagnostic criteria for either an Axis I or II DSM disorder, predominantly anxiety, mood, or avoidant personality disorders (Heiser et al., 2003). Taken together, these findings suggest an increased likelihood of some shy individuals being diagnosed with SAD, but this association is neither direct, nor specific. As well, these retrospective studies suggest that while shy children and adolescents are more likely to develop SAD, the majority of shy children do not develop SAD, and some will develop SAD without being shy.

A major limitation of studies relying on retrospective reports of shyness in clinical populations is that participants' recall and interpretation are susceptible to negative cognitive biases. In contrast, prospective longitudinal studies can avoid such confounds. However, many of the existing longitudinal studies of childhood shyness use only a single measurement of shyness during middle childhood to predict outcomes in adulthood (e.g., Caspi et al., 1988; Grose & Coplan, 2015; Kerr et al., 1996). Some of these studies also rely on a single item to measure shyness (e.g., Burnstein et al., 2011; Cox et al., 2005; Grose & Coplan, 2015), do not account for shyness in adulthood (Grose & Coplan, 2015), and assign participants to dichotomized (shy, not shy) groups, overlooking possible developmental changes and heterogeneity within shyness.

Although some studies have attempted to track the developmental trajectories of shyness and related constructs (e.g., behavioral inhibition and social withdrawal) during the early school age years (Degnan et al., 2014; Grady, Karraker, & Metzger, 2012) and adolescence (e.g., Karevold, Ystrom, Coplan, Sanson, & Mathiesen, 2014; Oh et al., 2008), none have reported on mental health outcomes beyond emerging adulthood. As well, the timing of the onset of shyness and corresponding life-course sequelae have received little attention.

The development of early versus later onset of shyness is potentially linked to different long-term consequences. Buss (1986) posited that there were at least two types of shyness: early and later developing shyness which he conceptualized as fearful and self-conscious shyness, respectively. Early shyness resembles behavioral inhibition, a biologically based temperamental antecedent to shyness characterized by reactivity that is undifferentiated in social and non-social contexts in early infancy (Kagan, 1994). Based on retrospective reports from young adults, early developing shyness involves more physiological anxiety symptoms than later developing shyness (Cheek & Krasnoperova, 1999; Cheek, Carpentieri, Smith, Ierdan, & Koff, 1986). In contrast, later versus early shyness reflects a broader personality phenotype that is largely driven by social contexts and the development of the self-concept, self-awareness, self-conscious emotions (e.g., shame, embarrassment), and a fear of negative evaluation, all of which require perspective taking skills and knowledge of social standards in early to middle childhood (Flavell, 2000; Harter, 2012; Lagattuta & Thompson, 2007). It is important to point out, however, that some behavioral signs of early self-conscious shyness begin in and increase across toddlerhood (Eggum-Wilkens, Lemery-Chalfant, Aksan, & Goldsmith, 2015), suggesting that self-conscious shyness may appear earlier in life than originally proposed by Buss (1986).

Shyness is hypothesized to be intensified during adolescence as social fears and self-awareness increase when social and peer relationships become more valued (Beidel & Alfano, 2011). Indeed, trajectory studies of social withdrawal extended into early adolescence have documented an increasing trajectory that resembles the self-conscious type of shyness (Oh et al., 2008). However, the related construct of social withdrawal refers to a behavioral style characterized by a lack of engagement in social interactions and social isolation, such as playing alone, watching peers from afar, and being unoccupied (Rubin, Burgess, Kennedy, & Stewart, 2003). Shyness overlaps with social withdrawal as some shy children are afraid and anxious to interact, some may lack motivation and avoid interactions (Coplan, Prakash, O'Neil, & Armer, 2004), but social withdrawal can result from other reasons, including peer rejection for child's immaturity or aggressiveness or a preference to be alone (Pope, Bierman, & Mumma, 1991; Rubin & Mills, 1988), or a combination of these reasons.

Still, in adolescence and adulthood, other shy subtypes based on different interpersonal (e.g., levels of sociability) and attachment styles can distinguish shy people who prefer involvement in social interactions from those who are withdrawn and depressed (Cheek & Buss, 1981), as well as shy people who are more well- adjusted, less shy, less depressed and lonely in family relationships and friendships (Cheek & Krasnoperova, 1999). Accordingly, it is important to track shyness over time as its expression, correlates, and consequences may differ depending on its onset.

Relatively few studies, however, have tracked and repeatedly assessed the phenomenon of shyness longitudinally. There are some researchers who have investigated constructs related to shyness longitudinally, such as behavioral inhibition and social withdrawal. For example, Degnan and Fox (2007) found that behavioral inhibition was only modestly stable across childhood. Similarly, social withdrawal has been reported to be moderately stable from early to middle childhood (Hymel, Rubin, Rowden, & LeMare, 1990; Rubin, Chen, McDougall, Bowker, & McKinnon, 1995) and during late childhood to adolescence (Schneider, Younger, Smith, Freeman, 1998. In adulthood, approximately 50% of non-shy college students reported being shy during early adolescence (Bruch, Giordano, & Pearl, 1986), and 90% of the general population reported being shy at one point in their lives (Zimbardo, Pilkonis, & Norwood, 1975). Interestingly, a recent prospective study showed that individuals whose behavioral inhibition remained high and stable across childhood were at greater risk for SAD in adolescence (Chronis-Tuscano et al., 2009) and anxiety disorders in emerging adulthood (i.e., late teens-early 20's; Frenkel et al., 2015). Whether these patterns extend to the fourth decade of life remains an empirical question.

It is also important to point out that social skills and peer relations are important contexts that should be examined in understanding the development of shyness and later psychopathology, as shy children often face greater peer rejection, victimization, and loneliness than their non-shy peers (Rubin et al., 2009). Positive and negative peer experiences may have different effects. Shy children who are socially excluded face a higher risk of internalizing problems (e.g., Gazelle & Ladd, 2003; Gazelle & Rudolph, 2004; Ladd, 2006). Likewise, positive and negative peer influences during adolescence can buffer or exacerbate mental health problems in young adults who were classified as behaviorally inhibited in childhood (Frenkel et al., 2015).

In addition to influences from the peer context, sex differences may also play a role in the development of shyness. Relative to shy girls, shy boys tend to face more peer exclusion and internalizing problems, although the latter involves mixed findings (see review, Doey, Coplan, & Kingsbury, 2014). There also appears to be mixed findings regarding the effects of sex differences on the long term consequences of childhood shyness (Asendorpf, Dennissen, & Van Aken., 2008; Caspi et al., 1988; Kerr et al., 1996).

The Present Study

We prospectively followed a cohort of individuals born between years of 1977 to1982 and assessed shyness in each of the first four decades of life (at ages 8, 12-16, 22-26, and 30-35).

At the most recent assessment (age 30-35), participants completed a structured psychiatric diagnostic interview and an attentional task assessing emotion processing biases.

There were three primary objectives in the present study. The first was to classify trajectories of shyness across the first four decades of life, because shyness varies on a continuous dimension but subgroups can be captured by patterns of stability (i.e., how shyness changes across time) within the population. Second, we examined whether these trajectories predicted mental health outcomes at age 30-35 years. Finally, given the trajectory analyses generated two shyness trajectories resembling early and later developing shyness, we conducted exploratory analyses to test potential social contexts that may moderate the links between shyness trajectories and mental health problems in adulthood.

We predicted that compared to low-stable and/or decreasing shyness trajectories in adulthood (age 30-35), a high-stable and/or increasing shyness trajectories would be associated with (1) higher risk for anxiety and mood disorders, particularly SAD (e.g., Chronis-Tuscano et al., 2009; Frenkel et al., 2015), substance-use and alcohol-use disorders as shy individuals may self-medicate with substances to cope with their shyness and use alcohol to facilitate social interactions (e.g., Carducci, 2009; Lahat et al., 2012; Lewis & O'Neil, 2000; Santesso, Schmidt, & Fox, 2004). Given the converging evidence in a series of electrocortical (Jetha, Zheng, Schmidt, & Segalowitz, 2012; Jetha, Zheng, Goldberg, Segalowitz, & Schmidt, 2013), neuroimaging (Beaton et al., 2008; Tang, Beaton, Schulkin, Hall, & Schmidt., 2014) and behavioral (Pérez-Edgar et al, 2010; Pérez-Edgar et al, 2011) studies that suggest shy and behaviorally inhibited individuals have affect-related attentional biases reflecting their hypervigilance to social threat (in the form of angry facial expressions), we also predicted that high-stable and/or increasing shyness trajectories would be associated with 2) greater attentional bias to angry facial expressions. On the other hand, we predicted that individuals who were shy in childhood but became less shy over time (i.e., those who "outgrew" their shyness) would not be at risk for these problems.

As our secondary goal, we explored potential 1) social contexts (e.g., peer victimization and social competence in childhood and adolescence) that may be linked to different shyness trajectories, 2) sex differences by shyness trajectory interactions, and (3) shyness trajectories by social competence by peer victimization interactions for the risk of mental disorders and attention bias to angry faces in adulthood.

Method

Participants and Overview

Participants were part of a larger longitudinal birth cohort study examining the development of extremely low birth weight (ELBW) and normal birth weight (NBW) children born from 1977 to 1982 in central-west Ontario (Saigal, Rosenbaum, Stoskopf, & Subckaur, 1984). The initial sample of ELBW at birth included 179 individuals. The NBW controls were recruited at age 8 and matched with the ELBW group on age, race, sex, and socioeconomic status (SES) (Saigal, Szatmari, Rosenbaum, Campbell, & King, 1991). At age 12-14, 141 ELBW and 122 NBW participated; at age 22-26, 149 ELBW and 133 NBW participated; finally, at age 30-35, 100 ELBW and 89 NBW participated. Among the initial sample who were eligible to participate, 160/309 (52%) nonimpaired participants (*n* for ELBW= 80, *n* for NBW= 80; 55 males, 105 females; *M* age= 32.29) had complete data for shyness across all four visits and were included in the trajectory analyses. Participants' birth weight and sex were extracted from their medical charts, and parental SES at age 8 was defined using the 2-factor Hollingshead Index (Hollingshead, 1969). Because ELBW and NBW groups did not differ on shyness at the initial assessment $t(158) = .27$, $p = .79$, and assignment in shyness-trajectories did not depend on birth weight $\chi^2(2) = 4.36$, $p = .11$, we collapsed the two groups. Importantly, we controlled for birth weight and childhood caregiving environment in all analyses, and ensured that the derived trajectories were not disproportionally represented by ELBW versus NBW participants on any of the outcome measures (*p*s > .05). We also controlled for any neurosensory impairments.

Participants were assessed at four time points: childhood (age 8), adolescence (age 12-16), young adulthood (age 22-26), and adulthood (age 30-35). Parent- and self-report questionnaires of emotional and behavioral problems were obtained across four time points using the Achenbach System of Empirically Based Assessment (Achenbach, 1991, 1997). Study procedures at each assessment were approved by the Hamilton Health Sciences Research Ethics Board.

Shyness Composites

At ages 8 and 12-16 years, parents completed the 113-item Child Behavior Checklist (CBCL) (30) and the Ontario Child Health Study-revised scales (OCHS-R) (Boyle et al., 1993; Saigal, Pinelli, Hoult, Kim, & Boyle, 2003) that contained some items adapted from the CBCL (Achenbach, 1991). At ages 22-26 and 30-35 years, participants completed the 130-item Young Adult Self Report (YASR) (Achenbach, 1997). We created composite measures of shyness at ages 8, 22-26, and 30-35, by summing *z*-scores of six interrelated items at age 8 that were conceptually related to shyness, and used the same six items at later time points to maintain measurement consistency. Because two of these items were unavailable at age 12-16 as the full CBCL was not used at this assessment, the shyness composite was created by summing *z*-scores of 4 items. Table 1.1 summarizes the items used to create the shyness composites at each time point. All four shyness composites were intercorrelated at each assessment, each was correlated with the widely used Cheek and Buss shyness scale (Cheek & Buss, 1981) measured in adulthood, and each had acceptable Cronbach alpha's, providing reliability and convergent validity of our construct (see Table 1.1). The construct captures the behavioral and cognitive aspects of shyness (see Supplemental Materials Online for details on factor structure). Baseline anxiety and depressive symptoms at age 8 were obtained from the CBCL anxious/ depressed subscale (excluding the "self-conscious/ easily embarrassed" item in our shyness composite) and used as a covariate in further analyses.

Outcome Measures in Adulthood (30-35 years)

MINI International Neuropsychiatric Interview. The MINI is a structured diagnostic interview that assesses psychiatric disorders in a manner consistent with the DSM-IV and the International Classification of Diseases, 10th Revision. It shows strong agreement with the Structured Clinical Interview for DSM-IV disorders and World Health Organization Composite International Diagnostic Interview, and strong interrater reliability (Sheehan et al., 1998). As the MINI focuses on current psychiatric disorders, we added modules from the MINI-Plus (Sheehan et al., 1998) to assess both current and lifetime prevalence of a subset of psychiatric disorders (Van Lieshout, Boyle, Saigal, Morrison, & Schmidt, 2015). Given our a priori hypotheses for examining anxiety-, mood-, and substance-related disorders and to maintain a minimum frequency of diagnoses (> 5), we included current SAD (generalized and non-generalized subtypes), agoraphobia, and generalized anxiety disorder, both current and lifetime panic disorder, major depressive disorder (MDD), alcohol abuse and dependence, and substance abuse and dependence. The MINI was administered by doctoral psychology students who were trained and blinded to the study's hypotheses.

Table 1.1. Selected items from the CBCL, YASR, and OCHS-R used to define shyness, intercorrelations among composite measures of shyness, inter-item alphas for each composite measure, and correlations with a valid shyness scale across the four assessments

Item	Age 8 CBCL (parent-rated)	Age 12-16 OCHS-R CBCL (parent-rated)	Age 22-26 and 30-35 YASR (self-rated)	
1	"shy or timid"	"self-conscious or easily embarrassed"	"I am too shy or timid"	
2	"self-conscious or easily embarrassed"	"withdrawn or isolates self"	"I am self-conscious or easily embarrassed"	
3	"likes to be alone"	"overly anxious to please"	"I would rather be alone than with others"	
4	"secretive, keeps things to self"	"doing things less with other kids"	"I am secretive or keep things to myself"	
5	"refuses to talk"		"I refuse to talk"	
6	"doesn't get involved with others"		"I keep from getting involved with others"	
	Shyness composite scores			
	1. Age 8	2. Age 12 - 16	3. Age 22 - 26	4. Age 30 - 35
1	--	.25**	.21**	.15*
2		--	.18**	.29**
3			--	.55**
4				--
Cronbach's alpha	.65	.58	.72	.68
Cheek and Buss Shyness scale at age 22-26	.31**	.21*	.61**	.44**

Note. 2-tailed, ***p* <.01, **p* < .05. CBCL= Child Behavior Checklist. OCHS-R= Ontario Child Health Study-revised scales. YASR= Young Adult Self Report.

Attentional Biases to Facial Emotions. Participants completed a visual dot-probe task (Mogg, Philippot, & Bradley, 2004) in a dimly lit, sound attenuated room, sitting ~ 100 cm away from the monitor (75 Hz vertical refresh rate). Visual stimuli consisted of four models (two females), each posing angry, happy, and neutral facial expressions from the NimStim face database (Tottenham et al., 2009). Each trial unfolded in the following sequence: a) a central fixation cross is presented for 500 ms; b) two faces of the same model were presented side-by side (angry-neutral, happy-neutral) for 104 ms; c) a probe (i.e., an asterisk) is presented in the left or right visual field. Participants were asked to indicate the probe location (left/right) on a custom-labeled response pad as fast and accurate as possible. Participants' response prompted each subsequent trial, however, trials would automatically begin if no response was recorded within 1500 ms of the probe presentation. Participants completed a practice block prior to the actual task.

A total of 128 trials were divided into 2 blocks. In each block, there were 32 angry-neutral trials and 32 happy-neutral trials. The order of stimulus was randomized for each participant within each block. All trials were balanced for the emotional stimuli and targets to appear with equal probability in the left and right visual fields. The probability (50%) of congruent (probe appears in same position as the emotional face) and incongruent (probe appears in same position as the neutral face) trials was also balanced.

Trials with reaction times faster than 150 ms were removed from the analysis to account for random or anticipatory responses. Attention bias scores for happy and angry faces were calculated as the difference between the mean incongruent reaction time and the mean congruent reaction time for that emotion. A positive attention bias score indicates vigilance, whereas a negative score indicates avoidance of a stimulus.

Social Relational Measures in Childhood and Adolescence

Peer Victimization. Retrospective reports of verbal and physical bullying frequencies throughout childhood to adolescence were obtained from two items adapted from the Childhood Experiences of Violence Questionnaire (Walsh, MacMillan, Trocme, Jamieson, & Boyle, 2008) at age 22-26. The items for verbal and physical bullying included: "Sometimes kids get hassled or picked on by other kids who say hurtful or mean things to them, how many times did this happen to you before age 16?", and "sometimes kids get pushed around, hit or beaten up by other kids or a group of kids, how many times did this happen to you before age 16?". Both items were scored on a 5-point scale (*1*=never; *5*=more than 10 times).

Social Competence. We created a theoretically and empirically derived composite score of social competence with peers by summing *z*-scores of the social competence scale from the self-perception profile for adolescents (Harter, 2012) and reversed *z*-scores on an item in the OCHS-R that tapped social competence (Saigal et al., 2003), "in the past 6 months, how well have you been getting along with other kids" that was scored on a 5-point scale (*1*= very well, no problems; *5*= not well at all, constant problems). These self-report measures were collected in the adolescent assessment. These two scales were correlated ($r = -.46$, $p < .001$), suggesting they both tap social competence and abilities to handle peer interactions. Thus, high scores on this composite reflect high self-perceived social competence at adolescence.

Covariates

We included birth weight, sex, presence of neurosensory impairment, anxiety and depressive symptoms from the CBCL subscale and SES at age 8 in all analyses to account for potential differences in the prevalence of psychiatric disorders, emotion processing, and socioeconomic inequalities that may be linked to anxiety and depressive symptoms across the lifespan.

Data Analyses

First, we estimated trajectories of shyness from middle childhood (age 8) to adulthood (age 30-35) with normalized shyness composite scores across the four time points using k-means for longitudinal data in the statistical analysis package R (Genolini & Falissard, 2011; Genolini, Alacoque, Sentenac, & Arnaud, 2015). K-means is an exploratory hill-climbing algorithm that derives clusters of homogenous subgroups within a larger heterogeneous population; simulations demonstrate comparable efficiency to latent class models in Proc Traj (Genolini & Falissard, 2011) and usage has been endorsed by other longitudinal studies (e.g., Pingault et al., 2013; Pingault et al., 2014). In this procedure, each observation is first arbitrarily assigned to a cluster, then optimal clustering is achieved by repeatedly calculating the mean of each cluster and reassigning each observation to its nearest mean until no further changes occur.

To obtain optimal solutions, we repeated the estimations 400 times, 100 times each for 2-, 3-, 4-, and 5-cluster solutions. We estimated these numbers of clusters as the literature (Booth-Laforce & Oxford, 2008; Chronis-Tuscano et al., 2009; Oh et al., 2008) suggests heterogeneous groups of shy people exist, but we do not know how many. To choose the best cluster solution, we considered a combination of fit/quality of partition statistics of the model, including the Calinski-Harabatz, BIC, and the global average of post-probabilities (the probability for each participant to effectively belong to the trajectory he/she was assigned), prior empirical findings, theory, and usefulness of classes.

Second, binary logistic regression models assessed the strength of association between membership in shyness-trajectories and risk for each psychiatric diagnosis, while accounting for sex (male, female), birth weight (ELBW, NBW), neurosensory impairment (yes, no), anxious/depressed symptoms and parental SES at age 8.

Third, separate one-way analysis of variance (ANOVAs) assessed the effect of different shyness-trajectories on each of the angry and happy attentional bias measures from the dot-probe task and separate social relational indices (i.e., social competence, and frequencies of verbal and physical victimization) as the dependent variable, while accounting for the same covariates. The Sidak post-hoc method assessed pairwise differences among the three shyness-trajectories.

Participant Attrition and Data Loss

We took a conservative approach in the trajectory analysis and included only participants who participated in the study at all four assessments in the trajectory analysis, and one of these participants was excluded for unusual data (N=160). Although we also imputed missing data for participants with only one missing data point of shyness and obtained largely similar results, there were slight differences (see Supplemental Materials Online for details), and hence we report findings based on the 160 participants with no missing shyness data. Of those who were included in the trajectory analyses versus those who were not, there were no differences in birth weight status, $\chi^2(1) = 3.52$, $p = .074$, or shyness, $\chi^2(1) = 2.37$, $p = .13$. However, males, $\chi^2(1) = 18.07$, $p < .001$, and the lowest and second lowest SES classes, $\chi^2(4) = 15.21$, $p < .001$, were less likely to consistently return to the study.

Of the 160 participants included in the analyses, some did not complete the MINI, the dot-probe task, or had missing data on other measures. Accordingly, the logistic regression analyses included 135 to 139 participants depending on the disorder category. The ANOVAs for the dot-probe task (owing to technical problems) included 119 participants; for the victimization and social competence measures, there were 155 and 144 participants, respectively.

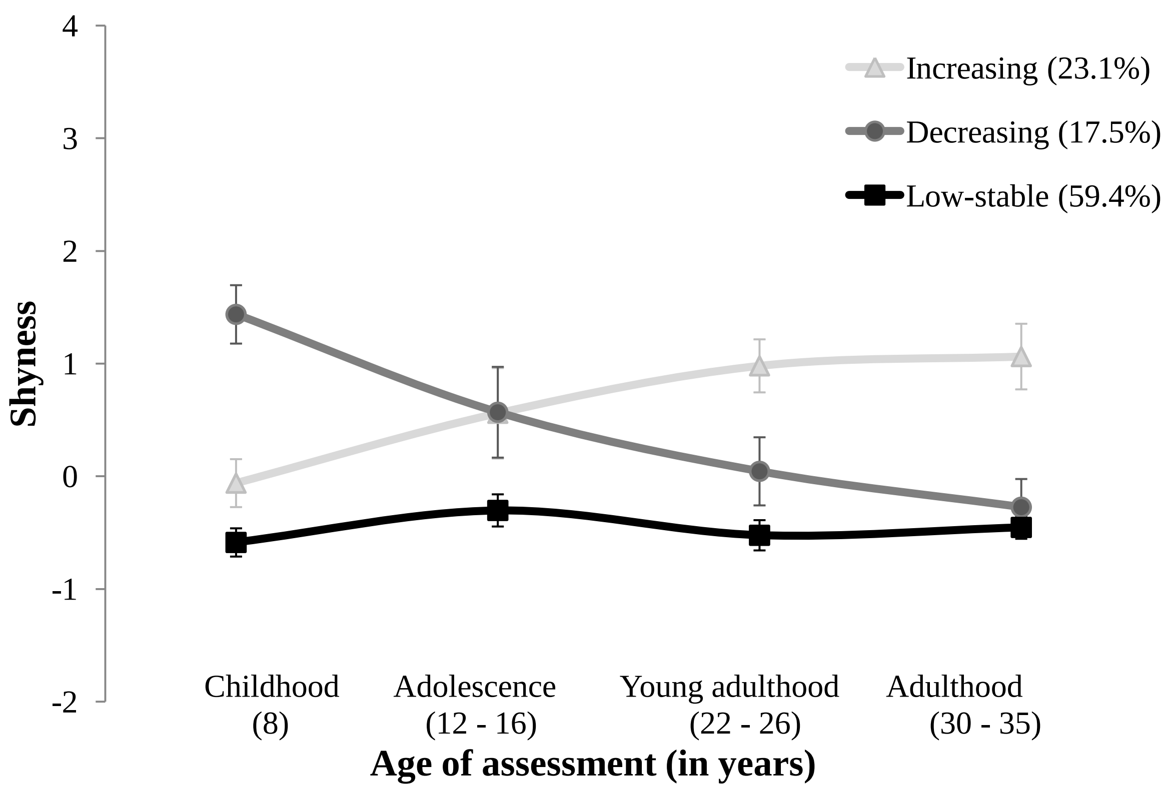
Results

Developmental Trajectories of Shyness

Three developmental trajectories of shyness were identified from the analysis (Figure 1.1): 1) a consistently low-stable non-shy trajectory (59.4%, *n*= 95), 2) an increasing shy trajectory beginning in adolescence (23.1%, *n*= 37), and 3) a decreasing shy trajectory beginning in childhood (17.5%, *n*= 28). The y-axis reflects the transformed shyness *z*-score. Although a *z*-score of zero reflects average shyness, it is not a good measure of central tendency as the distribution is positively skewed with most of the individuals in the low-stable non-shy trajectory, which we consider a baseline normative group to compare with the two shy trajectories. A multinomial logistic regression model that regressed shyness-trajectories on birth weight, sex, neurosensory impairment, and SES demonstrated these variables were not related to this shyness classification, p's > .05, consistent with the notion that shyness is a normal variation in the population.

Partition quality criteria for our 3-cluster model were as follows: Calinski Harabatz= 57.91, post probability global= .90, BIC= -1716.95. Values of the Calinski-Harbatz and posterior global average of post-probabilities across the 100 models for each of the 2-, 3-, 4-, and 5- cluster solutions (see Supplemental Materials) suggested the best fit for a 2-cluster model depicting a stable shy (34.4%) and a stable non-shy (65.6%) trajectories, followed by our 3-cluster solution (i.e., low-stable, increasing and decreasing trajectories), the 4-cluster solution, and lastly the 5-cluster solution. In contrast, values of the BIC suggested that 4- and 5- clusters solutions were best fitting. Due to discordance among fit statistics, we selected the 3-cluster model because theory and the literature suggests at least two different groups of shy people (one that stays relatively stable, and one that decreases over time) and another group characterized by low shyness (e.g., Chronis-Tuscano et al., 2009; Oh et al., 2008). We also believed that a 3-cluster solution was a more useful classification for understanding the development of shyness in association with mental health due to its specificity compared to a 2-cluster solution. Indeed, the two shy trajectories in the 3-cluster solution stem from the high-stable shy trajectory from the 2-cluster solution (see Supplemental Materials). We did not consider the 4- or 5- cluster solutions due to our small sample size, as there were decreases in the number of participants in each trajectory with increases in the number of clusters.

Figure 1.1. Mean shyness trajectories from childhood to adulthood



Note. Error bars are 95% confidence intervals for the means.

Prediction of Psychiatric Disorders in Adulthood. Table 1.2 displays frequencies and odds-ratios for shyness-trajectories associated with risk for different psychiatric disorders in adulthood. We chose the low-stable trajectory as the reference category due to our interest in examining how the two shy-trajectories contrasted with the larger non-shy trajectory. For anxiety disorders, the increasing trajectory had higher odds for a current diagnosis of SAD. For mood disorders, the increasing trajectory had higher odds for both current and lifetime diagnoses of MDD. For substance-related disorders, the increasing trajectory had higher odds for both current and lifetime diagnoses of substance abuse and dependence disorders, as well as current alcohol abuse and dependence.[1]

[1] Additional analyses examining sex differences by shyness trajectory interactions for outcome measures were performed. However, no sex differences by shyness trajectory interactions emerged for any of the mental health outcomes, attentional bias to angry faces, social competence, and verbal or physical bullying.

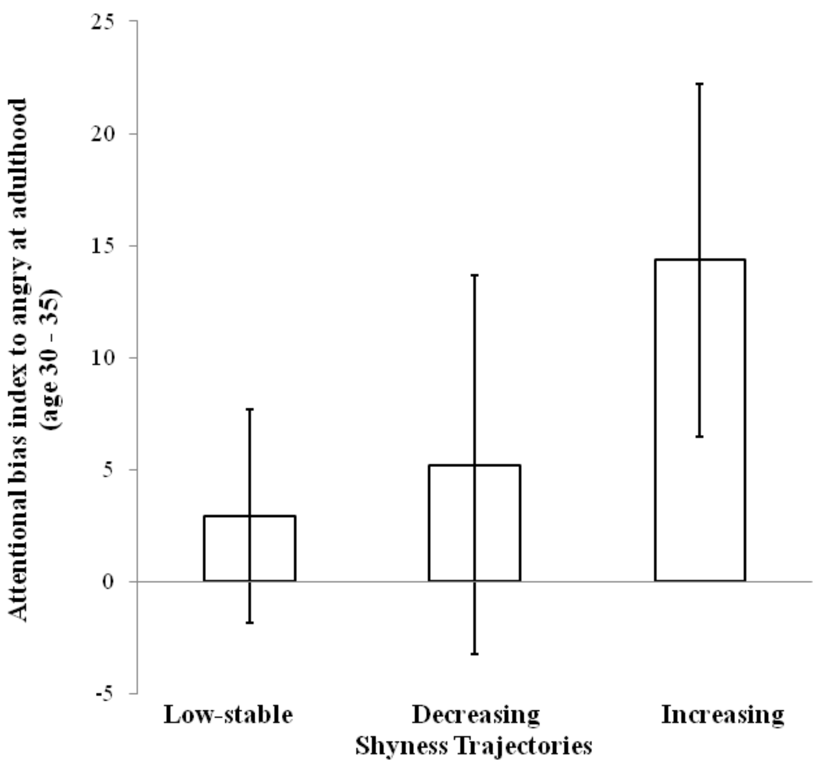
Table 1.2. Logistic regression results predicting anxiety (A), mood (B), and substance-related (C) disorders at adulthood (age 30-35)

	No. of cases in shyness trajectories			Odds ratio (95% confidence interval)	
DSM diagnosis	Low-stable	Decreasing	Increasing	Decreasing	Increasing
(A) Anxiety disorders					
Social anxiety disorder (current)	2 (2.4%)	0	6 (20%)	--	8.76 (1.30 - 59.11)*
Agoraphobia (current)	3 (3.6%)	0	7 (23.3%)	--	5.16 (.90 - 29.45)
Generalized anxiety disorder (current)	6 (7.1%)	1 (4%)	5 (16.7%)	.45 (.04 - 5.03)	2.04 (.48 - 8.71)
Panic disorder (current)	2 (2.4%)	1 (4.2%)	2 (6.9%)	1.42 (.10 - 22.45)	2.86 (.25 - 32.72)
Panic disorder (lifetime)	4 (4.8%)	3 (12%)	6 (20%)	1..07 (.13 - 9.17)	3.37 (.73 - 15.53)
(B) Mood disorders					
Major depression (current)	2 (2.4%)	0	4 (13.3%)	--	30.16 (1.14 - 800.84)*
Major depression (lifetime)	13 (15.9%)	4 (16.7%)	16 (55.2%)	.92 (.18 - 4.68)	8.75 (2.60 - 29.41)*
(C) Substance-related disorders					
Substance abuse and dependence (current)	3 (3.6%)	2 (8%)	6 (20%)	2.33 (.16 – 33.11)	13.18 (1.90 – 91.14)*
Substance abuse and dependence (lifetime)	11 (13.4%)	2 (8.3%)	7 (24.1%)	1.17 (.16 – 8.50)	4.18 (1.08 – 16.15)*
Alcohol abuse and dependence (current)	8 (9.9%)	2 (8.3%)	5 (16.7%)	2.88 (.36 – 22.69)	4.93 (1.08 - 22.53)*
Alcohol abuse and dependence (lifetime)	31 (36.9%)	5 (20%)	8 (26.7%)	.53 (.11 – 2.49)	1.00 (.32 – 3.23)

Note. DSM= Diagnostic and Statistical Manual of mental disorders. No.= number. Odds ratios are contrasted with the low-stable reference. "—" reflect unavailable odds ratios due to zero occurrences of a disorder in a group.

Prediction of Attentional Biases to Facial Expressions in Adulthood. The ANOVA for attentional bias to angry faces revealed a main effect for shy-trajectories, *F*(2, 112)= 3.00, *p*=.054, ηp^2= .05. The increasing trajectory (*M*=14.34; *SE*=3.96) showed greater bias for angry faces than the low-stable trajectory (*M*=2.94; *SE*= 2.40), *p*=.055 (see Figure 1.2). The decreasing and low-stable trajectories did not differ on attention bias to angry faces in adulthood. There were no differences on attention bias to happy faces.

Figure 1.2. Attentional biases to angry faces at adulthood (age 30-35)

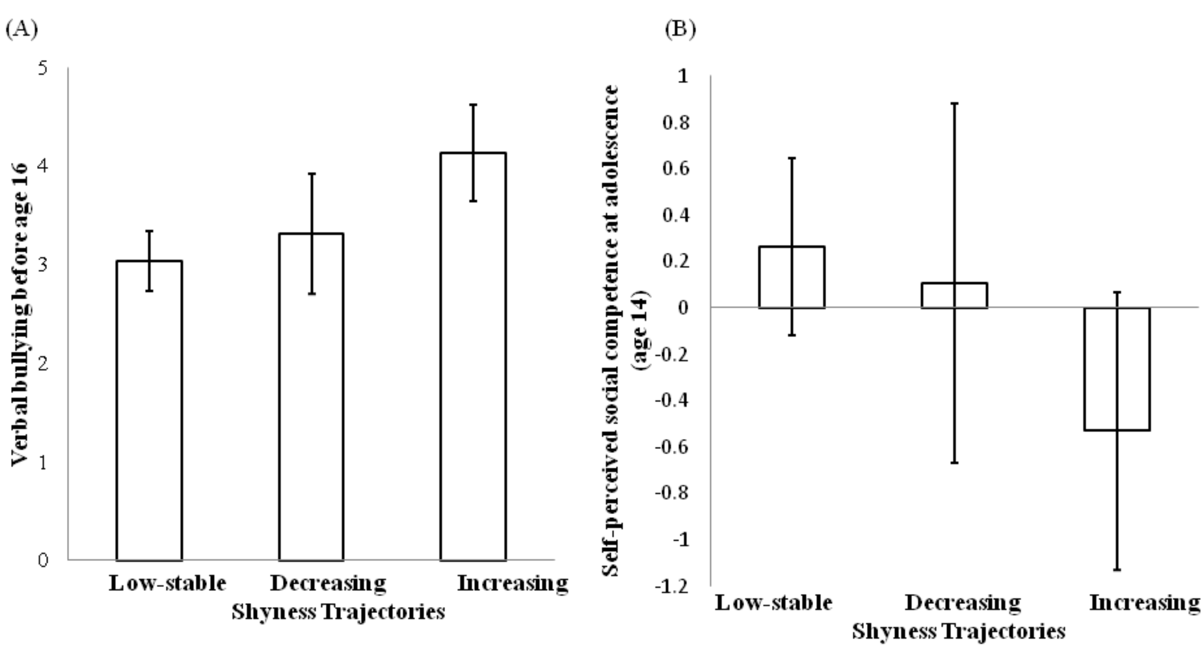


Note. Error bars are 95% conflidence intervals.

***Peer Victimization and Social Competence in Childhood and Adolescence*.** Retrospective reports of verbal bullying was different among the shyness-trajectories, $F(2,147)=6.92$, $p= .001$, $\eta p^2= .09$. The increasing trajectory (M=4.13; SE=.25) reported more verbal bullying than the low-stable trajectory (M=3.03; SE=.16), $p= .001$ (Figure 1.3A). However, there were no differences in the frequency of physical bullying among different shyness-trajectories.

However, there was only a trend depicting differences in self-perceived social competence among shyness-trajectories, $F(2,137)=2.43$, $p= .092$, $\eta p^2= .034$. The increasing trajectory reported lower social competence than the low-stable trajectory (Figure 1.3B).

Figure 1.3. Differences in verbal bullying incidences (A) and self-perceived social competence at adolescence (B) among shyness-trajectories



Note. Error bars are 95% confidence intervals.

Interactions among Shyness Trajectories, Social Competence, and Verbal Bullying

We performed logistic and linear regression models for separate binary and linear dependent variables of mental disorders and attention bias to angry faces regressed on predictors, including the highest order term for a three-way interaction (shyness trajectories by social competence by verbal bullying), their two-way interactions and main effects, and our control covariates (birth weight, sex, anxiety/depressive symptoms and SES at age 8, and neurosensory impairments). Conditional effects were probed using the PROCESS macro for SPSS (Hayes, 2013) to test simple slopes at low (1 *SD* below the mean), moderate (the mean), and high (1 *SD* above the mean) levels of the moderator. The only interactions that emerged are documented below.

Current agoraphobia: There was a 2-way interaction between shyness trajectories by verbal bullying, b= –1.49, SE=.69, p=.03. At low (b= 4.51, SE= 1.96, p=.02) and moderate (b=2.34, SE= 1.03, p=.02) levels of verbal bullying among individuals in the increasing trajectory, there were higher odds for having agoraphobia; In contrast, high levels of verbal bullying did not have different effects on trajectories, b=.17, SE=.58, p=.76 (see interaction in Supplemental Figure 1.3). The 3-way interaction was not significant.

Lifetime alcohol abuse and dependence: There was a 3-way interaction between shyness trajectories by verbal bullying by social competence, b= –.39, SE= .17, p=.025. At low levels of verbal bullying, social competence did not predict differences in the odds of having lifetime alcohol abuse and dependence among shyness trajectories (b=.18, SE=.34, p= .58). However, at high (b= .76, SE= .40, p=. 054) and moderate (b=.48, SE=.24, p=.046) levels of verbal bullying among those with higher social competence in the low-stable trajectory, there were higher odds for lifetime alcohol abuse and dependence. On the other land, there was a trend that higher social competence had a protective effect among those with high verbal bullying in the increasing shy trajectory, as they had lower odds for lifetime alcohol abuse and dependence (b= –.62, SE=.33, p=.06). The interaction is displayed in Supplemental Figure 1.4.

Discussion

We used a longitudinal prospective design to examine the development of shyness across the first four decades of life in predicting mental health across multiple domains of functioning. The analyses revealed at least four noteworthy findings.

First, we identified three trajectories of shyness that included a majority of individuals whose shyness was low and stable, a decreasing shyness trajectory from childhood on, and an increasing shyness trajectory beginning in adolescence. Notably, the decreasing and increasing shy trajectories replicate studies examining trajectories of social withdrawal from middle childhood to adolescence (Booth-Laforce & Oxford, 2008; Oh et al., 2008) and extends this finding to the fourth decade in life. However, we speculate that the late divergence in our decreasing and increasing shyness trajectories may respectively capture shyness limited to childhood versus shyness with a later onset. Moreover, the proportions of our trajectories were similar to studies that have observed the majority of the adult population is non-shy while less than half of the population regard themselves as shy (Heiser et al., 2003; Zimbardo, 1977).

Second, this three-trajectory model had predictive validity for different mental health outcomes in adulthood across multiple and converging measures. In support of our hypothesis, we found the increasing trajectory had higher risks specifically for SAD, as well as other mood-, and substance- related disorders compared to the low-stable trajectory, including MDD, and substance and alcohol use disorders. These findings converge with previous studies that found shyness and related constructs predicted higher risk for a number of anxiety (particularly SAD) and mood disorders (e.g., Caspi, Moffitt, Newman, & Silva, 1996; Chronis-Tuscano et al., 2009, Essex, Klein, Slattery, Goldsmith, & Kalin, 2010; Gladstone, Parker, Mitchell, Wilhelm, & Malhi, 2005; Heiser et al., 2003; McDermott et al., 2009) in adolescence and emerging adulthood. Further, these findings converge with studies that showed a combination of shyness and impulsive or sensation seeking characteristics are linked to substance-use (e.g., Ensminger, Juon, & Fothergill, 2002; Santesso et al., 2004) and that some shy individuals use alcohol as a social lubricant and to relieve their anxiety (Carducci, 2009; Lewis & O'Neil, 2000), though the opposite finding has also been found (e.g., Bruch et al., 1992). We also note that there was comorbidity among these distinct disorder categories.

Third, we found an increased attentional bias to angry facial expressions in the increasing trajectory that is indicative of hypervigilance to social threat and/or negative emotions. This pattern of attentional bias to threat is a correlate and risk factor for anxiety problems (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007) and is consistent with attentional styles associated with social phobia (Bogels & Mansell, 2004).

Fourth, we found that the decreasing shy trajectory, characterized by high childhood shyness that attenuated across time (i.e., the decreasing trajectory), was not associated with greater risks for adult psychopathology compared to the low-stable trajectory. These findings suggest that individuals who outgrew their childhood shyness were less likely to develop these psychiatric disorders and problem behaviors in adulthood. This finding is consistent with others who recently argued that most shy children do not grow up to develop SAD (Crozier, 2014), nor are shy children at risk for other social-emotional problems in adulthood (Schmidt et al., in press). However, we note that individuals in the decreasing shy trajectory were indistinguishable from those in the two other trajectories on attentional biases to angry faces.

Why Do Some Shy Children Outgrow their Shyness, while Other Children become Shy in Adolescence?

The emergence of different developmental patterns of shyness allowed us to further probe possible contexts moderating the links between the different shyness trajectories and mental health problems. For example, the increasing and decreasing shy trajectories that crossed during adolescence suggests possible influences in childhood and/or adolescence that might be responsible for reinforcing and/or ameliorating shyness.

Studies have shown that socially excluded shy children have more internalizing problems (Gazelle & Ladd, 2003; Gazelle & Rudolph, 2004; Ladd, 2006), and shy children become less socially competent adults (Grose & Coplan, 2015). Here, we found that the increasing trajectory retrospectively reported greater incidences of verbal bullying throughout childhood and adolescence and a trend of lower self-perceived social competence in adolescence relative to the low stable trajectory. However, the decreasing shy trajectory was indistinguishable on these social measures in contrast with the other two trajectories. Hence, we speculate that adverse peer relations during childhood and adolescence may reinforce the persistence of and/or ongoing increases in shyness into adulthood among individuals in the increasing trajectory. Perhaps, shy adolescents in the increasing trajectory were not socially skilled to build a social network and were discouraged from building social skills because they were victimized, as negative peer experiences may drive shy individuals to avoid social interactions. For example, shy preschoolers who are excluded by peers prefer to play alone (Coplan, Ooi, Rose-Krasnor, & Nocita, 2014). Similarly, children in an increasing shyness-trajectory from grades 1 to 6 and grades 5 to 8 face greater peer exclusion and loneliness (Booth-LaForce & Oxford, 2008; Booth-LaForce et al., 2012). In contrast, we found that shy adolescents in the decreasing trajectory reported less verbal bullying, so they might benefit from more peer acceptance and opportunities to build social skills and networks.

Similar recent findings showed that greater social involvement during adolescence buffers against anxiety in adulthood among individuals characterized by high and stable behavioral inhibition across childhood (Frenkel et al., 2015). Accordingly, adolescence may be a key developmental period linked to future adverse psychological and emotional consequences for shy individuals, depending on whether they were socially competent, as teenagers are expected to handle their interactions and initiate plans and activities with their peers rather than relying on their parents to do so. Future research should focus on the role of these social relations in the link between shyness and adult mental health.

With regards to the role of child sex in the development of shyness, we did not find any sex differences by shyness trajectory interactions for any of the outcomes. In examining long-term outcomes of shy children, some studies have reported sex differences in shyness with shy boys experiencing more unfavorable social outcomes in their 30s (Caspi et al., 1988). While some of these findings have been replicated (Kerr et al., 1996), other studies have not found sex differences (Asendorpf et al., 2008). These differences may be due to cultural as well as generational differences in the different cohorts. Also, because many of the prior studies on gender differences in shyness have been cross-sectional (see Doey et al., 2014), it is important for future research to conduct additional longitudinal studies to examine whether gender differences in shyness persist across development.

Strengths and Limitations

A number of strengths should be mentioned. First, we showed initial evidence of different developmental trajectories of shyness across four decades of life and their influence on mental health in adulthood. These detailed descriptions of different developmental trajectories of shyness are important, because they provide a fundamental basis for generating new hypotheses to examine factors, such as genetic, neural, or social processes that may play a role in the development of shyness and later psychopathology. Our study began at age 8 when shyness is fully manifested as a sense of self, self-conscious emotions, and perspective-taking skills, which are central to shyness, develop in early to middle childhood (Flavell, 2000; Harter, 2012; Lagattuta & Thompson, 2007). Second, we used a prospective longitudinal design and repeated assessments of shyness once every decade that allowed us to characterize developmental patterns of shyness and subgroups with greater resolution than prior studies that have used only two time points. Third, although we had hypotheses about how shyness develops in different individuals , the data-driven extraction of longitudinal trajectories was useful as it made no assumptions about the shape of shy trajectories which are not clearly defined in the "real" world, and affirmed our hypotheses. Although shyness showed modest stability across assessments, the trajectory analysis addressed both issues of subgroups and changes across time, as well as reasons for changes among subgroups. Lastly, rather than relying on one diagnostic measure of mental disorders, we established converging evidence in a comprehensive group of assessments, including clinical and behavioral measures.

There were also several limitations. First, although our sample size was more than adequate for trajectory analyses, the relatively small sample size for detecting clinical problems in the population may have contributed to some wide confidence intervals in the odds ratios. Second, we used subjective measures of shyness and different informants which could have possibly led to measurement variance. Although we used a prospective design and our composites at each age were conceptually and empirically derived measures of shyness that were correlated with a widely used shyness measure, it is possible that due to measurement variance, we were measuring other closely related phenomena to shyness, such as social withdrawal, depression, or low self-esteem, since our shyness measures were derived from items from the CBCL and YASR which may have reflected phenotypes related to shyness. Accordingly, it is possible that what we were measuring in the increasing shyness trajectory was a combination of shyness, and related phenomena, such as social withdrawal, anxiety, low self-esteem, and depression that would be obviously linked to our related psychiatric outcomes. Third, we did not measure shyness or its temperamental antecedents (e.g., behavioral inhibition) before age 8 to account for early child development, so we do not know whether earlier antecedents of shyness (e.g., temperamental inhibition) might be more sensitive predictors of later problems as has been reported in other studies (e.g., Chronis-Tuscano et al., 2009). Should behavioral inhibition overlap with shyness, then a consistently high shy trajectory beginning in infancy would be projected, which would not have confounding onsets of shyness, internalizing symptoms and disorders. Finally, although our sample was a statistically homogenous sample, we used a mixed sample of ELBW and NBW individuals to increase our sample size. Even though the ELBW group was more inhibited than the NBW group in young adulthood (Schmidt, Miskovic, Boyle, & Saigal, 2008) and have more psychiatric problems in adulthood (Van Lieshout et al., 2015), we a) controlled for birth weight in all analyses, b) found evidence of three similar shyness-trajectories in the NBW group only, and c) ensured both classification of trajectories and adult outcomes were not disproportionally represented by ELBW versus NBW participants. Nevertheless, future studies should include a larger, typically developing sample, objective measures of shyness beginning in early childhood to ensure reliability and generalizability of the present findings.

Conclusion and Implications

The present study appears to be the first prospective longitudinal study to use trajectory analyses to understand mental health outcomes of shyness across the first four decades of life. Our findings showed that only individuals whose shyness increased after adolescence were at greater risks for psychiatric and emotional problems in adulthood. Moreover, the peer and social contexts during adolescence may buffer against or exacerbate shyness, which in turn may be linked to detrimental mental health in adulthood. Finally, our findings not only provide theoretical understanding of how shyness develops overtime in different individuals, but also has clinical implications for interventions to decide whom, when, and what kinds of behaviors to target in order to promote healthy development.

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Supplemental Material

Factor Structure of Shyness Construct

Exploratory factory analysis with principle axis factoring and oblique (promax) rotation examined the number of factors best representing the shyness construct. Two factors were extracted using a threshold eigenvalue (> 1.0) and examining the scree plot. Factor one and two accounted for 35.52% and 8.84% of the variance, respectively. Supplemental Table 1.1 shows that behavioral aspects of shyness load highly on the first factor, while cognitive aspects of shyness load highly on the second factor; Factor loadings were above .40. As expected, the two factors were correlated, $r = .58$.

Supplemental Table 1.1. Factor loadings for the 6 items in the shyness composite in young adulthood (age 22-26).

	Factor	
Shyness at young adulthood (*n*=274)	1	2
I am shy		.76
I am self-conscious or easily embarrassed		.76
I keep from getting involved with others	.69	
I am sensitive or keeps things to self	.43	
I refuse to talk	.53	
I would rather be alone than with others	.64	

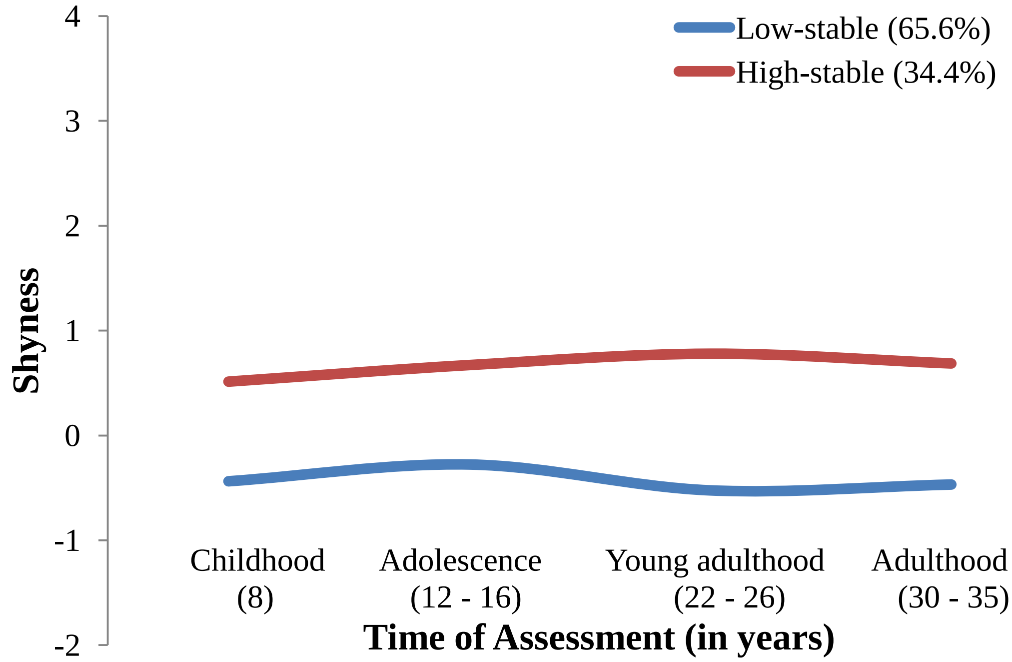
Quality Criterion/ Fit Indices of Different Cluster Models

Partition quality criterion for the first solution of the 2-, 3-, 4-, and 5- cluster models are presented in Supplemental Table 2. These statistical indices have no true "cut-off/ threshold" values; they are compared across cluster solutions to guide selection of the "best" model in a statistical sense. Higher values of the Calinski Harabatz indicate better quality of partitions that maximizes between-group distances and minimizes within-group distances. Higher values of the post probability global indicate higher likelihood that each individual was assigned to the correct category in the solution. BIC values that are closer to zero indicate better model fit.

Supplemental Table 1.2. Quality criterion and model fit indices for the first solution of the cluster models

Solution	Calinski Harabatz	Post probability global	BIC
2 cluster	70.14	0.91	-1723.12
3 cluster	58.44	0.89	-1722.44
4 cluster	56.32	0.89	-1697.53
5 cluster	53.52	0.85	-1721.33

Supplemental Figure 1.1. Mean shyness trajectories from childhood to adulthood using the 2-cluster solution



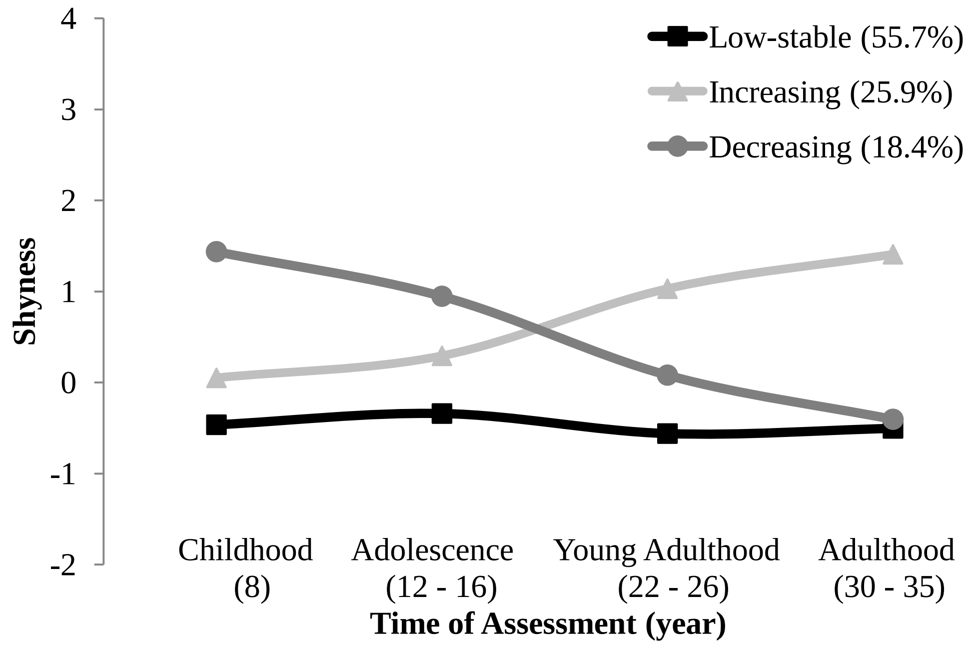
Similar to the 3-cluster solution presented in the main text, the 2-cluster solution depicts a low-stable non-shy trajectory with a similar proportion (65.6%) of individuals and a high-stable shy trajectory (34.4%) of individuals that combines the two increasing and decreasing shy trajectories from the 3-cluster solution. These results are more parsimonious and show that the low-stable trajectory is mostly retained in both solutions and is clearly non-shy; whereas, that the high-stable shy trajectory is refined into increasing and decreasing trajectories, both of which we interpret as shy, in the 3-cluster solution.

Data Imputation in Shyness Trajectories

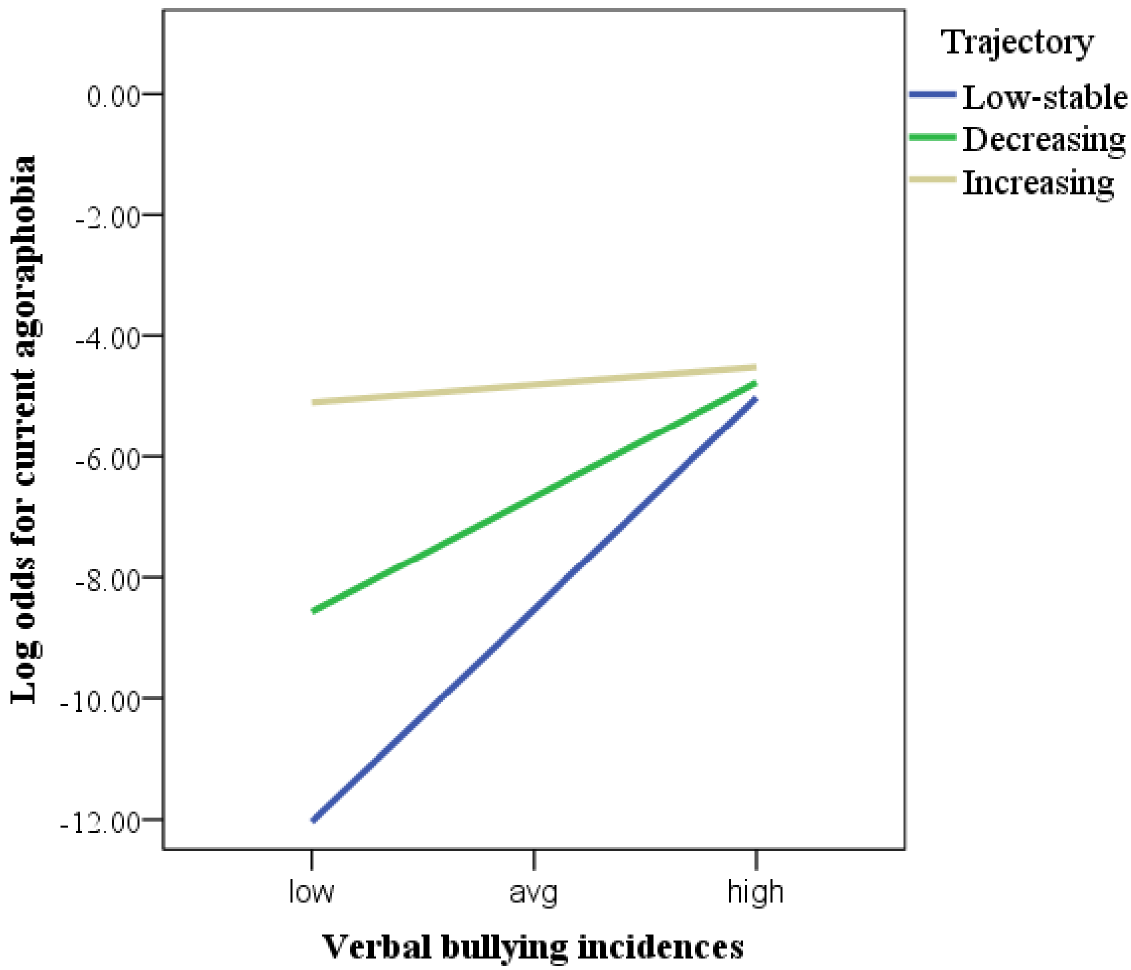
We imputed shyness scores for participants with only one missing data point for shyness using the Copy Mean method (Genolini & Fallisard, 2011). Copy mean uses linear interpolation to impute a value that is missing between two points, but also adds variation to the imputed value to follow the shape of the average trajectory.

This dataset with imputed values included 255 participants. The estimated trajectories on this imputed dataset are similar to those obtained without imputation, with the exception that the crossing point for the two shy trajectories is slightly shifted later after adolescence (Supplemental Figure 2). This shift may be due to more imputations in last two time points. However, results on psychiatric disorders and attention biases on this imputed dataset remain unchanged.

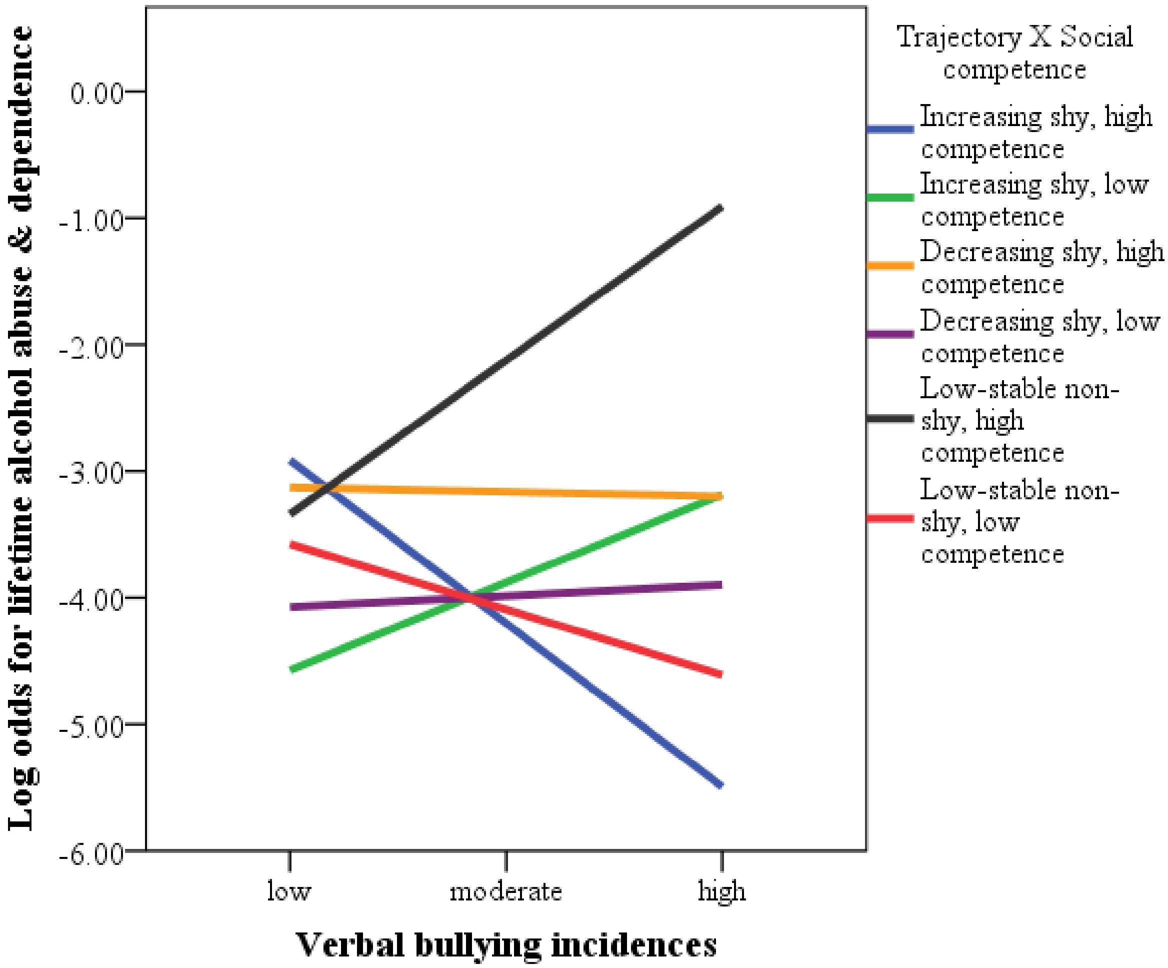
Supplemental Figure 1.2. Mean shyness trajectories from childhood to adulthood using the imputed dataset



Supplemental Figure 1.3. Two-way interaction between shyness trajectories and verbal bullying at adolescence and log odds of current agoraphobia.



Supplemental Figure 1.4. Three-way interaction among shyness trajectories, self-perceived social competence and verbal bullying at adolescence and log odds of lifetime alcohol abuse and dependence.



Note. Individuals with moderate levels of social competence are excluded in this graph for simplicity.

References in Supplemental Material

Genolini, C., & Falissard, B. (2011). Kml: K-means for longitudinal data. *Computational Statistics*, *25*, 317-328.

CHAPTER 3

Electrocortical Mechanisms in Processing Non-Social Threat and Shyness Subtypes

Study 2: ERPs in Children Processing Non-Social Novelty

Tang, A., Santesso, D.L., Segalowitz, S.J., & Schmidt, L.A. (2016). Distinguishing shyness and sociability in children: An event-related potential study. *Journal of Experimental Child Psychology*, *142*, 291-311.

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 in childhood and during the processing of non-social stimuli. Using a 3-stimulus auditory oddball task, we examined whether variations in shyness and sociability were related to the N200 and P300 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, 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.

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 related to inhibition/withdraw-related tendencies in social situations, and sociability/approach tendencies 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, Andrerson, & 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 (Czeschik & Nurk, 1995), Portugese (Neto, 1996), and Asian (Hussein, Fathy, Mawla, Zyada, & Hadidy, 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 suggest 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 to 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.

While there is mounting conceptual and empirical evidence to support shyness and sociability as orthogonal dimensions, studies examining the psychophysiology of shyness and sociability have primarily focused on adult samples during resting conditions or during socio-emotional stressors. Accordingly, the present study examined how shyness and sociability may play a role in the sensory information processing of *non*-social stimuli in a group of typically developing 10-year-old children. Using a 3-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, Schmidt, & Segalowitz, 2012; Jetha, Zheng, Goldberg, Segalowitz, & Schmidt, 2013) studies. Although these studies did not include *non*-social 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 *non*-social 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 behavioural (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", while 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 non-social sensory information differently than other children in 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 to 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 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 behaviourally 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). Also, 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 Present Study

The purpose of the present 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 non-social stimuli; second, we examined whether an interaction of shyness and sociability was associated with distinct electrocortical responses to non-social stimuli; and 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 3-stimulus auditory oddball task. Children heard three types of auditory tones. They responded to target tones but ignored two other types of tones, including 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, Tasche, & Beauducel, 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 which 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 as 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

Fifty-three 10-year-old children (*M* age= 10.1; *SD*= 0.3; 27 male) were recruited from a large database that contained birth records of children born within the McMaster University Medical Center and St. Joseph's Hospital (Hamilton, Ontario). This sample of children was primarily Caucasian (92%), right-handed, with no history of head injury. Consent and assent were obtained from the 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 toy for their participation.

Modified Cheek and Buss Shyness and Sociability Scales

Children completed a series of self- 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 five items and was scored on a 4-point scale (1 = "not at all true" to 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, $r = -.117$, $p = .202$, suggesting that the two dimensions were largely independent.

Junior Eysenck Personality Questionnaire- Revised (JEPQR-S)

The 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 with 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 11-12-year-olds: extraversion = .77 to .78, neuroticism = 0.70 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 to 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, 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 within the same block, presentation of two novels, two targets, or a target 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 subject. 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 standard and novel tones. Participants completed a practice session prior to the actual experimental task.

Electroencephalogram (EEG) Data Collection and Analyses

EEG recording. EEG was collected using a lycra EEG stretch cap (Electro-Cap International, Inc.). 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 Instrumental 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 in each condition and each participant. Latency is the time from stimulus onset to the maximum point of the negative and positive amplitude 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 ANOVAs with three conditions (target, novel, standard) and four scalp sites (Fz, FCz, Cz, Pz) as within-subjects 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*s were adjusted with Huynh-Feldt's epsilon. Post-hoc analyses included one-way repeated measures ANOVAs and pair-wise comparisons using Tukey's Least Significant Difference tests.

Data Analyses

A series of partial Pearson correlations assessed whether shyness (accounting for the variance in sociability) related to N200 and P300 components across four midline scalp sites (Fz, FCz, Cz, Pz), and whether the relations were specific to novel, target, and standard conditions. The same partial correlations assessed whether sociability (accoutng for the variance in shyness) related to the N200 and P300 components across scalp sites and conditions. One-tailed tests were used to test the hypotheses that higher shyness would be related to greater amplitudes and shorter latencies in the N200 and P300 components in target, novel, and standard conditions, whereas, sociability would be unrelated to the N200 and P300 components. 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 or 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 shyness who are both shy and sociable). To test whether the neurocognitive indices in the target condition are predictive of self-conscious shyness, as 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, 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 ($ß = .27$, $p = .05$) and frontal standard P300 amplitude ($ß = .34$, $p = .023$); in turn, frontal standard P300 amplitude predicted neuroticism ($ß = .33$, $p = .027$).[2]

[2] Relations for the target P300 amplitudes at posterior sites were also tested, however, the metric was unrelated to neuroticism and was therefore excluded from the model.

SEM was performed in the program, Amos (SmallWaters Corp., USA), applying the maximum likelihood algorithm for estimating path coefficients. A path coefficient is a regression weight representing the strength of a pathway. Suppose 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 one *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 χ^2 goodness-of-fit, Root Mean Square Error of Approximation (RMSEA), Tucker-Lewis Index (TLI), and Comparative Fit Index (CFI) that is 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 list-wise 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 as we had complete participant data for the following: in the target N200 analyses, n= 44; in the novelty N200 s, n= 35; 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. *N*'s 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

Figure 2.1 depicts the grand average waveforms of the N200 and P300 components across four midlines scalp sites in the three experimental conditions. Bivariate Pearson's correlations demonstrated strong 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 2.1).

Figure 2.1. Grand average waveforms depicting the N200 and P300 event-related potential (ERP) components across four midline scalp sites (Fz, FCz, Cz, Pz) in the standard, target, and novel conditions.

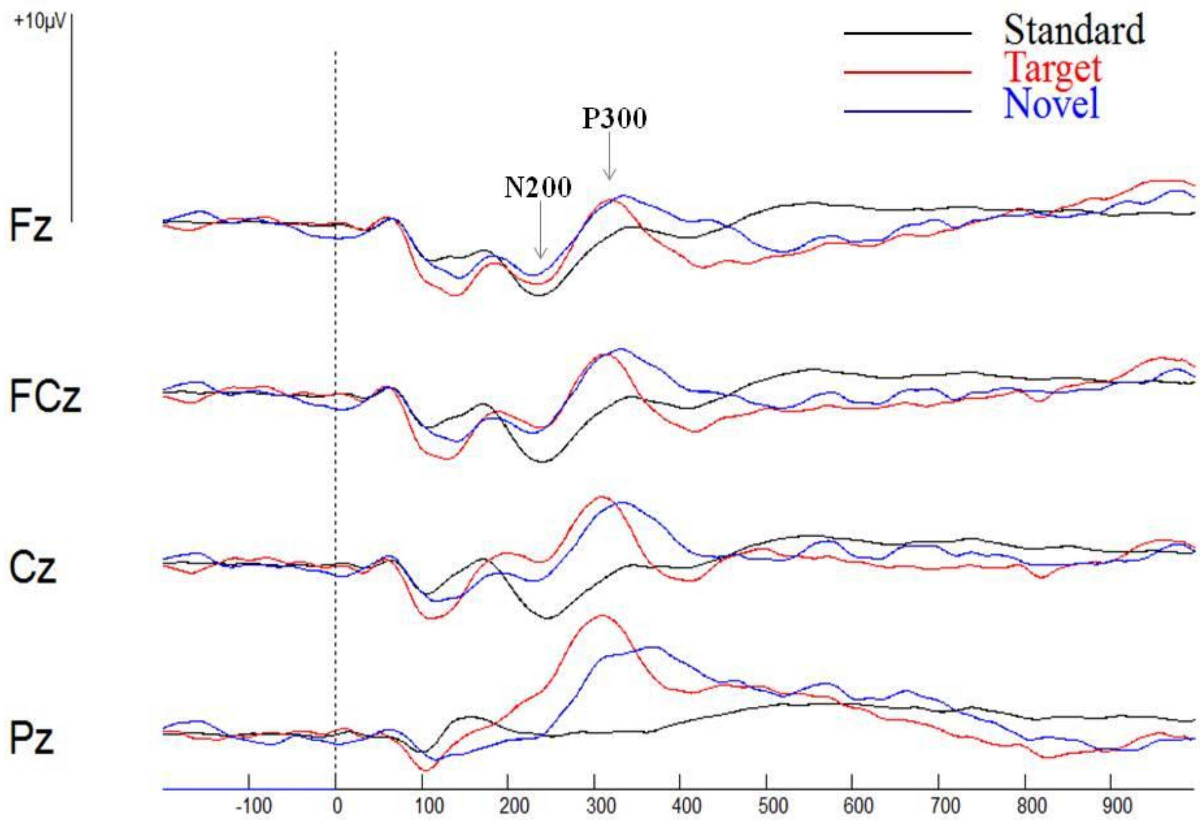


Table 2.1. Pearson's correlations among the amplitudes and latencies of the four scalp sites (Fz, FCz, Cz, Pz) within each condition (target, novel, standard) for the (A) N200 and (B) P300 ERPs.

(A)		**N200 Amplitude**				**N200 Latency**			
		Fz	FCz	Cz	Pz	Fz	FCz	Cz	Pz
Target	Fz	-	0.952**	0.833**	0.506**	-	0.932**	0.765**	0.496**
	FCz		-	0.913**	0.601**		-	0.817**	0.509**
	Cz			-	0.783**			-	0.668**
	Pz				-				-
Novel	Fz	-	0.945**	0.758**	0.478**	-	0.705**	0.558**	0.404*
	FCz		-	0.860**	0.528**		-	0.853**	0.441**
	Cz			-	0.755**			-	0.270
	Pz				-				-
Standard	Fz	-	0.945**	0.890**	0.669**	-	0.892**	0.818**	0.271
	FCz		-	0.950**	0.747**		-	0.927**	0.450**
	Cz			-	0.819**			-	0.529**
	Pz				-				-
(B)		**P300 Amplitude**				**P300 Latency**			
		Fz	FCz	Cz	Pz	Fz	FCz	Cz	Pz
Target	Fz	-	0.944**	0.811**	0.546**	-	0.821**	0.792**	0.673**
	FCz		-	0.866**	0.628**		-	0.821**	0.610**
	Cz			-	0.823**			-	0.652**
	Pz				-				-
Novel	Fz	-	0.924**	0.831**	0.524**	-	0.854**	0.616**	0.410**
	FCz		-	0.943**	0.683**		-	0.708**	0.495**
	Cz			-	0.798**			-	0.625**
	Pz				-				-
Standard	Fz	-	0.915**	0.750**	0.541**	-	0.966**	0.879**	0.604**
	FCz		-	0.876**	0.651**		-	0.883**	0.590**
	Cz			-	0.694**			-	0.631**
	Pz				-				-

Note. Pearson's correlations: two-tailed, ***p*< .01, **p*< .05.

For the N200 amplitudes, a site by condition interaction emerged, $F(3.96, 107.01)= 5.22$, $p= .001$, dfs were corrected with $\epsilon = .66$ due to violation of the sphericity assumption [Mauchly's test of sphericity, $\chi^2(20)= 83.02$, $p< .001$]. Decomposing the interaction: smaller (less negative) N200 amplitude at Cz to target tones ($M= 1.11$; $SE= .02$) was elicited relative to standard tones ($M= 1.06$; $SE=.009$), CIs for the difference= .005 to .085, $p=.03$.[3] Also, smaller (less negative) N200 amplitude at Pz to target tones ($M= 1.16$; $SE= .016$) was elicited relative to standard tones ($M= 1.08$; $SE=.006$), CIs for the difference= .045 to .107, $p<.001$, and in comparison to novel tones ($M= 1.11$; $SE=.015$), 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 calling 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, 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 ($M= 240.80$ ms; $SE= 4.61$), shorter N200 latencies were evoked to

[3] 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; 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 paper.

target (*M*= 213.10 ms; *SE*= 6.72), *p*= .002, and novel tones (*M*= 229.80 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, $F(3.28, 111.56)= 11.14$, $p < .001$, dfs were corrected with $\epsilon = .55$, due to a violation of sphericity [Mauchly's test, $\chi^2(20)= 124.75$, $p< .001$]. Greater P300 amplitudes at Fz were elicited to both target (*M*= 1.1; *SE*=.02) and novel (*M*= 1.12; *SE*=.015) tones relative to standard tones (*M*=1.05; *SE*=.007); CIs for difference between target and standard, and between the novel and standard= .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 (*M*= 1.13; *SE*= .02) and novel (*M*= 1.15; *SE*=.018) tones relative to standard tones (*M*= 1.06; *SE*= .007); CIs for difference between target and standard, and between the novel and standard= .027 to .113, *p*< .003, and .054 to .12, *p*< .001, respectively. Greater amplitudes at Cz were elicited to both target (*M*=1.17; *SE*=.018) and novel (*M*= 1.16; *SE*=.019) tones relative to standard tones (*M*=1.07; *SE*=.008), *p*< .001; CIs for difference between target and standard, and between the novel and standard= .071 to .145, *p*< .001, and .064 to .13, *p*< .001, respectively. Greater amplitudes at Pz were elicited to both target (*M*= 1.23; *SE*=.016) and novel (*M*= 1.21; *SE*=.017) tones relative to standard tones (*M*= 1.08; *SE*= .006); CIs for difference between target and standard, and between the novel and standard= .122 to .18, *p*< .001, and .094 to .154, *p*< .001, respectively. Overall, the means of the target P300 amplitudes were progressively greater 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 relative to novel tones, *p*=.052.

For the P300 latencies, a site by condition interaction emerged, $F(3.78, 128.40)= 3.36$, $p= .013$, dfs were corrected with $\epsilon = .63$ as the sphericity assumption was violated [Mauchly's test of sphericity, $\chi^2(20)= 58.88$, $p< .001$]. P300 latencies at Fz in both target (*M*=342.56; *SE*=13.45) and novel (*M*= 374.19; *SE*=10.07) conditions were shorter than the standard condition (*M*= 460.39; *SE*=15.95), CIs for difference between target and standard, and between the novel and standard= –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 target (*M*= 337.64; *SE*= 14.49) and novel (*M*= 359.07; *SE*=10.10) conditions were shorter than the standard condition (*M*= 456.54; *SE*= 16.47); CIs for difference between target and standard, and between the novel and standard = –159.00 to –78.79, $p< .001$, and -140.16 to –54.76, $p< .001$, respectively. Latencies at Cz in both target (*M*= 345.12; *SE*=15.46) and novel (*M*= 345.85; *SE*=10.10) conditions were shorter than the standard condition (*M*= 467.20; *SE*= 14.62); CIs for difference between target and standard, and between the novel and standard = –159.70 to –84.45, $p< .001$, and –159.17 to –83.51, $p< .001$, respectively. Latencies at Pz in both target (*M*= 345.96; *SE*=14.54) and novel (*M*= 374.82; *SE*= 10.91) conditions were shorter than the standard condition (*M*= 443.22; *SE*= 15.96); CIs for difference between target and standard, and between the novel and standard = –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 between Shyness, Sociability and the N200

Table 2.2 presents partial correlations between the N200, shyness (controlling for influences of sociability), and sociability (controlling for influences of shyness) for the (A) target, (B) novel, and (C) standard 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[4] (see Table 2.2). Latencies of the N200 to targets at Fz, FCz, and Cz were negatively correlated with shyness, but not sociability, *r*'s = –.35 to –.39, *p's* < .025 (see Table 2.2A). 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 Figure 2.2). However, there 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 2.2B & C).

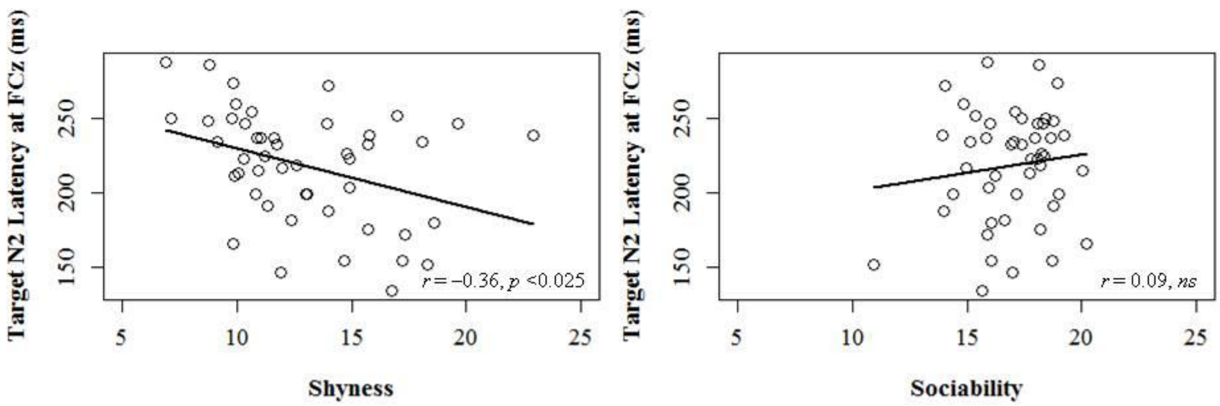
[4] Interpretation of the negative correlation is reversed due to the data-order of log-transformed N200 amplitude values (see previous note).

Table 2.2. Partial correlations between shyness, sociability, and the (A) target, (B) novelty, and (C) standard N200 components (amplitude & latency) across four scalp sites

(A) Target N200								
	Amplitude log(μV)				Latency (ms)			
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	0.036	0.026	0.98	0.18	–0.349**	–0.022	221.27	36.28
FCz	0.048	–0.013	1.01	0.19	–0.376**	–0.106	217.76	38.4
Cz	0.007	–0.010	1.07	0.16	–0.387**	–0.110	213.68	38.65
Pz	–0.069	–0.080	1.14	0.10	–0.189	–0.029	207.64	32.08
(B) Novelty N200								
	Amplitude log(μV)				Latency (ms)			
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	–0.073	0.061	1.04	0.09	0.056	–0.025	234.69	32.76
FCz	–0.141	–0.052	1.05	0.10	0.099	–0.080	231.91	30.16
Cz	–0.089	–0.028	1.08	0.09	0.137	–0.077	234.87	34.24
Pz	–0.054	–0.057	1.11	0.09	–0.090	–0.036	226.28	26.63
(C) Standard N200								
	Amplitude log(μV)				Latency (ms)			
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	0.022	–0.245	1.03	0.08	0.028	0.018	236.07	22.67
FCz	–0.044	–0.322**	1.03	0.09	–0.095	–0.016	239.80	23.21
Cz	–0.021	–0.383**	1.05	0.09	–0.019	–0.024	242.77	25.37
Pz	–0.038	–0.377**	1.14	0.06	0.069	0.138	239.95	37.60

Note: *p < .05, **p < .025, 1 tailed. In (A) target N200, n= 44, df= 41; in (B) novelty N200, n= 35, df= 32; in (C) standard N200, n= 44, df= 41. The significant negative correlations for the N200 amplitudes are interpreted as positive correlations due to the data-order of the log-transformed values of the N200 amplitudes.

Figure 2.2. Scatter plots displaying the target N200 ERP latency at the frontocentral scalp site and personality traits (shyness, sociability)



Note. Scatter plots display zero-order correlations.

Relation between Shyness, Sociability, and the P300

Table 2.3 presents partial correlations between the P300, shyness (controlling for influences of sociability), and sociability (controlling for influences of shyness) to (A) target, (B) novelty, and (C) standard stimuli. Amplitudes of the target P300 at Fz, Cz, and Pz scalp sites were positively correlated with shyness, r's = .27 to .29, $p < .05$, while this relation approached significance at FCz, $r = .24$, $p = .053$ (see Table 2.3A). As predicted, children scoring higher on shyness elicited larger P300 amplitudes in response to target tones across all midline scalp sites. In addition, shyness was also positively correlated with P300 amplitudes at Fz and FCz in the standard condition, r's= .32 to .34, $p < .025$ (Table 2.3C), 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, not sociability (see Figure 2.3A & 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 2.3B).

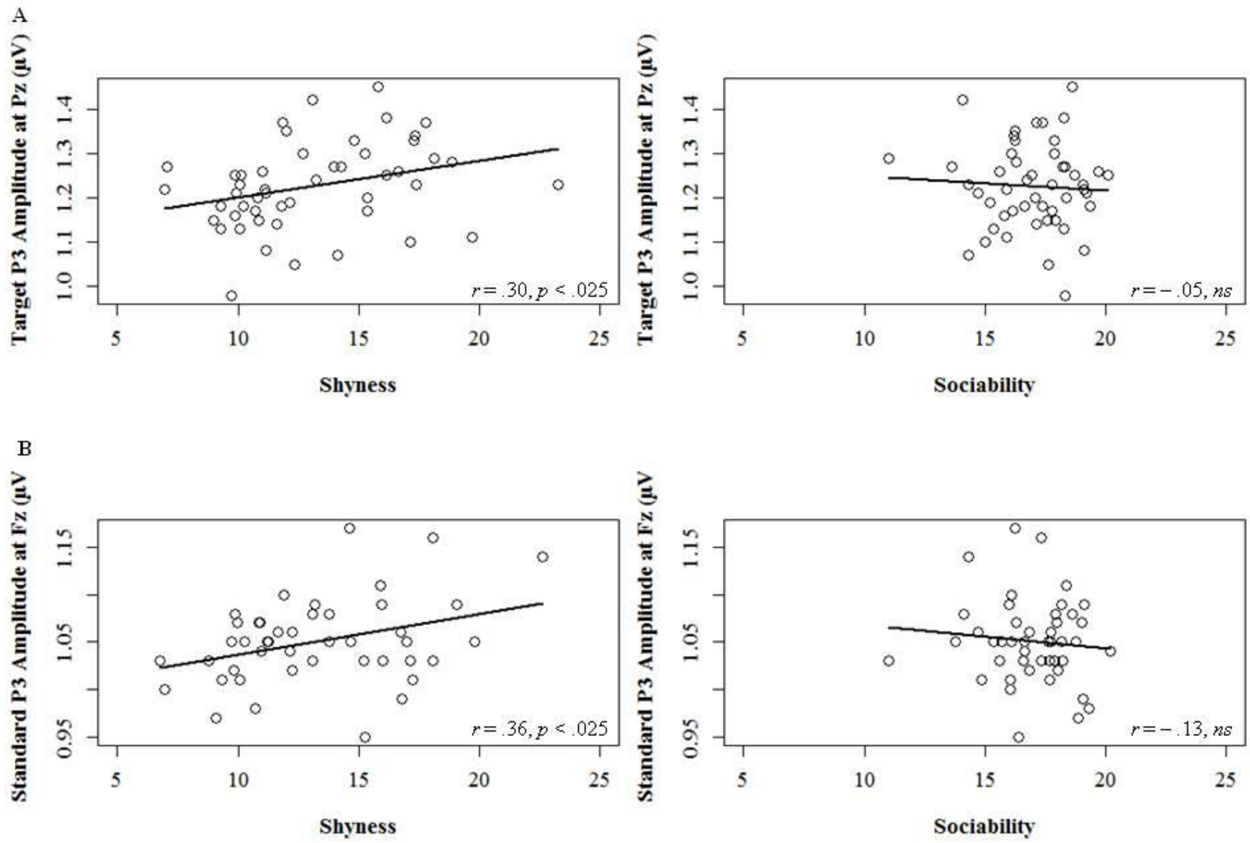
Latencies of the target P300 at anterior sites, Fz and FCz, were negatively correlated with shyness, r's = –.30 to –.35, p's < .025, while no relations were found between sociability and target P300 latencies (see Table 2.3A and Figure 2.4A). As predicted, children scoring higher on shyness had faster 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, $p \leq .06$ (see Table 2.3B). 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 Figure 2.4B), 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.

Table 2.3. Partial correlations between shyness, sociability, and the (A) target, (B) novelty, and (C) standard P300 components (amplitude & latency) across four scalp sites

(A) Target P300								
	Amplitude log(µV)				Latency (ms)			
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	0.267*	0.105	1.09	0.12	–0.300**	–0.042	342.79	74.47
FCz	0.238	0.034	1.12	0.13	–0.349**	–0.087	345.23	85.6
Cz	0.281*	0.075	1.16	0.11	–0.162	–0.135	347.47	89.25
Pz	0.289**	0.081	1.22	0.10	–0.216	0.021	343.28	81.19
(B) Novelty P300								
	Amplitude log(µV)				Latency (ms)			
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	–0.036	0.165	1.12	0.09	0.317*	–0.001	372.82	57.34
FCz	–0.070	0.077	1.14	0.10	0.256	–0.063	359.35	57.22
Cz	–0.009	0.108	1.16	0.11	0.262	–0.008	345.74	56.61
Pz	0.070	0.043	1.20	0.10	0.261	–0.092	376.09	62.45
(C) Standard P300								
	Amplitude log(µV)				Latency (ms)			
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	0.341**	0.019	1.05	0.05	–0.043	–0.011	459.70	90.94
FCz	0.319**	0.060	1.06	0.05	–0.048	0.116	454.37	96.56
Cz	0.186	0.008	1.07	0.05	–0.062	–0.041	465.33	85.85
Pz	0.108	–0.039	1.09	0.04	0.128	0.150	435.35	94.93

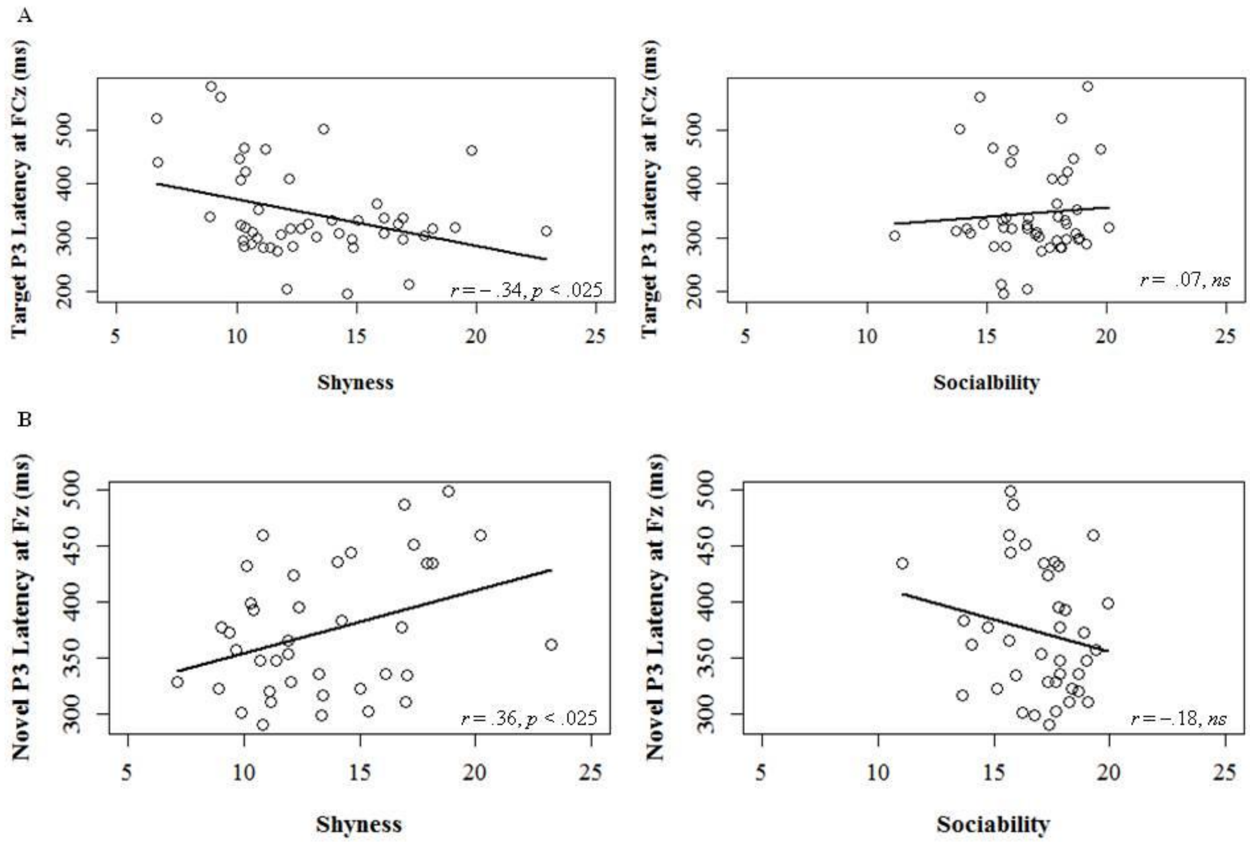
Note: *$p < .05$, **$p < .025$, 1 tailed. In (A) target P300, $n= 48$, $df= 45$; in (B) novelty P300, $n= 39$; $df= 36$; in (C) standard P300, $n= 44$, $df= 41$.

Figure 2.3. Scatter plots displaying the P300 ERP amplitude and personality traits (shyness, sociability) for (A) the target condition at the parietal scalp site, Pz; and (B) the standard condition at the frontal scalp site, Fz



Note. Scatter plots display zero-order correlations.

Figure 2.4. Scatter plots displaying the P300 ERP latency and personality traits (shyness, sociability) for (A) the target condition at the frontocentral scalp site, FCz; and (B) the novel condition at the frontal scalp site, Fz



Note. Scatter plots display zero-order correlations.

Relation between Shyness, Sociability, and Behavioral Performance

Table 2.4 displays partial correlations for shyness (controlling for influences of sociability) and sociability (controlling for influences of shyness) and the reaction time to target tones, and percent 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 as the task was relatively easy.

Table 2.4. Partial correlations between shyness, sociability, and behavioral performance in the auditory oddball task

	Shyness	Sociability	*M*	*SD*	*N*
Reaction time to targets (ms)	–0.107	–0.028	461.499	95.183	47
Percent error in target trials (%)	–0.055	–0.143	0.073	0.084	50
Percent error in novel trials (%)	–0.089	–0.055	0.186	0.147	40
Percent error in standard trials (%)	–0.023	–0.546**	0.006	0.008	49

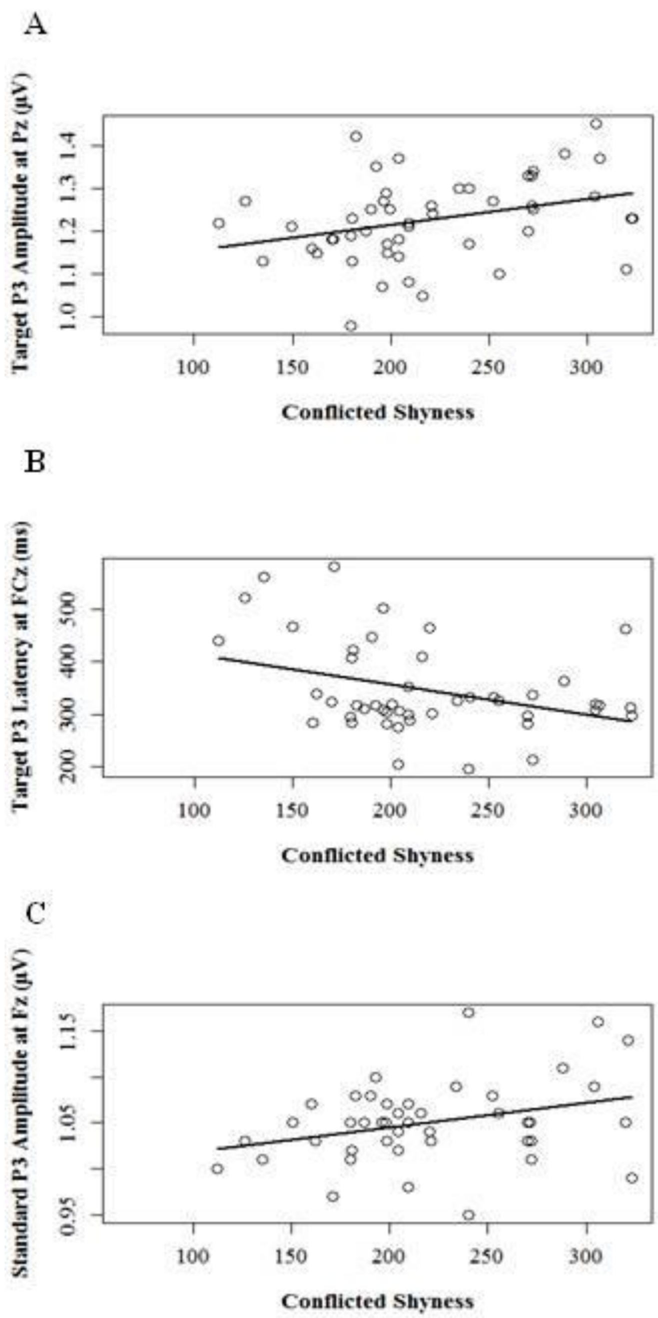
Note. ** $p < .025$.

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 ($ß= .30$, $p= .04$) and Pz ($ß= .32$, $p= .025$); marginal trends were demonstrated at anterior sites, Fz ($ß= .28$, $p= .055$) and FCz ($ß= .25$, $p= .09$). Similarly, shorter target P300 latencies significantly predicted higher scores of conflicted shyness at anterior sites, Fz ($ß= -.30$, $p= .039$) and FCz ($ß= -.36$, $p= .013$), but not posterior sites at Cz ($ß= -.19$, $p= .20$) and Pz ($ß= -.24$, $p= .10$) (see Figure 2,5 A & B).

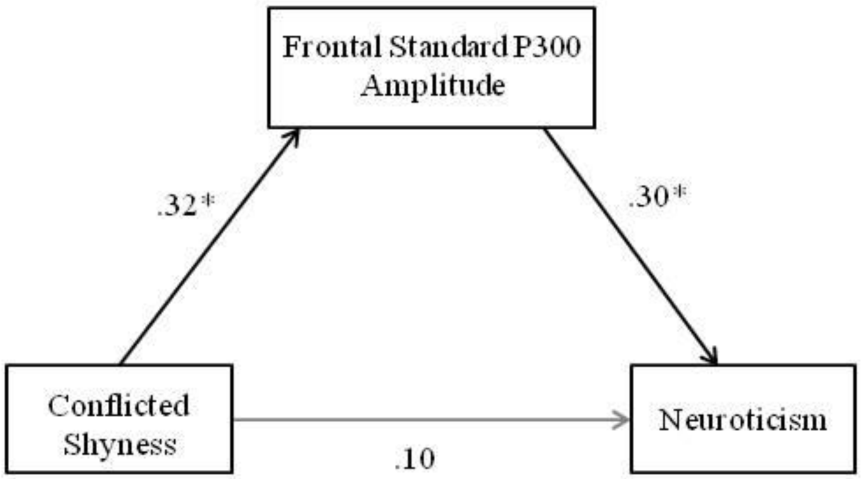
To further demonstrate a condition specific effect, additional simple linear regressions were performed with conflicted shyness as the dependent variable regressed on separate predictor variables of the amplitudes and latencies of the P300 to novel and standard tones. No relations were revealed, with the exception that higher standard P300 amplitudes significantly predicted higher levels of conflicted shyness at anterior sites, Fz ($ß= .34$, $p= .023$) and FCz ($ß= .33$, $p= .029$) (see Figure 2.5C).

Figure 2.5. Scatter plots displaying conflicted shyness versus (A & B) the target P300 ERP amplitude and latency and (C) the standard P300 ERP amplitude



In SEM, our hypothesized model with causal relations from conflicted shyness to neuroticism, mediated by the mean fontal standard P300 amplitude at Fz and FCz demonstrated good overall model fit as indicated by goodness-of-fit statistics, $\chi^2(4) = .92$, $p > .05$, *ns*, RMSEA < .001, TLI, CFI= 1. Conventional thresholds indicating good model fit are RMSEA ≤ .05, TLI and CFI ≥ .95 (Gunzler, Chen, Wu, & Zhang, 2013). A mediation effect was supported as three empirical conditions were fulfilled (Baron & Kenney, 1986; Little et al., 2007): First, the independent variable significantly predicted the mediator; increases in conflicted shyness predicted increases in frontal standard P300 amplitude (*ß*= .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 (*ß*= .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 (*ß*= .10, *b*= .0043, *SE*= .0063, *p*= .50, *ns*) (see Figure 2.6). Note this regression weight is reduced in comparison to the one obtained from a simple regression model that directly regressed neuroticism on conflicted shyness without accounting for indirect pathways (*ß*= .27, *p*< .05).

Figure 2.6. Mediated moderation model displaying the causal relation from conflicted shyness to neuroticism is mediated by frontal standard P300 amplitude at Fz and FCz



Note. **p* < .05. Standardized path coefficients are displayed.

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 3-stimulus (non-social) 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 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.

Specificity of Neurocognitive Correlates of Shyness and Related Constructs

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 on-going attentional and working memory processes (Polich, 2007) and the degree is proportional to the allocated cognitive resources used (Van Dinteren, Arns, Marijtje, 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 electrocorical 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; Squires,

Squires, & Hillyard, 1975; Snyder & Hillyard, 1976). Scalp distribution of the target and novelty P300 are also different as the production of the P300 is parietally distributed in response to targets but frontally distributed to novel tones in adults (Fabiani & Friedman, 1995; Kazmerski & Friedman, 1995). Although, across development from early childhood to adulthood, maximal P300 amplitudes to both target and novel tones have been observed at parietal sites (Cycowicz, Freidman, & Rothstein, 1996), which was consistent with our findings (see Table 2.2A & 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 may not be linked to shyness for non-social novel stimuli, at least at the age of 10. This accords with findings in a passive auditory oddball task as 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 in infancy is linked to greater positive slow wave amplitudes to infrequent deviant tones (Marshall, Reeb, & 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 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 Van Dinteren et al., 2014; Polich, 2007). 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 as 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 which 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 (Page, 1990; Miller, Schmidt & Villiancourt, 2008; 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 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 which overtime reinforces the motivationally conflicting approach and avoidant tendencies in these children.

Finally, it is important to note 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 shed insight on the positive correlation between sociability and the standard N200 amplitude as 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 homogenous sample, so we do not know if our results would generalize to more heterogeneous and/or clinical child samples. Second, as is routinely 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. Lastly, we note that our current mediated moderation model may be oversimplified, but nevertheless, useful in understanding how conflicted shyness contributes to emotional outcomes through neurcognitive processes. There are infinite alternative 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 present findings demonstrated 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 non-social contexts in children. The neurocognitive markers can help us understand subtypes of shyness in terms of their developmental risk to social-emotional problems and for understanding related constructs to shyness.

For example, while shyness is related to BI, the present results provide further evidence that they may differ not only on a conceptual level but on a neurocognitive empirical level. BI is generally regarded as a temperamental style defined as cautiousness and wariness to social and non-social 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; Laggattuta & Thompson, 2013). For instance, the self-conscious type of shyness emerges around the age of 4 to 5 (Buss, 1996); by age 8, 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, however, not mutually exclusive, for 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, 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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Study 3: ERPs and Neuroendocrine Responses in Adults Processing Non-Social Novelty

Tang, A., Santesso, D.L., Segalowitz, S.J., Schulkin, J., & Schmidt, L.A. (2016). Distinguishing shyness and sociability in adults: An event-related electrocortical-neuroendocrine study. *Biological Psychology, 119*, 200-209.

Abstract

Shyness and sociability are orthogonal personality dimensions, but little is known about how the two traits are instantiated in the brain and body. Using a 3-stimulus auditory oddball task, we examined whether shyness and sociability were distinguishable on P300 event-related potentials (ERPs) in processing task-relevant, novel, and standard auditory tones in 48 young adults. ERP amplitudes were measured at four midline scalp sites (Fz, FCz, Cz, Pz). We found that shyness, but not sociability, was related to reduced frontal novelty P300 amplitudes and to high emotionality. We also found that low baseline salivary cortisol levels mediated the relation between: (a) high shyness and reduced frontal P300 amplitudes to novels tones, and (b) high shyness and high scores of emotionality. We speculate that low baseline cortisol may serve as a putative mechanism influencing central attentional states of avoidance to threat and novelty and emotional arousal in adults who are shy.

Introduction

Shyness and sociability are conceptually and empirically orthogonal personality traits operationalized by distinct motivational behaviors, with shyness linked to social inhibition and withdraw-related tendencies, and sociability linked to social approach tendencies and a preference to be with others rather than being alone (Asendorpf, 1990; Cheek & Buss, 1981). The independence of shyness and sociability has been established in humans across development, including studies of children (Asendorpf & Meier, 1993; Coplan & Armer, 2007; Coplan et al., 2004; Tang et al., 2016), adolescents (Mounts, Valentiner, Andrerson, & Boswell, 2006; Page, 1990), and adults (Eisenberg, Fabes, & Murphy 1995; Schmidt, 1999; Schmidt & Fox, 1994; Sheeks & Birchmeier, 2007; but see Bruch, Gorsky, Collins, & Berger, 1989), across clinical populations (Goldberg & Schmidt, 2001; Jetha et al., 2009), and across cultures, including German (Czeschik & Nurk, 1995), Portugese (Neto, 1996), and Asian (Hussein, Fathy, Mawla, Zyada, & El-Hadidy 2011) samples. The independence of these two dimensions also has been reported in nonhuman animals (for a review, see Reale et al., 2007).

Beyond distinguishing shyness and sociability on behavioral and self-report measures, accumulating evidence supports the notion that the two personality traits are associated with specific physiological correlates of stress reactivity and vulnerability across autonomic and central measures. At a peripheral psychophysiological level, shyness and sociability have been distinguished in children in their everyday environments on heart rate measures (Asendorpf & Meier, 1993) and in young adults during the anticipation of unfamiliar social interactions on heart rate and heart rate variability measures (Schmidt & Fox, 1994).

At a neurophysiological level, distinct patterns of frontal electroencephalogram (EEG) asymmetry and event-related potentials (ERPs) have distinguished shyness and sociability in adult and child studies. For example, shy adults display greater relative right frontal EEG activity, whereas sociable adults exhibit greater relative left frontal EEG activity during rest (Schmidt, 1999); these patterns have also been replicated in clinical samples of adults with schizophrenia (Hussein et al., 2011; Jetha, Schmidt, & Goldberg, 2009). In typically developing 10-year-olds, we recently found that shyness, but not sociability, was linked to higher P300 ERP amplitudes in the processing of task-relevant and background auditory tones (Tang, Santesso, Segalowitz, & Schmidt, 2016).

Shyness, Vigilance, and Sensory Information Processing in the Brain

Research suggests that shy individuals are hypervigilant to threatening information and are biased to perceive ambiguous or neutral stimuli as threatening in social contexts. This hypervigilance has been linked to differential affect-related attentional mechanisms during early phases of processing, evident in a series of behavioral (e.g., Brunet, Heisz, Mondlock, Shore, & Schmidt, 2009; Matsuda, Okanoya, & Myowa-Yamakoshi, 2013), neuroimaging (e.g., Beaton et al., 2008), and ERP (e.g., Jetha, Zheng, Schmidt, & Segalowitz, 2012; Jetha, Zheng, Goldberg, Segalowitz, & Schmidt, 2013) studies that used threatening and negative facial expressions as experimental stimuli. Hypervigilance and reactivity in both social *and* non-social novelty are also signatures of other shy-fearful phenotypes, such as behavioral inhibition (BI), a temperamental feature of shyness identified in infancy (see Henderson, Pine, & Fox, 2015, for a review).

In understanding the extent to which typically developing children who are shy process non-social sensory information differently in the brain, we recently examined the N200 (a negative peak at 200 - 400 ms) and P300 ERPs (a positive peak at 300 to 500 ms), which increase in amplitude after stimulus onset to target and novel tones as opposed to standard tones in a 3-stimulus auditory oddball task (Tang et al., 2016). Although we found no relation between N200 amplitudes and children's shyness, the rationale for examining the P300 in that study and the present study was for its hypothesized role in attentional and working memory operations (Donchin, Karis, Bashore, Coles, & Gratton, 1986; Polich, 2007), and the positive relations between P300 amplitudes and high arousal levels that have been linked to personality (Brocke, Tasche, & Beauducel, 1997; DePascalis, 2004; Ditraglia, & Polich, 1991; Sternberg, 1992; Wilson & Languis, 1990). Because higher levels of baseline arousal and vigilance are common physiological components of shyness and other related anxiety constructs, such as BI and social anxiety, the P300 is a potential neurocognitive correlate of these shy-fearful phenotypes. Indeed, we recently found that 10-year-old children who were higher in shyness elicited higher P300 amplitudes to target and standard tones, while P300 amplitudes across all conditions were unrelated to sociability (Tang et al., 2016).

Using a similar auditory oddball task, others have found that adolescents characterized by high BI across childhood with higher novelty P300 amplitudes were more likely to have a lifetime diagnosis of an anxiety disorder compared to adolescents characterized by low BI (Reeb-Sutherland et al., 2009). However, the extant literature is limited to child and adolescent samples, and to the best of our knowledge, shyness, sociability, and the novelty P300 have not been examined in adults. As well, relatively little is known regarding whether the processing of social information generalizes to non-social information processing in shyness.

The primary goal of the present study was to extend our recent findings with children by examining whether shyness and sociability were distinguishable on the P300 in adults, using the same 3-stimulus auditory oddball task and ERP measures we used with children (e.g., Tang et al., 2016). We did not directly compare our child and adult samples, as there were differences in the ERP waveforms. For example, the N200 amplitudes were more negative in the target and novel (rare stimuli) conditions versus the standard (frequent stimulus) condition in adults, but the reverse pattern was observed in children. Possible developmental differences in the amplitude and latency of the P300 component that reflect brain maturation for neural processing power and speed across the lifespan have also been documented (see Van Dinteren, Arns, Jongsma, & Kessels, 2014, for the results of a recent meta-analysis).

Shyness, Neuroendocrine Functioning, and Emotional Arousal

In addition to brain measures of arousal/reactivity during information processing, neuroendocrine and subjective emotional arousal measures might also offer insight to shyness as arousal manifests on multiple levels in the brain and body. One neuroendocrine measure that has been used to study shyness is cortisol. Cortisol is a predominant glucocorticoid produced by the hypothalamic-pituitary-adrenal axis (HPA-axis) in humans to index stress reactivity and regulation in shy-fearful phenotypes, given the basic function of increased cortisol release is to mobilize energy for action during fight or flight situations mediated by the sympathetic nervous system.

At baseline, changes in cortisol levels are observed in shy-fearful phenotypes across development. In early childhood, BI and shy children exhibit increases and/or high baseline cortisol levels (Kagan, Reznick, & Snidman, 1988; Schmidt et al, 1997). By middle childhood, both high and low baseline cortisol levels are observed in shy children (Schmidt, Santesso, Schulkin, & Segalowitz, 2007). By young adulthood, decreases and/or low baseline cortisol are observed in shy adults, with lower levels negatively correlated with higher self-report social anxiety (Beaton et al., 2006; Beaton, Schmidt, Schulkin, & Hall, 2013).

The neuroendocrine system may influence emotion processing and regulation in shy individuals. For example, variation in the salivary cortisol awakening response (CAR) in shy adults is predictive of modulation in a distinct pattern of brain regions for processing angry faces relative to non-shy adults (Tang, Beaton, Schulkin, Hall, & Schmidt, 2014).

Others measures that have been used to index sympathetic arousal/reactivity are subjective measures of emotionality. Emotionality is the tendency to be aroused to negative emotions, including distress, fear, and anger, that is thought to have a physiological basis (Buss & Plomin, 1984). Indeed, emotional responding to emotionally charged stimuli is related to increased physiological reactivity across different measures (e.g., Bradley, Miccoli, Escrig, & Lang, 2008; Colder, 2001). There is also a positive relation between subjective reports of emotionality and shyness (e.g., Buss & Plomin, 1984; Eisenberg, Shepard, Fabes, Murphy, & Guthrie, 1998) that suggests shy individuals have a tendency to experience negative emotions more intensely. Accordingly, it is possible that sympathetic reactivity in shy individuals can influence their subjective levels of emotionality.

Following a multi-component approach, the second goal of the present study was to examine the relations among shyness, ERP and neuroendocrine responses, and emotionality. Relatively few studies have addressed the potential mechanism(s) underlying links between shyness and brain-behavior relations.

The Present Study

Based upon our two goals, we first examined the relations among shyness, sociability and ERP responses to a 3-stimulus auditory oddball task in a sample of undergraduates. Given shyness and sociability are conceptually and empirically independent constructs, and shyness is linked to hypervigilance in information processing, we predicted that increases in shyness, but not sociability, would be related to higher P300 amplitudes to target, novel, and standard tones, with the highest to novel tones, given unfamiliarity-novelty is salient in signaling danger and maintaining shyness reflected by greater attention allocation (e.g., Kagan, 1994). Shyness is also linked to self-presentation anxiety (Cheek & Buss, 1981; Schmidt & Buss, 2010, for reviews), which presumably motivates good performance in the target condition, to detect threatening information in the novel condition, and general hypervigilance in the baseline standard condition.

We next examined whether baseline salivary cortisol mediated the relation between shyness and the novelty P300 and the trait of emotionality by testing separate mediation models. We postulated that baseline salivary cortisol would mediate the relation between shyness and the novelty P300 and emotionality; specifically, we predicted that low baseline salivary cortisol levels (e.g., Beaton et al., 2006; 2013) would mediate the relation between high shyness and high novelty P300 amplitudes and subjective measures of negative emotionality.

Method

Participants

Forty-eight young adults (*M* age= 23.1; *SD*= 3.6; 15 male, 33 female), who were primarily Caucasian (61%), right-handed, with no history of head injury, were recruited from an introductory psychology course at McMaster University (Hamilton, Ontario). Participants received experimental course credit for their participation. The experiment was conducted with approval from the McMaster University Research Ethics Board.

Self-Report Measures

Cheek and Buss Shyness and Sociability Scales. Shyness and sociability were assessed using the five highest loaded (see Bruch et al., 1989) shyness items from the original Cheek and Buss (1981) scale and the 5 item Cheek and Buss (Cheek & Buss, 1981) sociability scale. The original scale for adults has a reported alpha coefficient of .79. Examples of shyness and sociability items include “I find it hard to talk to strangers” and “I like to be with people”, respectively. Items were scored on a 5-point scale (0 = “not at all characteristic” to 4 =

"extremely characteristic"). As expected, shyness was inversely, and unrelated to sociability in this sample, $r = -.24$, $p > .05$, suggesting the two dimensions were largely independent.

Emotionality Activity Sociability (EAS) Temperament Survey for adults. The EAS (Buss & Plomin, 1984) is a 10-item self-report measure capturing three temperamental traits: emotionality (with fearfulness, anger, and distress subscales), activity, and sociability. Reliability of this measure ranges from .75 to .85. The emotionality scale was used in the present study because it taps features of emotional arousal/ reactivity. An item on this dimension is "I get emotionally upset easily". Items were scored on a 5-point scale (1 = "not characteristic of me" to 5 = "very characteristic of me").

Auditory Oddball Paradigm

A 3-stimulus auditory oddball task was used to measure attentional processes. Participants heard three types of tones: a) standard low tones (800 Hz), b) target high tones (1500 Hz), and c) novel tones (20 unique tones varying between 800 to 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. 400 total trials were divided into five blocks of 80 trials with standard tones presented 80% of the time, and target and novel tones each presented 10% of the time. Following Fabiani and Friedman (1995), tones were randomly presented with the constraints that a) presentation of two of the same novel tones could not occur within the same block; b) presentation of two novels, two targets, or a target and a novel tone could not be presented in consecutive trials; and c) presentation of target or novel tones could not be the first trial in each block. The same randomized order of stimuli was used across participants. 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 standard and novel tones. Participants completed a practice session before the task.

EEG Data Collection and Analyses

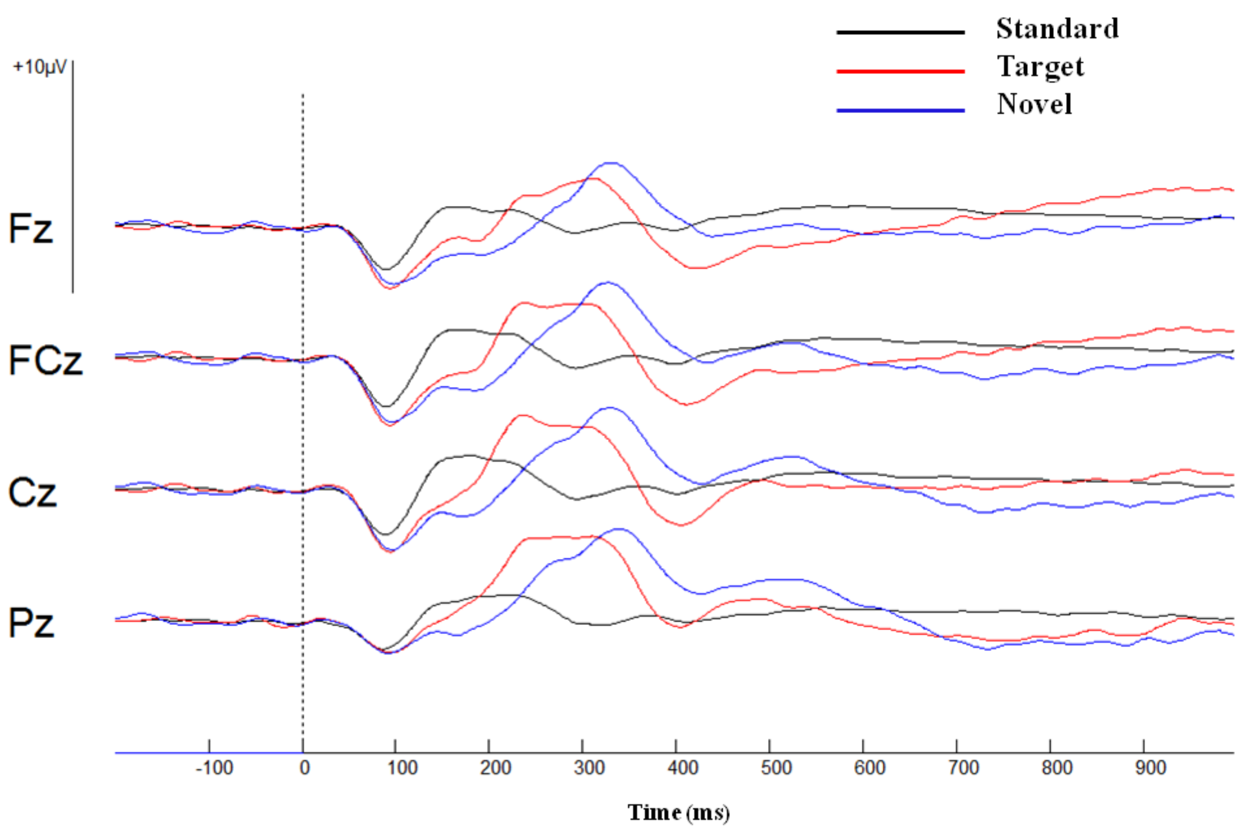
EEG recording. EEG was collected using a lycra EEG stretch cap (Electro-Cap International, Inc.). Electrodes were positioned according to the International 10/ 20 Electrode System (Jasper, 1958). The experimenter abraded the surface of the scalp underneath the selected electrodes using a Q-tip with abrasive gel (Nu-Prep). Each electrode site was filled with 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 the right ear and 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 Instrumental 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 512 Hz sampling rate.

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, which 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). Amplitude was the difference between the mean 200 ms pre-stimulus baseline voltage 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 600 ms for the P300 in each condition and each participant. Internal consistencies and descriptive analyses of the N200 and P300 components across scalp sites and conditions are reported in Supplementary Material.

Figure 3.1 depicts the grand average waveforms of the P300 component across four midlines scalp sites in the three experimental conditions.

Figure 3.1. Grand average waveforms depicting the P300 ERP components across four midline scalp sites (Fz, FCz, CZ, and Pz) in the target, novel, and standard conditions.



Salivary Cortisol

Procedure. All participants were tested at approximately the same time in the early afternoon to control for diurnal rhythms which are known to influence cortisol levels (Sharpley et al., 2016). Two saliva samples were collected after participants acclimated to the laboratory: the first sample was collected 10 min after entrance; the second was collected 15 min after the first sample while participants waited for the study to begin. A third saliva sample was collected 15 min after a visual discrimination task, when participants completed self-report questionnaires. For each sample, participants were asked to expectorate at least .75 ml of saliva into a sterile Nalgene cryotube. Samples were stored at –80 °C until assayed.

Enzyme-linked Immunoassay (EIA). Hormone assays from saliva were conducted at the Behavioural Endocrinology Laboratory in the Department of Biology at Queen's University (Kingston, Ontario). Samples were thawed, mixed, and centrifuged for 15 min at 1500g. A commercial competitive enzyme immunoassay kit optimized for saliva (HS-Cortisol High Sensitivity, Salimetrics®, LLC, State College, PA) derived salivary cortisol concentrations. Standards, controls, and samples were assayed in triplicate at a volume of 25 µl. Samples with a coefficient of variability exceeding 15% were repeated as a singleton on another plate. The average of triplicates was then used in subsequent analyses. The coated plate was incubated at room temperature for 1 h in the presence of 200 µl of tetramethybenzidine with 25 min incubation in darkness at room temperature. Within 10 min of adding 50 µl of stop solution, the plate was read at 492nm and 450nm with the optical density as the difference (VERSAmax ™, Molecular Devices, Sunnyvale, CA). No individuals were split across a plate, only intra-assay variance applies to within individual calculations across repeated samples. Intra-assay variance applies to within individual calculations across repeated samples. Intra-assay variability was calculated across each plate after the standard curve, in the middle, and at the end, which was more rigorous and accurate than the common intra-assay variability calculation based on placement immediately after the standard curve. Intra-assay variability was calculated at 46 µg/dl and 1.03 µl/dl, yielding intra-assay coefficients of variability, 5.4% and 13.8%, respectively. Comparable inter-assay coefficients of variability were 14.6% and 16.4%. Attempts were made to hold time of day constant for testing in the afternoon to eliminate systematic relations with the study measures. Due to a strong positive relation between the first two salivary cortisol samples ($r = .69$, $p = < .001$), the mean was calculated for each individual and used as the baseline cortisol level in our analyses.

Data Analyses

A series of partial Pearson correlations assessed whether individual differences in shyness (accounting for the variance in sociability) and sociability (accounting for the variance in shyness) contributed to N200 and P300 amplitudes and latencies across four midline scalp sites (Fz, FCz, Cz, Pz), and whether it was condition specific to novel, target, and standard stimuli.

A series of bivariate Pearson correlations assessed relations among shyness, emotionality, and cortisol measures, and whether individual differences in these measures contributed to P300 amplitudes across four midline scalp sites (Fz, FCz, Cz, Pz), and three conditions (novel, target, and standard).

Given significant relations among shyness, baseline cortisol, emotionality, and the novelty P300, Structural Equation Modeling (SEM), a multivariate technique, was performed to understand how long term changes in the neuroendocrine system of shy adults may influence their emotional and attentional reactivity/arousability. We built and tested two separate simple mediation models (Little, Card, Bovaird, Preacher, & Crandall, 2007) with hypothesized causal relations from the exogenous variable (shyness) to the endogenous outcome variables of reactivity (novelty P300 amplitudes at Fz, and scores of emotionality from the EAS), mediated by the endogenous mediator variable (baseline cortisol levels). This pathway of relations was established on *a priori* theoretical and empirical grounds, as low baseline cortisol has been hypothesized to arise from changes in the HPA-axis due to a history of coping with social stressors in shy adults (Beaton et al., 2006). Neurophysiological systems linked to heightened attention and emotional reactivity in shy individuals has been hypothesized (Kagan, 1994). Neural structures in the HPA-axis support both autonomic and endocrine functions (e.g., the hypothalamus; Ulrich-Lai & Herman, 2009), selective attention and detection of novel changes (e.g., the hippocampus; Vinogradova, 2000), and neural circuits overlap in stress and emotion regulatory functions (Herman, Ostrander, Mueller, & Figueiredo, 2005). Finally, scalp density analyses have shown that the novelty P300 is linked to frontotemporal, temporoparietal, and superior parietal regions, with possible neuroelectric sources including the cingulate cortex, and hippocampus (Yago, Escera, Alho, Giard, & Serra-Grabulosa, 2003).

SEM was performed in the program Amos (SmallWaters Corp., USA), applying the maximum likelihood algorithm to simultaneously estimate path coefficients, indirect and direct effects. Bootstrap estimations for 1000 samples were applied to derive 95% Confidence Intervals (CIs) for determining the significance of path coefficients, indirect and direct effects (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002; Preacher & Hayes, 2008) and to ensure reliability of estimations due to a small sample size. Goodness of fit statistics assessing our proposed models' ability to reproduce the original variance-covariance structure of the data included the χ^2 goodness-of-fit, Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI) that is recommended for smaller sample sizes (Hu & Bentler, 1998), and the Tucker-Lewis Index (TLI).

Missing Data

Due to equipment failure, excessive motor and eye movement artifact, failure to follow instructions, absence of clear ERP peaks, and missing cortisol samples, we lost data on several participants (see Supplemental Table 3.2). Pair-wise deletion preserved the maximum number of participants. In partial correlation analyses for the N200, we had complete participant data for 34 individuals in the target, 36 in the novel, and 32 in the standard conditions. In partial correlation analyses for the P300, we had complete participant data for 36 individuals in the target, 37 in the novel, and 36 in the standard conditions. In bivariate correlations between shyness, emotionality and P300 ERP amplitudes, we had complete participant data for 39 individuals in the target, 40 in the novel, and 39 in the standard conditions. In bivariate correlations between baseline cortisol and P300 ERP amplitudes, we had 30 individuals in the target, and 32 in the novel and standard conditions. In the SEM analysis, there were 32 individuals.

Results

Relations among Shyness, Sociability, and the Auditory Oddball P300 Amplitudes

Table 3.1 displays partial correlations for shyness (accounting for variance in sociability) and sociability (accounting for variance in shyness) to target (A), novelty (B), and standard (C) stimuli for the N200 and P300 amplitudes. Neither shyness nor sociability was related to N200 amplitudes across all scalp sites and conditions with the exception that higher sociability was related to less negative (smaller) novelty N200 amplitudes at Pz, $r = .37$, $p < .05$, and Cz at trend level, $r = .33$, $p = .055$.

For P300 amplitudes, higher shyness negatively correlated with lower novelty P300 amplitudes at Fz, $r = -.38$, $p < .05$ (Figure 3.2), a trend also emerged at FCz, $r = -.30$, $p = .079$, suggesting shy adults elicited smaller frontal novelty P300 amplitudes. However, shyness was unrelated with target and standard P300 amplitudes across all four scalp sites. Furthermore, higher sociability was positively correlated with increased standard P300 amplitudes at Fz, FCz, and Cz, *r*'s = .38 to .41, *p*'s < .05, but sociability was unrelated to target and novelty P300 amplitudes.

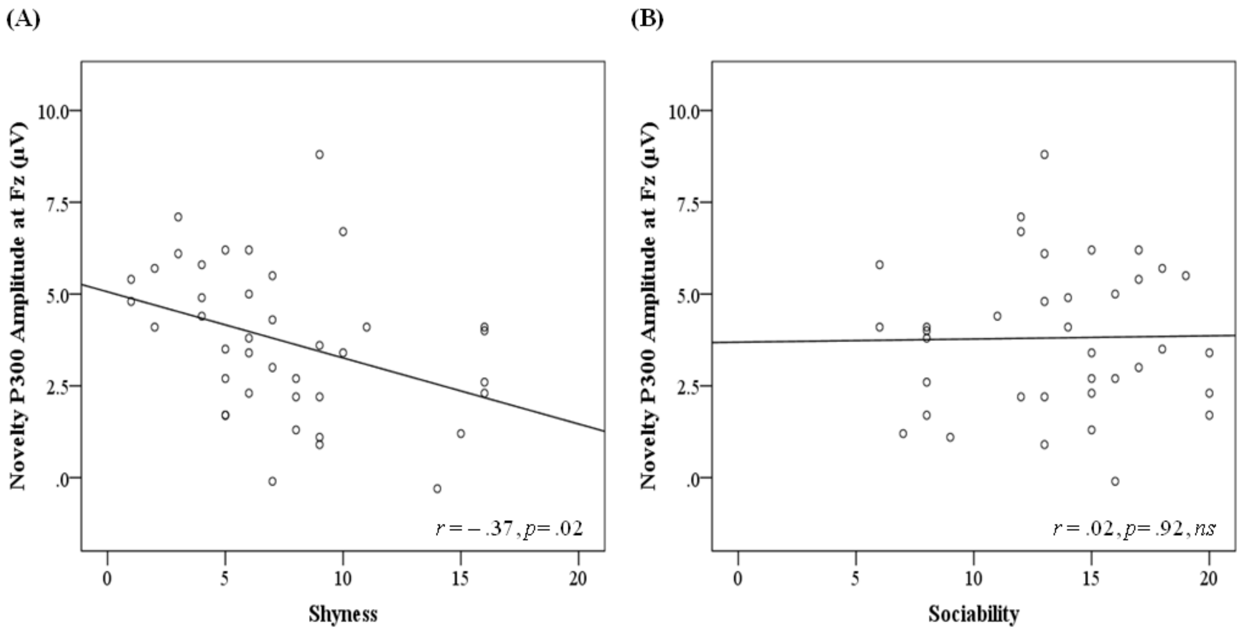
Relations among shyness, sociability, and N200 and P300 latencies are presented in Supplementary Table 3.3.

Table 3.1. Partial correlations among shyness (accounting for variance in sociability), sociability (accounting for variance in shyness), and the target (A), novelty (B), and standard (C) conditions for N200 and P300 amplitudes across four scalp sites.

(A) Target	**N200 amplitude(μV)**				**P300 amplitude(μV)**			
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	.24	.11	–1.90	1.52	–.12	.04	3.22	2.00
FCz	.29	.17	–2.05	1.86	–.10	.15	3.80	2.41
Cz	.32	.18	–1.38	1.81	–.08	.18	4.23	2.37
Pz	–.10	–.03	–.20	1.17	–.18	.05	4.67	1.98
(B) Novelty	**N200 amplitude(μV)**				**P300 amplitude(μV)**			
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	.11	.17	–2.07	1.48	–.38*	–.08	3.71	2.04
FCz	.18	.26	–2.31	1.58	–.30ǂ	.03	4.47	2.46
Cz	.14	.29	–1.95	1.54	–.27	.12	4.95	2.41
Pz	0	.27	–1.05	1.23	–.19	.17	5.30	1.98
(C) Standard	**N200 amplitude(μV)**				**P300 amplitude(μV)**			
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	–.18	.05	–.75	.82	–.01	.38*	1.39	.72
FCz	–.18	0	–.86	.84	–.07	.38*	1.38	.66
Cz	–.09	–.04	–.77	.75	–.04	.41*	1.27	.61
Pz	.06	–.12	–.52	.55	–.01	.30	1.07	.45

Note. *p** < .05, *p* ǂ < .08, two-tailed.

Figure 3.2. Scatter plots displaying the novelty P300 ERP amplitudes at the frontal scalp site and shyness (A) and sociability (B).



Note. Scatter plots display zero-order Pearson correlations

Relations among Shyness, Baseline Cortisol, Novelty P300, and Emotionality

Table 3.2 summarizes zero-order Pearson correlations among shyness, sociability, emotionality, and baseline cortisol. As predicted, shyness was positively correlated with emotionality, and negatively correlated with sociability and baseline cortisol. Given these significant associations, we focused on shyness and baseline cortisol to further understand their associations with neurocognitive indices and emotionality.

Table 3.2. Pearson correlations among shyness, sociability, emotionality, and baseline cortisol.

	1	2	3	4
1. Shyness	--	–.24	.44**	–.48**
2. Sociability		--	.08	.21
3. Emotionality			--	–.45**
4. Baseline cortisol				--

Note. $p^{**} < 0.01$, two-tailed.

Table 3.3 presents Pearson correlations among shyness, emotionality, baseline cortisol, and the P300 amplitudes for the target (A), novel (B), and standard (C) stimuli.[5] Lower target P300 amplitudes at Fz, FCz, and Pz were negatively correlated with increases in emotionality, *r*'s = –.36 to –.42, *p*'s = < .05, and this relation approached significance at Cz, *r*= –.31, *p* = .057 (Table 3.3A). A negative correlation between increases in emotionality and lower novelty P300 amplitudes at FCz, Cz, and Pz, *r*'s = –.27 to .30 emerged at a trend level, *p*'s < .08. Similar to the previous findings from partial correlations, reduced novelty P300 amplitudes at frontal sites, Fz and FCz were negatively correlated with increases in shyness, *r*'s = –.31 to –.37, *p*'s = < .05, and this relation approached significance at Cz, *r*= –.30, *p*= .058. Moreover, higher novelty P300 amplitudes at Fz, FCz, and Cz were positively correlated with increases in baseline cortisol, *r*'s = .35 to .39, *p*'s = < .05 (Table 3.3B). No relations were found among standard P300 amplitudes and shyness, emotionality, and cortisol measures (Table 3.3C). Overall, the

[5] The same correlational analyses were performed to examine the relations among shyness, emotionality, baseline cortisol, and the N200 amplitudes, but no statistically significant relations were found. Furthermore, neuroticism was tested in this sample and our child sample (Tang et al., 2016). In the child sample, neuroticism was a significant factor linking the P300 to shyness, as neuroticism, shyness, and frontal standard P300 amplitudes were positively correlated. In this adult sample, neuroticism was not a significant factor in linking the P300 to shyness, even though higher neuroticism was related to lower target P300 amplitudes across frontal to central scalp sites.

systematic patterns of interrelations among high shyness and emotionality, and low basal cortisol and frontal novelty P300 amplitudes represented a cluster of behavioral and biological indices linked to shyness in adults.

Table 3.3. Bivariate Pearson correlations between shyness, emotionality, and baseline cortisol, and the (A) target, (B) novelty, and (C) standard P300 amplitude across four scalp sites.

(A) Target P300 Amplitude(μV)			
Site	Shyness	Emotionality	Baseline cortisol
Fz	–.13	–.42**	.17
FCz	–.13	–.37*	.15
Cz	–.12	–.31ǂ	.09
Pz	–.19	–.36*	.01
(B) Novelty P300 Amplitude(μV)			
Site	Shyness	Emotionality	Baseline cortisol
Fz	–.37*	–.23	.39*
FCz	–.31*	–.28ǂ	.35*
Cz	–.30ǂ	–.27ǂ	.36*
Pz	–.23	–.30ǂ	.16
(C) Standard P300 Amplitude(μV)			
Site	Shyness	Emotionality	Baseline cortisol
Fz	–.10	.03	.13
FCz	–.16	.07	.14
Cz	–.14	.18	.01
Pz	–.07	.09	–.08

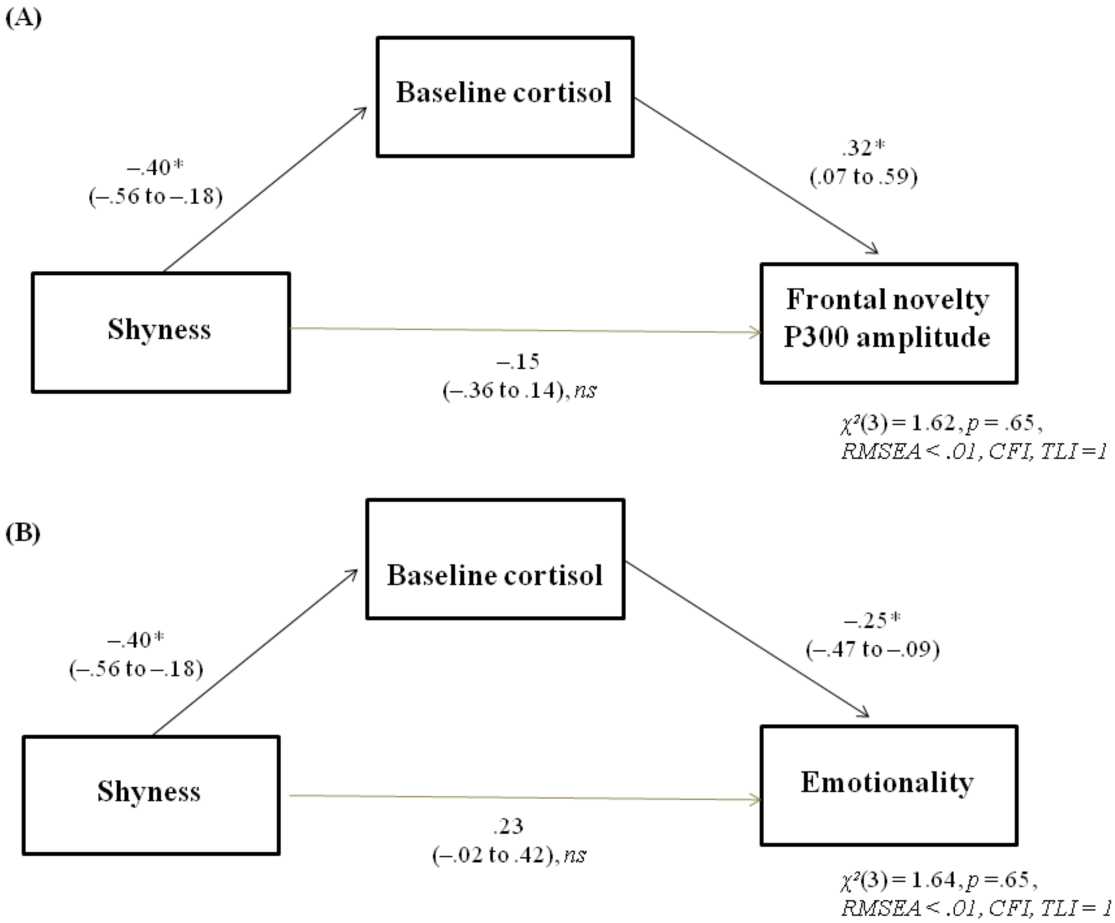
Note. $p^{**} < 0.01$, $p^{*} < 0.05$, *p*ǂ < 0.08, two-tailed.

Mediating influences of low baseline cortisol. The two separate simple mediation models with putative causal relations from shyness to frontal novelty P300 amplitudes and emotionality, mediated by baseline cortisol, demonstrated good overall model fit, $\chi^2(3) = 1.62$ to 1.64, $p > .05$, *ns*, *RMSEA < .05, CFI and TLI > .95*. In the first model (Figure 3.3A), increases in shyness predicted decreases in baseline cortisol (β= – .40, CIs= – .56 to – .18); in turn, decreases in baseline cortisol predicted decreases in frontal novelty P300 amplitudes (β= .32, CIs= .07 to .59). This indirect (mediated) effect of shyness on frontal novelty P300 amplitude (β= –.13, CIs= –.30 to –.02) was significant, whereas the direct (unmediated) effect of shyness on frontal novelty P300 amplitudes (β= –.15, CIs= –.36 to .14) was not significant.

Similarly, in the second model (Figure 3.3B), increases in shyness predicted decreases in baseline cortisol (β= – .40, CIs= – .56 to – .18); in turn, decreases in baseline cortisol predicted increases in emotionality (β= – .25, CIs= – .47 to – .09). Again, the indirect effect of shyness on emotionality (β= .10, CIs= .03 to .23) was significant, whereas the direct effect of shyness on emotionality (β= .23, CIs= –.02 to .42) was not significant.[6]

[6] In addition to conceptualizing the neuroendocrine measure (baseline cortisol) as the mediator, we also tested and ruled out alternative models with brain functioning (frontal novelty P300 amplitudes) as the mediator. These models either presented no mediating effects or poor model fit.

Figure 3.3. Mediation models displaying putative causal relations from shyness to frontal novelty P300 amplitude at Fz (A) and to emotionality (B) are mediated by baseline cortisol levels.



Note. Standardized coefficients with 95% confidence intervals and model fit indices are displayed. $p^* < .05$.

Discussion

Using a 3-stimulus non-social auditory oddball paradigm in adults, we first addressed whether individual differences in shyness and sociability were distinguishable on neurocognitive measures. In support of the independence hypothesis of shyness and sociability, we found that increases in shyness, but not sociability, were associated with reduced frontal novelty P300 amplitudes. However, this reduced pattern of novelty P300 amplitudes was not consistent with our prediction of greater amplitudes and findings in our recent study of shyness and sociability in children using the same task (Tang et al., 2016). In the child study, although shyness was unrelated to novelty P300 amplitudes, it was related to greater target and standard P300 amplitudes.

What do reduced novelty P300 amplitudes reflect in adult shyness?

The novelty P300 to novel tones is frontally distributed in adults (Fabiani & Friedman, 1995; Kazmerski & Friedman, 1995). It instantiates stimulus-driven involuntary attention orientation and further cognitive operations to unexpected events occurring with low probability that are task-irrelevant or contextually novel or salient (Courchesne, Hillyard, & Galambos, 1975; Knight & Scabini, 1998; Squires et al., 1975; Snyder & Hillyard, 1976). Reduced novelty P300 amplitudes have been reported in profiles with depressive (e.g., Bruder et al., 2009; Tenke, Kayser, Stewart, & Bruder, 2010), apathy (e.g., Daffner et al., 2001; Yamagata, Yamaguchi, & Kobayashi, 2004), and even antisocial (e.g., Iacono, Carlson, Malone, & McGue, 2002) characteristics and have been interpreted as attention-related deficits. Rather than explanations linked to impaired attention and in consideration of the ceiling behavioral performance[7], we speculate that reduced novelty P300 amplitudes in shy adults may reflect attenuated involuntary attention switching because the novelty P300 is thought to reflect involuntary and automatic attention switching from an attended to an unattended task-irrelevant event with larger amplitudes interpreted as increased distraction (Escera, Alho, Winkler, & Naatanen 1998). This dampening of novelty P300 amplitudes possibly imply that shy adults are less distracted by and

[7]Analyses for behavioral performance are reported in supplemental material.

can efficiently shift away from task-irrelevant deviant tones, or avoid task-irrelevant deviant tones.

Notably, the different findings across child and adult samples of shy individuals may be due to changes in attentional mechanisms. For example, shy adults elicit reduced, but not increased, P100 ERP amplitudes in processing fearful faces (Jetha, Zheng, Schmidt, & Segalowitz, 2012), which was suggested to reflect their hypervigilant and avoidant behavioral styles (Bögels & Mansell, 2004) captured by an initial hypervigilance to threatening and negative information within 100 ms of visual processing that is presumably followed by avoidance. Similarly, we found differential attentional mechanisms in shy adults with reduced, rather than increased, P300 amplitudes in processing novel auditory tones. Likewise, adults with social phobia elicit reduced P300 amplitudes to deviant tones in a 2-stimulus auditory oddball task (Sachs et al., 2004). Taken together, it is reasonable to speculate that these reduced electrocortical responses across visual and auditory domains may reflect attentional avoidance and a dampening "recalibration" of central attentional states in shy adults. That is, tendencies and sensitivities to orient and maintain attention to threatening information linked to arousal regulation systems may be attenuated in order to cope with chronic social stress across development.

What does low cortisol reflect in shyness?

We addressed the second goal to understand the links among shyness, brain-body functioning, and behavior by identifying a putative neuroendocrine mechanism in linking shyness and attentional and affective reactivity. Here, shy adults scored higher on emotionality and elicited lower baseline cortisol levels, consistent with the literature demonstrating that shyness is positively correlated with emotionality (e.g., Buss & Plomin, 1984) and neuroticism (e.g., Briggs, 1988; Heiser, Turner, & Beidel, 2003; Tang et al., 2016), and negatively correlated with baseline cortisol levels in laboratory settings (Beaton et al, 2006) and throughout the day in their everyday environments (Beaton et al., 2013). Similar to shyness, higher emotionality was related to reduced baseline cortisol levels. To further understand how long term changes in the neuroendocrine system in shy adults may influence their emotional and attentional reactivity/ arousability, the simple mediation models demonstrated the association between high shyness and high emotionality was mediated by low levels of baseline cortisol; likewise, the association between high shyness and reduced frontal novelty P300 amplitudes was mediated by low baseline cortisol.

We speculate that high and low cortisol levels hold complex functional implications for regulating social behavior and have different functional meaning at different developmental stages. For example, increases in baseline cortisol levels have been observed in socially dominant, competent, bold and exuberant children (Gunnar, 1994), and dominant nonhuman primates (e.g., Muller & Wrangman, 2004). In contrast, low and decreases in cortisol have been reported in socially competent children as well as shy and socially phobic adults (Beaton et al., 2006, 2013), and other profiles exposed to chronic stress (e.g., post-traumatic stress disorder; Yehuda & Seckl, 2011) and characterized as depressed and socially withdrawn (Gunnar & Valdez, 2001). Similar to other chronically stressed profiles, the decreased baseline cortisol pattern in shy adults is hypothesized to be linked to experience-induced changes in the HPA-axis and hormones (including cortisol) involved in stress vulnerability and reactivity due to lifelong coping with shyness and social situations (Beaton et al., 2013).

The neuroendocrine system in shy-fearful phenotypes may calibrate from relatively high baseline cortisol levels during childhood (e.g., Schmidt et al., 1997) to low levels during adulthood (e.g., Beaton et al., 2006). Chronic increases in cortisol levels can result in low baseline cortisol levels as increases in cortisol lead to an enhanced negative feedback loop, in which cortisol regulates it own release by binding to its receptors that are densely distributed in the brain and especially the cortiocolimbic system (Herman et al., 2005). Such recalibration of the neuroendocine system presumably impacts other autonomic and cognitive-affective neural processes linked to arousability. In particular, the hippocampus has functional roles in selective attention and detecting novel changes (Vinogradova, 2000), and is a neuroelectric source of the novelty P300 (Yago et al., 2003). Thus, low cortisol characterizing adult shyness may influence central attentional states when processing novel sensory information. Moreover, such long term changes in the neuroendocrine system of shy adults, reflected by low baseline cortisol, may be viewed as a putative mechanism in linking shyness to attentional avoidance of novelty and emotional arousability.

N200 Findings

Although N200 ERP amplitudes were unrelated with shyness, we note that this component may be functionally different compared to that in our child sample (Tang et al., 2016). For example, the N200 amplitudes were more negative in the target and novel conditions versus the standard condition in adults. This increased N200 amplitude to rare stimulus types (i.e., novel and target tones) is normally seen in comparison to the standard tone that occurs more frequently in the oddball task (Hoffman, 1990; Naatanen & Picton, 1986). However, the reverse pattern was observed in children, as more negative N200 amplitudes were elicited to the standard versus the target and novel conditions. We previously explained that the infrequent deviant stimuli might require ‘‘go” responses, whereas the frequent standard stimuli required ‘‘no-go” responses that are observed in cognitive control/inhibition tasks, 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 oddball task (see, Tang et al., 2016). Given differences in the functional meaning of the N200 ERP component across samples, they are not comparable.

Limitations

There are several limitations that warrant discussion. First, although the sample size was relatively large for ERP studies, the results are based on a small sample of undergraduates. Second, our measures of personality were subjective reports which are known to be inherently biased. Third, we used a cross-sectional design so we need to be cautious in any interpretations related to the development of shyness and sociability. Fourth, while we obtained three saliva samples to index cortisol and tested individuals and collected salivary samples at a restricted range of time in the afternoon to control for time of day effects, repeated measurements and continuous measures of time of day recorded at the exact time throughout the day and across days is a more optimal approach to characterize the diurnal rhythm, stability, and reliability of cortisol. Future longitudinal studies with larger and more representative community samples, objective behavioral measures of shyness, and repeated measurement of cortisol throughout, continuous measures of time of day recorded and across days at the same time of day are needed in order to ensure the reliability and generalizability of the results.

Conclusion and Implications

We found that shyness and sociability were largely orthogonal traits that were also separable on neurocognitive attentional indices to novelty in adults. These findings extend early studies which have reported the independence of shyness and sociability across a range of behavioral and physiological measures in child, adult, and clinical samples. It is also important to note that we found dissimilarities between our recent study of neurocognitive correlates of shyness and sociability (Tang et al., 2016) and the present study of adults across different scalp sites and auditory oddball conditions. We speculate that these dissimilarities possibly reflect developmental brain changes in the processing of non-social auditory stimuli in shyness. Our findings also suggest that low baseline cortisol may serve as a putative link involved in the maintenance of shyness and central states of avoidance to threat and novelty and emotional arousability in adults.

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Supplemental Material

Internal consistencies of the N200 and P300

Internal consistencies of the N200 and P300 amplitudes and latencies among scalp sites were tested within each condition using Pearson correlations. High internal consistencies in ERP measurements are evident in strong positive correlations for amplitudes and latencies among scalp sites within each condition for the N200 and P300 components separately (see Supplemental Table 3.1).

Supplemental Table 3.1. Pearson correlations displaying internal consistencies of amplitudes and latencies of the N200 (A) and P300 (B) across sites within each condition

(A)		**N200 Amplitude**				**N200 Latency**			
		Fz	FCz	Cz	Pz	Fz	FCz	Cz	Pz
Target	Fz	--	.89**	.73**	.57**	--	.96**	.92**	.93**
	FCz		--	.93**	.61**		--	.96**	.88**
	Cz			--	.68**			--	.88**
	Pz				--				--
Novel	Fz	--	.92**	.76**	.57**	--	.97**	.84**	.69**
	FCz		--	.91**	.70**		--	.87**	.68**
	Cz			--	.83**			--	.71**
	Pz				--				--
Standard	Fz	--	.92**	.81**	.61**	--	.80**	.48**	.50**
	FCz		--	.94**	.71**		--	.62**	.70**
	Cz			--	.81**			--	.62**
	Pz				--				--
(B)		**P300 Amplitude**				**P300 Latency**			
		Fz	FCz	Cz	Pz	Fz	FCz	Cz	Pz
Target	Fz	--	.96**	.89**	.82**	--	.96**	.86**	.69**
	FCz		--	.97**	.87**		--	.89**	.70**
	Cz			--	.89**			--	.82**
	Pz				--				--
Novel	Fz	--	.96**	.89**	.66**	--	.80**	.71**	.52**
	FCz		--	.96**	.75**		--	.88**	.61**
	Cz			--	.83**			--	.71**
	Pz				--				--
Standard	Fz	--	.93**	.80**	.52**	--	.79**	.77**	.48**
	FCz		--	.94**	.66**		--	.90**	.69**
	Cz			--	.78**			--	.72**
	Pz				--				--

Note. $p^{**} < .01$, two-tailed.

Descriptive Analyses of the N200 and P300

To examine the relations between scalp sites and conditions of the N200 and P300 components, two-way repeated measures ANOVAs with three conditions (target, novel, standard) and four scalp sites (Fz, FCz, Cz, Pz) as within-subjects factors were performed for the N200 and P300 amplitude and latency separately. Mauchly's test of sphericity indicated whether the sphericity assumption was violated, and when violated, *df*s were adjusted with Huynh-Feldt's epsilon. Post-hoc analyses included one-way repeated measures ANOVAs and pair-wise comparisons using Tukey's Least Significant Difference tests.

For the N200 amplitudes, a site by condition interaction emerged, $F(3.91, 113.30)= 11.60$, $p < .001$. Decomposing the interaction in the target condition: more negative N200 amplitudes were elicited at Fz ($M= –1.90$; $SE= .25$) and FCz ($M= –2.04$; $SE= .31$) relative to Cz ($M= –1.38$; $SE= .30$), and Pz ($M= –.20$; $SE= .19$). Likewise, more negative N200 amplitudes were elicited at Cz than Pz. In the novel condition, more negative N200 amplitudes were elicited at FCz ($M= –2.31$; $SE= .25$) relative to Fz ($M= –2.07$; $SE=.24$), Cz ($M= –1.95$; $SE= .25$), and Pz ($M= –1.05$; $SE= .20$). Less negative N200 amplitudes were elicited to novel tones at Pz relative to Fz and Cz. Lastly, in the standard condition, more negative N200 amplitudes were elicited at Fz ($M= –.75$; $SE= .14$), FCz ($M= –.86$; $SE= .14$), and Cz ($M= –.77$; $SE= .13$) relative to Pz ($M= –.52$; $SE= .09$); and more negative amplitudes were elicited at FCz compared to Fz. In summary, N200 amplitudes to all three conditions were maximal at fronto-central midline scalp sites, converging with the fronto-central distribution and the source in the anterior cingulate (Van Veen & Carter, 2002).

For N200 latencies, a site by condition interaction emerged, $F(4.89,141.82)= 3.57$, $p = .005$. N200 latencies among sites were not different in the target and novel conditions. However, in the standard condition, N200 latencies at Fz (*M*= 275.04; *SE*=7.73) were faster than FCz (*M*= 284.86; *SE*=6.81), Cz (*M*=292.17; *SE*=6.24), and Pz (*M*=297.31; *SE*=7.10); N200 latencies at FCz were also faster than Pz.

For the P300 amplitudes, a site by condition interaction emerged, $F(4.009, 140.332) = 22.486$, $p < .001$. Decomposing the interaction in the target condition: higher P300 amplitudes were elicited at Pz (*M*= 4.67; *SE*=.32) relative to Fz (*M*= 3.22; *SE*=.32), FCz (*M*= 3.8; *SE*=.39), and Cz (*M*= 4.23; *SE*=.38); higher amplitudes were elicited at Cz compared to Fz, and FCz; Higher amplitudes were elicited at FCz compared to Fz. In the novel condition: higher P300 amplitudes were elicited at Pz (*M*= 5.30; *SE*=.31) compared to Fz (*M*= 3.71; *SE*=.32), and FCz (*M*= 4.47; *SE*=.39); higher amplitudes were elicited at Cz (*M*= 4.94; *SE*=.39) compared to Fz, and FCz; higher P300 amplitudes were elicited at FCz compared to Fz. Thus, in both the target and novel conditions, increasingly higher P300 amplitudes were observed, moving from frontal to parietal scalp sites. However, this pattern was reversed in the standard condition, as reduced P300 amplitudes were elicited at Pz (*M*= 1.06; *SE*=.07) compared to Fz (*M*= 1.40; *SE*=.12), FCz (*M*= 1.40; *SE*=.11), and Cz (*M*= 1.28; *SE*=.10); and reduced P300 amplitudes were elicited at Cz compared to FCz. Overall, the higher target P300 amplitudes at posterior scalp sites is consistent with the literature (Johnstone et al., 1996; Polich, 2007), and higher novelty P300 amplitudes at parietal sites is consistent with our prior study in children (Tang et al., 2016) and across development (Cycowicz et al., 1996), even though others have found that it is frontally distributed in adults (Fabiani & Freidman, 1995; Kazmerski & Friedman, 1995).

For P300 latencies, main effects of condition emerged [$F(2, 70) = 62.57$, $p < .01$]. Faster P300 latencies were elicited in the target (*M*=325.35; *SE*=11.75) compared to novel (*M*=374.35;

SE=12.32) and standard (*M*=507.174; *SE*=12.389) conditions; faster P300 latencies were also elicited in the novel than standard condition.

Supplemental Table 3.2. List of measures and number of participants included in the analyses for that measure

Measure	*N* =48, total
Shyness	48
Sociability	45
Emotionality	48
Baseline cortisol	36
Target N200 Fz	37
Target N200 FCz	37
Target N200 Cz	37
Target N200 Pz	37
Novel N200 Fz	39
Novel N200 FCz	39
Novel N200 Cz	39
Novel N200 Pz	39
Standard N200 Fz	35
Standard N200 FCz	35
Standard N200 Cz	35
Standard N200 Pz	35
Target P300 Fz	39
Target P300 FCz	39
Target P300 Cz	39
Target P300 Pz	39
Novel P300 Fz	40
Novel P300 FCz	40
Novel P300 Cz	40
Novel P300 Pz	40
Standard P300 Fz	39
Standard P300 FCz	39
Standard P300 Cz	39
Standard P300 Pz	39

Relation among Shyness, Sociability, and the Auditory Oddball N200 and P300 Latencies

Supplemental Table 3.3 displays partial correlations for shyness (accounting for variance in sociability) and sociability (accounting for variance in shyness) to target (A), novelty (B), and standard (C) stimuli for the N200 and P300 latencies. Shyness and sociability were not related to N200 or P300 latencies, with the exception that higher sociability was related to faster P300 latencies at Cz to target tones.

Supplemental Table 3.3. Partial correlations among shyness (accounting for variance in sociability), sociability (accounting for variance in shyness), and the target (A), novelty (B), and standard (C) N200 and P300 latencies across four scalp sites

(A) Target		**N200 latency(ms)**				**P300 latency (ms)**		
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	.06	–.08	209.18	54.23	.03	–.24	334.21	89.38
FCz	.15	–.13	209.44	56.51	.08	–.31	326.65	81.13
Cz	.16	–.13	210.87	59.92	–.02	–.35*	336.01	89.71
Pz	.10	–.10	210.92	62.64	–.11	–.33ǂ	342.58	88.91
(B) Novelty		**N200 latency(ms)**				**P300 latency (ms)**		
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	.11	.04	214.17	43.8	.05	0	365.75	79.03
FCz	.14	.07	211.03	41.75	.11	–.03	380.73	92.28
Cz	.24	.19	214.18	45.75	.17	.13	375.85	89.66
Pz	.08	.02	204.71	46.04	.10	–.05	385.58	80.41
(C) Standard		**N200 latency(ms)**				**P300 latency (ms)**		
Site	Shyness	Sociability	*M*	*SD*	Shyness	Sociability	*M*	*SD*
Fz	–.11	.12	275.04	45.74	.21	.16	510.64	83.84
FCz	–.30	.18	284.86	40.26	.09	.17	505.48	87.34
Cz	–.14	.35	292.17	36.93	–.01	.15	516.15	78.98
Pz	–.35	–.03	297.31	42.02	–.18	.14	495.03	94.80

Note. p* < .05, pǂ < .09, two-tailed.

Relations among Shyness, Emotionality, Cortisol, and Behavioral Performance

To examine whether ERP amplitudes were associated with behavioral performance, additional bivariate Pearson correlations between error rates and P300 amplitudes in corresponding conditions were performed (Supplemental Table 3.4). Reduced novelty P300 amplitudes at all four scalp sites negatively correlated with increased error rates to novel tones (false alarms), r's= –.44 to –.52, p's = < .01. However, it is unclear whether reduced novelty P300 amplitudes can be stated as poorer performance, given the accuracy across all three conditions was ceiling with minimal variability. Additional bivariate Pearson correlations assessed relations among behavioral performance in each condition, shyness, emotionality, and basal cortisol (see Supplemental Table 3.5). In spite of the ceiling performance, some interesting trends emerged demonstrating links among increased shyness, emotionality, and increased accuracy in identifying target tones, converging with their known self-presentation anxiety and fear of negative evaluation to perform well: increased shyness and emotionality correlated with decreased error rates to target tones (misses), $r = –0.29$, $p = .067$ and $r = –0.30$, $p = .053$, respectively; and decreased baseline cortisol correlated with decreased error rates to target tones, $r = 0.31$, $p = .085$.

Supplemental Table 3.4. Pearson correlations displaying strengths of association between P300 ERP amplitudes and performance within each condition

	P300 Amplitude (μV)						
	Fz	FCz	Cz	Pz	Range (min- max)	*M*	*SD*
# errors to target	.04	.02	.01	.24	(0 - 6)	1.17	1.55
# errors to novel	–.52**	–.49**	–.52**	–.44**	(0 - 8)	2.35	2.33
# errors to standard	–.25	–.25	–.24	–.19	(0 - 21)	.69	3.26
Target reaction time (ms)	–.27	–.20	–.21	–.26	(226.78 - 595.13)	432.76	84.53

Note. **p < 0.001, two-tailed.

Supplemental Table 3.5. Pearson correlations among shyness, emotionality, baseline cortisol, and behavioral performance

	Shyness	Emotionality	Baseline cortisol
# errors to target	–.29ǂ	–.30ǂ	.31ǂ
# errors to novel	.05	–.09	–.25
# errors to standard	.05	–.05	.29
Target reaction time (ms)	.02	.06	–.01

Note. pǂ < .09, two-tailed.

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CHAPTER 4

Study 4: Electrocortical Mechanisms in Processing Social Exclusion and Shyness Subtypes

Tang, A., Lahat, A., Crowley, M.J., Wu, J., & Schmidt, L.A. (In preparation). Event-related neural oscillations to social exclusion in shyness and sociability among children, adolescents, and adults: Associations with social anxiety and substance use.

Abstract

Although neural correlates of social exclusion have been documented, no studies have directly compared individual differences in age, personality or psychological outcomes as a function of oscillatory EEG brain dynamics in response to social exclusion. During adolescence people increasingly value social relationships. Related brain maturation provides a critical age window in understanding the effects of social exclusion. Shyness has also been linked to peer victimization and internalizing problems across childhood and adolescence, but different subtypes of shyness have not been compared. This study directly compared event-related dynamics of theta EEG power and phase coherence to conditions of fair play and social exclusion in the Cyberball task across children (ages 10-12; *n*= 42), adolescents (ages 14-16; *n*= 53) and adults (ages 17-28; *n*= 71). The relation between variations in shyness and sociability and these neural indices were also examined. We found that children and adolescents elicited the highest theta power to rejection events, whereas adults elicited the highest theta power to "not my turn" events. Moreover, theta response to rejection was positively correlated with self-reported distress across the entire sample, but this relation was strongest in adolescents. We also found that substance-use and fear of negative evaluation in individuals characterized by conflicted shyness (i.e., high shyness and high sociability) were moderated by high levels of theta response to rejection. These findings suggest that adolescents are sensitive to distress from

social exclusion. As well, these findings identify individuals at risk for developing psychological problems by considering subtypes of shyness combined with neural indices of distress to rejection.

Introduction

Shyness and sociability are personality traits conceptualized as distinct social motivational behavioral tendencies (Asendorpf, 1990; Cheek & Buss, 1981; Schmidt & Buss, 2010). Shyness is linked to social withdraw-related tendencies in social situations, including an active avoidance and anxious self-preoccupation in response to real or imagined social interactions, whereas sociability is linked to social approach tendencies or a preference to be with others rather than being alone. The independence of shyness and sociability is supported by findings of distinct psychophysiological correlates across humans and non-human animals. In humans, across development, the dissociation of shyness and sociability is documented in studies of children (Asendorpf & Meier, 1993; Coplan & Armer, 2007; Coplan, Prakash, O'Neil, & Armer, 2004; Tang et al., 2016), adolescents (Mounts, Valentiner, Andrerson, & Boswell, 2006; Page, 1990), and adults (Eisenberg, Fabes, & Murphy, 1995; Sheeks & Birchmeier, 2007; Tang et al., 2014; 2016a), and across cultures (German, Czeschik & Nurk, 1995; Portugese, Neto, 1996; Asian, Hussein, Fathy, Mawla, Zyada, & Hadidy, 2011). In nonhuman animals, shyness and sociability are differentially captured as timid and bold behavioral tendencies (see Reale, Reader, Sol, McDougall, & Dingemanse, 2007).

Researchers have examined at least two subtypes of shy individuals moderated by high and low levels of sociability: 1) socially conflicted (SC) shyness and 2) socially avoidant (SA) shyness. SC shy individuals tend to be both shy and sociable, with conflicting inhibition and desires for social interactions. In contrast, SA shy individuals tend to be shy and unsociable and characterized by more withdraw-related behaviors (e.g., Coplan et al., 2004).

The predictive value of these shyness subtypes is evidenced by profiles of different behavior during social interaction, divergent psychological outcomes, and differing patterns of psychophysiological reactivity across development (see Schmidt & Buss, 2010; Schmidt & Miskovic, 2014, for reviews). For example, compared to their SA counterparts, SC individuals experience more anxious behavior during social interactions in childhood and adulthood (Asendorpf & Meier, 1993; Cheek & Buss, 1981; Coplan et al., 2004), and more anxiety and/or fear of negative evaluation (Fox et al., 1995; Nelson, 2013), and perceive that they contribute less to social interactions in adulthood (Arkin & Grove, 1990). In terms of mental health factors, SC individuals exhibit more internalizing and externalizing problems in early childhood (Kopala-Sibley & Klein, 2016), higher levels of neuroticism in middle childhood (Tang et al., 2016a) and more social anxiety in adulthood (Poole, Van Lieshout, & Schmidt, 2017). SC individuals also tend to engage in more substance-use and abuse in adolescence (Page, 1990) and adulthood (Santesso, Schmidt, & Fox, 2004; Poole, Van Lieshout & Schmidt, under review). In contrast, the SA subtype is known to be socially isolated in childhood (Coplan et al., 2004) and to have problems related to their social withdrawal. For example, SA adults report more self-harm behaviors and suicidal ideation (Nelson, 2013) and more problematic uses of the internet (i.e., playing violent video games, watching pornography, and online gambling), which in turn mediate later socially withdrawn behaviors, as well as externalizing behaviors, such as using illegal drugs, shoplifting, and smoking (Nelson, Coyne, Howard, & Clifford, 2016).

At a psychophysiological level, SC individuals present with a unique profile. Data indicate that socially conflicted children exhibit an autonomic pattern of higher heart rate and lower vagal tone (i.e., indicative of hyperaroused sympathetic reactivity and poor emotion regulation) in their everyday environments (Asendorpf & Meier, 1993). This autonomic pattern has been similarly observed in socially conflicted shy young adults during the anticipation of unfamiliar social interactions, compared to their SA counterparts (Schmidt & Fox, 1994). Both SC and SA adults exhibit greater relative right frontal electroencephalographic (EEG) asymmetry at rest, but socially conflicted adults also exhibited greater overall left frontal activity compared those who were socially avoidant (Schmidt, 1999). This EEG asymmetry pattern is consistent with the motivational tendencies in these two subtypes, since greater right frontal EEG asymmetry is related to negative affect and withdraw-related behaviors linked to shyness, while greater left frontal EEG asymmetry is related to positive affect and approach behaviors linked to sociability. Replication of similar frontal EEG asymmetry patterns at rest have been documented across clinical samples and across cultures (Hussein et al., 2011; Jetha, Schmidt, & Goldberg, 2009). However, beyond these descriptive psychophysiological correlates, few studies have examined how these brain measures might shape the psychological outcomes in these shyness subtypes (e.g., Tang, Santesso, Segalowitz, & Schmidt, 2016a; Tang, Santesso, Schulkin, Segalowitz, & Schmidt, 2016b), or how laboratory social challenges, such as social exclusion, might elicit different patterns of cortical reactivity and psychological outcome.

Given the central role of peer victimization (in varying forms) in the persistent cycle of internalizing problems and further victimization (Reijntjes, Kamphuis, Prinzie, & Telch, 2010), particularly among shy and socially withdrawn children and adolescents, examining brain correlates of social exclusion among different shy individuals would shed light on how they cope with social distress. Shy and socially withdrawn children and adolescents who are socially excluded have a higher risk for internalizing problems and social avoidance (Gazelle & Ladd, 2003; Gazelle & Rudolph, 2004; Ladd, 2006). Indeed, longitudinal studies show that peer victimization mediates children's social withdrawal and later loneliness; while loneliness reinforces further victimization, depressive mood and social withdrawal (Boivin, Hymel, & Bukowski, 1995). Peer victimization also reinforces a shy and socially withdrawn developmental pathway: individuals in an increasing socially withdrawn/shy trajectory across middle childhood to adulthood consistently report experiencing more peer victimization, exclusion and loneliness, compared to individuals in a stably non-shy trajectory (Booth-Laforce & Oxford, 2008; Booth-LaForce et al., 2012; Tang et al., in press). Heightened and/or negative emotional and neural responses to social exclusion and social evaluation have been observed in individuals characterized by shyness (Howarth, Guyer, & Perez-Edgar, 2012) and a behaviorally inhibited temperament involving negative reactivity to both social and non-social situations (Guyer et al., 2014; Lahat et al., 2014; Walker, Henderson, Degnan, Penela, & Fox, 2013), as well as high rejection sensitivity (Masten et al., 2009) and a history of rejection during childhood (Will, van Lier, Crone, & Güroğlu, 2016). These findings suggest that the way shy individuals processes social exclusion may be linked to their different outcomes.

To understand the neural underpinnings of social exclusion, studies have experimentally induced feelings of exclusion using Cyberball, an online virtual ball-tossing game. In Cyberball, the participant plays with two other presumably real participants, who are in fact virtual players. Initially, the study participant is included in the game (i.e., the ball is tossed to the player as well as to the other players) but ultimately excluded by other players (i.e., the ball is tossed between the other two players and not to the participant). Hundreds of studies document the mildly distressing effects of Cyberball (see meta-analysis, Hartgerink, van Beest, Wicherts, & Williams, 2015).

In understanding the neural regions in processing social exclusion, recent meta-analyses of fMRI Cyberball studies in healthy children, adolescents, and adults find that social exclusion reliably engages brain regions that underlie social uncertainty, rumination, and distress including the anterior insula (AI), anterior cingulate cortex (ACC) and orbital prefrontal cortex (PFC) (Cacioppo et al., 2013). Moreover, self-reported distress during the game is associated with ACC activity, with the ventral ACC (vACC) being more reliably activated to rejection in children than adults (Rotge et al., 2014). The vACC is thought to regulate negative emotions (Etkin, Egner, & Kalish, 2011). In adolescents, stronger negative feelings to rejection were associated with increased vACC engagement (Sebastian, Viding, Williams, & Blakemore, 2010; Sebastian et al., 2011).

Studies examining temporal neuroelectric activity to social exclusion in the Cyberball with EEG techniques find that a slow wave ERP (450 to 900 ms) to rejection is elicited at left frontal to frontal-central scalp sites in adults, children, and youth (Crowley et al., 2009; Crowley, Wu, Molfese, & Mayes, 2010; White et al. 2012; Sreekrishnan et al., 2014). Moreover, a more negative frontal slow wave to rejection is associated with higher self-reported distress during the game (Crowley et al., 2009, 2010; White et al., 2012, Sreekrishnan et al., 2014; but see Baddam et al., 2016).

ERPs are, however, limited to average phase locked EEG activity reflecting only the time domain, but not the frequency domain. This averaging procedure removes information pertaining to the event-related EEG oscillatory dynamics in different frequency ranges, which have been proposed to underlie the ERPs, and masks the phase-locking and power contributions (Basar, 1980, 1992, 1998). It has been proposed that spontaneous EEG oscillations in different frequency ranges are usually active and uncorrelated, but they become synchronized in some frequency ranges when evoked by internal or external stimulation (Basar, 1980). These oscillatory potentials linked to external or internal events are event-related oscillations (Yordanova & Kolev, 2008), which provide information that more closely reflects the activity of underlying neuronal assemblies. In each frequency range, there are two indices of such event-related reorganization of spontaneous EEG. The first, event-related spectral perturbation (ERSP) indexes power changes in the post-stimulus interval relative a prestimulus baseline. The second, inter-trial coherence (ITC), indexes the consistency in which EEG oscillations become phase aligned following stimulation across trials, independent of power changes (Makeig, Debner, Onton, & Delorme, 2004). Thus, ITC reflects the degree to which an event induces changes in phase synchrony or the phase re-ordering of ongoing oscillations, with values from zero to one reflecting the degree of association across trials. ITC measured at single locations, as in this study, reflects temporal coherence across trials.

Studies examining non phase-locked EEG oscillatory activity in the Cyberball have shown that children (Van Noordt, White, Wu, Mayes, & Crowley, 2015) and adults (Cristofori et al., 2013) elicit greater spectral power of the theta frequency band (4 to7 Hz) to rejection events, with higher theta spectral power to rejection correlated with higher self-reported distress in children (Van Noordt et al., 2015). Increases in theta oscillatory power has also been linked to cognitive control, salience and error detection, emotion regulation, and attention and memory processes (Buzsaki & Moser, 2013; Cavanagh, Zambrano-Vazquez, & Allen, 2012; Crowley et al., 2014; Ergen et al., 2014; Ma, Liu, & Chen, 2015; Mu, Fan, Mao, & Han, 2008; Nigbur, Cohen, Ridderinkhof, & Sturmer, 2007; Yordanova & Kolev, 2008). Converging with these findings and the fMRI literature, the ACC and AI, regions for processing emotions and uncertainty, have been identified as neural sources of theta oscillations during rejection in

Cyberball and other social rejection tasks using intracranial electrode recording (Cristofori et al, 2013) and source localization (Van der Molen, Dekkers, Westenberg, Van der Veen, & Van der Molen, 2016) techniques. Beyond state and condition EEG effects, no studies to date have reported on individual differences in age, personality or psychological outcomes as a function of oscillatory brain dynamics in response to social exclusion.

The Present Study

We examined both ERSP and ITC of the EEG theta frequency band during the Cyberball task in healthy samples of children, adolescents, and adults. Our study had three goals. First, we examined whether age was related to the processing of social exclusion and subjective ratings during the game (i.e., distress and fear of negative evaluation). Second, we examined whether shyness and sociability were related to the processing of social exclusion and subjective ratings during the game. Third, to the extent that individuals processed social exclusion differently, we examined whether such differences were linked to different psychological outcomes in two shyness subtypes (i.e., conflicted and avoidant shyness).

Given that adolescence is a period associated with increased value and awareness of social relationships and social fears (Beidel & Alfano, 2011) and significant changes in brain development and social-affective processing (Crone & Dahl, 2012), we predicted that adolescents, compared to adults and children, would show greater theta spectral power (ERSP) and theta synchrony (ITC) to rejection and report higher distress.

Given that individuals who are high on both shyness and sociability (i.e., conflicted shyness) have been observed to be display more anxious behaviors during social interactions and fear negative evaluation across development (Cheek & Buss, 1981; Coplan et al., 2004; Fox et al., 1995; Nelson, 2013), we predicted that individuals characterized by a combination of high shyness and sociability would report higher distress and fear of negative evaluation during Cyberball. Moreover we expected they would show and greater theta spectral power and theta synchrony responses to rejection. Finally, given interactions between shyness and sociability we examined whether theta neural indices of rejection moderated the known outcomes, such as fear of negative evaluation during the game, social anxiety, and substance and alcohol use , which have been previously linked to the conflicted shy phenotype (e.g., Page, 1990; Poole et al., 2017, under review; Santesso et al., 2004).

Method

Participants

A total of 201 participants, including 58 children (age range= 10-12; *M* age=10.83; *SD*=.82; 20 male), 61 adolescents (age range= 14-16; *M* age= 14.92; *SD*=.90; 24 male), and 82 young adults (age range= 17-28; *M* age= 19.37; *SD*=1.92; 34 male) participated. Young adults were recruited from psychology courses; children and adolescents were recruited from a large database that contained birth records of children born within the McMaster University Medical Center and St. Joseph's Hospital (Hamilton, Ontario). The ethnic composition of this sample was 69.5 % Caucasian, 14.5% Asian, 13.5% South East Asian, 1% Hispanic, and .5% African. There were no systematic differences in participant sex across age groups, $\chi^2(2)= .59$, $p=.75$. Consent was obtained from young adults, and consent and assent were obtained from parents of children and adolescents. The experiment was conducted with approval from the McMaster University Research Ethics Board. Children and adolescents received $30, whereas young adults received either $30 or $25 plus a course credit for their participation.

Measures of Temperament, Social Anxiety, and Substance Use

Shyness and Sociability. Young adult's shyness and sociability were self-reported using the five highest loaded (Bruch et al., 1989) shyness items from the original Cheek and Buss Shyness Scale (1981) and the 5 item Cheek and Buss Sociability Scale (Cheek & Buss, 1981). The original scale for adults has a reported alpha coefficient of .79. Examples of shyness and sociability items include “I find it hard to talk to strangers” and “I like to be with people”, respectively. Items were scored on a 5-point scale (*0* = not at all characteristic; *4* = extremely characteristic).

Children and Adolescents' shyness and sociability were parent-reported using the Colorado Child Temperament Inventory (CCTI; Buss & Plomin, 1984; Rowe & Plomin, 1977). The CCTI contains 30 items to assess six temperamental dimensions, however, only the shyness and sociability subscales were used in this study. Examples of shyness and sociability items include, "child tends to be shy" and "child prefers playing with others rather than alone", respectively. Items were scored on a 5-point scale (*0*= not at all/ strongly disagree; *4*= a lot/ strongly agree).

To obtain common measures of shyness and sociability for comparisons across age groups, scores of shyness and sociability were z-scored to normalize them and aggregated across age groups.

Social Anxiety. Adults completed the Liebowitz Social Anxiety Scale (LSAS; Liebowitz, 1987). The LSAS probes one's anxiety and avoidance in 24 social situations. Each situation is rated on a 4 point scale (anxiety: *0*= none; *3*= severe, avoidance: *0*= never; *3*= usually). A cut-off score (≥ 60) has been determined to be associated with generalized social anxiety disorder (SAD) in a previous study (Mennin et al., 2002) and used to create a binary variable. Children and adolescents' social anxiety symptoms were parent-reported using the 41-item Screen for

Child Anxiety Related Emotional Disorders (SCARED; Birmaher et al., 1999) that assessed five distinct aspects of anxiety symptoms (e.g., panic, generalized anxiety, social anxiety). The social anxiety subscale was of particular interest in this study. Examples of items linked to social anxiety include, "My child feels nervous with people he/she doesn't know well" and "My child worries about other people liking him/her". Items were scored on a 3-point scale (*0*= not true/ hardly ever true; *2*= true/ often true). A binary variable of whether the child or adolescent had generalized social anxiety was created using a cut-off score (≥ 8). The binary variables from the LSAS and SCARED that indicated clinically significant levels of generalized social anxiety was aggregated across age groups. Likewise, to obtain a common continuous measure of social anxiety across age groups, scores were z-scored and normalized on the LSAS and the social anxiety subscale of the SCARED were aggregated across age groups.

Substance- and Alcohol Use. Adolescents and Adults completed a subset of questions from the Youth Risk Behavior Surveillance System (Brener et al. 2013), a self-report national survey developed by the Centers for Disease Control and Prevention (Atlanta, GA) administered to youth and young adults in public high schools of the United States. Here, we assessed the lifetime and/or current prevalence of one of the six categories of health-risk behaviors, substance- and alcohol- use. The questions for substance- and alcohol-use probed the number of uses or days one engaged in alcohol use, binge drinking (≥ 5 drinks in a row), uses of marijuana, cocaine, inhalants/ sprays/ glue, and other illegal drugs in the past 30 days (i.e., current use) and in their life (i.e., lifetime use). These questions were originally rated on different ordinal scales (e.g., *1*= 0 days to *7*= 20 or more days; *1*= 0 times to *6*= 40 or more times), but transformed into dichotomous variables of prevalence (see Brener et al., 2013). For example, the variable of current binge drinking- having five or more alcoholic drinks in a row at least one day in the past

30 days- was dummy coded as *1*=yes, *0*= no. Other variables include current and lifetime alcohol use- at least one drink in the past 30 days and during life; current and lifetime substance use- used marijuana, cocaine, inhalants, sprays, glue, or other illegal drugs at least once in the past 30 days and during life.

Depressive Mood. Young adults completed the Adult Temperament Questionnaire (Evans & Rothbart, 2007). The sadness subscale measured negative affect and lowered mood and energy linked to exposure to suffering, disappointment, and object loss. Example of an item is "sometimes minor events cause me to feel intense sadness". Items are scored on a 7-point scale (*1*= Extremely untrue; *7*= Extremely true). Likewise, children and adolescents completed the Early Adolescent Temperament Questionnaire (Capaldi & Rothbart, 1992). The depressive mood subscale measured unpleasant affect and lowered mood, loss of enjoyment and interest in activities. An example is "I hardly ever feel sad (reversed)". Items are scored on a 5-point scale (*1*= Almost always untrue; *5*= Almost always true). To obtain a common measure of depressive mood across age groups to use as a covariate in analyses, scores on the sadness and depressed scales were z-scored to normalize them and aggregated across age groups.

Social Exclusion Task

Participants were led to believe that they would play an online ball-toss game, Cyberball, with two other players who were playing in other laboratories. In this game, the participant and players passed a white ball amongst themselves, but unbeknownst to the participant, the game was computerized with two other virtual players. Prior to the game, an experimenter took a photograph of the participant to use in the game. While the participant sat in front of a computer, one experimenter pretended to use a telephone to call the other laboratories and told the second experimenter that the other players are ready. Before beginning the game, the participant provided his/her age, sex and ethnicity, which was automatically used by the computer program to match the other players on the screen with similar age, ethnic appearance and sex by drawing from a bank of stock photos of opponent pictures. Next, a Google™ webpage appeared, followed by a "Cyberball" webpage, and a screen with a green "loading" status bar. A female voice narrated the instructions for the participant to choose one of the six gloves and to choose the two opponents with whom he/she wished to play.

When the game began, the participant's glove was at the bottom center of the screen, whereas the gloves of the other two players were at the left and right corners of the screen center. Pictures of the other players as well as that of the participant appeared above their own names and gloves. Participants were instructed to use their right index and middle fingers on a keyboard to respond by pressing 1 and 4 to pass to the right- and left-side players on the screen. When the participants understood how to respond in the game, the experimenters left the room and turned off the lights. Each trial began with the ball in the glove of one of the two players for duration of 1000 to 3000 ms. Before each throw event, the ball disappeared for 500 ms and a yellow outline cue is displayed for another 500 ms around the glove to signal that a throw will occur. In the throw event, the ball would reappear on the path to the receiving player and its color changed to yellow or orange depending on the trial type (visualization of the sequence of events has been reported in van Noordt et al., 2015).

A total of 155 trials were divided into two blocks, fair play and exclusion. The fair play block consisted of 108 trials divided into three types of events: a) There were 36 times when the virtual players threw the ball at each other but not to the participant, which represented "not my turn" events; b) 36 times when the participant threw back to the other players; and c) 36 times when the virtual players threw the ball to the participant; which represented "favor" events. The frequency in which the ball was thrown to the participant during any one trial was pseudo-random and predetermined within a list, such that the participant waited either 0, 1, 2, or 3 throws by the other players before receiving the ball again (event frequency, 12, 12, 10, and 2, respectively). Seamlessly, the fair play block transitioned to the exclusion block with 47 trials, in which the virtual players passed the ball to each other and not to the participant. During the exclusion block, the ball was passed to the participant only three times (on trials 14, 25, 39) to maintain attention to the task. Only 36 "rejection" events in the exclusion block were used in EEG analyses (the first five trials, and the three throws to the participants were excluded).

Immediately after the game, the experimenter asked the participants to follow instructions given by the female voice that narrated items from the Need Threat Scale (NTS; VanBeest & Williams, 2006) and Fear of Negative Evaluation scale (FNE; Crowley & Marquez, 2012) by using the mouse to select their answers. The NTS is a valid and reliable measure that included 21 items to evaluate feelings of distress to being ostracized along four dimensions: belonging, self-esteem, meaningful existence, and control (Crowley et al., 2010; VanBeest & Williams, 2006). Examples of items include: "I felt rejected" and "I felt invisible". Items were rated on a 5-point scale (*1*= Not at all; *5*= Extremely/ a lot). A total score was obtained by summing the four scales to provide an index of ostracism distress that is often used in the literature to link brain correlates to distress during the task. Higher values on this total score represented higher distress.

The FNE is a new scale consisting of 14 items to assess participants' fears and worries about their interaction with and how they appeared to other players during Cyberball (Crowley & Marquez, 2012). Examples of items include: "I worried about seeming foolish to the other players" and "when the other players did not throw to me, I worried about what they thought of me". Items were rated on a 5-point scale (*1*= Not at all; *5*= Extremely/ or a lot). In this sample, this scale had an internal consistency of α= .85.

EEG Data Collection and Analyses

EEG recording and preprocessing. Continuous EEG was collected using a high-density 128 Ag/AgCl electrode Hydrocel net (Electrical Geodesics Incorporated (EGI), Inc.) with Netstation (EGI, Inc.) and high impedance amplifiers, sampled at 250 Hz (.1 Hz high pass, 100 Hz low pass). All electrodes were referenced to the central (Cz) scalp site for recording. Before beginning, impedances at or below 40 kΩ were considered acceptable. The E-prime (Psychology Software Tools, Inc.) software package delivered the stimulus presentation.

EEG data were preprocessed offline in Netstation through a 0.1 Hz first order high-pass filter and a 30 Hz low-pass filter. Continuous EEG data were segmented into 2000 ms epochs with a 700 ms pre-stimulus baseline, and a 1300 ms post-stimulus interval. Eye channels were visually inspected. As well, channels that likely had poor connection to the scalp, either flat (no EEG signal) or those that likely reflected white noise were manually marked as contaminated and interpolated by surrounding channels. Automatic artifact rejection removed segments that contained extreme voltage fluctuations (> 200 µV). Epochs with eye blinks or eye movements (> 150 µV) were rejected. Epochs with more than 10 bad channels (40% or more segments marked as bad) were also rejected. The remaining bad channels were replaced by interpolating from surrounding channels. Statistical eye-blink removal was applied (blink slope threshold= 14 µV /ms; Gratton, Coles, & Donchin, 1983). Bad channels were replaced again by interpolating from surrounding channels. The single trial data were re-referenced from Cz to an average reference of all electrodes for a better representation of a true zero (Junghoter, Elbert, Tucker, & Braun, 1999). The data were baseline corrected to the 700 ms pre-stimulus interval.

Participants who had at least 10 artifact free trials per condition (22 excluded due to inadequate number of trials, 55% of those were children; 7 excluded for lack of EEG recordings due to the system not working; 3 did not complete the task at all) and who were right handed (3 excluded for left handedness) were included in further EEG data analyses (*N*= 166; *n* children= 42; *n* adolescents= 53; *n* young adults= 71).

EEG Time-frequency Decomposition. Theta (4 to 7 Hz) ERSP and ITC were examined in EEGLab version 13.4.4b, MATLab version R2013a. To obtain our scalp regions and temporal range of interest, we first examined the scalp distribution of mean theta ERSP in each age group by each condition (see Supplemental Materials). ERSP changes in scalp regions surrounding the left frontal (F3), frontocentral (FCz), and right parietal (P4) sites were commonly modulated across age groups to rejection from 200 to 600 ms. These space and time distributions were largely consistent with Cyberball studies that have observed theta oscillations to rejection at frontal medial regions (FCz and Cz inclusive) in children (van Noordt et al., 2015), and a slow wave distributed in the frontal-central regions in children (Crowley et al., 2010) and left frontal regions in adults (Crowley et al., 2009). As well as a right posterior cluster found in children (Crowley et al., 2010). To make analyses comparable, the same electrodes were used to examine ITC, which included the FCz and surrounding sites that showed the most prominent ITC changes, but at a different temporal range from 100 to 400 ms (see Supplemental Materials).

Accordingly, we focused on extracting peak ERSP values across F3 (mean of electrodes 18,19, 22, 23, 24), FCz (mean of electrodes 6, 7, 106, 129), and P4 (mean of electrodes 86, 92, 93, 98) clusters at 200 to 400 and 400 to 600 ms using the "*new timef*" function in EEGLab that uses algorithms for implementing a time X frequency spectrogram (Delorme & Makeig, 2004). Peak ITC values were extracted across the same F3, FCz, and P4 clusters at 100 to 400 ms.

ERSP and ITC calculations relied on both fast Fourier Transform (at the lowest frequency) and wavelet decomposition (at the highest frequency). The standard settings in EEGLab were used, cycles set as 3, 0.5, cycles linearly increase with frequency from 0 for fast Fourier Transform (same window width at all frequencies) to 1 for wavelet (same number of cycles at all frequencies). The software uses 3 cycles at lowest frequency to 11.25 cycles at the highest frequency. The time-frequency decomposition yields a time X frequency transform with a complex number for every time point, frequency and trial. ERSP and ITC were obtained at 53 linear-spaced frequencies, 4 to 30 Hz, and 290 linear-spaced time points from -280 to 880 ms relative to the stimulus onset. ERSP and ITC data were collected every 4 ms and every 0.5 Hz. Peak ERSP values were extracted from the pre-computed matrices between 200 to 400ms and 400 to 600 ms and peak ITC values were extracted between 100 to 400 ms for the theta (4 to 7 Hz) frequency band and used in further analyses. Since oscillatory activity from different frequency ranges can be simultaneously generated, with each underlying a specific reactivity to experimental variables (Basar et al, 2000), peak ERSP and ITC in the same time windows and regions for alpha (8 to 13 Hz) and beta (14 to 30 Hz) frequency bands were extracted for further complementary analyses (see Supplemental Materials).

Data Analyses

Task differences. To examine peak theta spectral power across scalp regions, conditions and time windows, a three-way repeated measures analysis of variance (ANOVA) with within-subject factors, scalp clusters (F3, Cz, P4), three conditions (favor, not my turn, exclusion), and two time ranges (200 to 400 ms, 400 to 600 ms) was performed. Likewise, for peak theta ITC, a two-way repeated measures ANOVA with within-subject factors, including the three scalp clusters and three conditions was performed.

Age differences. Given that the initial analysis showed differences in peak theta power at the two time windows (200 to 400 and 400 to 600 ms) across conditions and theta power at the two time windows have been thought to underlie different functions (e.g., Van Noordt et al., 2015), further analyses in examining age effects were separated by the time windows. Three-way repeated measures ANOVAs with three scalp clusters (F3, FCz, P4), three conditions (favor, not my turn, exclusion) as within-subject factors and three age groups (children, adolescents, adults) as the between-subject factor were performed for peak theta spectral power at 200 to 400 ms and at 400 to 600 ms separately. To examine age differences in peak theta ITC at 100 to 400 ms in relation to scalp region and conditions, a three-way repeated measures ANOVA was performed with three scalp clusters and three conditions as within-subject factors and the three age groups as the between-subject factor.

Interactions in ANOVAs were decomposed with two-way and one-way repeated measures ANOVAs and Tukey's least significant difference tests and *t*-tests when appropriate. When the sphericity assumption was violated, *p* values were adjusted with Huynh-Feldt’s epsilon, but *df*s remained unchanged.

Distress to task. A series of Pearson partial correlations were performed to test whether self-reported distress was related to higher theta spectral power across scalp clusters (F3, FCz, P4) and time (200 to 400ms, 400 to 600 ms) to rejection during the Cyberball, while accounting for age. The same set of analyses tested whether distress was related to theta ITC across the three scalp sites at 100 to 400 ms.

Given a positive correlation between frontal medial theta power to rejection and distress emerged across age, a series of Pearson correlations further tested whether this relation was consistent in each age group.

Shyness and Sociability

Because individuals characterized by a combination of high shyness and sociability display more anxious behaviors during social interactions and fear negative evaluation across development (Cheek & Buss, 1981; Coplan et al., 2004; Fox et al., 1995; Nelson, 2013), these individuals were expected to report higher subjective ratings of FNE and distress during Cyberball, and exhibit higher theta power and ITC to rejection. Therefore, the product of shyness and sociability scores from the CCTI for children and adolescents and the Cheek and Buss shyness and sociability scales for adults were separately calculated to create an interaction term of "conflicted shyness", which was then z-scored to normalize the measure and aggregated across age groups to capture the conflicted subtype of shyness (Cheek & Buss, 1981; Tang et al., 2016a). On this conflicted shyness spectrum, low scores represent low levels of conflicting approach and withdraw motivational tendencies (resembling introverts who are neither shy, nor sociable), whereas high scores represent high levels of conflicting approach and withdraw tendencies (resembling the self-consciously shy subtype who are both shy and sociable). A series of partial Pearson correlations were then performed to test whether this conflicted shyness variable was related to higher subjective ratings of FNE and distress, as well as higher theta power across scalp clusters (F3, FCz, P4) and time (200 to 400ms, 400 to 600 ms) and higher theta ITC across the three scalp clusters to rejection, while accounting for age.

Given that interactions between shyness and sociability (i.e., conflicted shyness) were related to theta power, but not ITC, to rejection (i.e., at FCz and P4 at 400 to 600 ms), we further examined whether outcomes such as FNE, social anxiety, and substance and alcohol use that have been linked to the conflicted shy phenotype (e.g., Cheek & Buss, 1981; Page, 1990; Poole et al., 2017, under review; Santesso et al., 2004) were moderated by this neural index. Separate linear and logistic regression models were performed to test our hypothesis that an interaction among high shyness and sociability and heightened neural processing of exclusion would predict outcomes linked to social anxiety (i.e., fear of negative evaluation, social anxiety) and substance-use. To examine this interaction, each outcome was regressed on the three-way interaction among shyness X sociability X frontocentral or right parietal theta spectral power to rejection at 400 to 600 ms, their two-way interactions, main effects, while accounting for age, sex, and depressive mood. These analyses were performed using the PROCESS macro for SPSS (Hayes, 2013), which also generated simple slope tests at low (mean -1 *SD*), moderate (the mean), and high (mean +1 *SD*) levels of the moderators to evaluate conditional effects.

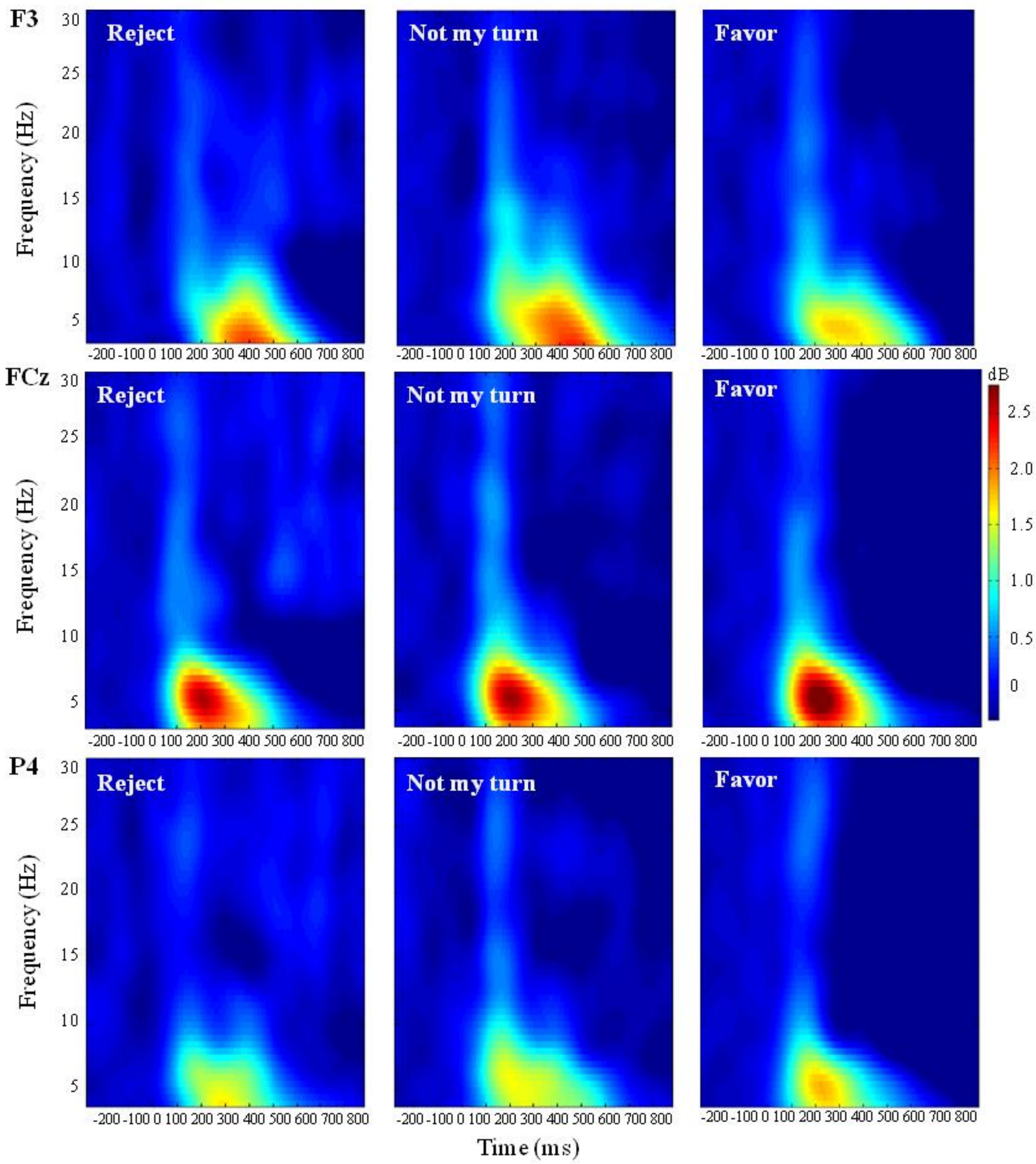
Results

Cyberball Task Differences

Event-related Spectral Perturbations. Theta ERSP changes across the three scalp regions and conditions for the entire sample is visualized in Figure 4.1. The ANOVA revealed a time by region interaction, $F(2,330)= 110.88$, $p <.001$. Decomposing the effect at 200 to 400 ms, there was a region effect, $F(2, 330)= 18.632$, $p <.001$: F3 and FCz elicited higher theta spectral power than P4, although the two frontal sites were not different. At 400 to 600 ms, there was a region effect, $F(2, 330)= 44.70$, $p<.001$: F3 elicited higher theta power than both FCz and P4, although FCz and P4 were not different. The ANOVA model also revealed a time X condition interaction, $F(2,330)= 9.81$, $p<.001$. The condition effect was significant at 400 to 600 ms but not at 200 to 400 ms, $F(2, 330)= 4.95$, $p.008$: higher theta power was elicited to rejection and not my turn compared to favor, but rejection and not my turn were not significantly different.[8]

[8] Similar results were found for alpha ERSP, as higher alpha power was elicited to rejection at 400 to600 ms than favor, though rejection did not differ from not my turn. In contrast, beta

Figure 4.1. Time-frequency plots for event-related spectral perturbations for the three conditions across F3, FCz, and P4 scalp clusters and across the entire sample.

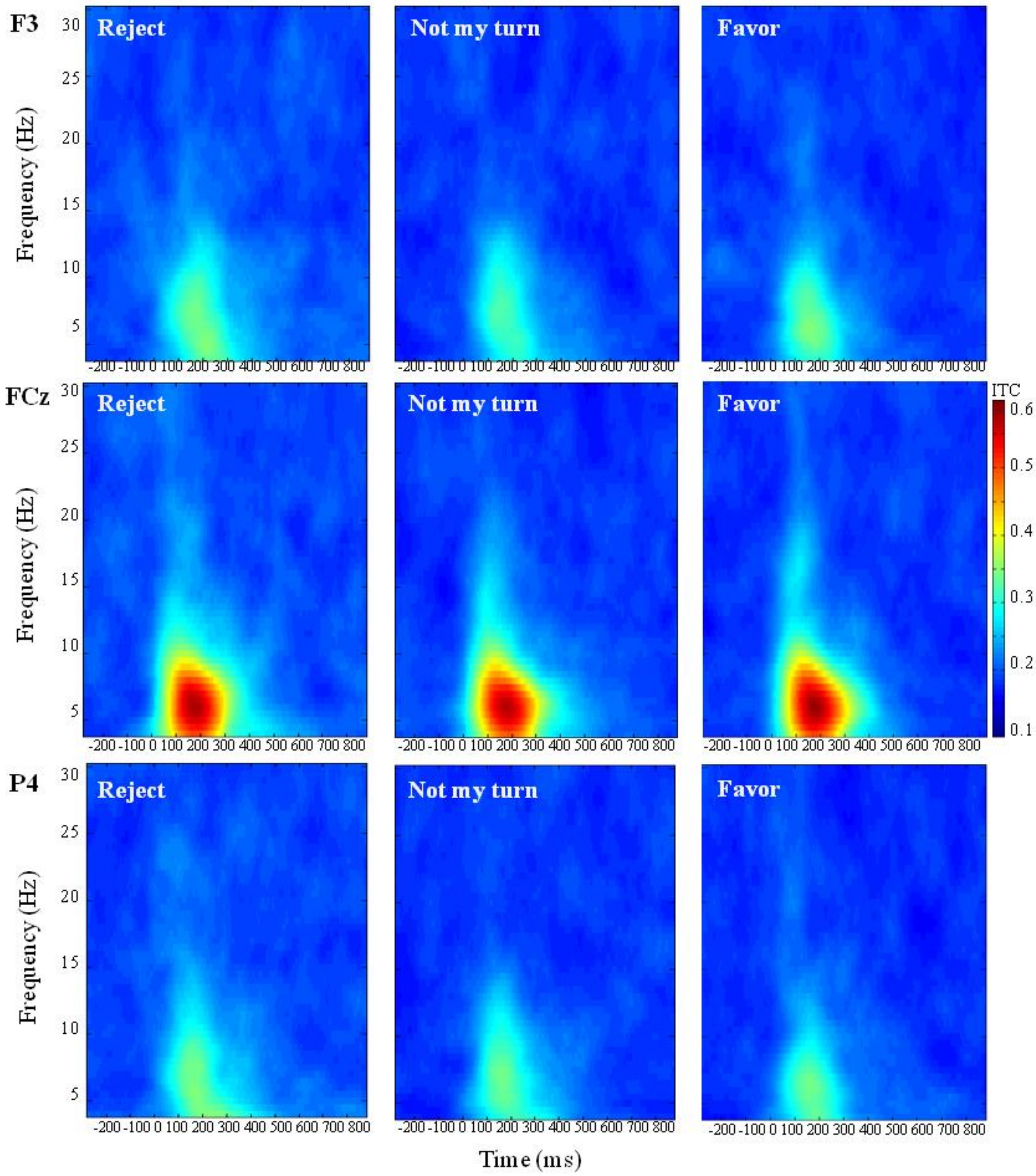


Note. Frequency ranges from 4 to30 Hz (y-axis). Strong changes in spectral power in the theta, 4 to7 Hz, frequency range during 200 to 400 ms (x-axis) is observed. See patterns of theta power scalp distribution in each condition by age group in Supplemental Materials.

ERSP was higher in response to rejection at 400 to 600 ms compared to both not my turn and favor conditions (see Supplemental Table 1).

Inter-Trial Coherence. Theta ITC changes in the three scalp sites and conditions across the entire sample is visualized in Figure 4.2. For theta ITC, the ANOVA revealed a region effect, $F(2, 330) = 162.54$, $p < .001$, with the FCz ($M = .74$; $SE = .014$) cluster eliciting higher theta ITC than both F3 ($M = .53$; $SE = .009$) and P4 ($M = .54$; $SE = .01$), p's <.001. There was also a condition effect, $F(2, 330) = 4.09$, $p = .018$, with higher ITC elicited in rejection ($M = .62$; $SE = -.12$) than in not my turn ($M = .59$; $SE = .011$) and favor ($M = .59$; $SE = .011$) conditions, p's < .02.

Figure 4.2. Time-frequency plots for inter-trial phase coherence for the three conditions across F3, FCz, and P4 scalp clusters and across the entire sample.



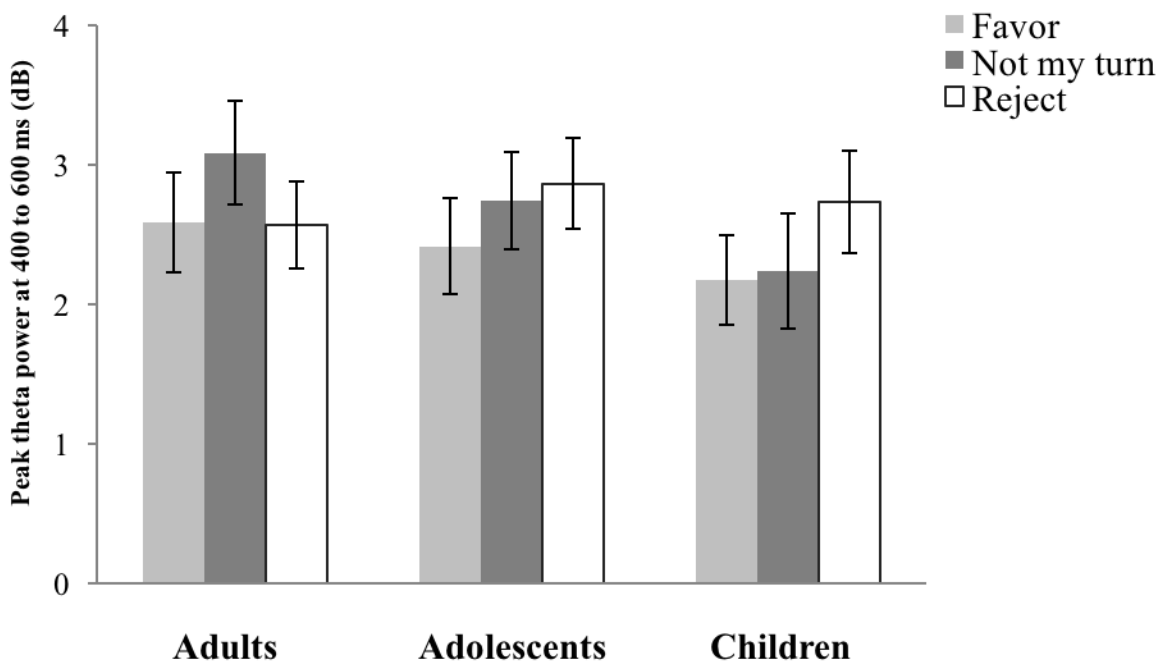
Note. Frequency ranges from 4 to 30 Hz (y-axis). Strong changes in inter-trial coherence (ITC) in the theta, 4 to7 Hz, frequency range during 100 to 400 ms (x-axis) is observed. See patterns of theta ITC scalp distribution in each condition by age group in Supplemental Materials.

Age Differences in Cyberball Task

Event-related Spectral Perturbations. The ANOVA for peak theta spectral power at 200 to 400 ms revealed a region effect, *F*(2, 326)= 18.31, *p* < .001, with FCz (*M*= 3.54; *SE*= .88) eliciting higher theta power than F3 (*M*= 3.25; *SE*= .13) and P4 (*M*=2.85; *SE*=.09), *p*'s < .05. There was, in addition, an age effect, *F*(2, 163)= 6.26, *p*=.002, in which adults (*M*= 3.57; *SE*=.12) elicited higher theta power than both adolescents (*M*=3.20; *SE*= .14) and children (*M*=2.88; *SE*=. 16), *p*'s <.05, but adolescents and children did not differ, *ns*. However, there were no age interactions.

The ANOVA for theta power at 400 to 600 ms revealed a region effect, *F*(2, 326)=38.17, *p*< .001, with higher theta power elicited at F3 (*M*=3.16; *SE*=.14) than FCz (*M*= 2.31; *SE*= .07) and P4 (*M*= 2.33; *SE*= .09). An age by condition interaction also emerged, *F*(4, 326)= 3.67, *p*= .006 (see Figure 4.3): Decomposing the interaction within group: children showed a condition effect, *F*(2, 82)= 4.15, *p*= .02, with higher theta power elicited to rejection than both not my turn and favor conditions, *p*'s < .04. The same condition effect was observed in adolescents, *F*(2, 104)= 2.97, *p*= .056, with higher theta power to rejection than favor, *p*=.019, though theta power to rejection and not my turn were not different, *ns*. Adults, on the other hand, elicited higher theta power to not my turn than favor and rejection, *p's* <.05, but theta power to favor and rejection were not different, *ns*. Decomposing the interaction across groups, an age effect appeared in only not my turn, *F*(2, 163)= 4.70, *p*= .01, in which adults elicited higher theta power than children, *p* = .003, but adults and adolescents were not different, *ns*. No further age differences were found in rejection or favor conditions. Overall, at 400 to 600 ms, children and adolescents elicited the highest theta power to rejection compared to the other conditions, whereas adults elicited the highest theta power to not my turn.[9]

Figure 4.3. Age by condition differences in theta spectral power at 400- 600 ms.



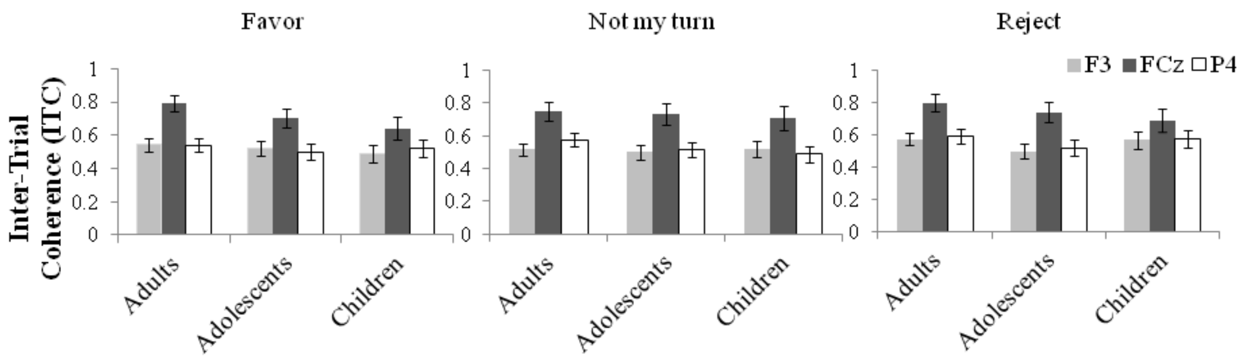
Note. Error bars are 95% confidence intervals.

Inter-Trial Coherence. For theta ITC, there was an age by condition by region interaction, *F*(8,652)= 2.24, *p*=.027. Decomposing the interaction across groups in each condition, an age by region interaction emerged in favor, *F*(4,326)=2.70, *p*=.04, with adults eliciting higher theta ITC at FCz than adolescents, *t*(122)= 2.16, *p*= .03, and children, *t*(111)= 3.50, *p*= .001. An age by region interaction was also marginally significant in the rejection condition, *F*(3, 326)= 2.26, *p*=.06, with adolescents eliciting lower theta ITC to rejection at F3

[9] The same age by condition pattern was found for alpha ERSP at 400 to 600 ms (see Supplemental Table 4.2).

compared to adults, *t*(122)= 2.54, *p*= .012, and children, *t*(93)= 2.20, *p*=.03. Adolescents also elicited lower theta ITC at P4 than adults, *t*(122)= 2.13, *p*= .035 (see Figure 4.4). There was no age by region interaction in not my turn.

Figure 4.4. Age by condition by region interaction for theta ITC at 100 to 400 ms.



Note. Error bars are 95% confidence intervals.

Distress to Social Exclusion

The mean of distress across items on the NTS for the entire sample, *M*= 3.12, *SE*= .05, was similar to other Cyberball studies in samples of children (van Noordt et al., 2015), adolescents and adults (Sebastian et al., 2011). There were no age differences in distress, *F*(2, 195)= .51, *p*=.60.

Partial correlations showed that higher distress was related to higher theta power at FCz to rejection at 400 to 600 ms, while controlling for age (Table 4.1A). To provide discriminant validity, additional analyses showed that distress was unrelated to theta spectral power across scalp clusters and time for favor and not my turn conditions, while accounting for age, *r*'s = - .06 to - .11, *p*'s >.05. This suggested that increases in frontal medial theta spectral power to rejection at 400 to 600 ms is a correlate of social exclusion, irrespective of age.[10] However, when these relations were examined separately in adults, adolescents, and children, stronger correlations between distress and theta spectral power to rejection at 400 to 600 ms and at 200 to 400 ms were evident in adolescents $r(53)= .24$ to 26, p's $< .04$.

In contrast, distress was unrelated to theta ITC across scalp clusters at 100 to 400 ms and conditions, while controlling for age (see Table 4.1B). Distress was also unrelated to theta ITC across scalp clusters to not my turn and favor conditions, r's= - .08 to .07, p's $> .05$.

Shy- Sociable Individuals (i.e., conflicted shyness): Subjective and Electrocortical Responses to Exclusion

Partial correlations among conflicted shyness and subjective and electrocortical responses to exclusion while controlling for age are displayed in Table 4.1. As expected, higher conflicted shyness was related to higher FNE and distress to Cyberball. However, unexpectedly, conflicted shyness was related to lower, rather than higher, theta spectral power to exclusion across FCz and P4 clusters at both 200 to 400 and 400 to 600 ms (Table 4.1A). No relations were revealed at F3 to rejection. Conflicted shyness was also unrelated to theta ITC across scalp clusters at 100 to 400 ms to rejection, while controlling for age (see Table 4.1B).

[10]Given the finding that beta ERSP increased to rejection and was significantly distinguishable from the other two conditions (see the first footnote), additional partial correlations were performed to test whether distress was related to beta ERSP to rejection. Results show an inversed correlational pattern between beta ERSP at F3 to rejection and distress (see Supplemental Table. 4.6), suggesting that theta and beta ERSP to rejection may tap different functions.

Table 4.1. Partial correlations among conflicted shyness, distress, FNE, and (A) theta power to rejection across scalp clusters (F3, FCz, P4) and across time windows (200 to 400, 400 to 600 ms), and (B) theta ITC across scalp clusters at 100 to 400 ms.

			(A) Max theta spectral power to rejection						(B) Max theta ITC to rejection		
			200 to 400ms			400 to 600 ms			100 to400ms		
	Distress	FNE	F3	FCz	P4	F3	FCz	P4	F3	FCz	P4
Distress	--	.69*	0.09	0.11	0.04	0.08	.13*	-0.04	-0.08	0.08	0.03
Conflicted shyness	.13*	.16*	-0.01	-.16*	-.18*	0.05	-.13*	-.12†	0.08	0.00	0.09

Note. One-tailed. **p* <.05, † *p*< .06. FNE= fear of negative evaluation scale. In distress and FNE, *n*= 196, *df*=193. In theta power and ITC, *n*=166, *df*=163.

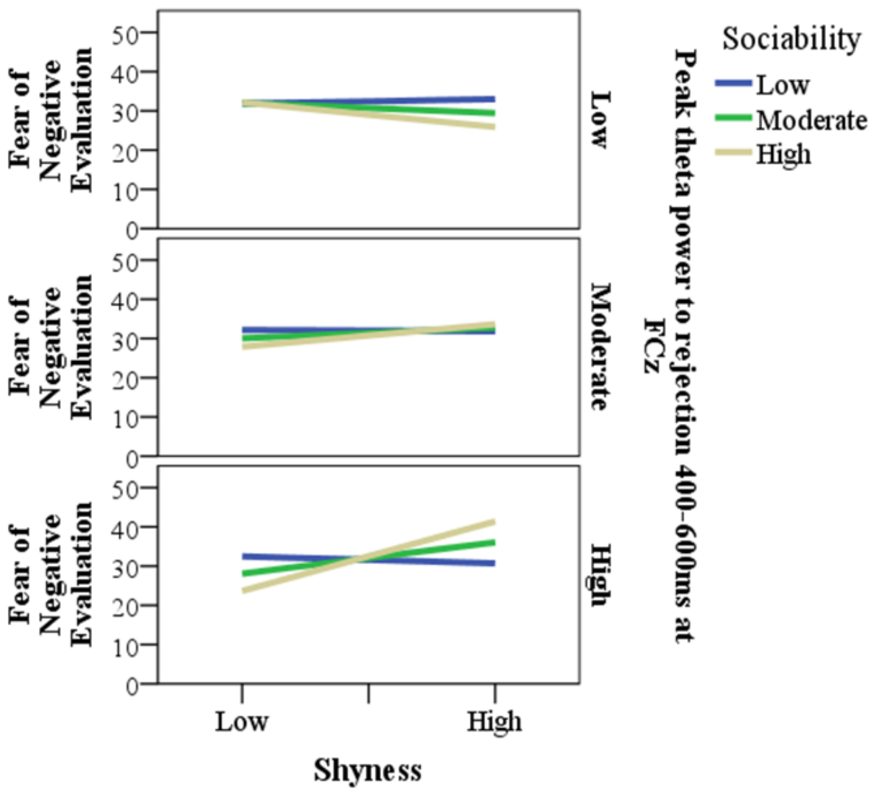
Electrocortical correlates of Social Exclusion as Moderators of Psychological Outcomes in Shy-Sociable Individuals

Fear of Negative Evaluation. The 3-way interaction of shyness X sociability X theta power to rejection at FCz 400 to 600 ms was significant, *b*= 2.50, *SE*=.92, *p*= .007. Conditional effects of shyness X sociability was significant at high levels of FCz theta power to rejection 400 to 600 ms, *b*=5.04, *SE*=1.41, *p*<.001, but not at moderate or low levels: increases in shyness in combination with moderate (*b*=3.97, *SE*=1.62, *p*=.015) and high (*b*=8.81, *SE*=2.64, *p*=.001) levels of sociability were related to higher FNE (see Figure 4.5).

Social Anxiety. The 3-way interaction of shyness X sociability X theta power to rejection at P4 400 to 600 ms was significant, *b*= -.10, *SE*=.04, *p*=.034. Conditional effects of shyness X sociability was significant at high levels of P4 theta power to rejection 400-600 ms, *b*= -.21, *SE*= .10, *p*=.03, but not at moderate or low levels: increases in shyness in combination with low (*b*=.39, *SE*=.13, *p*=.002) levels of sociability were related to higher social anxiety (see Figure

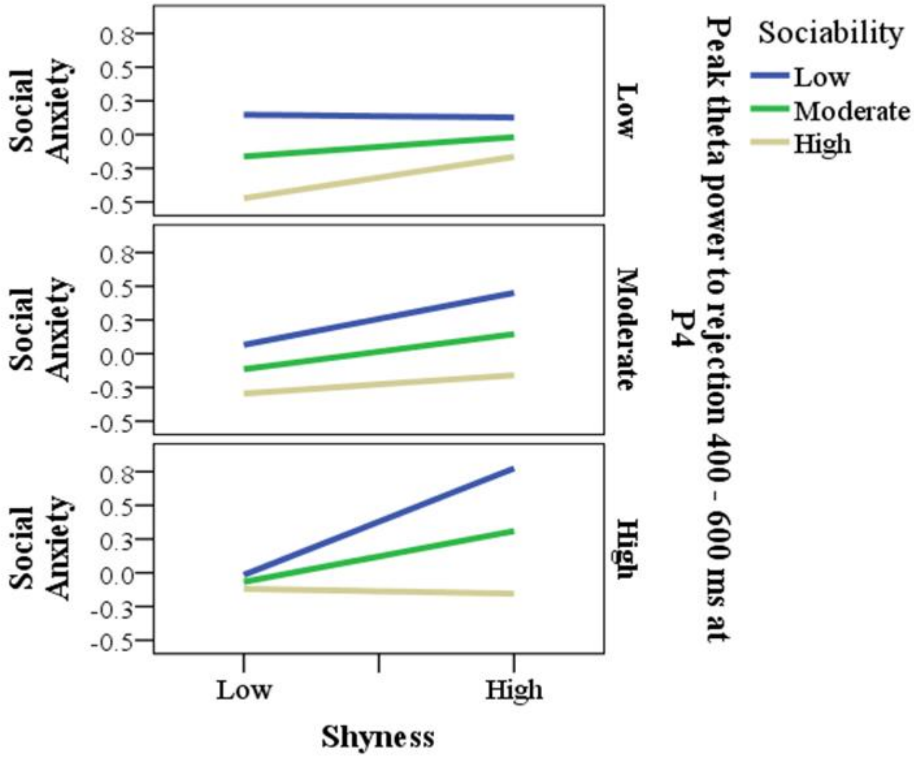
4.6). The same 3-way interaction was replicated in predicting clinically significant levels of generalized social anxiety at a trend level, *b*= -.31, *SE*=.17, *p*=.066.

Figure 4.5. Interaction plot among shyness and sociability and frontal-central peak theta spectral power to social exclusion 400 to 600 ms in predicting fear of negative evaluation across age.



Note. Estimates account for age groups, sex, and depressive mood. *n*= 165.

Figure 4.6. Interaction plot among shyness and sociability and right parietal peak theta spectral power to social exclusion 400 to 600 ms in predicting social anxiety across age.

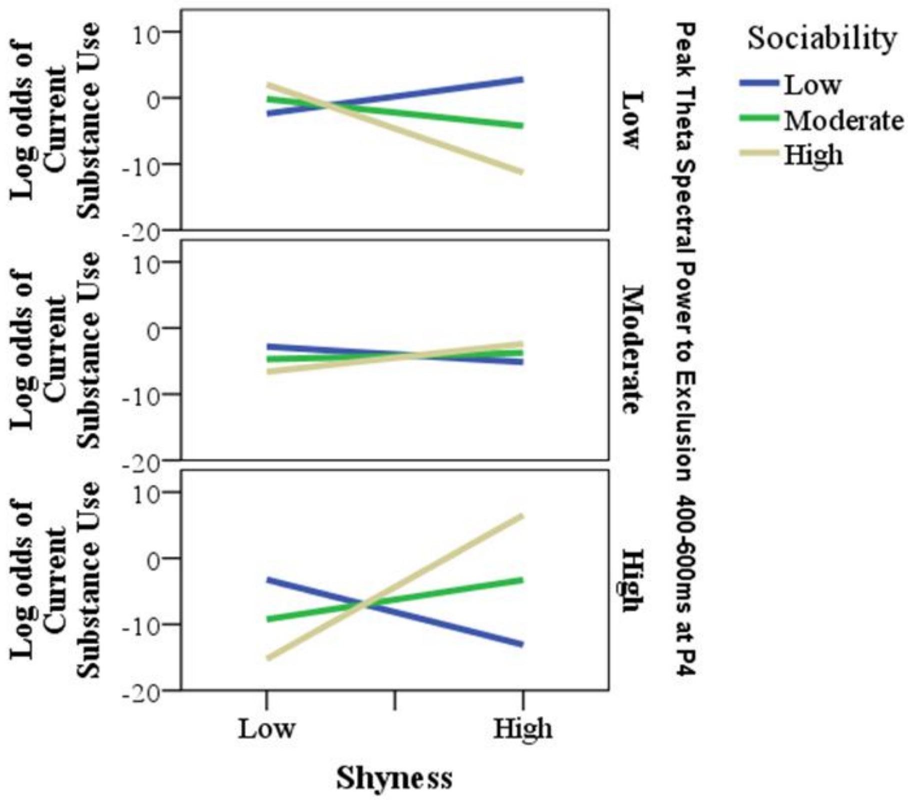


Note. Estimates account for age groups, sex, and depressive mood. *n*= 165.

Substance-Use. No significant 3-way interactions predicted lifetime or current substance use when adults and adolescents were collapsed in the same analyses. Accordingly, we performed the same analyses in the two age groups separately with the same terms in the previous regression model but removing the age group covariate. In adolescents, the 3-way interactions among shyness, sociability, and peak theta spectral power at P4 400 to 600ms to exclusion predicted lifetime substance use, b=2.54, SE=1.06, p=.02. Conditional effects of shyness X sociability was significant at high levels of P4 theta power to rejection 400 to 600 ms, b=5.61, SE=2.33, p=.02, but not at moderate or low levels: increases in shyness in combination with moderate (b=4.68, SE=1.84, p=.011) and high (b=9.69, SE=3.68, p=.008) levels of sociability were related to higher likelihood of engaging in uses of substances at least once in their lifetime.

Likewise, the same 3-way interaction emerged in predicting current substance use, b=4.97, SE=2.52, p=.048. At high levels of P4 theta power to exclusion 400 to 600 ms, adolescents with higher shyness and sociability were more likely to engage in substance use at least once in the past 30 days, b=11.86, SE=6.47, p=.066 (Figure 4.7). In the analyses for adults, there were no 3-way interactions.

Figure 4.7. Interaction plot among shyness and sociability and right parietal peak theta spectral power to social exclusion 400 to 600 ms in predicting current substance use in adolescents.



Note. Estimates account for sex and depressive mood. n= 52.

Alcohol-Use. For current binge drinking, there was a 2-way interaction between shyness and peak theta power to exclusion 400 to 600 ms at FCz, b= 1.06, SE= .34, p=.002. Adults and adolescents with a combination of high shyness and low frontal-central theta power to exclusion 400 to 600 ms had a lower likelihood of engaging in binge drinking in the past 30 days, b=-.154, SE=.53, p=.004. There was also a main effect of age, as adolescents were less likely to engage in binge drinking than adults, b= -1.67, SE=.60, p=.005. There was no 3-way interaction. Likewise, for current alcohol use, the same 2-way interaction between shyness and peak theta power to exclusion 400 to 600 ms at FCz emerged, b= .49, SE= .24, p=.04. Adults and adolescent with a combination of high shyness and low frontal-central theta power to exclusion 400 to 600ms were less likely to have at least one drink in the past 30 days, b= -.75, SE=.33, p=.025. Again, adolescents were less likely to have at least one drink in the past 30 days, b= -.179, SE=.47, p< .001. There was no 3-way interaction.

Similarly, for lifetime alcohol use, there was a 2-way interaction between shyness and peak theta power to exclusion 400 to 600 ms at P4, b=.75, SE=.24, p=.001. Adults and adolescents with a combination of high shyness and low right parietal theta power to exclusion at 400 to 600ms were less likely to have had at least one drink in their lifetime, b= -1.50, SE=.44, p<.001. Again, adolescents were less likely to ever have one drink in their life compared to adults, b= -2.37, SE=.54, p<.001. There was no 3-way interaction.

Discussion

We applied event-related EEG dynamics to examine individual differences in age and the personality traits of shyness and sociability during the processing of social exclusion. We also examined whether these neural indices moderated the psychological outcomes in different shyness subtypes.

One of our study goals was to determine whether children, adolescents, and adults processed social exclusion differently and whether adolescents would be more distressed by exclusion. Our findings suggest that adolescents may use different brain processing strategies than children and adults and are more distressed by social exclusion. In terms of theta oscillatory power, we found that adolescents and children elicited the highest theta spectral power to rejection, whereas adults elicited the highest spectral power to not my turn events at 400 to 600 ms. Greater theta spectral power to processing social exclusion reflects a more salient response to being excluded compared to other more neutral conditions during fair play, when children and adolescents did not have a turn or received the ball. We note that our sample of children was transitioning into early adolescence, which may explain the similar patterns in adolescents. The finding that children exhibited greater theta spectral power in response to rejection during later processing stages compared to not my turn has also been observed in another sample of children (Van Noordt et al., 2015). However, we note that theta power between rejection and not my turn conditions were not significantly different in our sample of adolescents. On the other hand, greater theta spectral power to processing not my turn events at 400 to 600 ms in adults may suggest that condition, which provides a more neutral and ambiguous threat of rejection, may be more salient to adults. In fact, the slow wave ERP to both not my turn and rejection events have been associated with ostracism distress in adults (Crowley et al., 2009).

In linking this neural index to subjective ratings of distress, we found that greater medial frontal theta spectral power to rejection, but not to other conditions, in later stages of processing (i.e., 400 to 600 ms) was specifically associated with greater distress across the entire sample. Nevertheless, this relation was predominately in adolescents and was observed throughout the rejection events (i.e., at 200 to 400 and 400 to 600 ms). The spatial and temporal range of theta linked with distress converged with other EEG/ERP Cyberball studies demonstrating that frontal medial theta power at 400 to 800 ms to rejection was associated with distress in children (Van Noordt et al., 2015) and that a left and medial frontal slow wave around 450 to 900 ms to rejection was linked to distress across samples of children and adults (Crowley et al., 2009, 2010; Sreekirshnan et al., 2014; White et al., 2012). Moreover, the frontal medial location converged with fMRI Cyberball studies that have found correlations between activation of the ACC and feelings of distress (Rotge et al. 2014).

In terms of theta phase coherence, we observed prominent ITC changes in theta around 100 to 400 ms and extracted ITC values at this temporal range (see Figure 4.2), but not at the time range of the slow wave (e.g., 400 to 900 ms) which has been linked to rejection and distress in ERP Cyberball studies (e.g., Crowley et al., 2009). This observation is likely because the slow wave is not a strongly phase-locked ERP component relative to earlier ERP components, which emphasizes the complementary nature of oscillatory dynamics. Nevertheless, age related differences were observed, with adolescents eliciting less theta ITC at the left frontal region for rejection events compared to children and adults. Given ITC is a measure of consistency, this finding of lower theta phase coherence to rejection possibly reflects that adolescence is a period accompanied by greater flexibility in brain functioning that may be influenced by social demands that adolescents face (see, Crone & Dahl, 2012; Giedd & Denker, 2015), such as a need to belong to peer groups. Because information provided by the ITC measure is limited, future studies are needed to pinpoint the processing strategies that are different in adolescents.

The second goal of our study was to test the hypothesis that individuals characterized by a combination of high shyness and sociability (i.e., conflicted shyness) would show greater levels of distress to being rejected across behavioral and neural indices during Cyberball. In support of this hypothesis, conflicted shyness was related to higher subjective ratings of distress and fear of negative evaluation during Cyberball, irrespective of age. However, in contradiction to our hypothesis, conflicted shyness was related to lower, rather than higher, theta spectral power throughout the rejection events (i.e., 200 to 400 and 400 to 600 ms) and across frontal medial and right parietal regions.

Frontal medial theta activity has been proposed to be a neural correlate of self-regulation (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003). In the 200 to 400 ms window, theta activity to contexts of uncertainty has been thought to reflect cognitive control under conflicts and expectancy violation (Cavanagh & Frank, 2014; Cavanagh & Shackman, 2015) across different experimental tasks, such as the go/no-go, flanker task, and time-estimation tasks (Van Noordt, Campopiano, & Segalowitz, 2016). Aside from these experimental tasks, this theta burst at 200 to 400 ms has also been observed in a social evaluation task when participants received unexpected social rejection feedback (Van der Molen et al., 2016). Indeed, expectancy violation is also a property of the Cyberball as participants no longer receive the ball in the exclusion block (Somerville, Heatherton, & Kelley, 2006). As such, increased theta power at 200 to 400 ms can be understood as a threat detection mechanism that engages attentional processes, possibly for later behavioral adaptations, with a larger theta burst occurring when an expectation is violated. Accordingly, the reduced theta power to rejection at the earlier temporal window (200 to 400 ms) elicited in conflicted shy individuals may be because they already held an expectation that they would be rejected. Hence, there were not many discrepancies between what happened and what they expected during rejection events. This idea could be tested with the social evaluation task, in which expectancy is directly manipulated. For example, adults diagnosed with social anxiety disorder display a greater feedback-related negativity ERP to social acceptance, rather than to rejection, that is also negatively correlated with lower daily life acceptance expectancy (Cao, Gu, Bi, Zhu, & Wu, 2015). This cognitive bias has been similarly observed in adults with high levels of social anxiety who had lower expectations for positive social feedback (Caouette et al., 2015).

In contrast, increases in theta power only at later stages of processing (e.g., 400 to 800 ms) during the Cyberball are related to the severity of emotional distress (Van Noordt et al., 2015). In support of this idea, theta power at 400 to 600 ms was positively correlated with distress across the entire sample. Increases in theta activity in later processing stages has also been linked to the experience of undesirable outcomes (Cohen, Elger, & Ranganath, 2007), perceived unpleasant and pleasant feelings (Vecchiato et al., 2011), and negative emotional states (Luu et al., 2003), as well as during cognitive reappraisal of negative emotional contents, with higher theta power associated with higher regulation success (Ertl, Hildebrandt, Ourina, Leicht, & Mulert, 2013). Accordingly, given that individuals characterized as conflicted reported higher self-reported distress and FNE during the Cyberball, the lower theta power to rejection at the later temporal window (400 to 600 ms) shown by conflicted shy individuals may reflect ineffective regulation to the distress in rejection events. Alternatively, the reduced theta power to rejection events in conflicted shy individuals may reflect less distress at the moment of processing because their social expectations (i.e., that they would be rejected) were not violated.

The functionality of increased theta power is clearer in the examination of whether psychological outcomes for different shyness subtypes are moderated by theta oscillatory dynamics. Here, we found that irrespective of age, individuals characterized by conflicted shyness (those who are both shy and sociable) and high levels of frontal medial theta power to rejection were most fearful of negative evaluation in the Cyberball. This cognitive component of

FNE is central to a self-conscious subtype of shyness. In contrast, we found that regardless of age, individuals characterized by avoidant shyness (those who are shy and unsociable) and high levels of right parietal theta power to rejection were most socially anxious. Although this latter finding seems contradictory, it is important to note that FNE is only a part of a global social anxiety measure which includes other avoidant behaviors, and affective and somatic symptoms. Thus, it may be those individuals with avoidant shyness exhibiting a higher theta response to rejection that may be at risk for social anxiety.

Moreover, adolescents characterized by conflicted shyness and high levels of right parietal theta response to rejection were most likely to have engaged in substance within the past 30 days and across their lifetime. Adolescents have been shown to be more likely than children or adults to engage in risky behaviors such as taking drugs (Steinberg, 2008), and exhibit a hyperactivated reward neural circuitry compared to adults (Barkley-Levenson & Galvan, 2014). These findings again highlight adolescence as a developmental period with brain functioning that is adaptive to social demands and risk taking behaviors. The implications of parietal brain regions should also be highlighted for their relation to stable individual differences, such as extraversion and impulsiveness. For example, extraversion has been positively correlated with theta and other frequency spectrum power in posterior regions and negatively related to frontal regions across different tasks (Knayzev, 2009), and replicated when examining resting theta EEG power (Wacker, Chavnon, & Stemler, 2010). Knayzev (2009) interpreted this finding to indicate that posterior brain areas are linked to involuntary attention shifting and orienting function, which matches with impulsive characteristics linked to extraverts. Parietal regions have also been linked to dopaminergic neural projections in the brain that fit with extraversion and impulsiveness. These findings may help us understand why right parietal theta power to rejection is linked to different shyness personality subtypes and substance-use.

In conclusion, the present study is the first to directly compare developmental differences and examine personality differences in EEG dynamics underlying the processing of social exclusion. Our findings support the idea that adolescence is a period during which people are sensitive to the distress caused by social exclusion, with heightened theta spectral power to both rejection and not my turn events. Moreover, our findings highlight the neural correlates linked to distress from rejection that distinguish the two social conflicted and socially avoidant shyness subtypes and moderate their different psychological outcomes, to thereby demonstrate that not all shy individuals are alike.

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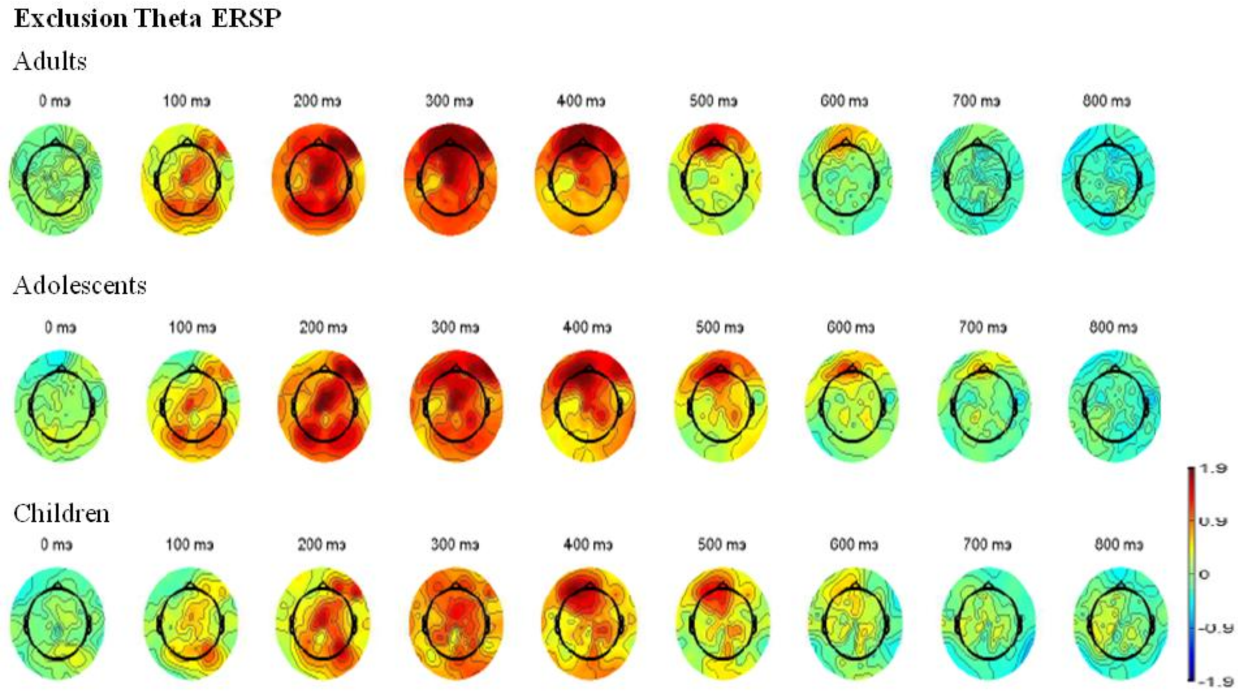
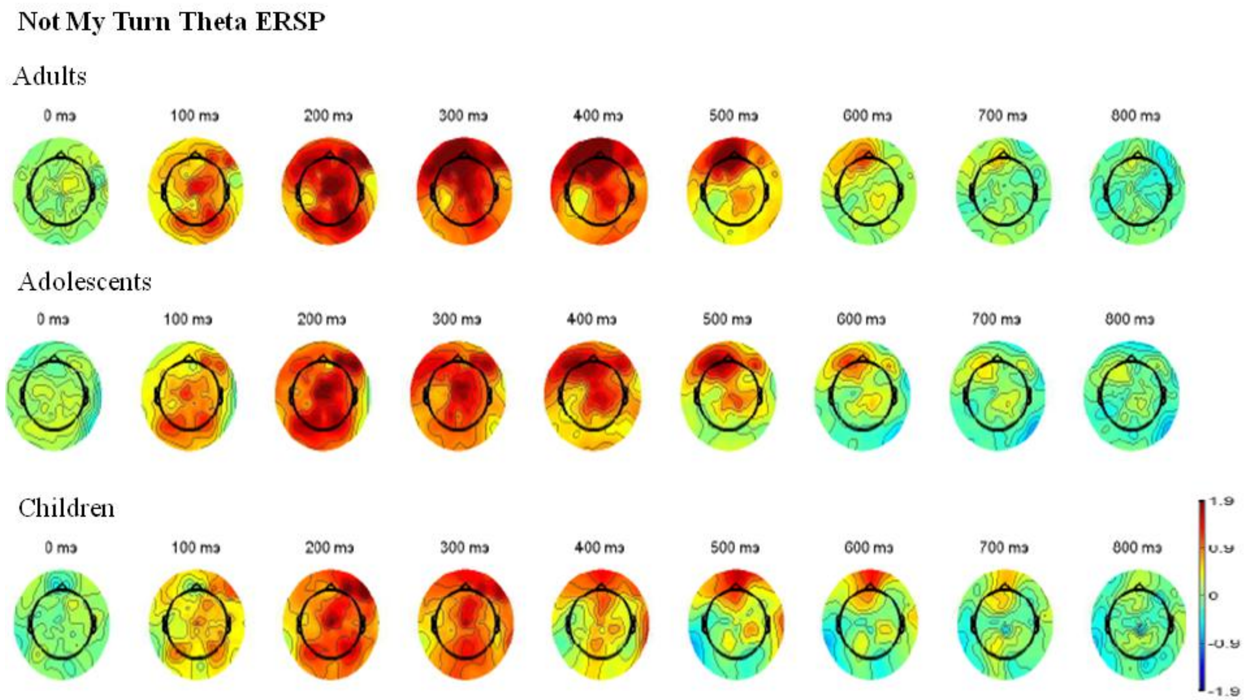
Supplemental Materials

Spatial and Temporal Distribution of Event-Related Theta Spectral Power

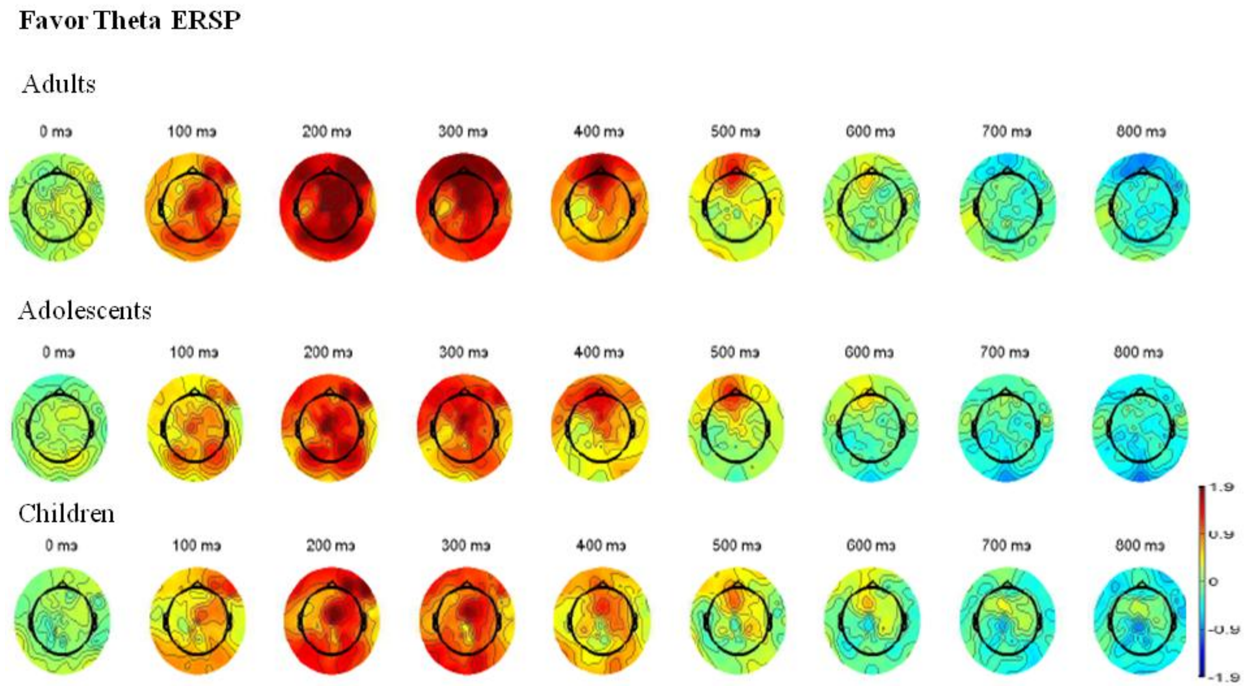
Supplemental Figure 4.1. Topoplots of mean theta ERSP to rejection in adults, adolescents, and children.



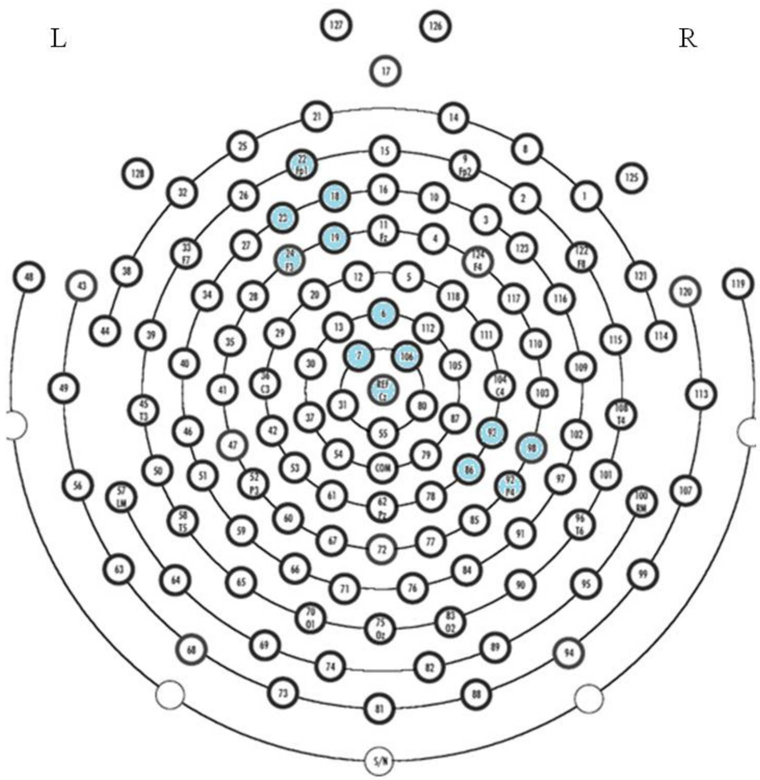
Supplemental Figure 4.2. Topoplots of mean theta ERSP to not my turn in adults, adolescents, and children.



Supplemental Figure 4.3. Topoplots of mean theta ERSP to favor in adults, adolescents, and children.



Supplemental Figure 4.4. Selected left frontal (F3), frontal medial (FCz) and right parietal (P4) scalp clusters from a high density Hydrocel EEG array (EGI, Inc.).



Alpha and Beta ERSP to Cyberball

Supplemental Table 4.1. Three-way repeated measures ANOVA for max alpha and beta ERSP, with region (F3, FCz, P4), condition (favor, not my turn, reject) and time (200 to400 ms and 400 to600ms) as within subjects factors.

Max ERSP			
Alpha	site	F(2,330)= 22.78, p < .001	
	time	F(1,165)= 184.40, p< .001	
	condition	F(2,330)= 10.16, p< .001	
	Time X site	F(2,330)= 56.31, p <.001	At 200 to400ms, region effect, F(2,330)= 20.26, p < .001: P4< F3 and FCz. F3=FCz. At 400 to600ms, region effect, F(2, 330)= 37.24, p <.001: F3> FCz and P4. P4 > FCz.
	Time X condition	F(2,330)= 4.12, p=.017	At 200 to400ms, condition effect, F(2, 330)=6.50, p=.002: Not my turn > favor. Reject > favor (marginal p=.06). Reject= not my turn. At 400 to600ms, condition effect, F(2,330)= 11.27, p <.001: favor < rejection and not my turn. Rejection = not my turn.
Beta	site	F(2,330)= 9.34, p <.001	
	time	F(1,165)= 24.00, p <.001	
	condition	F(2,326)= 9.22, p <.001	
	Time X condition	F(2,326)= 11.23, p <.001	
	Time X condition X site	F(4,660)= 2.63, p=.035	At F3, no time X condition interaction, *ns*. At FCz, time X condition interaction, F(2, 330)=7.57, p=.001: at 400 to 600 ms, beta ERSP to rejection > both not my turn and favor. Not my turn > favor. At P4, time X condition interaction, F(2, 330)= 10.10, p < .001:at 400 to600ms, beta ERSP to rejection > both not my turn and favor. Not my turn > favor.

Age Differences in Alpha and Beta ERSP at 200 to400ms

Supplemental Table 4.2. Three-way repeated measures ANOVA for max alpha and beta ERSP at 200 to400 ms, with region (F3, FCz, P4) and condition (favor, not my turn, reject) as within subjects factors, and age group (children, adolescents, adults) as between-subjects factor.

Max ERSP	200 to 400 ms		
Alpha	Site	F(2, 326)= 19.80, p< .001	F3=FCz. P4 < F3 and FCz
	condition	F(2, 326)=5.41, p=.005	Not my turn > favor, rejection > favor (marginal p .062). Not my turn = reject
	No age effects, *ns*		
	No age interactions, *ns*		
Beta	Site	F(2, 326)=5.56, p=.004	F3> FCz and P4. FCz= P4.
	No condition effect, *ns*	F(2,326)= 9.30, p <.001	
	No age effect, *ns*		
	No age interactions, *ns*		

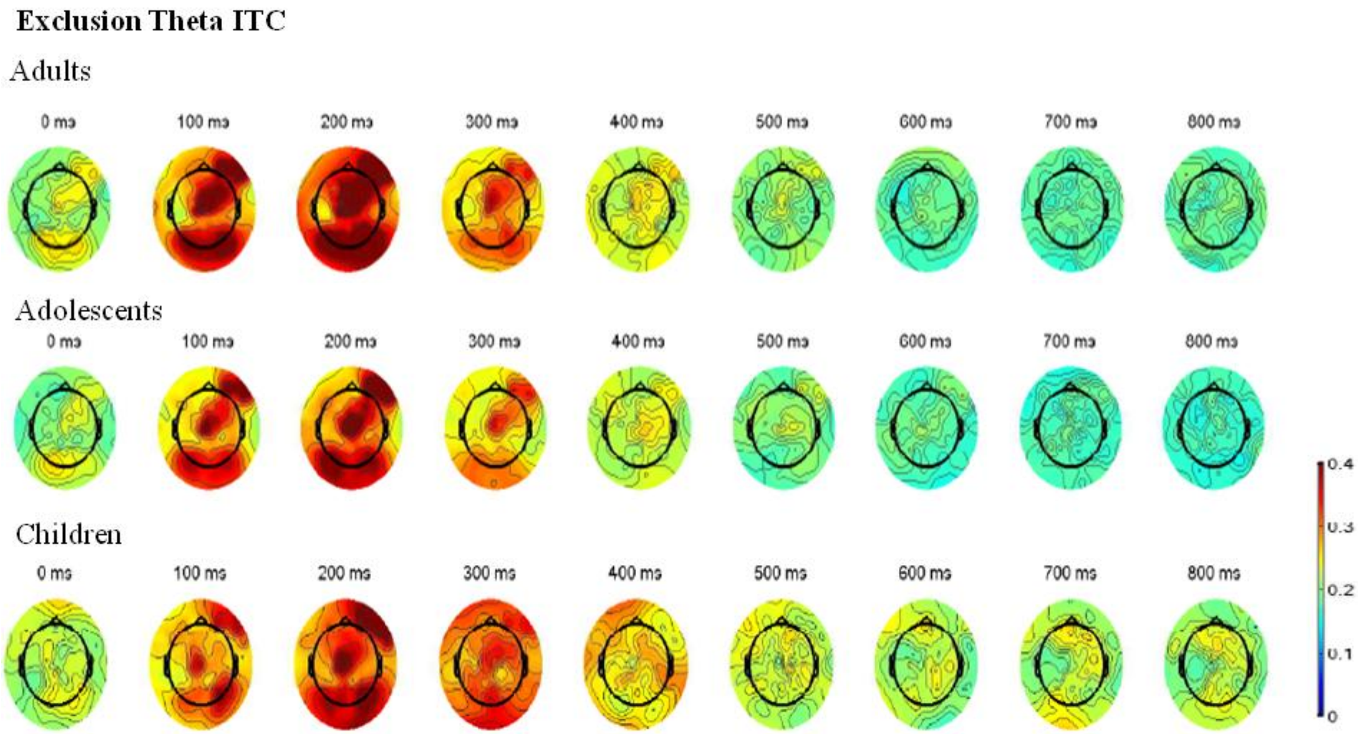
Age Differences in Alpha and Beta ERSP at 400 to 600 ms

Supplemental Table 4.3. Three-way repeated measures ANOVA for max alpha and beta ERSP at 400 to600 ms, with region (F3, FCz, P4) and condition (favor, not my turn, reject) as within subjects factors, and age group (children, adolescents, adults) as between-subjects factor

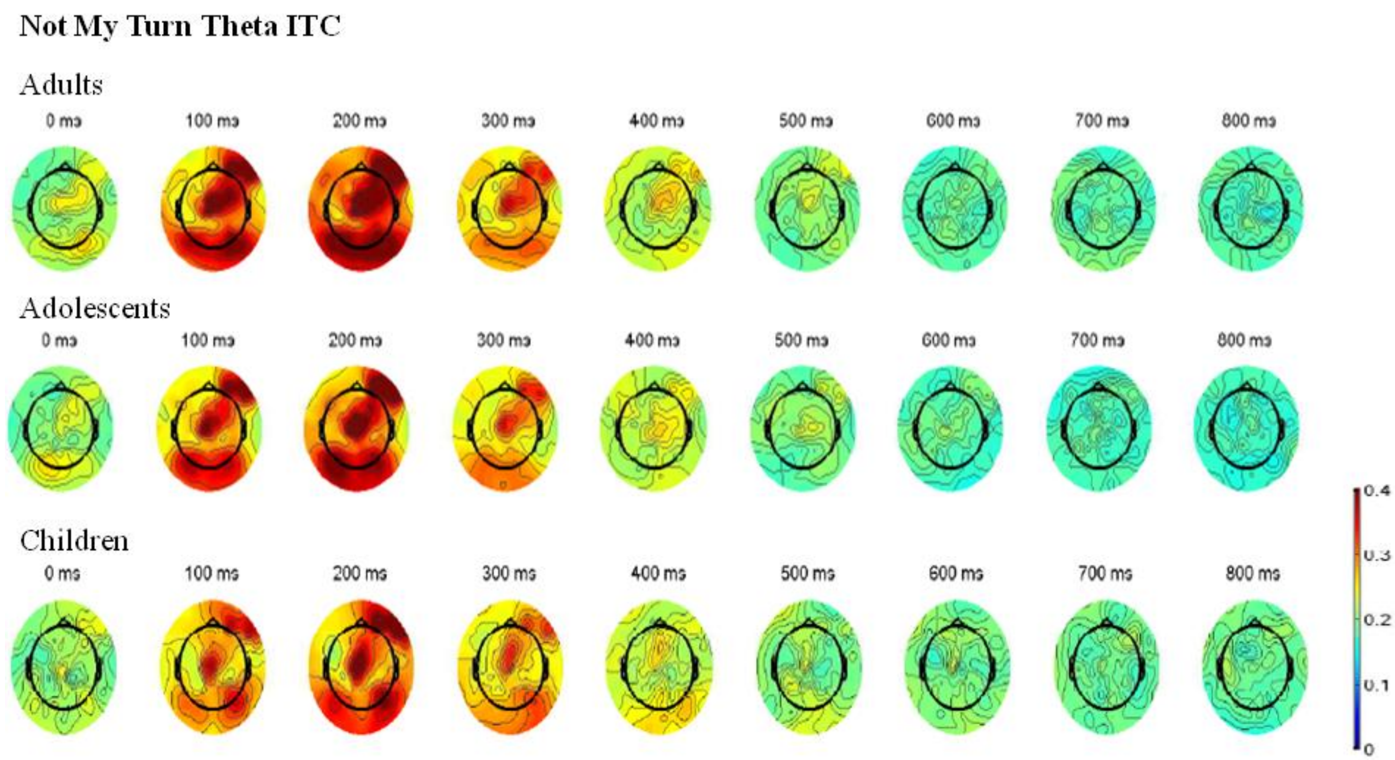
Max ERSP 400 to 600 ms			
Alpha	Site	F(2, 326)=33.32, p < .001	F3 > FCz and P4. P4 > FCz
	condition	F(2, 326)=10.02, p < .001	Not my turn > favor, rejection > favor (marginal p .062). Not my turn = reject
	Condition X age No age effects, *ns*	F(4, 326)=2.88, p=.023	Within-group effects: adults show a condition effect F(2,140)=8.16, p <.001. Not my turn > favor and rejection. Adolescnets showed a condition effect F(2, 104)=4.40, p=.015, whereby higher alpha power is elicited to rejection and not my turn than favor, but rejection = not my turn. In children, there was a condition effect, F(2, 82)=4.30, p=.017, with higher alpha power was elicited to rejection than both not my turn and favor. But not my turn and favor were not different. No between group difference in each favor, not my turn, or rejection conditions. This finding is similar to results of theta
Beta	Site	F(2, 326)=7.09, p=.001	FCz and P4. FCz = P4
	Condition effect No age effect, *ns*	F(2,326)=16.27, p <.001	Rejection > not my turn and favor. Not my turn > favor.

Spatial and Temporal Distribution of Event-Related Theta Phase Synchrony

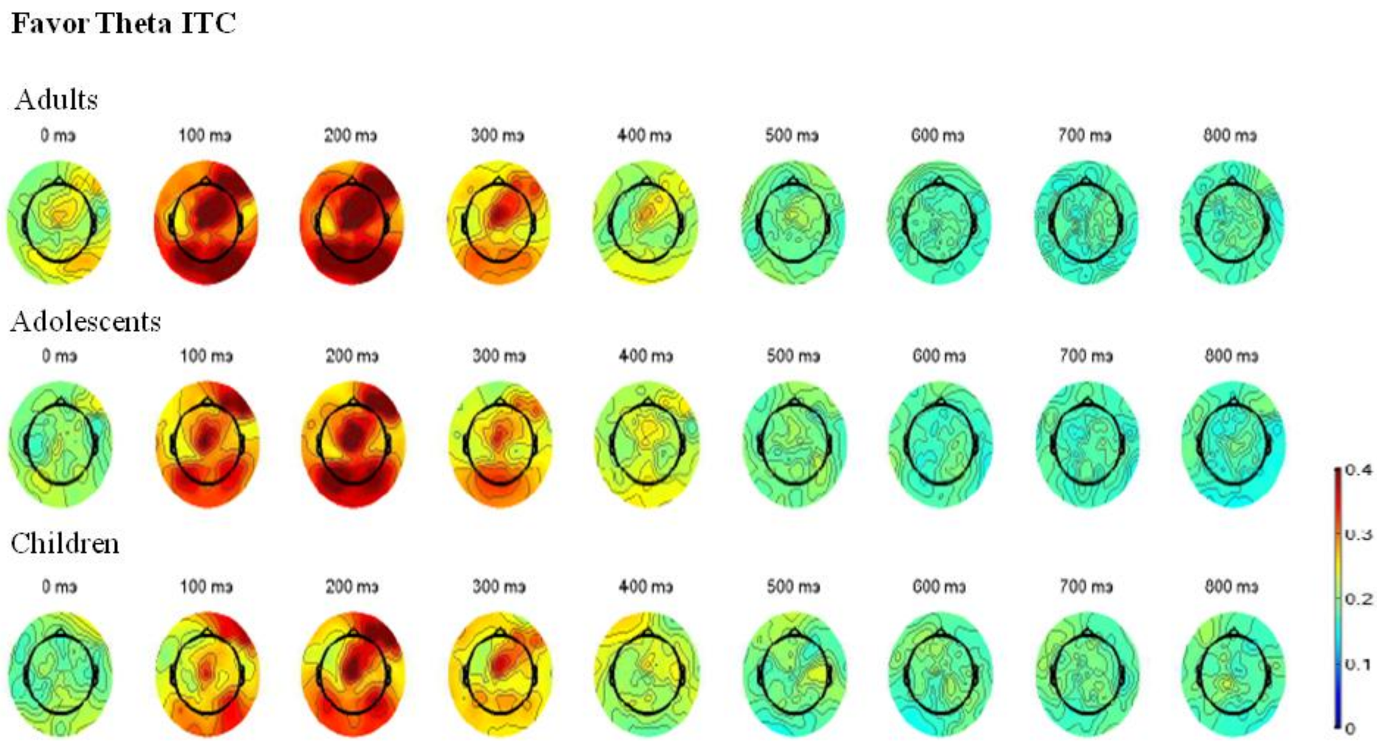
Supplemental Figure 4.5. Topoplots of mean theta ITC to exclusion in adults, adolescents, and children.



Supplemental Figure 4.6. Topoplots of mean theta ITC to not my turn in adults, adolescents, and children.



Supplemental Figure 4.7. Topoplots of mean theta ITC to favor in adults, adolescents, and children.



Alpha and Beta ITC to Cyberball

Supplemental Table 4.4. Two-way repeated measures ANOVA for max alpha and beta ITC at 100 to400 ms, with region (F3, FCz, P4) and condition (favor, not my turn, reject) as within subjects factors.

Max ITC		
Alpha	site	F(2, 330)= 90.73, p <.001. FCz> F3 and P4. F3= P4
	condition	F(2, 330)=4.00, p =.019 Rejection > favor and not my turn. Not my turn = favor.
Beta	site	F(2, 330)= 8.92, p <.001 FCz > F3. F3 = P4.
	condition	F(2, 330)= 11.89, p<.001. Rejection > favor and not my turn. Not my turn = favor.

Age Differences in Alpha and Beta ITC

Supplemental Table 4.5. Three-way repeated measures ANOVA for max alpha and beta ITC at 100 to400 ms, with region (F3, FCz, P4) and condition (favor, not my turn, reject) as within subjects factors, and age group (children, adolescents, adults) as between subjects factor.

Max ITC		
Alpha	site	F(2,326)=80.75, p <.001. FCz > both F3 and P4
	condition	F(2,326)=3.97, p =.02. Rejection > both favor and not my turn
	Age, *ns*	
Beta	site	F(2,326) 9.69, p<.001. FCz > both F3 & P4.
	condition	F(2,326)=13.59, p<.001. Rejection >both favor and not my turn.
	Age	F(2,163)= 8.69, p<.001. Children > both adults and teens.

Relations between distress to Cyberball and alpha and beta ERSP and ITC to rejection across the entire sample

Supplemental Table 4.6. Partial correlations between distress and alpha and beta ERSP and ITC across scalp clusters and time windows to rejection, controlling for age.

(A)	Alpha max spectral power to rejection						Alpha max ITC to rejection		
	200 to 400ms			400 to 600 ms			100 to400ms		
	F3	FCz	P4	F3	FCz	P4	F3	FCz	P4
Distress	0.07	0.11	0.02	0.09	0.05	-0.01	-0.05	0.00	0.01
(B)	Beta max spectral power to rejection						Beta max ITC to rejection		
Distress	-0.22*	-0.05	-0.09	-0.15†	0.00	-0.03	-0.04	-0.13	-0.01

Note. Two-tailed. **p* <.05, † *p*< .055.

Regression tables for analyses in examining shyness X sociability X theta power to rejection in predicting fear of negative evaluation, social anxiety, substance- and alcohol-use

Supplemental Table 4.7. Linear regression model regressing fear of negative evaluation on shyness X sociability X frontal medial theta spectral power to rejection at 400 to 600 ms, their two-way interactions, main effects, and covariates of age, sex, and depressive mood.

Dependent variable: Fear of negative evaluation				
	R^2	*F*	*dfs*	*p*
	0.35	8.13	(10, 154)	< 0.001
	b	*se*	*t*	*p*
Constant	28.58	1.64	17.42	0.00
Sociability	-0.64	0.90	-0.71	0.48
Shyness	1.34	0.91	1.48	0.14
Theta spectral power to rejection FCz at 400 to600 ms	0.48	0.65	0.74	0.46
Shyness X Sociability	1.57	0.93	1.69	0.09
Shyness X Theta spectral power to rejection FCz at 400 to600 ms	1.88	0.78	2.40	0.02
Sociability X Theta spectral power to rejection FCz at 400 to600 ms	0.81	0.74	1.09	0.28
Shyness X Sociability X Theta spectral power to rejection FCz at 400 to600 ms	2.49	0.92	2.71	0.01
Depressive mood	5.88	0.93	6.35	0.00
Age	0.99	1.10	0.90	0.37
Sex	2.75	1.91	1.44	0.15

Supplemental Table 4.8. Linear regression model regressing social anxiety on shyness X sociability X right parietal theta spectral power to rejection at 400 to 600 ms, their two-way interactions, main effects, and covariates of age, sex, and depressive mood.

Dependent variable: Social anxiety				
	R^2	*F*	*dfs*	*p*
	0.23	4.48	(10, 154)	0.00
	b	*se*	*t*	*p*
Constant	-0.11	0.14	-0.85	0.40
Sociability	-0.25	0.08	-3.35	0.00
Shyness	0.13	0.07	1.78	0.08
Theta spectral power to rejection P4 at 400 to600 ms	0.07	0.05	1.39	0.17
Shyness X Sociability	-0.06	0.08	-0.85	0.40
Shyness X Theta spectral power to rejection P4 at 400 to600 ms	0.04	0.05	0.76	0.45
Sociability X Theta spectral power to rejection P4 at 400 to600 ms	-0.01	0.05	-0.20	0.84
Shyness X Sociability X Theta spectral power to rejection P4 at 400 to600 ms	-0.10	0.04	-2.14	0.03
Depressive mood	0.26	0.08	3.37	0.00
Age	-0.03	0.09	-0.32	0.75
Sex	0.23	0.16	1.46	0.15

Supplemental Table 4.9. Logistic regression models regressing (A) current substance use and (B) lifetime substance use on shyness X sociability X right parietal theta spectral power to rejection at 400 to 600 ms, their two-way interactions, main effects, and covariates of sex, and depressive mood in adolescents.

Dependent variable:	**(A)** Current substance use				**(B)** Lifetime substance use			
	Cox & Snell R^2				Cox & Snell R^2			
	0.26	52			0.24			
	b	*se*	*Z*	*p*	*b*	*se*	*Z*	*p*
Constant	-2.28	1.22	-1.88	0.06	-2.36	0.97	-2.44	0.01
Sociability	-0.29	1.01	-0.29	0.77	-1.05	0.69	-1.53	0.13
Shyness	0.52	1.46	0.35	0.72	1.79	0.83	2.17	0.03
Theta spectral power to rejection P4 at 400 to600 ms	-1.31	0.89	-1.47	0.14	-1.00	0.50	-2.00	0.05
Shyness X Sociability	2.00	2.44	0.82	0.41	1.71	0.99	1.72	0.09
Shyness X Theta spectral power to rejection P4 at 400 to600 ms	1.78	1.08	1.64	0.10	1.88	0.76	2.46	0.01
Sociability X Theta spectral power to rejection P4 at 400 to600 ms	1.57	1.36	1.16	0.25	0.03	0.63	0.05	0.96
Shyness X Sociability X Theta spectral power to rejection P4 at 400 to600 ms	4.97	2.52	1.98	0.05	2.54	1.06	2.38	0.02
Depressive mood	0.18	0.90	0.20	0.84	-0.24	0.50	-0.47	0.64
Sex	-3.23	1.85	-1.75	0.08	0.25	1.03	0.24	0.81

n=52

Supplemental Table 4.10. Logistic regression models regressing (A) current binge drinking and (B) alcohol use on shyness X sociability X frontal medial theta spectral power to rejection at 400 to 600 ms, their two-way interactions, main effects, and covariates of age, sex, and depressive mood in adolescents and adults.

Dependent variable:	**(A)** Current binge drinking Cox & Snell R^2 0.24				**(B)** Current Alcohol use Cox & Snell R^2 0.21			
	b	*se*	*Z*	*p*	*b*	*se*	*Z*	*p*
Constant	-0.73	0.44	-1.66	0.10	0.13	0.40	0.32	0.75
Sociability	0.08	0.29	0.29	0.77	0.21	0.24	0.89	0.37
Shyness	-0.35	0.33	-1.08	0.28	-0.14	0.24	-0.57	0.57
Theta spectral power to rejection FCz at 400 to600 ms	0.03	0.24	0.13	0.90	-0.16	0.18	-0.89	0.37
Shyness X Sociability	-0.06	0.35	-0.17	0.86	0.15	0.26	0.59	0.56
Shyness X Theta spectral power to rejection FCz at 400 to600 ms	1.06	0.34	3.15	0.002	0.49	0.24	2.06	0.04
Sociability X Theta spectral power to rejection FCz at 400 to600 ms	0.46	0.26	1.75	0.08	0.24	0.20	1.17	0.24
Shyness X Sociability X Theta spectral power to rejection FCz at 400 to600 ms	0.32	0.34	0.92	0.36	0.07	0.25	0.28	0.78
Depressive mood	-0.09	0.30	-0.31	0.76	0.09	0.27	0.34	0.73
Sex	-0.05	0.55	-0.10	0.92	0.34	0.50	0.67	0.50
Age	-1.67	0.60	-2.79	0.01	-1.79	0.47	-3.78	0.001

n=123

Supplemental Table 4.11. Logistic regression model regressing lifetime alcohol use on shyness X sociability X right parietal theta spectral power to rejection at 400 to 600 ms, their two-way interactions, main effects, and covariates of age, sex, and depressive mood in adolescents and adults.

Dependent variable: Lifetime alcohol use				
	Cox & Snell R^2		0.32	
	b	*se*	*Z*	*p*
Constant	1.60	0.50	3.23	0.00
Sociability	0.13	0.25	0.50	0.62
Shyness	-0.29	0.28	-1.05	0.29
Theta spectral power to rejection P4 at 400 to600 ms	0.01	0.18	0.06	0.95
Shyness X Sociability	0.23	0.28	0.81	0.42
Shyness X Theta spectral power to rejection P4 at 400 to600 ms	0.78	0.24	3.28	0.001
Sociability X Theta spectral power to rejection P4 at 400 to600 ms	-0.10	0.23	-0.45	0.65
Shyness X Sociability X Theta spectral power to rejection P4 at 400 to600 ms	0.11	0.32	0.35	0.73
Depressive mood	0.29	0.28	1.02	0.31
Sex	0.64	0.55	1.16	0.25
Age	-2.37	0.54	-4.43	0.001

n=123

Chapter 5

General Discussion

Summary of Findings and Implications

In this thesis, I examined how shyness develops across the first four decades of life to shape adult mental health outcomes using a prospective, longitudinal design. In addition, in a series of cross-sectional studies, I also examined neural responses to threatening social and non-social contexts, and the relationship between these neural responses and socioemotional outcomes in children, adolescents and adults with varying levels of shyness. The overarching theme of the findings is that there is much heterogeneity among the population of shy individuals, with subtypes that can be identified based on the temporal stability of this trait and based on levels of sociability. Moreover, defining shyness subtypes provides meaningful predictive utility, as different subtypes present different behavioral and biological reactions to both social and non-social situations that involve self-presentation elements. These different biological responses may act as potential mechanisms to mediate or moderate their differential outcomes.

Chapter 2 was the first study to delineate different developmental pathways of shyness from middle childhood to middle adulthood (age 8 to 30-35) and to link these developmental pathways to mental health outcomes and to attentional biases in adulthood. Notably, the shapes of the three shyness trajectories converge with other developmental trajectory studies on social reticence and social withdrawal in early childhood from ages 2 to 5 (Degnan et al., 2014), and in childhood to adolescence from grades 1 to 6 (Booth-LaForce & Oxford, 2008) and grades 5 to 8 (Oh et al., 2008). These studies also describe a normative low-stable trajectory that consisted of the majority of individuals, as well as two socially withdrawn trajectories, one that increases and one that decreases.

In Chapter 2, I also demonstrated that childhood shyness was not directly linked to adverse mental health outcomes, and that not all shy children continue to be shy throughout the lifespan. It was particularly those individuals in the increasing shy trajectory who were at risk for clinical social anxiety, depression, and substance-use, and were hypervigilant to angry facial expressions, which has been observed in social phobia (Bogels & Mansell, 2004) and is thought to maintain anxiety disorders (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007). Given that mental disorders are debilitating to daily functioning, our group has also found that the increasing shy trajectory had worse socioemotional and demographic outcomes in their 30s: these individuals reported more loneliness and risk-taking behaviors, and were less likely to hold a full-time job and own their own home (Schmidt, Tang et al., 2016). Though no other trajectory studies have examined attentional biases or mental disorders in adulthood, an increasing shy/socially withdrawn trajectory has been linked to more internalizing problems compared to a low-stable trajectory in childhood and adolescence (Degnan et al., 2014; Booth-LaForce & Oxford, 2008). Likewise, individuals with high-stable patterns of behavioral inhibition in childhood have higher risks for developing social anxiety and anxiety disorders in adolescence (Chronis-Tuscano et al., 2009) and in emerging adulthood (Frenkel et al., 2015).

In understanding the developmental course of psychopathology, these diverse trajectories reflect the concepts of equifinality and multifinality (Cicchetti & Rogosch, 1996). Rather than expecting a certain adaptive or maladaptive outcome as the exclusive result of a certain developmental pathway, equifinality reflects the observation that different developmental pathways may result in the same outcome. An example of equifinality from Chapter 2 is conveyed through the observation that some individuals who were on clearly distinct low-stable non-shy and increasing shy trajectories nevertheless developed the same mental disorders in adulthood. On the other hand, multifinality reflects the observation that individuals who began on the same developmental pathway can diverge depending on the interim processes and result in different patterns of adaptation or maladaptation. In multifinality, a certain event and outcome are not expected to be directly related to each other. For example, in Chapter 2, individuals who began with higher levels of shyness in both increasing and decreasing trajectories than the low-stable non-shy trajectory had diverging pathways after adolescence. As their shyness increased or decreased so did their risk for mental health problems, suggesting that there are dynamic interactions between biological and social contexts and the individual in the development of shyness and corresponding outcomes.

In terms of social contextual factors that reinforce an increasing shy trajectory, negative peer experiences in childhood and adolescence seem to play a role. In Chapter 2, individuals in the increasing shy trajectory reported more verbal bullying incidences before adolescence. Other trajectory studies have also linked the increasing trajectory to peer exclusion and victimization, poor quality and unstable friendships in childhood and adolescence (Booth-LaForce & Oxford, 2008; Booth-LaForce et al., 2012; Oh et al., 2008). Indeed, a combination of high-stable behavioral inhibition in childhood and less positive peer relations in adolescence is linked to greater risk for anxiety disorders in emerging adulthood (Frenkel et al., 2015). While social factors play a role in maintaining different developmental trajectories of shyness, biological factors also play a role. For instance, a behaviorally inhibited temperament that is heritable (e.g., Smith et al., 2012) during infancy is associated with greater likelihood of being in either an increasing or decreasing shy trajectory, as opposed to the low-stable non-shy trajectory (Degnan et al., 2014).

Still, most of these findings are descriptive contextual factors, rather than mechanistic explanations of how and why different children grow up to have specific outcomes. Moreover, individuals are active, rather than passive, in shaping their environments which ultimately reinforces their personality development (Caspi & Roberts, 2001). Thus, how an individual reacts to threatening social and non-social situations may potentially influence his/her developmental course and outcomes. To explore this possibility, Chapters 3 and 4 reported electrocortical measures to examine the neural mechanisms and correlates during the processing of different threatening situations, and whether these putative neural indices mediated or moderated the outcomes in different subtypes of shyness based on levels of sociability.

Experiments reported in Chapter 3 were designed to examine how 10-year-old children and adults processed novelty in the auditory domain using ERPs and a three-stimulus oddball task. In this task, participants heard standard low tones (80%), target high tones (10%), and novel tones that were in between the tones of standards and targets (10%), and responded to target tones by pressing a button. As stated in Chapter 3, children and adults were examined separately because there were developmental differences in the ERP waveforms that suggested that children and adults treated the task differently. The P300 component was of particular interest because of its association with arousal, working memory, and attentional operations, with increased amplitudes elicited in response to rare versus frequent stimuli (Polich, 2007). Here, I addressed two primary questions: (1) Given that shyness and sociability are distinct personality dimensions, can they be distinguished on this neurocognitive measure? Moreover, is this effect specific to a condition, such that shyness is related to the processing of non-social novelty? (2) To the extent that the P300 is related to shyness and sociability, does this neurocognitive measure mediate the socioemotional outcomes in shy individuals?

To answer the first question, Chapter 3 reported that children's shyness, but not sociability, was related to higher amplitudes of the P300 to both target and background tones, but not to novel tones. Indeed, adolescents classified by high behavioral inhibition in childhood also do not show higher novelty P300 amplitudes; though those with higher novelty P300 amplitudes had a greater likelihood of having anxiety disorders compared to adolescent characterized as low on behavioral inhibition during childhood (Reeb-Sutherland et al., 2009). The correlational pattern in children was not observed adults. Shyness in adults, but not sociability, was related to *lower* amplitudes of the P300 to novel tones, but was unrelated to target and background tones. These results suggest that shyness and sociability were largely separable on this electrocortical measure, however, shyness in neither childhood nor adulthood were directly related to heightened processing of non-social novelty.

The different correlation pattern between shyness and the P300 across different conditions in children and adults suggest that shyness at different developmental stages may be linked to different attentional operations that underlie the novelty and target P300. The novelty P300 has a frontal scalp distribution and is linked to attention orienting and shifting processes (e.g., Fabiani & Friedman, 1995; Courchesne, Hillyard, & Galambos, 1975; Knights & Scabini, 1998; Snyder & Hillyard, 1976; Squires, Squires, & Hillyard, 1975). Contrary to the prediction that shyness would be related to sensitive and heightened attentional shifts to novelty, the lower novelty P300 amplitudes linked to shyness suggest that shy adults' attention shifting for task-irrelevant novel stimuli may be dampened. Though in middle childhood, the lack of relation between shyness and novelty P300 amplitudes suggested that automatic modes of attention orientation might not be directly linked to shyness in response to non-social novelty either.

In contrast, the target P300 has a posterior scalp distribution and is linked to greater attention allocation and processing of the stimuli (Courchesne et al., 1975; Cycowicz, Friedman, & Rothstein, 1996; Donchin & Coles, 1988; Grillon, Courchesne, Ameli, Elmasian, & Braff, 1990). Accordingly, shy children may exert more cognitive resources to processing task-relevant stimuli and during baseline, which possibly facilitates the detection of targets. However, such hypervigilant and controlled processes exerted during baseline conditions, where they are not required, may cost shy children more cognitive resources. Indeed, this vigilant processing strategy generalized to a "baseline" condition may contribute to greater emotional instability in conflicted shy children, as Chapter 3 showed that conflicted shy children (i.e., with high levels of shyness and sociability) exhibited higher P300 amplitudes to background auditory tones, which in turn mediated their higher levels of neuroticism.

Furthermore, Chapter 3 explored why shy adults exhibit a dampened response to novelty by examining their neuroendocrine functioning through baseline salivary cortisol measures in the afternoon. It should be emphasized that cortisol is a metabolic steroid hormone that has regulatory roles in energy mobilization; it is related to stress but it does not cause stress. Shyness in adulthood has been linked to lower levels of cortisol in lab assessments (Beaton et al., 2006) and throughout the diurnal rhythm in their everyday settings (Beaton, Schmidt, Schulkin, & Hall, 2013). These lower levels have been hypothesized to be linked to a recalibration of the neuroendocrine system due to a history of coping with chronic social stress (Beaton et al., 2013). Indeed, reduced cortisol levels can be observed in some withdrawn, depressed and chronically stressed profiles, such as post-traumatic stress disorders (Gunnar & Vazquez, 2001; Yehuda &

Seckl, 2011). In Chapter 3, adult's shyness was related to lower cortisol levels that played a mechanistic role in influencing their dampened attentional states to threat and novelty, as well as higher emotional arousal. These findings speak to the importance of examining both central and peripheral systems, as changes in the neuroendocrine system may impact other autonomic and cognitive-affective neural processes linked to arousability. In the case of cortisol, this may happen presumably through changes in energy levels which would obviously be linked to arousal and attention.

Given that shy children and adolescents who experience peer victimization are at higher risk for internalizing problems (Gazelle & Ladd, 2003; Gazelle & Rudolph, 2004; Ladd, 2006), which was also evident in individuals on an increasing shy trajectory in Chapter 2, I further examined the neural correlates of social exclusion and their relation to mental health outcomes in Chapter 4. Using dense-array EEG, I focused on examining the event-related theta oscillations that has been linked to distress from being excluded in the Cyberball task (Van Noordt, White, Wu, Meyes, & Crowley, 2015) in children (ages 10-12), adolescents (ages (14-16), and adults (ages 17-28) with varying levels of shyness. In the Cyberball task, participants played a ball-toss game with two virtual players, they were initially included in the fair play block, in which they were passed the ball and waited for their turn, but seamlessly excluded in the exclusion block, in which they were not passed the ball. Findings in Chapter 4 showed effects of age, as well as personality to rejection.

The age-related differences provide the initial direct comparison of EEG oscillatory correlates of social rejection across typically developing children, adolescents, and adults in the Cyberball. Most studies using fMRI or EEG methods have separately examined children (e.g., Crowley, Wu, Molfese, & Mayes, 2010; Van Noordt et al., 2015), adolescents (e.g., Masten et al., 2009; Sebastian et al., 2011) and adults (e.g., Crowley et al., 2009; Eisenberger, Lieberman, & Williams, 2003). Though Gunther Moor et al. (2012) have directly examined neural correlates of social rejection across children, adolescents, and adults using fMRI. This fMRI study showed that most neural activity to rejection and "not my turn" events overlap across age, the only difference was that children exhibited more subgenual anterior cingulate cortex activity to rejection than favor relative to adolescents and adults (Gunther Moor et al., 2012). Given fMRI measures do not have the necessary temporal resolution, the event-related EEG oscillations examined in Chapter 4 are superior in picking up age-related differences in real-time processing to complement these fMRI findings.

In Chapter 4, adolescents showed a different pattern of brain functioning to rejection than adults and children, with the higher theta spectral power to both rejection and "not my turn" events than favor evens. Children also showed higher theta spectral power to rejection versus favor events, but "not my turn" events were not different from favor. In contrast, adults showed the highest theta spectral power to "not my turn" events than favor and rejection. To establish the importance of theta power to rejection, this neural index was positively correlated with self-reported distress across the entire sample, in line with previous findings in a sample of children (Van Noordt et al., 2015). This correlation, however, was strongest in adolescents. Moreover, adolescents also elicited lower theta phase synchrony to rejection than children and adults, suggesting they may engage in less consistent or more flexible neural functioning to rejection.

Overall, these differential brain functioning patterns to social exclusion observed in adolescents support the notion that adolescence is a sensitive period to social influences as there is an increasing motivation for peer acceptance (O'Brien & Bierman, 1988), which may drive certain brain processes and behaviors. In convergence with our findings, a behavioral study of the Cyberball, adolescents (ages 11-16) reported reduced overall mood compared to adults (Sebastian, Viding, Williams, & Blakemore, 2010). The brain also undergoes much anatomical development across adolescence in to adulthood, with grey matter volume reduction and white matter increase in the association cortices involved in social cognition (Brain Development Cooperative Group, 2012; Sowell et al., 2003; Tamnes et al., 2013), as well as other cortical and subcortical regions (see review, Giedd & Denker, 2015). These anatomical changes have been proposed to result in more flexible brain functioning that allow adolescents to adapt to the new environmental demands, including social ones (Giedd & Denker, 2015), consistent with the finding that adolescents elicited lower theta phase synchrony (a measure of consistency) to rejection compared to children and adults.

Aside from developmental differences, Chapter 4 also showed that irrespective of age, conflicted shy individuals were more fearful of negative evaluation and distressed by the Cyberball and elicited a differential pattern of reduced theta spectral power to rejection. Although the reduced theta spectral power to rejection contradicted our hypothesis that conflicted shy individuals would elicit higher theta power to rejection, this result could be because theta power indexes expectancy violation at the earlier processing window (200 to 400 ms), as well as distress at the later processing window (400 to 600 ms). The reduced theta power may mean that conflicted shy individuals have low expectations for success in being socially included despite their strong desires for affiliation; Rather than being disappointed, they expect to be not accepted because it is distressing and hurtful when social expectancies are violated. This is a description of a cognitive bias that is both defensive and handicapping to conflicted shy individuals.

In patients with social anxiety disorder, a similar negative bias in expectations and interpretations of social evaluation (Creswell, Murray, & Cooper, 2014; Franklin, Huppert, Langner, Leiberg, & Foa, 2005) and "defensive" behaviors that follow to avoid social contact (Heimberg, Brozovich, & Rapee, 2010) have also been described. In particularly, a negative acceptance bias has been related to brain functioning during social evaluation. For example, adults diagnosed with social anxiety disorder display a greater feedback-related negativity ERP to social acceptance, rather than to rejection, that is also negatively correlated with lower daily life acceptance expectancy (Cao, Gu, Bi, Zhu, & Wu, 2015). Aside from the clinical population, this cognitive bias has been observed in adults with high levels of social anxiety who had lower expectations for positive social feedback (Caouette et al., 2015).

In examining whether the neural correlates of social exclusion moderated different psychological outcomes in shyness subtypes, I found that, regardless of age, conflicted shy individuals who elicited high levels of theta power to exclusion were most fearful of negative evaluation. This result is consistent with findings that conflicted shy individuals present greater anxiety and fear of negative evaluation in social situations (e.g., Arkin & Grove, 1991; Cheek & Buss, 1981). Whereas those socially avoidant shy individuals (i.e., with high shyness and low sociability) who elicited high levels of theta power to exclusion were most socially anxious. Although this finding is inconsistent with our hypothesis as well as a recent study that found conflicted shy adults report greater social anxiety (Poole, Van Lieshout, & Schmidt, 2017), it is important to realize that this result does not speak to only a combination of high shyness and low sociability, but also heightened sensitivity to social exclusion in brain functioning. Thus, different subtypes' reaction to social exclusion may have predictive value with respect to outcomes.

Interestingly, I also found that conflicted shy adolescents who elicited high levels of theta power to exclusion were most likely to engage in substance-use in the past 30 days and in their lifetime. However, the same interaction was not found in conflicted shy adults. This may be explained by the fact that adolescents are more likely to do drugs than adults and children (Steinberg, 2008), and exhibit a hyperactivated reward neural circuitry compared to adults (Barkley-Levenson & Galvan, 2014), which would have obvious implications for reinforcing substance-use. Others have also found that adolescents who show higher neural activity linked to distress and social exclusion during the Cyberball, including the dorsal and subgenual ACC and anterior insula, were most likely to engage in risk taking behaviors while driving in a simulator in the presence of peers (Falk et al., 2014). Perhaps, it is a combination of sensitivity to social exclusion and rewards during adolescence that interact with personality in conferring this outcome, which would require further testing. At the least, these findings highlight adolescence as a period that is sensitive to both social exclusion and rewards.

Limitations and Future Directions

This thesis aimed to examine different subtypes of shyness, as well as social and biological factors that shape these individual differences and outcomes. One obvious limitation is that all of the studies pertaining to shyness subtypes that are categorized by levels of sociability use cross-sectional (i.e., Chapters 3 and 4) rather than longitudinal, designs. Only one longitudinal study across infancy to toddlerhood has looked at the development of behaviors in self-conscious shyness that resembles the conflicted shy subtype (Eggum-Wilkens, Lemery-Chalfant, Aksan, & Goldsmith, 2015). As such, the developmental course of socially conflicted or socially avoidant shyness subtypes and their corresponding long-term outcomes are unknown. Although, these shyness subtypes have been observed throughout childhood (e.g., Tang, Santesso, Segalowitz, & Schmidt, 2016), adolescence (e.g., Page, 1990), and adulthood (e.g., Cheek & Buss, 1981), it is not known whether the outcomes in cross-sectional studies would apply in a longitudinal study. It is also not known which individuals would be able to grow into or out of these shyness subtypes. Future research should explore these questions.

Furthermore, though Chapter 2 identified different developmental trajectories of shyness and their different outcomes, many of the biological (e.g., genetics) and social (e.g., relationships with friends and romantic partners) factors, and person-environment transactions which all shape personality development (Caspi & Robert, 2001) remain unexplored. Transactions are the continuous dynamic interactions between an individual and his/her environment, and the development of a child is the product of such transactions (Sameroff, 2014). Since one's interpersonal environment and experiences are usually not random (Caspi & Roberts, 2001). For example, because shyness is heritable (Smith et al., 2012), a shy child is more likely to be raised by shy parents, who express inhibited behaviors and engage in overprotective parenting (Rubin & Burgess), which provide an environment that reinforces shyness, this child may then express behaviors and emotions in others that reinforce this personality overtime. Using cross-lagged models, studies have shown that personality predicts problem behavior, and in reverse, problem behavior also predicts personality overtime (e.g., Kilmstra, Akse, Hale, Raaijmakers, & Meeus, 2010). Thus, the analyses of interdependent effects of the child and environment can help us understand *how* certain pathways are reinforced across development, which would complement descriptions of different shapes or types of developmental pathways.

Finally, given that adolescents showed a differential pattern of theta EEG oscillations (i.e., in magnitude) to social exclusion in Chapter 4, it is possible that there would be differences in the underlying neuroelectric sources of this signal across adolescents, children and adults.

Accordingly, source localization techniques could be applied to gain a more qualitative, rather than quantitative, understanding of this difference in the adolescent brain during the processing of social exclusion.

Conclusions and Implications

This thesis demonstrated that shyness is a heterogeneous phenomenon. Shyness subtypes can be identified based on the temporal stability of this trait across development and based on levels of sociability. Separation of these shyness subtypes provides meaningful predictive power for different behavioral signatures, and psychological outcomes. Moreover, differential behavioral and biological reactions to social and even non-social situations may act as potential mechanisms to mediate or moderate their differential outcomes. Given that individual differences in personality shapes one's outcomes in different domains, and different social and biological contexts during certain developmental periods contribute to such development, these findings can inform clinical practice and policies on promoting healthy developmental pathways and increasing social inclusiveness.

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