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The Error Related Negativity (ERN) in Response to Social Stimuli in Individuals with High Functioning Autism

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UNIVERSITY OF MIAMI

THE ERROR RELATED NEGATIVITY (ERN) IN RESPONSE TO SOCIAL STIMULI
IN INDIVIDUALS WITH HIGH FUNCTIONING AUTISM

By

Camilla M. Hileman

A DISSERTATION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

Coral Gables, Florida

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The Error Related Negativity (ERN) in Response to Social Stimuli in Individuals with High Functioning Autism.

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In this study, behavioral (post-error response time) and electrophysiological (ERN amplitude and latency) indices of error-monitoring were examined in individuals with autism and typical development. Participants were presented with a series of faces, and they were asked to quickly and accurately determine the gender or the affect of the faces. Younger participants showed post-error slowing for the Gender Task, while older participants showed post-error slowing for the Affect Task. With age, participants showed a greater differentiation between correct and incorrect responses on both ERN amplitude and ERN latency. For the Gender Task only, participants with typical development showed a greater differentiation between correct and incorrect responses than participants with autism on ERN amplitude. Evidence of more error monitoring on the Affect Task was associated with less autistic symptomology, fewer internalizing problems, and better social skills. Evidence of more error monitoring on the Gender Task was associated with greater autistic symptomology and fewer internalizing problems. Overall, age, regardless of diagnostic group, had a substantial effect on face processing and error monitoring abilities. Individuals with autism showed an ability to engage in

error monitoring, with only mild impairments in error monitoring. The data suggest that error monitoring is not a core deficit of autism; however, individual differences in error monitoring may significantly moderate the expression of autism.

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CHAPTER 1: INTRODUCTION

The Diagnostic and Statistical Manual of Mental Disorders – Fourth Edition – Text Revision (DSM-IV-TR) lists 3 criteria for a diagnosis of autism: a “qualitative impairment in social interaction”, “qualitative impairments in communication”, and “restricted, repetitive, and stereotyped patterns of behavior, interests, and activities” (American Psychiatric Association, 2000). Many individuals with autism exhibit additional impairments that are not specifically outlined in the DSM-IV-TR. The focus of this dissertation is on executive functioning, a cognitive area commonly impaired in individuals with autism (Hill, 2004), but not specifically delineated in the diagnostic criteria for autism.

Executive functioning is a broad term used to encompass several cognitive skills, such as planning, set maintenance, error monitoring, inhibition of a prepotent response, and flexibility (Ozonoff, Pennington, & Rogers, 1991). In this dissertation, the executive functioning domain of error monitoring is examined. Due to deficits in social functioning, individuals with autism may have more difficulty monitoring their errors in an affective context, as compared to a non-affective context. To investigate this possibility, error monitoring was examined when individuals with autism were asked to separately make a determination about the affect of a face and the gender of a face. Since individuals were making a determination about the same faces in both conditions, they were expected to attend to the stimuli equally across conditions. Therefore, the only difference between the conditions was whether participants were asked to focus their attention on an affective or non-affective aspect of the face.

Participants in this study ranged in age from 9-19 years old. During the gender discrimination task, participants were presented with pictures of faces, and they were asked to quickly and accurately push a button on a response pad to indicate whether the face was male or female. Similarly, during the affect discrimination task, participants were presented with pictures of faces, and they were asked to quickly and accurately indicate whether the face was happy or angry. The primary dependent variables of interest from these two tasks were post-error response time, Error-Related Negativity (ERN) amplitude, and ERN latency. These dependent variables were evaluated with respect to individual differences in Autistic Symptomology, Internalizing Problems, and Social Cognition.

The Theoretical Background

The Theory of Executive Dysfunction is a prominent theory that has been forwarded to explain the cognition of autism (Hill, 2004). While executive dysfunction is seen across multiple disorders, such as ADHD and conduct disorder, it has been hypothesized that individuals with autism exhibit a unique pattern of executive dysfunction. The Theory of Executive Dysfunction is one of the few theories to offer a viable explanation for the repetitive behaviors seen in individuals with autism. Difficulties with inhibiting a prepotent response and set shifting may lead an individual with autism to get “stuck” in a particular set of repetitive behaviors. While the connection between executive dysfunction and social/communication impairment is less clear, some researchers argue that executive functioning skills are a necessary prerequisite to the development of a theory of mind and other mentalizing abilities that are critical for social

skill competency (Hill, 2004). Zwaigenbaum et al. (2005) examined executive functioning abilities in the infant siblings of children with autism, and they found that the inability of infants to disengage visual attention at one year of age was predictive of higher ADOS scores at two years of age (Zwaigenbaum et al., 2005).

Surprisingly little research has been conducted on the executive functioning skills of children with autism in an affective, or more social context, compared to a non-affective, or less social context. Ozonoff (1995) examined how individuals with autism performed on the Wisconsin Card Sorting Test, an assessment that measures cognitive flexibility, when the test was administered by an examiner versus by a computer. Individuals with typical development performed similarly on both versions of the test. Individuals with autism performed better on the computer administration version of the test, as the social demands of the task were reduced. The results of this study suggest that executive functioning may interact with the social demands of a task. For children with autism, executive dysfunction appears to be greatest when the social demands of the task are highest.

Dichter and Belger (2007) recently conducted an fMRI study in which participants were presented with two different types of Flanker tasks: a nonsocial task consisting of five arrows and a social task consisting of five faces. They were asked to respectively determine the direction of the middle arrow and the direction of eye gaze for the middle face. During congruent trials, all arrows or all eye gazes pointed in the same direction. During incongruent trials, the middle arrow or eye gaze pointed in an opposite direction from the surrounding stimuli. Thus, incongruent trials required participants to inhibit their prepotent response of indicating the direction in which the majority of the

stimuli pointed. Behaviorally, participants with typical development made more errors on incongruent trials for the arrow stimuli, but not for the gaze stimuli. Participants with autism made more errors on incongruent trials for both the arrow and gaze stimuli. In response to incongruent trials for arrow and gaze stimuli, typically developing participants recruited a specific brain network that involved the prefrontal cortex, the insular cortex, and the anterior cingulate, among other brain regions. Participants with autism only recruited this specific brain network in response to incongruent trials for the arrow stimuli, not the gaze stimuli. For individuals with autism, the social nature of the stimulus seemed to interfere with the participant's ability to access this cognitive control neural network. The results of this study suggest that executive functioning abilities interact with stimulus type. Executive dysfunction in individuals with autism appears to be selectively worse for social stimuli compared to nonsocial stimuli.

Ozonoff (1995) and Dichter and Belger (2007) both present evidence to suggest that executive dysfunction in autism is more pronounced in the social realm than in the non-social realm. It may be that non-social executive function tasks tap an individual's executive functioning abilities, while social executive function tasks tap both an individual's executive functioning abilities and social processing abilities. Individuals with typical development are experts at social processing, so this added task demand may not impact task performance, or it may even facilitate task performance due to the automaticity of processing. However, individuals with autism are poor at social processing, so this added task demand may impair task performance.

This discrepant social/non-social pattern of performance is seen across multiple domains of autism research; it is not limited to executive functioning. For example,

Dawson, Meltzoff, Osterling, Rinaldi, and Brown (1998) examined how children with autism orient to social and non-social stimuli. They found that children with autism were impaired on orienting to all stimuli; however, this impairment was more extreme for social stimuli. Lepisto et al. (2005) further studied social orienting in an ERP study that examined the P3a in response to speech and non-speech sounds. Similarly, Lepisto et al. (2005) found impairments in orienting to both speech and non-speech sounds, but individuals with autism were most impaired in orienting to speech sounds. Thus, the pattern of greater dysfunction in response to social stimuli than nonsocial stimuli is evident across multiple domains of functioning. However, this pattern is only beginning to be investigated with respect to executive dysfunction in autism.

The Literature on the Error-Related Negativity (ERN)

The ERN as an Index of Error Monitoring

The Error-Related Negativity (ERN) is a negative Event-Related Potential (ERP) that generally appears within 100 milliseconds after a person incorrectly responds to a stimulus (Holroyd & Coles, 2002). The ERN is greatest at frontal-central scalp sites, and researchers have suggested that it is generated within the caudal region of the anterior cingulate cortex (O'Connell et al., 2007). The ERN is generally accepted to be an electrophysiological index of error monitoring, such that the ERN is produced whenever there is a mismatch between the participant's actual (erroneous) response and the participant's intended (correct) response (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000). Some researchers, however, offer a slightly different theoretical interpretation of the ERN. Yeung, Botvinick, and Cohen (2004), for example, suggest that the ERN is an

electrophysiological index of conflict monitoring, such that the ERN is produced whenever there is conflict during response selection. Thus, a greater ERN would be produced for trials with incompatible stimuli than for trials with compatible stimuli.

Recent research supports that the ERN is an index of error monitoring, rather than conflict monitoring (Burle, Roger, Allain, Vidal, and Hasbroucq, 2008; Masaki, Falkenstein, Sturmer, Pinkpank, and Sommer, 2007). In addition, when participants are presented with a single stimulus, thereby avoiding any conflict in stimulus presentation, participants still show an ERN response (Compton et al, 2007). Following similar methodology, participants in this study will be presented with a single face stimulus. Therefore, in this study, it will be possible to specifically attribute the ERN response to error monitoring, as opposed to conflict monitoring.

The ERN in Response to Happy/Positive Stimuli vs. Angry/Negative Stimuli

The majority of studies examining the ERN have used neutral, non-social stimuli. Only a handful of studies have examined the ERN in response to affective and/or social stimuli. Compton et al. (2007) presented participants with a series of photographs of faces that were angry, happy, or neutral. Participants viewed one face at a time, and they had to determine whether that face was male or female. There was a main effect of accuracy on reaction time, such that participants responded more quickly on correct trials. Furthermore, Compton et al. (2007) found a significant interaction between anxiety level, facial affect, and accuracy of response in predicting ERN amplitude. Compared to participants with low state anxiety, participants with high state anxiety had a larger ERN amplitude for incorrect trials of happy and neutral faces and a smaller ERN amplitude for

incorrect trials of angry faces. This finding is interpreted in relation to the expectancy violation model of Holroyd and Coles (2002), which suggests that the ERN is greatest when expectations of performance are violated. Angry faces may prime high anxiety individuals to expect failure. Thus, an error in response to an angry face may be consistent with expectations and result in a low amplitude ERN. Conversely, happy faces may prime high anxiety individuals to expect success. An error in response to a happy face may violate expectations and result in a high amplitude ERN.

Larson, Perlstein, Stigge-Kaufman, Kelly, and Dotson (2006) used a letter Flanker task in their study, and they superimposed the letter stimuli on pleasant, neutral, or unpleasant backgrounds. Participants had a longer reaction time for emotionally arousing backgrounds (both pleasant and unpleasant) than for emotionally neutral backgrounds. ERN amplitude was larger for incorrect trials with pleasant backgrounds than incorrect trials with neutral or unpleasant backgrounds. Again, this study suggests that ERN amplitude is greatest when expectations are violated, such as when the participant is primed by a pleasant background to expect success but the trial results in an error.

Overall, ERN amplitude seems to be larger in response to happy/positive stimuli than in response to angry/negative stimuli. As noted in the above studies, this may be a result of expectation violation. An alternative theoretical explanation is that a negative or unpleasant prime disrupts cognitive processing. When Eastwood, Smilek, and Merikle (2003) asked participants to count certain features of negative schematic faces and positive schematic faces, for example, participants took significantly longer to count the features of negative faces. Yet, when stimuli were inverted to reduce holistic processing, there was no difference in the amount of time participants took to count the features of

negative and positive faces. This result suggests that a negative facial expression may capture a participant's attention and reduce his/her performance on associated cognitive tasks. During ERN tasks that involve negative or unpleasant stimuli, participants' attention may be partially captured by the stimuli, leaving participants less able to cognitively engage in error-monitoring. In this study, I expected the ERN to be largest in response to happy faces, as happy faces may violate an individual's expectations and angry faces may disrupt an individual's cognitive processing.

Individuals Differences in the ERN: Development, Psychopathology, and Empathy

Across multiple studies, the ERN doesn't appear to mature fully until adulthood; ERN amplitude continues to increase with age across adolescence (Davies, Segalowitz, & Gavin, 2004; Hogan, Vargha-Khadem, Kirkham, & Baldeweg, 2005; Ladouceur, Dahl, & Carter, 2007; Santesso & Segalowitz, 2008). This suggests that the cognitive process of error-monitoring and the development of the anterior cingulate cortex continue to mature until adulthood. Davies et al. (2004) examined the ERN in individuals ranging in age from 7 to 25 years old. The ERN was very small in children under the age of 12, yet these children still displayed other evidence of error-monitoring. Behaviorally, the children tended to grimace when they made an error; they had a slower response time on trials following an error than a correct response; and electrophysiologically, the children showed a large Pe, a positive deflection after the ERN. These results suggested that children recognized their errors, but there was some dissociation between error recognition and ERN production in young children. Since participants in the current study ranged in age from 9-19 years old, it is important to be aware of developmental

influences on the ERN. Consistent with the prior literature, I expected the ERN amplitude to increase with the age of the participant.

The ERN has also been examined with respect to individual differences in psychopathology. ERN amplitude is greater for individuals with depression, anxiety, and/or obsessive-compulsive disorder (Chiu & Deldin, 2007; Gehring, Himle, & Nisenson, 2000; Hajcak, McDonald, & Simons, 2003a; Holmes & Pizzagalli, 2008; Ladouceur, Dahl, Birmaher, Axelson, & Ryan, 2006). Individuals with high internalizing symptomatology may be hypersensitive to errors and may engage in excessive performance monitoring, which leads to an enhanced ERN. Conversely, individuals with temperament scores that are associated with low socialization and antisocial behavior have small ERN amplitudes (Santesso, Segalowitz, & Schmidt, 2005). These individuals may not be concerned about their errors and may not actively monitor their performance. Thus, an ERN amplitude that is either unusually high or low may be associated with a negative psychopathology outcome.

Munro et al. (2007) examined individual differences in the ERN using both a non-social letter Flanker task and a social face Flanker task. In the letter Flanker task, participants were asked to determine the identity of the middle letter (S or H), which was flanked by 4 other letters; in the face Flanker task, participants were asked to determine the affect of the middle face (angry or fearful), which was flanked by 2 other faces. Control subjects produced an ERN of similar size for both the letter Flanker and face Flanker tasks. Violent offenders at a maximum security facility produced a similarly sized ERN for the letter Flanker task but a reduced ERN for the face Flanker task. Furthermore, ERN amplitude on the face Flanker task was related to scores on the

Psychopathy Checklist – Revised, such that a smaller ERN was associated with greater psychopathy. Psychopaths may be less aware of their errors in an affective context, leading to a reduced ERN in the face Flanker task. This study suggests that individuals with abnormal socialization may have a selective impairment in error-monitoring in the affective/social context, which parallels the conclusion of the executive dysfunction and autism literature, as discussed earlier (Dichter & Belger, 2007; Ozonoff, 1995).

Most recently, Larson, Fair, Good, and Baldwin (2010) evaluated individual differences in post-error response time and ERN amplitude as a function of empathy. Adult participants were given a modified version of the Stroop task, in which they were asked to press a button corresponding to the color of the word presented on a computer screen, while ignoring the word itself. Participants with a longer post-error response time showed greater emotional distress in response to perceived distress in others, and participants with a larger ERN amplitude showed greater empathy. Both of these associations remained after controlling for negative affect. Larson et al. (2010) suggest that error monitoring and empathy may both result from environmental vigilance. Error monitoring requires vigilance to one's own actions, whereas empathy requires vigilance to the actions and feelings of other people. Furthermore, both error monitoring and empathy may be rooted in an underlying desire for a successful outcome. Error monitoring aims to reduce errors, while empathy aims to reduce negative affect in others.

The present study examined how the ERN related to individual differences in the constructs of Autistic Symptomology, Internalizing Problems, and Social Cognition. I expected that better error-monitoring (a larger ERN amplitude and a longer post-error

response time) on both the Affect and Gender Tasks would be associated with less Autistic Symptomology, greater Internalizing Problems, and greater Social Cognition.

Error-Monitoring in Autism

While much research has supported the idea of executive dysfunction in autism (Hill, 2004), the exact profile of executive dysfunction in autism is somewhat unclear. Many studies have shown that individuals with autism have a specific impairment in error-monitoring (e.g., Russell & Jarrold, 1998), though not all studies have demonstrated a more general impairment in response monitoring (Hill & Russell, 2002; Russell & Hill, 2001). Error-monitoring is a term used to describe error recognition and avoidance, whereas response monitoring is a broad term that encompasses error-monitoring and other related abilities, such as memory for actions and intention reporting.

In a study conducted by Russell and Jarrold (1998), individuals with autism played a computer program in which they tried to get a ball to hit a target by pressing one of two computer keyboard keys. If they pressed the wrong key and recognized their mistake, they could correct their error by quickly pressing the correct key. Children with autism were less likely to correct their errors in both external error-monitoring conditions (children could visually see the ball on the computer screen) and internal error-monitoring conditions (children could not visually see the ball on the computer screen). Thus, this study suggests that children with autism simply don't monitor their actions to the extent of typically developing children, regardless of visual cues that suggest they've made an error.

Bogte, Flamma, van der Meere, and van Engeland (2007) used a different methodology to measure error-monitoring in autism. After making an error, most people slow down before responding to the next trial, so Bogte et al. (2007) investigated post-error response time in adults with autism. Participants were asked to complete multiple trials of a memory search task on a computer. Individuals with typical development slowed their response time after making an error. Individuals with autism had a slower response time in general, however they did not significantly adjust their response time after making an error.

Henderson et al. (2006) specifically examined the ERN in children with autism. They examined the ERN in response to a modified Flanker task, in which participants identified the direction of the middle arrow in a set of five arrows. They found a main effect of diagnostic group on latency, such that individuals with autism had a longer ERN latency than individuals with typical development. Furthermore, Henderson et al. (2006) examined how ERN amplitude related to individual differences in autism. A larger ERN amplitude was related to fewer symptoms of social interaction impairment on the Social Communication Questionnaire. Initial analyses also suggested that a larger ERN amplitude was related to fewer internalizing symptoms and more externalizing symptoms, but these analyses failed to reach significance after controlling for verbal IQ or medication status.

Groen et al. (2008) examined error monitoring in a probabilistic learning paradigm in which children had to use performance feedback to figure out which keys to press for which stimuli. There were no differences in ERN amplitude for participants with and without an ASD diagnosis. When comparing performance on an earlier section

of the task with performance on a later section of the task, children with typical development showed a learning effect in which ERN amplitudes were larger for the later section of the task. Children with ASD did not show this learning effect to the same degree as children with typical development. A larger ERN amplitude was related to greater internalizing problems but was unrelated to autistic symptomology.

Vlamings, Jonkman, Hoeksma, van Engeland, and Kemner (2008) administered an auditory decision task to children with typical development and children with autism. Children with autism showed a smaller ERN in response to incorrect trials compared to children with typical development. ERN amplitude was not related to autistic symptomology. In addition, children with typical development significantly increased their response time after making an error, whereas children with autism did not increase their response time. These results suggest that children with autism may not be as adept at recognizing their errors, and thus they don't seem to engage in appropriate error-avoidance behaviors. Thus, the above studies offer both behavioral and electrophysiological evidence that individuals with autism have an impairment in error-monitoring.

The Current Study

The majority of the research studies on the ERN have focused on typical populations and used nonsocial stimuli. The present study is unique in several ways: 1) The present study uses face stimuli, and few studies have examined the ERN in response to social/affective stimuli. 2) The present study focuses on individuals with autism, and few studies have examined the ERN in this specific population. 3) To date, no research

study has examined the ERN in response to social/affective stimuli in individuals with autism. Given the social difficulties associated with autism, this is a particularly important area for research. In addition, the present study evaluated the ERN in response to faces under two conditions: when participants were asked to identify the affect of a face and when participants were asked to identify the gender of a face. By using the same stimuli for both conditions, this design investigates whether error monitoring performance in individuals with autism is worse in an affective context versus a non-affective context. 4) Since no research study has examined the ERN in response to social/affective stimuli in autism, similarly no research study has investigated how individual differences in social/affective presentation are related to the ERN in response to social/affective stimuli in autism. The present study examines how the ERN relates to individual differences in Autistic Symptomology, Internalizing Problems, and Social Cognition. Thus, in these four ways, the present study significantly expands both the depth and breadth of the current literature on autism and the ERN response.

Specific hypotheses were generated for this study with respect to both the task and individual differences associated with the task. The following task hypotheses were generated:

Hypothesis 1a) Individuals with autism will have poor error monitoring compared to individuals with typical development, indexed by a faster post-error response time, a smaller ERN amplitude, and a longer ERN latency. Furthermore, there will be an interaction between diagnostic group and task, such that diagnostic

group differences in error monitoring are more pronounced during the Affect Task than the Gender Task.

Hypothesis 1b) There will be a main effect of affect on ERN amplitude, such that happy faces will elicit a larger ERN amplitude than angry faces.

Hypothesis 1c) There will be a main effect of age on ERN amplitude, such that older participants will have a larger ERN amplitude than younger participants.

Individual differences on Autistic Symptomology, Internalizing Problems, and Social Cognition were examined with respect to post-error response time, ERN amplitude, and ERN latency. The following individual difference hypotheses were generated:

Hypothesis 2a) Poorer error monitoring, indexed by a longer ERN latency, a smaller ERN amplitude, and a faster post-error response time, will be related to greater Autistic Symptomology.

Hypothesis 2b) Better error monitoring, indexed by a larger ERN amplitude and a slower post-error response time, will be related to greater Internalizing Problems.

Hypothesis 2c) Better error monitoring, indexed by a larger ERN amplitude and a slower post-error response time, will be related to greater Social Cognition.

It was not clear whether ERN latency would relate to Internalizing Problems or Social Cognition. These hypotheses were expected to hold for both individuals with autism and individuals with typical development, to the extent that there was sufficient variability of Autistic Symptomology, Internalizing Problems, and Social Cognition within each diagnostic group

CHAPTER 2: METHOD

Participants

The initial sample for this study was composed of 114 participants: 60 participants with High-Functioning Autism (HFA) and 54 participants with typical development. In this study, HFA refers to an individual with an Autism Spectrum Disorder (ASD) diagnosis and a verbal IQ greater than 70. Seventeen participants with HFA were excluded from the final sample: 2 participants were unable to complete the WISC, 4 participants were unable to complete the EEG protocol, 6 participants did not meet the diagnostic criteria for autism when evaluated in the lab, 1 participant responded too slowly to all stimuli during the Affect Task, and 4 participants were excluded for matching purposes (see below for a full explanation). Eleven participants with typical development were excluded from the final sample: 7 participants met the diagnostic criteria for autism when evaluated in the lab and 4 participants were excluded for matching purposes (see below for a full explanation). The literature suggests that participants with a mental health disorder, such as a mood disorder, may occasionally meet autism cut-off scores (Sikora, Hartley, McCoy, Gerrard-Morris, & Dill, 2008), which explains why some participants with typical development met diagnostic criteria for autism in the lab.

The final sample for this study was composed of 86 participants: 43 participants with HFA (38 males and 5 females) and 43 participants with typical development (37 males and 6 females). Although included and excluded participants did not significantly differ on verbal IQ, $t(110) = 0.41$, $p = 0.68$, or gender distribution, $\chi^2(1, N = 114) = 1.24$,

$p = 0.27$, excluded participants were more likely to be younger, $t(112) = 2.33$, $p = 0.02$, and have a lower performance IQ, $t(110) = 2.18$, $p = 0.03$, than included participants.

All participants were recruited from a database of participants who previously completed or expressed interest in completing a research study in Dr. Heather Henderson's HFA lab at the University of Miami. Participants with HFA were originally recruited from the University of Miami Center for Autism and Related Disabilities. Participants with typical development were originally recruited from local public and private elementary, middle, and high schools.

All participants were screened before coming into the lab and again after coming into the lab. In the initial screening, participants were excluded from participation if they had a history of seizures, a genetic condition (such as Fragile X Syndrome), a reading level below the second grade, psychotic symptoms (such as hallucinations), a previously abnormal EEG, or if they were nonverbal. Participants with autism had to have an ASD diagnosis in accordance with DSM guidelines from a community mental health professional. Typically developing participants could not have such a diagnosis.

Although participants with HFA had already been diagnosed by a community mental health professional, this diagnosis was verified in the lab. Participants with HFA were required to meet 2 of the following 3 diagnostic criteria for autism: a cutoff score of 7 on the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, Dilavore, & Risi, 2002), a cutoff score of 13 on the Social Communication Questionnaire (SCQ; Berument, Rutter, Lord, Pickles, & Bailey, 1999), and a cutoff score of 13 on the Autism Spectrum Screening Questionnaire (ASSQ; Ehlers, Gillberg, & Wing, 1999). Given that participants already had an ASD diagnosis from a community mental health professional,

meeting 2 out of 3 cut-off scores was sufficient for confirming diagnosis.¹ Participants with typical development were excluded from the sample if they met any of the above cut-off scores for autism on the ADOS, SCQ, or ASSQ.² Additionally, all participants regardless of diagnostic group had to have a verbal IQ of 70 or greater, as assessed by the Wechsler Intelligence Scale for Children (WISC; Wechsler, 2003) Verbal Comprehension Index.

Individuals with HFA and typical development were mismatched on verbal IQ in the initial sample. In order to address this mismatching, the 4 participants with HFA with the lowest verbal IQ and the 4 participants with typical development with the highest verbal IQ were removed from the sample. Table 1 presents demographic information on the final sample of participants. The diagnostic groups did not significantly differ on age, $t(84) = 0.03, p = 0.98$, verbal IQ, $t(84) = -1.94, p = 0.06$, performance IQ, $t(84) = -1.22, p = 0.23$, or gender distribution, $\chi^2(1, N = 86) = 0.10, p = 0.75$. Although there were no significant differences on these variables, verbal IQ approached significance and was thus controlled for in the analyses.

In the HFA group, participants had parent-reported comorbid diagnoses of ADHD ($n = 9$), learning disability ($n = 3$), anxiety ($n = 1$), mood disorder ($n = 1$), and OCD ($n = 1$). In the typical development group, participants had parent-reported diagnoses of ADHD ($n = 3$), learning disability ($n = 3$), and dyslexia ($n = 1$). The ethnic distribution for the sample was: 43.0% Caucasian, Non-Hispanic; 41.9% Hispanic; 7.0% Mixed,

¹ Although one participant did not have a formal ASD diagnosis from a community mental health professional, this participant had been referred to receive such a diagnosis and met all 3 diagnostic cut-off scores. Thus, this participant was included in the HFA group.

² One participant with typical development did not complete the ADOS due to time constraints. A second participant with typical development scored 7 on the ADOS. Neither of these participants showed other indicators of autism, so both participants were retained in the typical development group.

Hispanic; 3.5% no response; 2.3% Black, Non-Hispanic; 1.2% Mixed, Non-Hispanic; and 1.2% Asian. The diagnostic groups did not significantly differ on ethnic distribution, $\chi^2(5, N = 83) = 5.35, p = 0.37$.

Measures

Most participants in this research project previously participated in research in Dr. Heather Henderson's HFA lab. Thus, many participants recently completed assessments needed for the current project. If a participant completed the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV) or the Autism Diagnostic Observation Schedule (ADOS) within the previous two years, he/she was not re-assessed on this measure, and scores from the previous assessment were used. The reasoning behind this decision was threefold: 1) Both the WISC-IV and the ADOS show good test-retest reliability (Lord et al., 2000; Weschler, 2003), 2) Retesting participants on these measures over a short period of time could artificially elevate or reduce scores due to practice effects, and 3) This decision minimized the burden on research participants. If the participant completed the Social Anxiety Scale for Children – Revised (SASC-R), the Behavior Assessment System for Children (BASC) Self Report, the Eyes Task, or the Strange Stories Task within the previous six months, he/she was not reassessed on this measure, and scores from the previous assessment were used. Similarly, if the participant's parent completed the Social Responsiveness Scale (SRS), the Autism Spectrum Screening Questionnaire (ASSQ), or the Social Communication Questionnaire (SCQ) within the previous six months, scores from the previous assessment were used.

Cognitive

Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV; Wechsler, 2003) & the Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV; Wechsler, 2008): The majority of participants were assessed using the WISC-IV ($n = 67$).

Participants older than the age of 16 years who had not been assessed on the WISC-IV in the previous two years were assessed using the WAIS-IV ($n = 19$). Both assessments have well-established reliability and validity. In addition, scores on the WISC-IV are highly correlated with scores on the WAIS-IV (Wechsler, 2008). To minimize the assessment burden, an abbreviated version of the scales was administered to participants. The Vocabulary and Similarities subscales were used to estimate the participant's Verbal Comprehension Index (VCI), and the Matrix Reasoning and Block Design subscales were used to estimate the participant's Perceptual Reasoning Index (PRI). These subscales were chosen because they have the best test-retest reliabilities, the highest estimates of internal consistency, and the strongest loadings on the VCI and PRI respectively (Williams, Weiss, & Rolfhus, 2003) for the WISC-IV. The VCI was used to confirm that all participants in the study had a verbal IQ greater than or equal to 70. These assessments were administered and scored by doctoral students in developmental psychology and child clinical psychology.

Autistic Symptomology

Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000, 2002): The ADOS is a semi-structured observational assessment that evaluates an individual's language and communication, reciprocal social interaction, imagination, and stereotyped

behaviors and restricted interests. Participants engage in a variety of activities with the examiner, from telling a story in a book to conversing about friends and marriage.

Behaviors are generally rated on a scale from 0-3, with higher numbers indicating greater impairment. The ADOS has high reliability and validity, with an algorithm that is both specific and sensitive in identifying individuals with and without autism. ADOS Modules 3 and 4 were used in the present study. Module 3 was used for children and younger adolescents with fluent speech while Module 4 was used for older adolescents and young adults with fluent speech. In this study, the ADOS Communication and Social Interaction Total with a cut-off score of 7 was used to confirm the diagnosis of study participants. This assessment was administered and scored by doctoral students in developmental psychology and child clinical psychology.

Autism Spectrum Screening Questionnaire (ASSQ; Ehlers, Gillberg, & Wing, 1999): The ASSQ is a 28-item questionnaire completed by the participant's parent. Parents rate their child's behaviors as being the same, somewhat different, or different from the behaviors of other children. This measure has good reliability and has been validated against other assessments of behavioral disorders. In this study, the ASSQ Total Score with a cut-off score of 13 was used to confirm the diagnosis of study participants. In addition, it was used as an indicator of Autistic Symptomology.

Social Communication Questionnaire (SCQ; Berument et al., 1999): Parents of participants fill out this questionnaire. The first 19 questions inquire about the participant's current behavior, and the last 21 questions inquire about the participant's behavior between the ages of 4-5. Parents must respond yes or no to each question. This questionnaire was developed from the 40 critical items of the Autism Diagnostic

Interview (ADI). As with the ADI, this questionnaire focuses on the domains of reciprocal social interaction, communication, and repetitive and stereotyped patterns and behaviors. The SCQ shows high reliability and has been validated by high correlations with the ADI. In this study, the SCQ Total with a cut-off score of 13 was used to confirm the diagnosis of study participants. In addition, it was used as an indicator of Autistic Symptomology.

Social Responsiveness Scale (SRS; Constantino, 2004; Constantino et al., 2003):

This 65-item questionnaire is completed by parents and focuses on their child's behavior in the last 6 months. Parents must rate each statement on a 4-point scale, ranging from not true to almost always true. Items on the questionnaire focus on social awareness, cognition, communication, motivation, and mannerisms. The questionnaire was originally piloted on the parents of 1,900 children between the ages of four and fifteen, and the questionnaire was found to have excellent short-term and long-term test-retest reliability. The questionnaire was validated through high correlations with the ADI. The SRS Total was used as an indicator of Autistic Symptomology in this study.

Internalizing Problems

Behavior Assessment System for Children (BASC; Reynolds & Kamphaus, 1998): The Self Report version of the BASC was used in the present study. Participants are given a series of statements about how they may think, feel, or act in certain situations. In the first part of the BASC, they decide whether a statement is true or false for them; in the second part of the BASC, they use a 4-point scale, ranging from never to almost always, to evaluate how often the statements are true for them. The BASC has

been standardized and normed on a national sample of 9,861 children, and it has well-established reliability and validity. In this study, the BASC Self Report Anxiety Scale and the BASC Self Report Depression Scale were used as measures of Internalizing Problems.

Social Anxiety Scale for Children – Revised (SASC-R; La Greca & Stone, 1993):

The Self Report version of the SASC-R was used in the present study.

Participants were asked to respond to 22 statements on social anxiety, using a 5-point scale that ranges from not at all true to all of the time true. This scale has adequate reliability and has been validated against children's self perceptions of competence. The SASC Total was used as an indicator of Internalizing Problems in this study.

Social Cognition

Eyes Task (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001): In the Eyes Task, participants are presented with a photograph of a person's eyes and four emotion words. Participants are asked to choose the emotion that best describes what the person in the picture is thinking or feeling. Participants are asked to evaluate 28 photographs, thus the total score for this measure ranges from 0-28. Individuals with autism have impaired performance on this task, but not on a gender recognition control task, which validates this task as an appropriate measure of social cognition in individuals with autism. The Eyes Task Total Score was used as a measure of Social Cognition in this study.

Strange Stories Task (Happe, 1994): In the Strange Stories Task, participants read a series of 12 stories and then answered a few questions about each story. The stories assess the participant's mentalizing ability by featuring specific social situations or

sayings, such as a lie, sarcasm, or figure of speech. The participant is first asked a Reality Question to confirm that they understood the events of the story. Second, the participant is asked a Justification Question to explain why the events of the story unfolded in that particular manner. Participants may provide a physical explanation or mental explanation of the events in the story. This measure was validated by its associations with first-order and second-order theory-of-mind tasks. Participants' responses were coded separately by two undergraduate students with special training. When the coders did not agree, they discussed the scoring between themselves to resolve any differences. If the coders still did not agree, the scoring was resolved in collaboration with doctoral students in developmental psychology and child clinical psychology. The number of Reality and Justification Questions that the participant answered correctly and the number of mental explanations given to the Justification Questions, regardless of whether those explanations were correct or incorrect, served as measures of Social Cognition in this study.

Composite Scores

As described above, these measures formed composite scores for Autistic Symptomology, Internalizing Problems, and Social Cognition. The Autistic Symptomology composite score was derived from the SRS Total, ASSQ Total, and SCQ Total; the Internalizing Problems composite score was derived from the SASC-R Total (Self Report), the BASC Anxiety Scale (Self Report), and the BASC Depression Scale (Self Report); and the Social Cognition composite score was derived from the Eyes Task

Total, the Strange Stories Mental Explanations Scale, and the Strange Stories Number of Reality and Justification Questions Correct Scale.

Intraclass correlation coefficients (ICC) were computed to index reliability among the three measures that formed each composite score. See Table 2 for ICC values for the whole sample and within each diagnostic group. Across all participants, ICC values demonstrated adequate reliability, ranging from .64 – .91. Thus, the three measures for each composite score were standardized and averaged together to form the appropriate scores.

Stimuli

The stimuli used for the Gender and Affect Tasks were color photographs of faces. These stimuli were taken from the NimStim Face Stimulus Set (Tottenham et al., 2009). Identical photographs were used across the Gender and Affect Tasks. Photographs were selected to vary in affect (angry vs. happy). Figure 1 displays sample stimuli. There were 52 different angry faces and 52 different happy faces, for a total of 104 different photographs in the ERN tasks.

Procedure

This study was divided into two sections: an EEG face processing section and a questionnaire/direct assessment section. The questionnaire/direct assessment section of the study included some or all of the following, depending on whether and when participants or their parents previously completed these measures: WISC-IV, ADOS, ASSQ, SCQ, SRS, BASC, SASC-R, Eyes Task, and the Strange Stories Task.

Before the EEG section of the study, the participant's scalp was measured, and an appropriately sized 128-lead Geodesic sensor net was soaked in a potassium-chloride electrolyte solution. The electrodes on the net were evenly spaced, and the net covered the participant's scalp from the left ear to the right ear and from the nasion to the inion. When possible, impedances were kept below 40 k Ω . Participants were seated approximately 20 inches from the computer monitor used for stimulus presentation. The EEG signal was amplified (x1000) and filtered (0.1 Hz high-pass filter and 100 Hz elliptical low-pass filter) using a preamplifier system. The conditioned signal was multiplexed and digitized at 250 Hz using an analog-to-digital converter and a Macintosh computer. All 128 channels were continuously recorded and streamed to the computer's hard drive. A Dell computer, interfaced and synchronized via serial port, generated the stimuli using e-Prime software. Stimulus presentation and response time were recorded in order to later segment the data. The VRef (Cz) electrode was used as the reference during data collection, and the data were re-referenced to an average reference configuration after data collection.

Within the EEG section of the study, the order in which participants completed the Gender and Affect Tasks was randomized. Participants viewed a series of faces, and they used a four-pronged button box to make decisions about the faces. In the Gender Task, participants pressed "1" on the button box for male faces and "2" for female faces. In the Affect Task, participants pressed "3" on the button box for angry faces and "4" for happy faces. Both tasks were divided into three sections: a Practice Section, a Timing Section, and a Trial Section.

During the Practice Section, participants were presented with a series of 15 face photographs. Each photograph was presented for 750 ms, thus participants had 750 ms to make a decision on the gender/affect of the face. After participants made a decision, there was a 500 ms pause before participants received feedback on their decision. If participants made a correct decision within the allotted 750 ms, they viewed a screen with the word “correct.” If participants make an incorrect decision within the allotted 750 ms, they viewed a screen with the words “not correct.” If participants did not make a decision within 750 ms, they viewed a screen with the words “too slow to respond.” After receiving feedback on their response, a blank screen was presented for 500 ms, which allowed for a pause before the next face photograph was presented. The goal of the Practice Section was to ensure that participants were familiar with the demands of the task.

During the Timing Section, participants were presented with a series of 30 face photographs. As in the Practice section, photographs appeared on the computer screen for 750 ms, thus participants had 750 ms to make a decision on the gender/affect of the face. After a 500 ms pause, participants received feedback on their decision. Following this feedback, there was another 500 ms pause before the next photograph was presented.

An average accuracy score, a 40th percentile reaction time score, and a 75th percentile reaction time score were calculated from each participant’s responses to the 30 faces in the Timing Section. If a participant did not respond to a face stimulus within the allotted time, the reaction time for that face was recorded as the maximum reaction time, 750 ms. The participant’s performance on the Timing Section of the task was used to individually titrate the length of time photographs were presented in the Trial Section of

the task. If participants were at least 70% accurate in their responses, the face photographs in the Trial Section were presented for participants' 40th percentile reaction time.³ If participants were less than 70% accurate in their responses, the face photographs in the Trial Section were presented for participants' 75th percentile reaction time. The goal of the Timing Section was to individually titrate the timing parameters for the Trial Section of the task.

During the Trial Section, participants were presented with 3 blocks of 104 face photographs. Each photograph was presented for the participants' 40th or 75th percentile reaction time in the Timing Section, thus participants had this length of time to make a decision about the gender/affect of the face. Again, as in the Practice and Timing Sections, there was a 500 ms pause before participants received feedback on their decision. After receiving feedback, there was a 500 ms pause before the next photograph was presented. Between blocks, participants had the opportunity to take a short break. The goal of the Trial Section was to evaluate participants' responses to a series of 312 faces.

EEG Data Editing and Reduction

The following EEG/ERP software programs were used in processing the EEG data: NetStation (Luu et al., 2010), EEGLAB (Delorme & Makeig, 2004), and ERPLAB (Lopez-Calderon & Luck, 2010). Data were re-filtered at a lowpass of 30 Hz. Data were segmented into the following four categories: correct responses to happy faces, incorrect responses to happy faces, correct responses to angry faces, and incorrect responses to

³ A 50th percentile reaction time was mistakenly used on the Gender Task for two participants and on the Affect Task for one participant. A 75th percentile reaction time was mistakenly used on the Affect Task for one participant.

angry faces. A channel with more than $200 \mu\text{V}$ between its minimum and maximum amplitude values (performing a moving average of 80 ms) for a given segment was identified as a bad channel for that segment. A channel was marked as a bad channel throughout the whole recording if it was marked bad for more than 25% of the segments. Segments with more than 15 bad channels were rejected. If a segment had 15 or fewer bad channels, the data in the bad channels were replaced with data interpolated from nearby good channels, using spherical splines (Electrical Geodesics, Inc., 2004).

Data were baseline corrected to the interval -100 to 0 ms before the participant's response. Independent components analysis was run on all channels. Components that were indicative of eye blinks were removed from the data. Step-like artifact detection was performed on electrode sites of interest in order to detect a step-like change in voltage greater than $100 \mu\text{V}$. Segments that contained step-like artifacts were removed from the data. In addition, all segments were manually inspected, and any noisy segments remaining in the data were manually removed. Throughout the data editing process, an average of 3.3% / 2.7% of segments were removed from the Affect Task and an average of 4.6% / 4.1% segments were removed from the Gender Task respectively for participants with typical development / HFA. Data were then re-referenced to an average reference. Segments were averaged within participants to create four grand-averaged segments for each participant: correct responses to happy faces, incorrect responses to happy faces, correct responses to angry faces, and incorrect responses to angry faces.

Data Analyses

Trials in which the participant responded in less than 100 ms were removed from all data analyses. Accuracy was operationalized and analyzed in two ways: 1) the number of correct responses compared to the total number of recorded responses (i.e., response accuracy) and 2) the number of correct responses compared to the total number of face stimuli (i.e., overall accuracy). The first definition of accuracy excludes trials for which the participant did not respond or responded too slowly, and the second definition of accuracy includes these trials. Reaction time was also operationalized and analyzed in two ways: 1) the reaction time for correct responses (i.e., correct reaction time) and 2) the reaction time for all responses (i.e., overall reaction time).

Participants were only included in the data analyses for post-error response time if they had at least 10 instances of error trials directly followed by correct trials (i.e., error-correct trials) and at least 10 instances of correct trials directly followed by correct trials (i.e., correct-correct trials) on both the Gender and Affect Tasks. Six participants with HFA were excluded from the post-error response time analyses because they did not meet this criterion. Post-error response time was calculated as the mean reaction time of error-correct trials minus the mean reaction time of correct-correct trials. Thus, a positive post-error response time is indicative of slowing down on trials following an error (i.e., post-error slowing), and a negative post-error response time is indicative of speeding up on trials following an error (i.e., post-error speeding).

Participants were only included in the data analyses for ERN amplitude and latency if they had at least 10 artifact-free trials for all 4 EEG categories on both the Gender and Affect Tasks. Five participants with HFA and four participants with typical

development were excluded from the ERN amplitude and latency analyses because they did not meet this criterion. ERN amplitude and latency values were extracted for the four EEG categories across both the Gender and Affect Tasks. ERN amplitude was calculated as the mean amplitude between 25-75 ms following the participant's response. ERN latency was calculated as the latency of the local negative peak (i.e., the peak with a more negative amplitude than the average of the four points on either side of it) within the 25-75 ms following the participant's response. If a local negative peak could not be found, then ERN latency was calculated as the latency of the absolute negative peak within the 25-75 ms following the participant's response. The 25-75 ms time window was determined by visual inspection. ERN amplitude and latency were examined across the following electrode sites on the 128-lead Geodesic sensor net: 11 (Fz), 6 (Fcz), VRef (Cz), 55 (Cpz), and 62 (Pz). Figure 2 displays these electrode sites.

CHAPTER 3: RESULTS

Preliminary Analyses

A preliminary ANOVA on overall reaction time was performed to ensure that participants did not have a bias in pushing a particular button on the button box. For the Gender Task, participants were instructed to press “1” for male faces and “2” for female faces. Gender (male vs. female) was the within-subjects factor. The analysis did not yield a main effect of gender, $F(1, 85) = 0.71, p = 0.40$, showing that there was no consistent bias in participants’ responses on the Gender Task. For the Affect Task, participants were instructed to press “3” for angry faces and “4” for happy faces. Affect (angry vs. happy) was the within-subjects factor. The analysis did not yield a main effect of affect, $F(1, 85) = 0.24, p = 0.63$, showing that there was also no consistent bias in participants’ responses on the Affect Task.

A preliminary ANOVA analysis on ERN amplitude was performed 1) to confirm that an ERN (i.e., a more negative amplitude for incorrect trials than correct trials) was observed across participants and 2) to determine which electrode sites most clearly showed the ERN response. Task (Gender Task vs. Affect Task), Electrode Site (11, 6, VRef, 55, 62), and Accuracy (correct response vs. incorrect response) were the within-subjects factors. The analysis yielded a main effect of Electrode Site, $F(4, 304) = 94.07, p < 0.01, \eta^2_p = 0.55$, and a main effect of Accuracy, $F(1, 76) = 74.32, p < 0.01, \eta^2_p = 0.49$, which were qualified by a significant interaction between Electrode Site and Accuracy, $F(4, 304) = 20.96, p < 0.01, \eta^2_p = 0.22$. Post hoc probing showed that incorrect trials had a more negative amplitude than correct trials across all electrode sites; however, the

difference between correct and incorrect trials was particularly salient for electrode sites 6, $t(76) = 9.55, p < 0.01$, and VRef, $t(76) = 8.00, p < 0.01$. Thus, the expected ERN response was observed across participants, and this response was most visible at electrode sites 6 (Fcz) and VRef (Cz).

In the following ERN analyses, the difference score between correct and incorrect trials was analyzed, with the amplitude of incorrect trials subtracted from the amplitude for correct trials (i.e., ERN Amplitude Difference) and the latency of incorrect trials subtracted from the latency for correct trials (i.e., ERN Latency Difference). Thus, a positive ERN Amplitude Difference is indicative of a more negative amplitude for incorrect trials than correct trials. A negative ERN Latency Difference is indicative of a longer latency for incorrect trials than correct trials. Given that amplitude values at electrode sites 6 and VRef and latency values at electrode sites 6 and VRef were highly correlated ($r = .68 - .95$ for amplitude within group correlations, $r = .21 - .71$ for latency within group correlations), the ERN Amplitude Difference and the ERN Latency Difference were calculated as the average of the difference scores across these two electrode sites.

Task Results

ANCOVAs were used to evaluate the following dependent variables: response accuracy, overall accuracy, correct reaction time, overall reaction time, timing parameters generated from the Timing Section and applied to the Trial Section, post-error response time, ERN Amplitude Difference, and ERN Latency Difference. See Tables 3 and 4 for partial correlations among these dependent variables for the Gender and Affect Tasks,

controlling for age and verbal IQ. Diagnostic group (HFA vs. typical development) was a between-subjects factor for all analyses. Task (Gender Task vs. Affect Task) and affect (happy faces vs. angry faces) were within-subjects factors for the accuracy, reaction time, ERN amplitude, and ERN latency analyses; task was the only within-subjects factor for the timing parameter and post-error response time analyses. Age and verbal IQ were initially included as continuous covariates in all analyses. Verbal IQ did not have a significant effect in any of the analyses; thus, verbal IQ was removed from the analyses as a covariate. Age was a variable of theoretical interest, so it was retained as a covariate in the analyses regardless of whether its effect was significant.

The ANCOVA assumption of parallel regression slopes was examined by testing for an interaction between diagnostic group and age. The interaction term was not significant for any of the ANCOVA analyses. Thus, the assumption of parallel regression slopes was met, and the interaction terms were removed from further analyses.

Accuracy

The analysis evaluating response accuracy yielded a main effect of age, $F(1, 83) = 10.71, p < 0.01, \eta^2_p = 0.11$, such that accuracy increased with age. The analysis evaluating overall accuracy also yielded a main effect of age, $F(1, 83) = 7.51, p = 0.01, \eta^2_p = 0.08$, again such that accuracy increased with age. Diagnostic groups did not differ significantly on response accuracy or overall accuracy. Table 5 shows the mean values for response accuracy and overall accuracy.

Reaction Time

The analysis evaluating correct reaction time yielded a main effect of affect, $F(1, 83) = 4.46, p = 0.04, \eta^2_p = 0.05$, which was qualified by a significant interaction between affect and age, $F(1, 83) = 3.97, p = 0.05, \eta^2_p = 0.05$. Post hoc probing was conducted to interpret the affect by age interaction effect. The marginal means for affect were estimated at 12.42 years (one standard deviation below the mean age), 15.17 years (the mean age), and 17.92 years (one standard deviation above the mean age), as suggested by Aiken and West (1991). The marginal means at each age were then compared using t -tests. At 12.42 years, there was a significant effect of affect, $t(83) = 2.85, p = 0.01$, such that the reaction time for correct responses was faster for happy faces than angry faces. At 15.17 years, $t(83) = 0.85, p = 0.40$, and 17.92 years, $t(83) = -1.16, p = 0.25$, there was not a significant effect of affect. See Figure 3. The analysis evaluating overall reaction time did not yield any significant findings. Diagnostic groups did not differ significantly on correct reaction time or overall reaction time. Table 5 shows the mean values for correct reaction time and overall reaction time.

Timing Parameters

The analysis evaluating the timing parameters for the Trial Section did not yield any significant findings. Diagnostic groups did not differ significantly on the timing parameters, demonstrating that the task was of comparable difficulty across individuals with HFA and typical development. Table 6 shows the mean values for the timing parameters.

Post-Error Response Time

Hypothesis 1a) Individuals with autism will have poor error monitoring compared to individuals with typical development, indexed by a faster post-error response time, a smaller ERN amplitude, and a longer ERN latency. Furthermore, there will be an interaction between diagnostic group and task, such that diagnostic group differences in error monitoring are more pronounced during the Affect Task than the Gender Task.

The analysis evaluating post-error response time yielded a main effect of task, $F(1, 77) = 4.14, p = 0.05, \eta^2_p = 0.05$, which was qualified by a significant interaction between task and age, $F(1, 77) = 4.33, p = 0.04, \eta^2_p = 0.05$. Post hoc probing was conducted to interpret the task by age interaction effect. The marginal means for affect were estimated at 12.35 years (one standard deviation below the mean age), 15.14 years (the mean age), and 17.94 years (one standard deviation above the mean age), as suggested by Aiken and West (1991). The marginal means at each age were then compared using t -tests. At 12.35 years, there was a significant effect of task, $t(77) = -2.87, p = 0.01$, such that there was more post-error slowing for the Gender Task than for the Affect Task. At 15.14 years, there was not a significant effect of task, $t(77) = 0.10, p = 0.92$. At 17.94 years, there was a significant effect of task, $t(77) = 3.06, p < 0.01$, such that there was more post-error slowing for the Affect Task than for the Gender Task. Diagnostic groups did not differ significantly on post-error response time. See Figure 4. Table 6 shows the mean values for post-error response time.

ERN Amplitude

*Hypothesis 1a) Individuals with autism will have poor error monitoring compared to individuals with typical development, indexed by a faster post-error response time, a **smaller ERN amplitude**, and a longer ERN latency. Furthermore, there will be an interaction between diagnostic group and task, such that diagnostic group differences in error monitoring are more pronounced during the Affect Task than the Gender Task.*

Hypothesis 1b) There will be a main effect of affect on ERN amplitude, such that happy faces will elicit a larger ERN amplitude than angry faces.

Hypothesis 1c) There will be a main effect of age on ERN amplitude, such that older participants will have a larger ERN amplitude than younger participants.

Figures 5 and 6 respectively show the grand-averaged waveforms for participants with autism and typical development, and younger and older participants. The analysis evaluating ERN Amplitude Difference yielded a main effect of age, $F(1, 74) = 15.61, p < 0.01, \eta^2_p = 0.17$, such that participants showed a greater amplitude difference between correct and incorrect responses with age. The analysis yielded a marginal main effect of diagnostic group, $F(1, 74) = 2.85, p = 0.10, \eta^2_p = 0.04$, such that individuals with typical development showed a greater amplitude difference than individuals with HFA. This main effect was qualified by a marginal interaction between diagnostic group and task, $F(1, 74) = 3.37, p = 0.07, \eta^2_p = 0.04$. Post hoc probing was conducted to interpret the diagnostic group by task interaction effect. A follow-up MANOVA showed that

diagnostic group had a significant effect on amplitude for the Gender Task, $F(1, 74) = 5.77, p = 0.02, \eta^2_p = 0.07$, such that individuals with typical development showed a greater amplitude difference between correct and incorrect responses than individuals with HFA. Diagnostic group did not have a significant effect on amplitude for the Affect Task, $F(1, 74) = 0.01, p = 0.93$. Follow-up ANCOVAs showed that task did not have a significant effect on amplitude for participants with typical development, $F(1, 37) = 0.23, p = 0.64$, or for participants with HFA, $F(1, 36) = 1.88, p = 0.18$. See Figure 7. Table 7 shows the mean values for ERN Amplitude Difference.

ERN Latency

Hypothesis 1a) Individuals with autism will have poor error monitoring compared to individuals with typical development, indexed by a faster post-error response time, a smaller ERN amplitude, and a longer ERN latency. Furthermore, there will be an interaction between diagnostic group and task, such that diagnostic group differences in error monitoring are more pronounced during the Affect Task than the Gender Task.

See Figures 5 and 6 for the grand-averaged waveforms. The analysis evaluating ERN Latency Difference yielded a main effect of age, $F(1, 74) = 9.25, p < 0.01, \eta^2_p = 0.11$, such that participants showed a greater latency difference between correct and incorrect responses with age. The analysis also yielded a marginal interaction between task and affect, $F(1, 74) = 2.83, p = 0.10, \eta^2_p = 0.04$. Post hoc probing was conducted to interpret the task by affect interaction effect. Follow-up ANCOVAs showed that affect had a marginal effect on latency for the Gender Task, $F(1, 75) = 3.28, p = 0.07, \eta^2_p =$

0.04, such that participants showed a greater latency difference between correct and incorrect trials on happy faces than angry faces. Affect did not have a significant effect on latency for the Affect Task, $F(1, 75) = 0.23, p = 0.63$. Task had a marginal effect on latency for angry faces $F(1, 75) = 3.16, p = 0.08, \eta^2_p = 0.04$, such that participants showed a greater latency difference between correct and incorrect trials on the Gender Task than the Affect Task. Task did not have a significant effect on latency for happy faces, $F(1, 75) = 0.37, p = 0.54$. As suggested by Figure 8, with age, participants show a greater latency difference between correct and incorrect trials across all stimuli; however, the latency difference between correct and incorrect trials for angry faces on the Gender Task seems to increase more steeply with age than the latency difference for the other stimuli. See Figure 8. Diagnostic groups did not differ significantly on ERN Latency Difference. Table 7 shows the mean values for ERN Latency Difference.

Individual Difference Results

Hierarchical linear regressions were used to evaluate individual differences on the composite scores Autistic Symptomology, Internalizing Problems, and Social Cognition. For each composite score, three hierarchical linear regressions were performed. For all regressions, diagnostic group, age, and verbal IQ were entered in the first block of predictors; the designated error-monitoring variables (post-error response time, ERN amplitude, or ERN latency) for both Affect and Gender Tasks were centered and entered in the second block of predictors, and the interactions between those designated error monitoring variables and diagnostic group were entered in the third block of predictors. The first set of regressions analyzed post-error response time, with post-error response

time on the Affect and Gender Tasks as the designated error-monitoring variables. The second set of regressions analyzed ERN amplitude, with ERN Amplitude Difference on the Affect and Gender Tasks as the designated error-monitoring variables. Finally, the third set of regressions analyzed ERN latency, with ERN Latency Difference on the Affect and Gender Tasks as the designated error-monitoring variables.

Autistic Symptomology

Hypothesis 2a) Poorer error monitoring, indexed by a longer ERN latency, a smaller ERN amplitude, and a faster post-error response time, will be related to greater Autistic Symptomology.

Post-error response time: The first block significantly predicted autistic symptomology, $F(3, 76) = 192.34, p < 0.01$. The second block, $\Delta F(2, 74) = 0.25, p = 0.78$, and the third block, $\Delta F(2, 72) = 0.67, p = 0.51$, did not significantly predict autistic symptomology above and beyond the previous block. In addition, none of the predictors added in the second and third blocks were significant predictors of autistic symptomology. Thus, the first block was retained as the final model and predicted 88.4% (87.9% adjusted) of the variance in autistic symptomology. In this model, diagnostic group significantly predicted autistic symptomology, $t(76) = 23.33, p < 0.01$, such that participants with HFA showed more autistic symptomology than participants with typical development. See Table 8.

ERN amplitude: The first block significantly predicted autistic symptomology, $F(3, 73) = 193.47, p < 0.01$. The second block, $\Delta F(2, 71) = 0.66, p = 0.52$, and the third

block, $\Delta F(2, 69) = 0.09, p = 0.92$, did not significantly predict autistic symptomology above and beyond the previous block. In addition, none of the predictors added in the second and third blocks were significant predictors of autistic symptomology. Thus, the first block was retained as the final model and predicted 88.8% (88.4% adjusted) of the variance in autistic symptomology. In this model, diagnostic group significantly predicted autistic symptomology, $t(73) = 23.24, p < 0.01$, as described previously. See Table 9.

ERN latency: The first block significantly predicted autistic symptomology, $F(3, 73) = 193.47, p < 0.01$. The second block marginally predicted autistic symptomology above and beyond the first block, $\Delta F(2, 71) = 2.73, p = 0.07$. The third block did not significantly predict autistic symptomology above and beyond the second block, $\Delta F(2, 69) = 1.67, p = 0.20$. However, the interaction between diagnostic group and ERN Latency Difference on the Affect Task in the third block marginally predicted autistic symptomology, $t(69) = -1.72, p = 0.09$. Thus, a fourth block including the predictors from the second block and the interaction between diagnostic group and ERN Latency Difference on the Affect Task was run; however, this fourth block did not significantly predict autistic symptomology above and beyond the second block, $\Delta F(1, 70) = 1.91, p = 0.17$. Thus, the second block was retained as the final model and predicted 89.6% (88.9% adjusted) of the variance in autistic symptomology. In this model, diagnostic group significantly predicted autistic symptomology, $t(71) = 23.78, p < 0.01$, as described previously. ERN Latency Difference on the Affect Task marginally predicted autistic symptomology, $t(71) = -1.79, p = 0.08$, such that a greater latency difference between correct and incorrect responses was associated with less autistic symptomology. ERN Latency Difference on the Gender Task marginally predicted autistic symptomology,

$t(71) = 1.93, p = 0.06$, such that a greater latency difference between correct and incorrect responses was associated with more autistic symptomology. See Table 10.

Internalizing Problems

Hypothesis 2b) Better error monitoring, indexed by a larger ERN amplitude and a slower post-error response time, will be related to greater Internalizing Problems.

Post-error response time: The first block significantly predicted internalizing problems, $F(3, 76) = 14.94, p < 0.01$. The second block marginally predicted internalizing problems above and beyond the first block, $\Delta F(2, 74) = 2.99, p = 0.06$. The third block did not significantly predict internalizing problems above and beyond the second block, $\Delta F(2, 72) = 0.92, p = 0.41$. In addition, none of the predictors added in the third block were significant predictors of internalizing problems. Thus, the second block was retained as the final model and predicted 41.8% (37.9% adjusted) of the variance in internalizing problems. In this model, diagnostic group significantly predicted internalizing problems, $t(74) = 5.92, p < 0.01$, such that individuals with HFA showed more internalizing problems than individuals with typical development. Verbal IQ marginally predicted internalizing problems, $t(74) = -1.95, p = 0.06$, such that individuals with a lower verbal IQ showed more internalizing problems than individuals with a higher verbal IQ. Post-error response time on the Affect Task, $t(74) = -1.77, p = 0.08$, and post-error response time on the Gender Task, $t(74) = -1.76, p = 0.08$, marginally predicted internalizing problems, such that more post-error slowing was associated with fewer internalizing problems. See Table 8.

ERN amplitude: The first block significantly predicted internalizing problems, $F(3, 73) = 12.30, p < 0.01$. The second block, $\Delta F(2, 71) = 0.26, p = 0.77$, and the third block, $\Delta F(2, 69) = 0.04, p = 0.96$, did not significantly predict internalizing problems above and beyond the previous block. In addition, none of the predictors added in the second and third blocks were significant predictors of internalizing problems. Thus, the first block was retained as the final model and predicted 33.6% (30.8% adjusted) of the variance in internalizing problems. In this model, diagnostic group significantly predicted internalizing problems, $t(73) = 5.43, p < 0.01$, as described previously. See Table 9.

ERN latency: The first block significantly predicted internalizing problems, $F(3, 73) = 12.30, p < 0.01$. The second block, $\Delta F(2, 71) = 0.42, p = 0.66$, and the third block, $\Delta F(2, 69) = 0.98, p = 0.38$, did not significantly predict internalizing problems above and beyond the previous block. In addition, none of the predictors added in the second and third blocks were significant predictors of internalizing problems. Thus, the first block was retained as the final model and predicted 33.6% (30.8% adjusted) of the variance in internalizing problems. In this model, diagnostic group significantly predicted internalizing problems, $t(73) = 5.43, p < 0.01$, as described previously. See Table 10.

Social Cognition

Hypothesis 2c) Better error monitoring, indexed by a larger ERN amplitude and a slower post-error response time, will be related to greater Social Cognition.

Post-error response time: The first block significantly predicted social cognition, $F(3, 76) = 24.74, p < 0.01$. The second block, $\Delta F(2, 74) = 2.14, p = 0.13$, and the third

block, $\Delta F(2, 72) = 0.68, p = 0.51$, did not significantly predict social cognition above and beyond the previous block. However, post-error response time on the Affect Task in the second block marginally predicted social cognition, $t(74) = 1.97, p = 0.05$. Thus, a fourth block including the predictors from the first block and post-error response time on the Affect Task was run, and this fourth block marginally predicted social cognition above and beyond the first block, $\Delta F(1, 75) = 3.79, p = 0.06$. This fourth block was retained as the final model and predicted 51.8% (49.3% adjusted) of the variance in social cognition. In this model, diagnostic group significantly predicted social cognition, $t(75) = -4.67, p < 0.01$, such that individuals with HFA showed more social cognitive difficulties than individuals with typical development. Age significantly predicted social cognition, $t(75) = 4.17, p < 0.01$, such that younger individuals showed more social cognitive difficulties than older individuals. Verbal IQ significantly predicted social cognition, $t(75) = 4.59, p < 0.01$, such that individuals with a lower verbal IQ showed more social cognitive difficulties than individuals with a higher verbal IQ. Post-error response time on the Affect Task marginally predicted social cognition, $t(75) = 1.95, p = 0.06$, such that more post-error slowing was associated with better social cognitive skills. See Table 8.

ERN amplitude: The first block significantly predicted social cognition, $F(3, 73) = 19.37, p < 0.01$. The second block, $\Delta F(2, 71) = 0.71, p = 0.50$, and the third block, $\Delta F(2, 69) = 0.29, p = 0.75$, did not significantly predict social cognition above and beyond the previous block. In addition, none of the predictors added in the second and third blocks were significant predictors of social cognition. Thus, the first block was retained as the final model and predicted 44.3% (42.0% adjusted) of the variance in social cognition. In this model, diagnostic group, $t(73) = -4.38, p < 0.01$, age, $t(73) = 4.23, p <$

0.01, and verbal IQ, $t(73) = 3.98$, $p < 0.01$, significantly predicted social cognition, as described previously. See Table 9.

ERN latency: The first block significantly predicted social cognition, $F(3, 73) = 19.37$, $p < 0.01$. The second block, $\Delta F(2, 71) = 0.07$, $p = 0.94$, and the third block, $\Delta F(2, 69) = 1.49$, $p = 0.23$, did not significantly predict social cognition above and beyond the previous block. In addition, none of the predictors added in the second and third blocks were significant predictors of social cognition. Thus, the first block was retained as the final model and predicted 44.3% (42.0% adjusted) of the variance in social cognition. In this model, diagnostic group, $t(73) = -4.38$, $p < 0.01$, age, $t(73) = 4.23$, $p < 0.01$, and verbal IQ, $t(73) = 3.98$, $p < 0.01$, significantly predicted social cognition, as described previously. See Table 10.

Summary

In sum, the results from the task analyses show that response accuracy and overall accuracy on both the Gender and Affect Tasks increase with age. For correct responses, younger participants responded more quickly to happy faces than angry faces, but this response pattern did not continue for participants at the mean age or older. Younger participants showed more evidence of post-error slowing on the Gender Task than the Affect Task, whereas older participants showed more evidence of post-error slowing on the Affect Task than the Gender Task. With age, participants showed both a greater ERN Amplitude Difference and a greater ERN Latency Difference between correct and incorrect responses. For the Gender Task only, participants with typical development showed a greater ERN Amplitude Difference between correct and incorrect responses

than participants with HFA. Also, on the Gender Task only, participants showed a greater ERN Latency Difference between correct and incorrect trials for happy faces than angry faces. For angry faces, participants showed a greater ERN Latency Difference between correct and incorrect trials on the Gender Task than on the Affect Task.

The results from the individual differences analyses for all children show that a smaller ERN Latency Difference on the Affect Task and a larger ERN Latency Difference on the Gender Task were associated with greater autistic symptomology. More post-error slowing on the Affect and Gender Tasks was associated with fewer internalizing problems. More post-error slowing on the Affect Task was associated with better social cognitive skills.

CHAPTER 4: DISCUSSION

The current study examined error monitoring, with a specific focus on post-error response time, ERN amplitude, and ERN latency, in 9-19 year old individuals with autism and typical development. Overall, age, regardless of diagnostic group, was the most salient predictor of enhanced error monitoring across all three indices of error monitoring. Individuals with autism showed a mild impairment in error monitoring, rather than a complete absence of error monitoring. Indices of error monitoring, specifically post-error response time and ERN latency, were predictive of individual differences in autistic symptomology, internalizing problems, and social cognition for both participants with HFA and typical development.

Developmental Effects

In the current study, age significantly influenced task performance (i.e., response accuracy, overall accuracy, and correct reaction time) and the ability to monitor one's own performance (i.e., post-error response time, ERN amplitude, and ERN latency). None of the other factors analyzed, including diagnostic group, had such a strong and ubiquitous effect on both task performance and error monitoring as age. These results clearly demonstrate the critical role of age in the development of face processing and error-monitoring abilities. These results are consistent with the developmental effects reported in both the face processing (e.g., Batty & Taylor, 2006; Bruce et al., 2000; MacDonald, Kirkpatrick, & Sullivan, 1996) and error monitoring literatures (e.g., Davies et al., 2004; Hogan et al., 2005; Ladouceur et al., 2007; Santesso & Segalowitz, 2008),

and these results support Hypothesis 1c regarding the effect of age on ERN amplitude. To date, this is the first study to concurrently examine face processing and behavioral and electrophysiological indices of error monitoring in children.

The interaction between task and age on post-error response time demonstrated that younger children tended to more closely monitor their errors in response to the gender of a face whereas older children and adolescents tended to more closely monitor their errors in response to the affect of a face. The most plausible explanation for this pattern of results is that gender is the most salient quality of a face for younger children whereas affect is the most salient quality of a face for older children and adolescents. Younger children may be more apt to classify faces according to gender (i.e., mom or dad, girl or boy classmate), thus younger children may tend to engage in error monitoring with respect to gender. Older children and adolescents may be more apt to classify faces according to affect (i.e., happy or angry parent, happy or angry classmate), thus older children and adolescents may tend to engage in error monitoring with respect to affect. Hajcak, Moser, Yeung, and Simons (2005) show that increased error monitoring is associated with greater task engagement, supporting the interpretation that younger children were more engaged in the Gender Task while older children were more engaged in the Affect Task.

The developmental literature suggests that gender may be a particularly salient classification for children whereas affect may be a particularly salient classification for adolescents. Children, for instance, are much more likely to be friends with a same-sex peer than an other-sex peer, but this gender friendship boundary fades in adolescence (e.g., Shrum, Cheek, & Hunter, 1998). In addition, at a young age, children are sensitive

to gender categories and gender stereotypes (e.g., Durkin & Nugent, 1998; Johnston, Bittinger, Smith, & Madole, 2001; Poulin-Dubois, Serbin, Eichstedt, & Sen, 2002), with some evidence suggesting that gender stereotypes may become more flexible in adolescence (Alfieri, Ruble, & Higgins, 1996). Conversely, Somerville, Jones, and Casey (2010) suggest that adolescence is characterized by heightened responsiveness to emotional cues, such as facial expressions. Hare et al. (2008) showed that adolescents have a heightened amygdala response to emotional facial expressions compared to both children and adults. Thus, the literature supports the idea that gender may be a salient face quality for younger children whereas affect may be a salient face quality for adolescents.

The interaction between affect expression and age on correct reaction time shows that younger children more quickly categorize the affect and gender of happy faces than angry faces. This effect fades with age, but shows a possibility of reversing in adulthood. The oldest participants in the current study are age 19, so the effect of affect on reaction time in adulthood is not fully explored in the current study. Two feasible explanations can be forwarded to explain this pattern of results. 1) Younger children may have less advanced face processing skills and may process the emotion happy more easily than the emotion angry. Children may have more experience with happy faces than angry faces, which may facilitate the processing of happy faces. With age, as children develop greater face processing expertise and potentially have more exposure to angry faces, the emotions happy and angry may become equally easy to process. This explanation may be most accurate if affect is not shown in future studies to affect reaction time in adults. 2) With age, children and adolescents become increasingly independent from their parents

and responsible for their own well-being. Thus, with age, children and adolescents may show increased attention for threatening stimuli, such as angry faces, and may increasingly process angry faces more quickly than happy faces. This explanation may be most accurate if affect is shown in future studies to have a reverse effect on reaction time in adults.

Overall, it is clear that face processing and error monitoring ability each undergo significant developmental changes over late childhood and adolescence for both individuals with HFA and typical development. Given the primary role of age in these results, it is strongly recommended that future studies examining face processing and/or error monitoring in children include age as a continuous factor, as it was included in the current study. The exclusion of age or the inclusion of age as a categorical factor (younger vs. older children) may not account for or may underestimate the effects of age as well as overestimate the effects of other factors in the analyses (e.g., Henderson et al., 2006; Vlamings et al., 2008).

Diagnostic Group Effects

The literature shows that individuals with autism have an impairment in error monitoring (e.g., Bogte et al., 2007; Groen et al., 2008; Henderson et al., 2006; Russell & Jarrold, 1998; Vlamings et al., 2008), but the exact nature of this impairment is still unclear. Individuals with autism may not have a general impairment in response monitoring, a broad term used to encompass error-monitoring and other related abilities, such as memory for actions and intention reporting (Hill & Russell, 2002; Russell & Hill, 2001).

In the current study, individuals with autism did not show a complete absence of error monitoring relative to typically developing participants; rather, individuals with HFA showed reduced error monitoring as indexed by ERN amplitude, but not as indexed by post-error response time and ERN latency. Thus, individuals with autism did show an error monitoring impairment, but this impairment was not as ubiquitous as predicted by Hypothesis 1a.

With respect to ERN amplitude, individuals with HFA seemed to have difficulty monitoring their errors on the Gender Task, but not the Affect Task. It is important to be cautious in interpreting this pattern of results, however, as this pattern was not observed for other error monitoring variables (post-error response time and ERN latency). Interestingly, this pattern of results is in direct contradiction to the pattern predicted by Hypothesis 1a, wherein individuals with HFA were expected to have particular difficulty monitoring their errors on the Affect Task. These results may reflect an underlying executive functioning impairment in set-shifting in individuals with HFA, an impairment that has already been documented in the literature (e.g., Dichter et al., 2010).

The literature suggests that individuals with autism engage in automatic processing of facial expressions, as they show reflex-like EMG activity in response to emotional expressions (Magnée, de Gelder, van Engeland, & Kemner, 2007; Oberman, Winkielman, & Ramachandran, 2009). Already engaged in the processing and monitoring of facial affect, it may be difficult for individuals with HFA to then disengage from affect and shift their attention to the processing and monitoring of gender. While individuals with typical development may also automatically process and monitor facial expressions, they may more quickly and smoothly shift their attention to processing and

monitoring gender, if requested to do so by an experimenter. Thus, it is not clear whether individuals with HFA have a specific error monitoring impairment in processing gender, or whether these results are reflective of an underlying executive functioning impairment in set-shifting.

Overall, the prediction that individuals with HFA would have a greater error monitoring impairment on the Affect Task than the Gender Task was not supported (Hypothesis 1a), with the ERN amplitude results even suggesting the opposite pattern. However, this prediction remains consistent with the executive functioning literature on autism that shows more executive dysfunction in a social versus nonsocial context (e.g., Ozonoff, 1995; Dichter & Belger, 2007). Thus, it is possible that this prediction holds for a select subgroup of individuals with autism. Participants in the present study were high functioning (i.e., a verbal IQ greater than 70). These participants may have had a greater awareness, either innate or learned, of the importance of facial affect, and may therefore have automatically engaged in error monitoring of affect. Individuals with autism who are less high functioning may not have the same awareness of the importance of face affect and may not automatically engage in error monitoring of affect. These individuals may show a different pattern of results with respect to error monitoring of gender and affect.

Alternatively, although the literature shows that individuals with autism have a particular executive functioning impairment in a social versus nonsocial context (e.g., Ozonoff, 1995; Dichter & Belger, 2007), this impairment may not have been adequately tested in the current study. Faces may be intrinsically social stimuli, regardless of whether task demands direct the focus to the affect or gender of the face. The current

study was designed to use the same stimuli across conditions, such that one condition emphasized a more social aspect of the stimulus (affect) and one condition emphasized a less social affect of the stimulus (gender). This design allowed for differences between conditions to be clearly attributed to condition (affect vs. gender), rather than perceptual differences between stimuli. However, given the intrinsically social nature of faces, this design may not have truly allowed for a comparison between social and nonsocial stimuli. Future studies should employ perceptually comparable stimuli that are more clearly delineated as social versus nonsocial, such as using social words (sad, proud, etc.) versus nonsocial words (new, yellow, etc.).

Interestingly, the pattern of error monitoring abilities and limitations in participants with autism was not analogous to the pattern of error monitoring abilities and limitations in younger participants. This supports the idea that individuals with autism do not have a “developmental lag” in their error monitoring abilities. Rather, individuals with and without autism seem to have qualitatively different patterns of error monitoring abilities and limitations.

Considering the current study and the previous literature (e.g., Groen et al., 2008; Henderson et al., 2006), error monitoring does not seem to be a core impairment in individuals with HFA. There is evidence to suggest that individuals with HFA are impaired in error monitoring (e.g., Bogte et al., 2007; Groen et al., 2008; Henderson et al., 2006; Russell & Jarrold, 1998; Vlamings et al., 2008), but this impairment does not seem to be as severe or as widespread as previously anticipated. Future studies should clarify the exact nature of the error monitoring impairment in individuals with HFA. In particular, future studies should more closely examine error monitoring in a social

context, to better determine whether individuals with HFA have a specific impairment in error monitoring within a social context compared to a nonsocial context.

Other Task Effects

While there is a debate in the literature about whether the ERN indexes error monitoring (i.e., the ERN is produced when a participant incorrectly responds to a stimulus) or conflict monitoring (i.e., the ERN is produced when there are conflicting stimuli during response selection), the ERN clearly indexed error monitoring in the current study. The stimulus presentation scheme for the current study did not allow for conflicting stimuli, as a single face stimulus was presented in each trial. Although some researchers argue that the ERN indexes conflict monitoring (Burle et al., 2008; Masaki et al., 2007), and the ERN may indeed reflect a combination of error monitoring and conflict monitoring in some studies, the present study provides support for the ERN as an index of error monitoring in the absence of conflicting stimuli.

Although Hypothesis 1b predicted that happy faces would elicit a larger ERN amplitude than angry faces, this effect was not observed in the current study. The studies that have previously shown a larger ERN amplitude for happy/positive stimuli (Compton et al., 2007; Larson et al., 2006) have examined the ERN response in typically developing adult participants. Since the ERN is not fully mature until adulthood (Davies et al., 2004; Hogan et al., 2005; Ladouceur et al., 2007; Santesso & Segalowitz, 2008), this effect may be absent in younger participants. Future studies should confirm that this ERN effect is absent for children and adolescents.

Individual Differences

Overall, the individual difference composite scores for both participants with HFA and typical development were predicted by at least one error-monitoring variable, but these scores were not predicted by all three of the error-monitoring variables, as had been hypothesized. These results suggest that there is a genuine relation between error monitoring and individual differences in Autistic Symptomology, Internalizing Problems, and Social Cognition, but either 1) this relation is not as strong as originally hypothesized, or 2) limitations in the measurement of these individual differences, as will be discussed shortly, did not allow the strength of this relation to be fully realized.

The three indices of error-monitoring (post-error response time, ERN amplitude, and ERN latency) were not highly correlated, which suggests that these variables may have indexed different aspects of error monitoring or that these variables did not all index error monitoring to the same extent. Behavioral indices of error monitoring are thought to mature before electrophysiological indices of error monitoring (Davies et al., 2004), which may partially explain the absence of strong correlations between post-error response time and ERN amplitude/latency. Other studies have also found a dissociation between post-error response time and ERN amplitude/latency (Hajcak, McDonald, & Simons, 2003b; Wiersema, van der Meere, & Roeyers, 2007), suggesting that the ERN may be related to error detection while post-error response time may be related to compensatory mechanisms following error detection. ERN amplitude and latency may naturally index different aspects of error monitoring, with ERN amplitude indexing the degree to which participants recognize mistakes and ERN latency indexing the speed with which participants recognize mistakes.

Autistic Symptomology

An interesting pattern emerged in the prediction of individual differences in Autistic Symptomology, such that the ERN Latency Difference between correct and error trials from both the Affect and Gender Tasks predicted Autistic Symptomology, but in different directions. For the Affect Task, a greater ERN Latency Difference (i.e., more error monitoring) was predictive of less Autistic Symptomology, a result that is consistent with Hypothesis 2a. For the Gender Task, however, a greater ERN Latency Difference (i.e., more error monitoring) was predictive of more Autistic Symptomology, a result that is not consistent with Hypothesis 2a. These results may reflect the critical role of automatically engaging in error monitoring of affect during reciprocal social interactions. Throughout a conversation, for example, individuals may need to regularly monitor and reevaluate the affect of their conversation partner. Individuals who do this successfully may show less social skill impairment. Conversely, individuals who regularly monitor and reevaluate the gender of their conversation partner, a quality that is of less importance and will not change throughout the interaction, may not pick up on important social cues and may show more social skill impairment. These results are consistent with literature showing individuals with autism spend less time attending to pertinent aspects of social stimuli (e.g., Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002; Riby & Hancock, 2009; Sasson et al., 2007), such that greater attention to irrelevant stimuli is associated with greater autistic symptomology. It may be that individuals with autism who attend to and monitor affective facial expressions are

more responsive to social skill interventions than those who attend to and monitor the gender of a face.

Internalizing Problems

Post-error slowing on both the Affect and Gender Tasks was associated with fewer Internalizing Problems, although Hypothesis 2b predicted that post-error slowing would be associated with more Internalizing Problems. While studies have shown that an increase in the ERN and post-error slowing is associated with greater internalizing problems (e.g., Chiu & Deldin, 2007; Gehring et al., 2000; Hajcak et al., 2003a; Holmes & Pizzagalli, 2008; Ladouceur et al., 2006; Robinson, Meier, Wilkowski, & Ode, 2007; Steele, Kumar, & Ebmeier, 2007), this association has generally been examined in clinical populations without an ASD (i.e., individuals with a clinical diagnosis of or clinically elevated levels of depression/anxiety). Conversely, Compton et al. (2008) examined the association between the ERN and reactivity to stress in 50 undergraduate students with typical development and found that individuals who showed more error-monitoring, as indicated by a larger ERN amplitude, were less reactive to stress. These researchers suggest that cognitive and emotional self-regulation share a common set of skills in non-clinical participants, such that individuals who have better cognitive self-regulation are more likely to have better emotional self-regulation. This is consistent with the temperament literature, in which cognitive self-regulation (i.e., effortful control) is adaptive and associated with less negative affect (e.g., Derryberry & Rothbart, 1988; Rothbart, Ellis, Rueda, & Posner, 2003).

There may be a non-linear association between error monitoring and internalizing problems, such that these constructs are negatively correlated in typical populations (Compton et al., 2008), but positively correlated in populations with clinical levels of anxiety/depression (e.g., Chiu & Deldin, 2007; Gehring et al., 2000; Holmes & Pizzagalli, 2008; Ladouceur et al., 2006). Given that only two participants in the current study had parent-reported diagnoses of Anxiety Disorder and most participants did not show clinical levels of anxiety/depression, the sample in this study may be more reflective of a typical population in terms of internalizing problems than a population with clinical levels of anxiety/depression. The results of this study parallel those of Compton et al. (2008), as well as those of Henderson et al. (2006), in which a larger ERN amplitude was associated with fewer internalizing problems in children with HFA before controlling for verbal IQ or medication status. The results of this study differ from the Groen et al. (2008) study, in which a larger ERN amplitude was associated with greater internalizing problems in children with ASD. However, the majority of participants with ASD in the Groen et al. (2008) study showed clinical levels of internalizing problems, which may importantly differentiate the participants of the Groen et al. (2008) study from the current study.

Together, these studies suggest that error monitoring and internalizing problems may be negatively related in participants with and without an HFA diagnosis who don't have clinical levels of anxiety/depression. For individuals with an HFA diagnosis, subclinical internalizing problems may be secondary to the HFA diagnosis and may result from poor social skills and poor error monitoring of social skills. For these individuals, heightened error monitoring ability may be protective against the development of clinical

levels of internalizing problems. Conversely, for individuals with anxiety/depression, heightened error monitoring ability may lead to clinical levels of internalizing problems. A longitudinal study is needed to more clearly determine the direction of effects for the underlying association between error monitoring ability and internalizing problems in ASD populations.

Social Cognition

In accordance with Hypothesis 2c, post-error slowing on the Affect Task was related to better social cognition. This result is consistent with the literature, which shows that individuals who engage in error-monitoring have better social skills, specifically empathy (Larson et al., 2010). Interestingly, error monitoring on the Gender Task was not related to better social cognition. This is similar to the pattern of results seen with Autistic Symptomology. Error monitoring of affect seems to be related to less autistic symptomology and better social cognition. Error monitoring of gender, however, seems to be related to more autistic symptomology and unrelated to social cognition. Again, it may be that automatic error monitoring of affect facilitates the ability to engage in reciprocal social interactions while automatic error monitoring of gender is not necessary for or may even hinder the ability to engage in reciprocal social interactions. However, without longitudinal data, it is not possible to determine whether error monitoring influences the development of social skills or conversely whether social skills influence the development of error monitoring.

Limitations of Individual Difference Analyses

While these results shed light on the associations between error monitoring and individual differences in autistic symptomology, internalizing problems, and social cognition, they must be interpreted with caution given the following limitations: 1) The ASSQ, SCQ, and SRS were used as indicators of Autistic Symptomology, but these measures are all parent report measures of autistic symptomology. In the future, it may be helpful to include an observational assessment of autistic symptomology. While the recently developed severity scores for the ADOS (Gotham, Pickles, & Lord, 2009) could provide a useful observational assessment of autistic symptomology, severity scores are not yet available for ADOS Module 4. Since the current study assessed participants with Modules 3 and 4, it was not possible to use ADOS severity scores for the current study. 2) There may not have been enough variability in autistic symptomology and social cognition in the typical development group to adequately assess individual differences. Participants with typical development tended to be close to floor on the autistic symptomology measures and close to ceiling on the social cognition measures. 3) Most of the measures used to capture individual differences in this study have been primarily used with and validated on children and younger adolescents. Given the wide age range of participants in this study (ages 9-19), these measures may not have adequately captured individual differences in older participants. 4) The first block of predictors in each regression (age, verbal IQ, and diagnostic group) accounted for much of the variance in the dependent variables. This was particularly true for Autistic Symptomology, in which 88% of the variance was accounted for by the first block of predictors. When so much variance is usurped by these initial predictors, there is little variance left in the dependent

variables to be explained by the error-monitoring variables. In future studies, it may be helpful to use individual difference measures that have less strong relations with age, verbal IQ, and diagnostic group. Despite these limitations, the individual difference analyses still provide informative and interesting results on the relations between error monitoring and autistic symptomology, internalizing problems, and social cognition in individuals with and without autism.

General Limitations

Limitations related to specific findings have been presented throughout the discussion as appropriate. However, there are some general limitations of the present study that may have affected the results and their interpretation. First, many eye blinks were observed in the current EEG data set. Although these eye blinks were removed using independent components analysis, the best method currently available for removing eye blinks from EEG/ERP data, even independent components analysis is not a surefire method for removing eye blinks. In independent components analysis, a prototypical eye blink is created for each participant. When an eye blink occurs in the data, a participant-specific prototypical eye blink is regressed from the data. Although this method generally works well, there are false positives and false negatives, such that noise not associated with an eye blink is occasionally misidentified as an eye blink and noise associated with an eye blink is occasionally missed. Even though each person has his/her own prototypical eye blink, not every eye blink perfectly matches this prototypical eye blink, which may induce some level of noise when the prototypical eye blink is regressed from the data. Eye blinks are particularly problematic when they occur more frequently for

some participants (i.e., children, clinical populations) than other participants, which may cause the data to be selectively noisier for those participants.

Additionally, when participants blink their eyes, there is a moment (approximately 95 ms) in which participants are unable to see the stimulus on the screen (Jandziol, Prabhu, Carpenter, & Jones, 2001). If that moment co-occurs with the presentation of the stimulus, participants may not have enough time to adequately process the stimulus and/or may be delayed in their response to the stimulus. Although eye blinks occur quickly, this length of time is worth noting, given that stimulus duration, reaction time, and ERN latency are also quantified in milliseconds. Thus, although the most rigorous eye blink removal method was employed in the current study, even this methodology cannot completely subtract out the effects of eye blinks.

Second, although the face stimuli used in the current study were valid and reliable with respect to participants' judgments of affect, the happy faces tended to have higher validity and reliability than the angry faces (Tottenham et al., 2009). In addition, the face stimuli were only normed on affect; they were not normed on gender (Tottenham et al., 2009). Thus, in the current study, it may have been easier for participants to determine the gender /affect of certain faces than other faces. This may have resulted in inconsistencies with face processing and error monitoring, such that participants may have had a quicker reaction time, a shorter ERN latency, and a larger ERN amplitude in response to faces in which affect/gender could more easily be determined. Fluctuations in response time across faces may have partially obscured the post-error response time results. In addition, ERN amplitude and latency results may have been diluted by any faces for which it was particularly difficult to determine gender/affect, as these faces may

not have elicited an ERN response. Although the face stimuli were normed with respect to affect and are fairly straightforward with respect to gender, subtle differences in difficulty level may have affected the results of the current study.

Third, error rates for this task were high compared to error rates for other ERN studies with participants with autism and typical development (Groen et al., 2008; Henderson et al., 2006; Vlamings et al., 2008). Participants may not have had an adequate amount of time to make reasonable determinations of gender and affect on this task. Due to the difficulty of the task, some participants may not have been motivated to attend to the task or may have had more difficulty creating mental representations of “correct” versus “incorrect” responses, such that behavioral and electrophysiological indices of error monitoring did not accurately reflect their error monitoring abilities. In particular, participants who found the task to be more difficult, such as younger participants or participants with autism, may have been more likely to mentally disengage from the task or may have had more difficulty creating mental representations of “correct” versus “incorrect” responses. If this were the case, indices of error monitoring would have been masked for those participants who showed particular difficulty on the task. However, given that the rates of average response accuracy ranged from 58-67% across conditions and diagnostic groups, all values greater than chance, the difficulty of the task did not seem to prevent most participants from attending to the task.

Lastly, sample size is both a limitation and relative strength of the current study. It is a limitation, as a bigger sample size would have resulted in more power to detect significant differences. In particular, there were several trends in the data that likely would have reached standard statistical significance with a bigger sample size. However,

given the difficulty in collecting data with children with autism, particularly EEG/ERP data, sample size is also a relative strength of the current study. The final sample size for the current study was 86 participants, with some of these participants excluded from specific analyses. Only three other studies have examined the ERN response in children with and without autism, with respective sample sizes of 41 participants (Henderson et al., 2006), 37 participants (Groen et al., 2008), and 26 participants (Vlamings et al., 2008). Thus, the sample size of the current study is more than double that of the largest sample size previously reported in the literature.

Future Directions

This study was the first to examine the ERN in response to social stimuli in participants with autism, and it has accordingly paved the way for future research in this area. The results of the current study and their interpretations suggest several specific avenues for future research. Future research will need to confirm that a subgroup of individuals with autism have a tendency to automatically engage in error monitoring of face affect, such that it may be difficult for them to focus on other face qualities like gender. Furthermore, future research should clarify whether error monitoring of face gender is less automatic, such that individuals who easily engage in error monitoring of gender may have less developed social skills or greater autistic symptomology. The present study has not resolved the question of whether individuals with autism have worse error monitoring in response to social stimuli versus nonsocial stimuli. Future studies can more fully investigate this question by 1) employing participants who are not

high functioning (i.e., a verbal IQ less than 70) and 2) using stimuli that can be more clearly delineated as either social or nonsocial.

More generally, as the current study has clearly shown the influence of development on the ERN, future research should investigate whether the ERN develops differently across individuals with and without autism. It may be that individuals with autism show greater evidence of error monitoring impairment with age, such that children with and without autism show some differences in error monitoring but adults with and without autism show many differences in error monitoring. Additionally, there may be developmental changes in the localization of the ERN response, and these developmental changes in localization may differ across individuals with and without autism.

The current study is the first to examine the ERN in such a broad age range of individuals with autism. In addition, it is the first study to examine the ERN in older adolescents and young adults with autism. In order to fully assess developmental changes in the ERN with respect to diagnostic group, it will be necessary to examine multiple indicators of error monitoring in a longitudinal study from childhood to adulthood. A longitudinal study will offer further clarification of the directionality of the individual difference effects observed in the current study. Autistic symptomology, internalizing problems, and social cognition may influence the development of error monitoring ability or conversely error monitoring ability may influence the development of autistic symptomology, internalizing problems, and social cognition.

It will also be important to continue to examine error monitoring ability in the context of face processing in autism. Future studies on error monitoring ability in face processing may be designed in response to the literature on face processing. For instance,

the face processing literature shows that individuals with typical development have a face inversion effect, such that they have more difficulty processing inverted compared to upright faces than individuals with autism (Hobson, Ouston, & Lee, 1988). This begs the question as to whether individuals with typical development monitor errors of affect/gender only in response to upright faces, while individuals with autism monitor errors of affect/gender in response to both upright and inverted faces. Such a finding might indicate that the ability of individuals with autism to process inverted faces is not merely a raw, savant-like talent, but rather an ability that has been cultivated through response monitoring. The literature on face processing in autism is a rich literature that will provide much guidance in better understanding error monitoring ability in face processing.

Finally, the literature shows that self-monitoring interventions in autism have the capacity to reduce stereotypic, disruptive or inappropriate behaviors (Koegel & Koegel, 1990; Koegel, Koegel, Hurley, & Frea, 1992; Loftin, Odom, & Lantz, 2008; Pierce & Schreibman, 1994), increase appropriate social responses and appropriate social play (Koegel et al., 1992; Loftin et al., 2008; Stahmer & Schreibman, 1992), and increase use of daily living skills (Pierce & Schreibman, 1994). Interventions that teach self-monitoring skills can have a widespread impact by singularly addressing multiple areas for intervention, rather than individually addressing each area for intervention (Hume, Loftin, & Lantz, 2009). Thus, a better understanding of error monitoring ability in individuals with autism will be integral to the development of successful interventions in the future.

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TABLES

Table 1

Participant characteristics

	HFA			Typical Development		
	<i>M</i>	<i>SD</i>	Range	<i>M</i>	<i>SD</i>	Range
Age (months)	182.12	31.96	115-231	181.93	34.42	113-230
Verbal Comprehension Index	103.19	15.68	77-140	108.63	9.72	81-128
Perceptual Reasoning Index	103.07	14.87	69-135	107.07	15.46	75-143

Table 2

Intraclass correlation coefficients for Autistic Symptomology, Internalizing Problems, and Social Cognition

	All Participants	HFA	Typical Development
Autistic Symptomology	0.91	0.67	0.57
Internalizing Problems	0.85	0.84	0.67
Social Cognition	0.64	0.62	0.45

Table 3

Partial correlations among dependent variables for the Gender Task, controlling for age and verbal IQ

	1.	2.	3.	4.	5.	6.	7.	8.
HFA								
1. Response Accuracy	1.00							
2. Overall Accuracy	.80**	1.00						
3. Correct Reaction Time	.73**	.57**	1.00					
4. Overall Reaction Time	.73**	.57**	1.00**	1.00				
5. Timing Parameter	.37*	.29	.81**	.81**	1.00			
6. Post-Error Response Time	.25	.13	.43*	.45**	.39*	1.00		
7. ERN Amplitude Difference	.33	.37*	.37*	.38*	.18	-.01	1.00	
8. ERN Latency Difference	-.21	-.18	-.17	-.17	-.13	-.07	-.20	1.00
Typical Development								
1. Response Accuracy	1.00							
2. Overall Accuracy	.90**	1.00						
3. Correct Reaction Time	.72**	.71**	1.00					
4. Overall Reaction Time	.73**	.71**	1.00**	1.00				
5. Timing Parameter	.53**	.60**	.92**	.91**	1.00			
6. Post-Error Response Time	.21	.29	.07	.08	-.08	1.00		
7. ERN Amplitude Difference	.43**	.44**	.41*	.40*	.33*	.20	1.00	
8. ERN Latency Difference	-.15	-.08	-.05	-.06	.09	-.15	-.58**	1.00

Note. ** $p < 0.01$, * $p < 0.05$.

Table 4

Partial correlations among dependent variables for the Affect Task, controlling for age and verbal IQ

	1.	2.	3.	4.	5.	6.	7.	8.
HFA								
1. Response Accuracy	1.00							
2. Overall Accuracy	.87**	1.00						
3. Correct Reaction Time	.80**	.73**	1.00					
4. Overall Reaction Time	.80**	.72**	1.00**	1.00				
5. Timing Parameter	.67**	.62**	.93**	.93**	1.00			
6. Post-Error Response Time	.44*	.51**	.54**	.54**	.51**	1.00		
7. ERN Amplitude Difference	.48**	.33	.18	.18	.03	0.00	1.00	
8. ERN Latency Difference	-.17	-.09	-.19	-.19	-.07	.08	-.29	1.00
Typical Development								
1. Response Accuracy	1.00							
2. Overall Accuracy	.72**	1.00						
3. Correct Reaction Time	.72**	.61**	1.00					
4. Overall Reaction Time	.74**	.62**	1.00**	1.00				
5. Timing Parameter	.30	.50**	.62**	.61**	1.00			
6. Post-Error Response Time	.48**	.32	.48**	.50**	.16	1.00		
7. ERN Amplitude Difference	.51**	.51**	.41*	.44**	.17	.23	1.00	
8. ERN Latency Difference	-.22	.08	.01	-.02	.18	-.16	-.23	1.00

Note. ** $p < 0.01$, * $p < 0.05$.

Table 5

Proportion of correct trials and reaction time (ms), evaluated at a mean age of 182.02 months

	Affect Task		Gender Task	
	Angry Faces	Happy Faces	Angry Faces	Happy Faces
Response Accuracy				
HFA	0.58 (0.02)	0.61 (0.02)	0.62 (0.02)	0.61 (0.02)
Typical Development	0.59 (0.02)	0.62 (0.02)	0.64 (0.02)	0.67 (0.02)
Overall Accuracy				
HFA	0.45 (0.02)	0.46 (0.02)	0.46 (0.02)	0.45 (0.02)
Typical Development	0.46 (0.02)	0.49 (0.02)	0.50 (0.02)	0.50 (0.02)
Correct Reaction Time				
HFA	288.90 (13.72)	288.02 (13.22)	268.33 (10.73)	269.70 (10.66)
Typical Development	292.52 (13.72)	289.35 (13.22)	269.45 (10.73)	268.83 (10.66)
Overall Reaction Time				
HFA	285.87 (13.37)	286.56 (13.12)	264.10 (10.58)	264.47 (10.52)
Typical Development	288.41 (13.37)	286.78 (13.12)	265.78 (10.58)	264.43 (10.52)

Note. Standard errors are in brackets.

Table 6

Timing parameters (ms) and post-error response time (ms), evaluated at a mean age of 182.02 months

	Affect Task	Gender Task
Timing Parameters		
HFA	397.82 (16.86)	375.47 (13.88)
Typical Development	409.16 (16.86)	352.91 (13.88)
Post-error Response Time		
HFA	-0.18 (3.14)	-0.93 (2.67)
Typical Development	-0.72 (2.91)	-0.35 (2.47)

Note. Standard errors are in brackets.

Table 7

ERN Amplitude Difference (μV) and ERN Latency Difference (ms), evaluated at a mean age of 182.17 months

	Affect Task		Gender Task	
	Angry Faces	Happy Faces	Angry Faces	Happy Faces
ERN Amplitude Difference				
HFA	1.48 (0.35)	1.48 (0.32)	0.98 (0.31)	0.70 (0.34)
Typical Development	1.28 (0.34)	1.74 (0.32)	1.66 (0.30)	1.82 (0.33)
ERN Latency Difference				
HFA	-4.71 (2.81)	-2.16 (2.41)	-6.60 (2.56)	-7.13 (2.33)
Typical Development	-6.54 (2.78)	-6.72 (2.40)	-6.85 (2.53)	-7.83 (2.30)

Note. Standard errors are in brackets.

Table 8

Final Hierarchical Regression Models for Post-Error Response Time

	Autistic		Internalizing		Social Cognition	
	Symptomology		Problems			
	<i>B</i>	β	<i>B</i>	β	<i>B</i>	<i>B</i>
Diagnostic Group	1.75 (0.08)**	0.93	0.99 (0.17)**	0.54	-0.61 (0.13)**	-0.38
Age	0.00 (0.00)	0.03	0.00 (0.00)	0.13	0.01 (0.00)**	0.34
Verbal IQ	0.00 (0.00)	-0.04	-0.01 (0.01)*	-0.18	0.02 (0.01)**	0.38
Affect PERT			-0.01 (0.00)*	-0.16	0.01 (0.00)*	0.16
Gender PERT			-0.01 (0.00)*	-0.16		

Note. Standard errors are in brackets. PERT = Post-Error Response Time. ** $p < 0.05$,

* $p < 0.10$.

Table 9

Final Hierarchical Regression Models for ERN Amplitude Difference

	Autistic		Internalizing		Social Cognition	
	Symptomology		Problems			
	<i>B</i>	β	<i>B</i>	β	<i>B</i>	<i>B</i>
Diagnostic Group	1.76 (0.08)**	0.93	0.97 (0.18)**	0.53	-0.57 (0.13)**	-0.39
Age	0.00 (0.00)	0.02	0.00 (0.00)	0.07	0.01 (0.00)**	0.37
Verbal IQ	0.00 (0.00)	-0.03	-0.01 (0.01)	-0.12	0.02 (0.01)**	0.36

Note. Standard errors are in brackets. ** $p < 0.05$.

Table 10

Final Hierarchical Regression Models for ERN Latency Difference

	Autistic		Internalizing		Social Cognition	
	Symptomology		Problems			
	<i>B</i>	β	<i>B</i>	β	<i>B</i>	<i>B</i>
Diagnostic Group	1.77 (0.07)**	0.94	0.97 (0.18)**	0.53	-0.57 (0.13)**	-0.39
Age	0.00 (0.00)	0.04	0.00 (0.00)	0.07	0.01 (0.00)**	0.37
Verbal IQ	0.00 (0.00)	-0.05	-0.01 (0.01)	-0.12	0.02 (0.01)**	0.36
Affect ERN LD	-0.01 (0.00)*	-0.07				
Gender ERN LD	0.01 (0.00)*	0.08				

Note. Standard errors are in brackets. LD = Latency Difference. ** $p < 0.05$, * $p < 0.10$.

FIGURES



Angry Faces

Happy Faces

Figure 1. Sample stimuli.



Figure 3. The interaction between affect and age on correct reaction time.

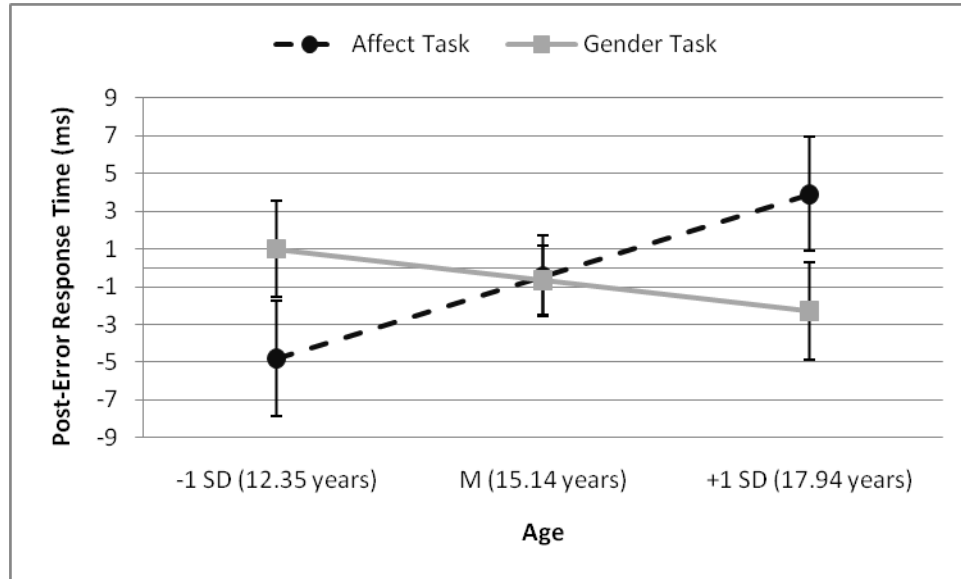


Figure 4. The interaction between task and age on post-error response time.

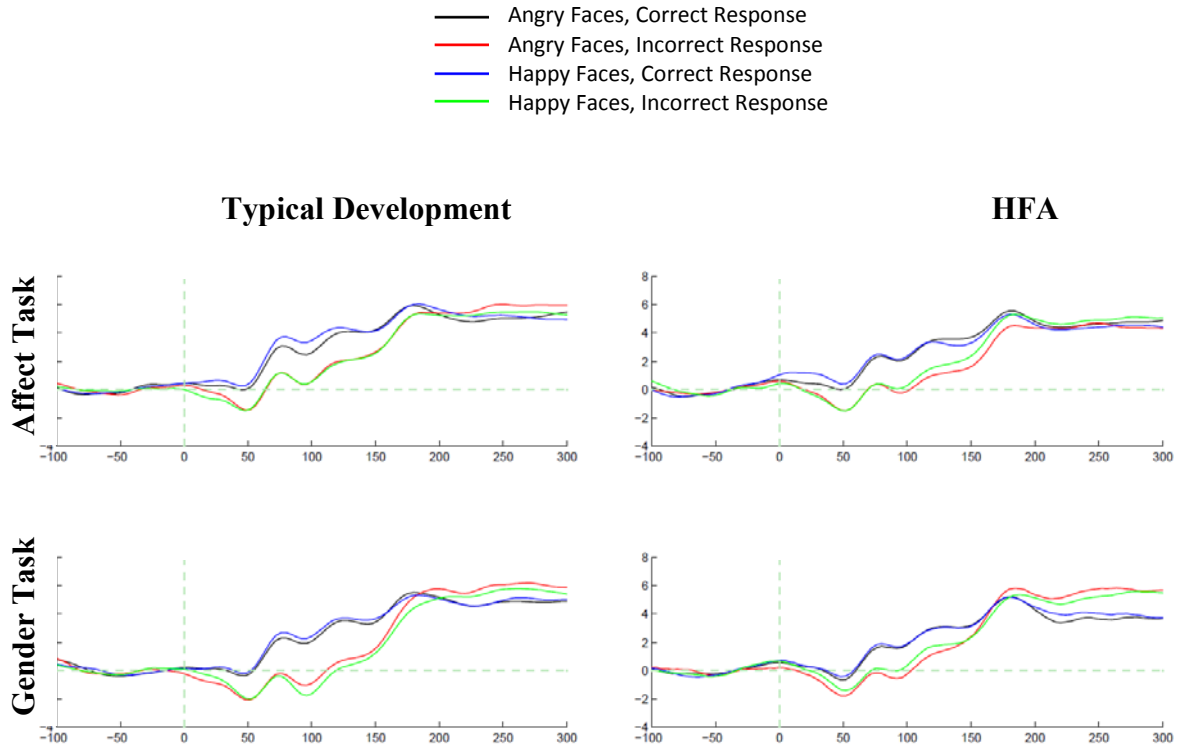


Figure 5. Grand averaged ERP waveforms for participants with typical development and HFA, regardless of age, on the Affect and Gender Tasks. Electrode 6 (Fcz) is used as the prototypical electrode. All waveforms have a 100 ms pre-stimulus and a 300 ms post-stimulus interval, and waveforms have been baseline corrected to the pre-stimulus interval.

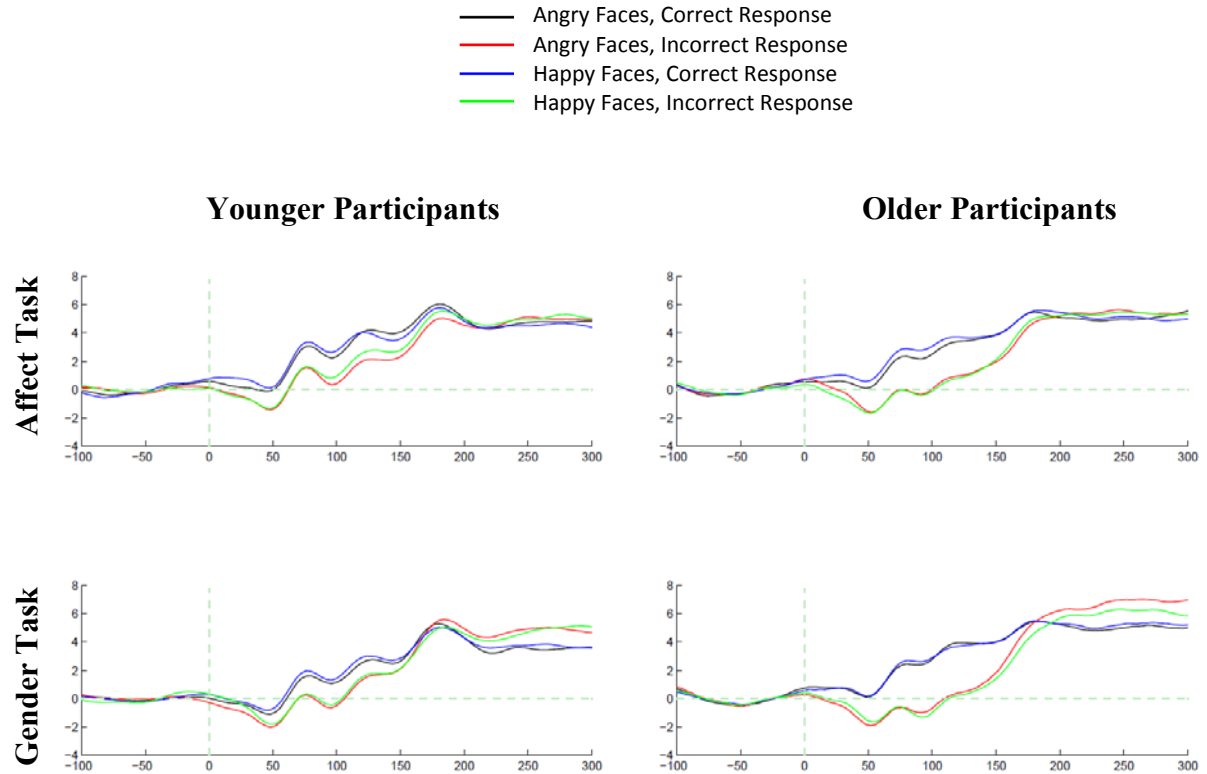


Figure 6. Grand averaged ERP waveforms for younger and older participants, regardless of diagnostic group, on the Affect and Gender Tasks. Electrode 6 (Fcz) is used as the prototypical electrode. All waveforms have a 100 ms pre-stimulus and a 300 ms post-stimulus interval, and waveforms have been baseline corrected to the pre-stimulus interval.

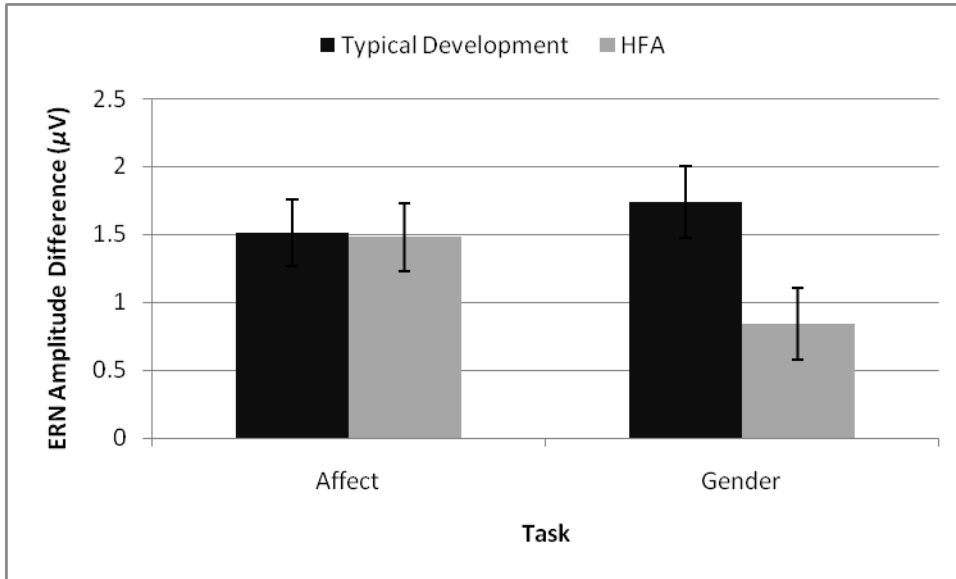


Figure 7. The interaction between task and diagnostic group on the ERN Amplitude Difference.



Figure 8. The interaction between task and affect on the ERN Latency Difference.

Although there was not a significant three-way interaction, age is included in the figure to more accurately depict the two-way interaction between task and affect. Standard error bars were removed from the figure to improve clarity.