THESIS

A NEUROLOGIAL APPROACH MEASURING ATTENTIONAL VARIATIONS AMONG CHILDREN WITH HIGH-FUNCTIONING AUTISM SPECTRUM DISORDER, SENSORY PROCESSING DIFFICULTIES AND AGE-MATCHED PEERS

Submitted by

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ABSTRACT

A NEUROLOGIAL APPROACH MEASURING ATTENTIONAL VARIATIONS AMONG CHILDREN WITH HIGH-FUNCTIONING AUTISM SPECTRUM DISORDER, SENSORY PROCESSING DIFFICULTIES, & AGE-MATCHED PEERS

Children with high functioning autism (HFA) and children with sensory processing difficulties (SPD) can have challenges processing auditory stimuli, which may contribute to difficulties with performance of everyday tasks. Few studies assess relationships between neurological measures with behavioral attention measures, yet the benefits of doing so are invaluable in understanding the brain and behavior connections in children who have difficulties processing sensory information. Therefore, this study focuses on examining the impact of neurological auditory processing on performance on tasks that require attention among children with HFA, SPD and typically developing (TD) controls.

Participants included 20 children with HFA (mean age = 8.94 ± 2.03 years), 9 children with SPD (mean age = 6.57 ± 1.26 years), and 22 TD gender and age-matched peers (mean age = 8.46 ± 2.39 years). Groups were compared according to behavioral assessment of everyday task performance and a neurological paradigm. The Test of Everyday Attention for Children (TEA-Ch) evaluates a child's attention during tasks that correspond with three subtypes of attention, while the orientation and habituation electroencephalography (EEG) paradigm allows for sensory gating and habituation neural processing measurement and analysis.

Based on the TEA-Ch scores, children in with HFA and SPD groups had significant differences with attention demands, especially in the domains of control/shift and sustained attention, when compared to the TD group. On the neurological measures, children with HFA displayed similar sensory gating abilities as compared to TD peers, including a reduction of both N1 and N2 amplitudes from tone 1 to tone 2, while children with SPD showed difficulties with sensory gating of N1 amplitudes only. Habituation analysis revealed significantly larger N2 amplitudes at tone 8 when compared to tone 2 among all groups suggesting that habituation does not occur for N2 amplitude among children in all three groups. A significant interaction occurred between tone and group for N1 amplitudes of children with SPD and the control group suggesting that the children in the control group did not habituate but the children in the SPD group did habituate. Analysis of N1 and N2 amplitude responses to tone 1 in a train without a deviant resulted in no significant differences among all three groups. However, while no differences were found between groups for the first tone, for N1 both HFA and TD groups had significant larger amplitude to the deviant tone in the 5th position, as compared to amplitude of brain response to the tone prior to the deviant. Children with SPD also had significantly larger N1 and N2 amplitudes to the deviant tones in the 4th and 5th positions, when compared to the amplitudes to the tone prior to the deviant. SPD and TD groups had an interaction at N2 amplitudes in the train with the deviant in the 4th positions. The SPD group displayed increased amplitudes at N2 to the deviant while TD decreased N2 amplitudes to the deviant.

Regression analysis was conducted to assess relationships between the subtests of the TEA-Ch data and the neurological auditory processing phenomena. For the TD group this analysis revealed a strong relationship between attentional control/shift tasks and N2 amplitudes at tone 1 in the series without a deviant. For children with HFA, there was a significant

relationship between attentional control/shift tasks and N1 amplitudes at tone 1 in the train without a deviant. Children with SPD also had a relationship between selective attention measures and N1 amplitudes at tone 1 in the train without a deviant.

Results suggest that children with HFA, SPD and TD controls have distinct neuronal profiles related to attention. A better understanding of these group differences may help to elucidate the differential impact of auditory processing capacities on task performance in children with disabilities. This knowledge may inform how occupational therapists select therapeutic approaches, scaffold attention demands, and stimulate the adaptive response during interventions focused toward improving everyday task performance.

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CHAPTER 1

Autism Spectrum Disorders

The U.S. Centers for Disease Control and Prevention (CDC) provide estimates of 1 in 68 children to be diagnosed with an autism spectrum disorder (ASD) in the United States (CDC, 2014), while the National Health Statistics Report estimated as many as 2% of children age 6-17 are diagnosed with ASD and emphasize a significant increase since the 2007 report of 1.16% prevalence (Blumberg et al., 2013). Further, the U.S. Department of Health and Human Services propose approximately 36,500 in every 4 million children born each year in the U.S. to be diagnosed with ASD (U.S. Department of Health and Human Sciences, 2012). Improved knowledge about the neurological underpinnings of dysfunctional behavior in children with ASD may provide meaningful insights for guiding clinical reasoning around how to promote functional outcomes among children with an ASD.

ASD is a neurodevelopmental disorder characterized by deficits in social communication, as well as restricted, repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2013). According to the Diagnostic and Statistical Manual of Mental Disorders (5th ed.; DSM-5; American Psychiatric Association, 2013), there are three main diagnostic criteria for ASD. First, there are deficits in social communication and social interactions such as social-emotional reciprocity, nonverbal communicative behaviors, and capacities to develop, maintain and understand relationships. The second criterion is that the child must present with restricted, repetitive patterns of behavior, interests of activities that present in at least two of the following ways 1) stereotyped or repetitive motor movements, use of objects, or speech, 2) persistence on sameness, rigidity or routines, ritualized pattern of verbal or nonverbal behavior, 3) exceedingly restricted or fixated interests, or 4) hyper- or hypoactivity to sensory input of odd interest to sensory aspects of the environment. Lastly, these symptoms must be present in early childhood, cause significant impairments to social or other areas of functioning, and are not better explained by other intellectual or developmental disabilities (American Psychiatric Association, 2013). The DSM-5 criteria emphasize the importance of the differences in how children with ASD respond to sensory experiences when compared to age-matched peers.

As early as infancy, parents of children with ASD often express concerns about their child's response to various sensory stimuli, including auditory stimuli (Tomchek & Dunn, 2007). Parents may report that their child is inconsistent in responding to auditory stimuli, sometimes over responding in a hypersensitive manner and at other times oblivious. Tomchek & Dunn (2007) found in a sample of 281 children with ASD and age-matched peers, differences with auditory filtering occurred 77.6% of the time. As such, sensory processing in children with ASD has become increasingly studied over the past decade. It is hypothesized that auditory processing difficulties may contribute to attention difficulties that, in turn, contribute to core deficits or what Courchesne et al. (2005) describe as the behavioral red flags for autism, which among others include a lack of coordination of gaze, facial expression, gesture, and response to sound.

Sensory Processing Difficulties (SPD)

Ahn, Miller, Milberger & McIntosh (2004) surveyed 710 families and found that 5.3% of children enrolled in kindergarten met their specified SPD criteria, which correlates to 1 in 20 children, and conservatively over 220,000 children in the U.S. (Ahn et al., 2004). Ben-Sasson, Carter & Briggs-Gowan (2009) also studied prevalence of children with sensory over-responsivity, described by the authors as a form of SPD, and defined this difficulty as having at least four bothering tactile or auditory sensations. Ben-Sasson, Carter & Briggs-Gowan (2009) conducted this study with 925 families over four academic school years and used a variety of measures and parental surveys including the Infant Toddler Social Emotional Assessment, Sensory Over-responsitivity Inventory, the Child Behavior Checklist, and the Adaptive Social Behavior Rating. This study concluded that at least 16.5% of children aged 7–11 years old have SPD, specifically with what these authors refer to as “over-sensitivity” to sensory stimuli (Ben-Sasson, Carter & Briggs-Gowan, 2009).

Sensory processing and sensory integration (SI) are comprehensive terms that refer to the theories and treatments that have been developed to enhance the understanding of and clinical reasoning for therapists when working with children with SPD. The theories themselves describe the ways in which the neuronal processes of the central nervous systems take in various sensory stimuli from each of the seven senses within an individual’s environment (Ayres, 1979; Stackhouse et al., 2014). Children with SPD often have difficulties with one or more aspects of these sensory integration processes. Davies and Tucker (2010) conducted a systematic review of the literature to determine SPD subtypes, however, these authors found inconsistencies in the literature and insufficient comprehensive studies in order to do so. Below the levels of SI as originally described by A. Jean Ayres (1979) are presented. Brief descriptions of a few theoretical models used for treating children with SPD and examples of behavioral manifestations when optimal auditory processing is impaired are also provided.

Ayres (1979) described the root problem of children with sensory integration challenges (or what is referred to as sensory processing difficulties in this thesis) as a dysfunction or malfunction of the neurons within the brain, with the actual neurons interconnected in irregular ways. Ayres (1979) used the terminology sensory integration (SI) and described this theory as being divided into four sequential levels. The primary level involves the basic sense modalities such as tactile, which provide opportunities for early emotional attachment and sucking, along with integration of vestibular and proprioceptive inputs that allow for ocular control, posture and balance, muscle tone, and gravitational security. The second level of SI according to Ayres (1979) moved the tactile, proprioceptive and vestibular functions into the development of emotional stability, a well-organized body precept, coordination of both right and left sides of the body, purposeful motor planning, and the abilities to focus attention and maintain appropriate activity levels. At the third level of SI, speech, language, visual perception, purposeful activity and eye-hand coordination can develop. Foundational to the Ayres (1979) SI approach, she defined adaptive response as “a purposeful, goal-directed response to a sensory environment” (p.6) which can occur at any level. At this fourth level, she suggests that organization of adaptive responses occurs as communications of neurons are strengthened, and the different brain regions become specialized. At this level, skill development includes the ability to concentrate and organize; demonstration of self-esteem, self-control, and self-confidence; academic learning ability; capacity for abstract thought and reasoning; and specialization of each side of the body and the brain (Ayres, 1979). When there are disruptions or challenges at any of the levels along the way, the difficulties will affect the subsequent levels, or the child may develop “splinter skills” or compensations to perform a task (Ayres, 1979).

Ayres’s SI theory has since been revised by Bundy & Murray (2002). These theorists produced a model that depicts relationships among the sensory systems and correlating behaviors. Within this framework, Bundy & Murray (2002) display SI theory divided into two major functions consisting of modulation and praxis. At the core of this model, the central nervous system (CNS) is depicted and the processing of each of the senses (visual, vestibular, proprioceptive, tactile, and auditory) feed into either expression of dyspraxia or, with the addition of the limbic and reticular systems, feeds into modulation function. If the function of the CNS site is for the expression of dyspraxia, the processing that is required for posture and discrimination then create difficulties with bilateral integration and sequencing (BIS) and somatodyspraxia. Accompanying behaviors such as clumsiness, clowning, avoidance of motor behavior, and exaggerated or diminished force can be evident in children with these classifications. If the function of the CNS site is for the expressions of modulation dysfunction, processing that is required for aversive responses, gravitational insecurity, defensiveness (in tactile, auditory, or visual senses) and under-responsiveness can develop. Accompanying behaviors here include avoidance, distractibility with increased activity, withdrawn and sensory seeking (Bundy & Murray, 2002).

Most recently Ayres' concepts of SI theory have been defined by Stackhouse et al. (2014). These researchers and clinicians described sensory processing as having two primary functions: sensory discrimination and sensory modulation. Stackhouse et al. (2014) described the term sensory discrimination as being able to identify differences among various sensory input, to apply meaning to the specific input and then use it during the performance of a specific skill, such as making an appropriate response to a verbal request (Stackhouse et al., 2014). Sensory discrimination difficulties can be apparent among any of the sensory systems including auditory functioning. Sensory modulation, the other primary function, is described by Stackhouse et al. (2014) as the way a person responds to sensory input and neurologically makes use of the information by means of arousal, alertness, attention, organization, coping/adaptation or self-regulation functions. They provide subtypes of sensory modulation difficulties that include sensory hyperarousal, over activity, poor attention and coping (Stackhouse et al., 2014).

Dunn (1997) depicts four sensory processing patterns that stem from various thresholds of brain processing and self-regulation strategies. These patterns include: 1) low-registration; high versus passive, 2) sensory avoiding; low versus active, 3) sensory seeking; high versus active, and 4) sensory sensitivity; low versus passive (Dunn, 1997). In addition, Dunn (1999) created an assessment tool, The Sensory Profile, which is a parent survey about a child's behaviors in response to sensory input during everyday activities. The Sensory Profile provides nine categories which include: sensory seeking, emotionally reactive, low endurance/tone, oral sensory sensitivity, inattention/distractibility, poor registration, sensory sensitivity, sedentary, and fine motor/perceptual (Dunn, 1999). Recently a second edition of this Sensory Profile (Dunn, 2014) has been published. This second edition only contains four categories that are sensory seeking, avoiding, sensitivity, and registration (Dunn, 2014).

Studies are beginning to provide evidence for the neurological basis of sensory processing and the difficulties that can result from such deficits. Of specific interest to this thesis study, we understand that children with SPD can have difficulties processing auditory information (Ayres, 1979; Burleigh, McIntosh & Thompson, 2002). However, much of the field's current knowledge is based on behavioral data or parent reports regarding sensory processing. Examples of the behavioral manifestations of children with poor auditory processing can be vast (Bellis, 2002). Behaviors seen in classroom can include daydreaming, forgetfulness, difficulties sitting still or following verbal directions or challenges recognizing differences between similar sounds (Bellis, 2002; Burleigh, McIntosh & Thompson, 2002; Stackhouse et al., 2014). Within the realm of social-emotional functioning, behaviors such as talking too loud or too soft for optimal functioning, increased anxiety and tension, low self-confidence, attention seeking, increased frustrations can develop. Lastly, if a child has difficulty with disinhibition of auditory stimuli, behaviors such as irritability, hyperactivity, impulsivity or oppositional behaviors may arise (Bellis, 2002; Burleigh, McIntosh & Thompson, 2002; Stackhouse et al., 2014). Recent advances of non-invasive techniques such as electroencephalography have allowed researchers in this field to begin to study the neural basis for come of these behaviors.

Relationships Between Attention and Behavioral Phenotypes

Impairments with attention have been reported both in children with ASD (Belmonte, 2000; Belmonte & Yurgelun-Todd, 2003; Burack, 1994; Chan et al., 2011; Goldstein, Johnson, & Minshew, 2001; Johnson et al., 2007; Johnson, Gillis, & Romanczyk, 2012) and in children with SPD (Ayres, 1979; Burleigh, McIntosh & Thompson, 2002; Hanft, Miller, & Lane, 2000). While there is vast interest with this attentional deficit hypothesis there is a lack of consistent terminology regarding the components and dimensions relating to attention. Here we describe two approaches to describe three main components of attention.

Neurophysiological Approach

Posner & Petersen (1990) provide a basis for understanding the attention system through analysis of the anatomical areas of attention processing systems within the brain. They categorized the attention system into three subsystems as a way to differentiate between various attentional functions. These subsystems include 1) orienting to sensory events (i.e., a change or shift in attention to a particular stimulus), 2) executive control, previously named target detection, is detecting signals for focal processing (i.e., the selection of a particular relevant stimulus and inhibition of an irrelevant stimulus), and 3) alerting is maintaining a vigilant or alert state (i.e., the ability to sustain vigilance and performance of a task over time) (Posner & Petersen, 1990; Petersen & Posner, 2012). An understanding of the neuronal processing among children with ASD and SPD allows for an understanding of these attentional subsystems.

Behavioral Approach

Another way attention has been defined in the literature is by the authors of the Test of Everyday Attention for Children (TEA-Ch). The TEA-Ch is an assessment that looks at the various subsystems of attention in children (Manly, Robertson, Anderson, & Nimmo-Smith, 2001). In our current study, the TEA-Ch was utilized to measure differences in performance for tasks that require various attentional demands among groups. While similar in meaning to the previously presented Posner & Petersen (1990) terms, Manly et al. (2001) refer to attentional components as attentional control/shift which correlates with Posner's term attentional switching, selective attention which correlates with Posner's term target detection or executive, and sustained attention which correlates with Posner's term alerting (Manly, et al., 2001; Posner & Petersen 1990; 2012). Below Table 1.1 below depicts differences in attention terminology, along with definitions of each term and associated examples.

Table 1.1: Attention terminology defined with correlating subtests of the TEA-Ch and examples.

Neurological Approach[a]	**Behavioral Approach**[b]	**Example**
Target detection, Executive The selection of a particular relevant stimulus and inhibition of an irrelevant stimulus	**Selective Attention** Sky Search, Map Mission	Child listens to the teachers instructions and does not respond to the noisy radiator nearby
Alerting The ability to sustain vigilance and performance of a task over time	**Sustained Attention** Score, Code Transmission, Walk, Don't Walk, Score DT, Sky Search DT	Child works on math problems for 15 consecutive minutes
Orienting A change or shift in attention to a particular stimulus	**Attention Control/Shift** Creature Counting, Opposite Worlds	Child listens to rules of game being described by multiple peers at recess

a. Posner & Petersen (1990); Petersen & Posner (2012)
b. Manly, Robertson, Anderson & Nimmo-Smith (2001)

Next we will take a closer look at the three components of attention in relation to behaviors of children with ASD. Subsequently we provide further explanation of measuring attention through the task demands of each subtest of the TEA-Ch. While there is some literature on the subtypes of attention that have been studied among children with ASD there has yet to be published reports discussing the subtypes of attention among children with SPD. However, the theories and descriptions I presented previously of SPD allow one to make educated hypotheses regarding the relationships between the subtypes of attention and the behaviors of children with SPD. Potential differences in attention found in typically developing (TD) children, children with high functioning autism (HFA) and those with SPD will also be presented.

Attention Differences in Children with HFA and SPD using a Behavioral Approach

Attentional Control/Shift

Individuals with ASD have difficulties with their ability to shift attention rapidly (Belmonte & Yurgelun-Todd, 2003; Courchesne et al., 1994; Magnee, de Gelder, van England & Kemner, 2011). This attention difficulty has been attributed to damage of cerebellar functioning (Courchesne et al., 1994) and is an underlying factor in multisensory integration (of auditory and visual processing tasks) in adults with ASD (Magnee, de Gelder, van England & Kemner, 2011). Therefore, it is likely that these deficits in cerebellar function could be a contributing factor in social-emotional reciprocity, a key component of the deficits in social communication and social interactions among children with ASD (Courchesne et al. 1994). Typically conversations are comprised of an array of various auditory and visual stimuli including the dialogue itself, tone of voice, facial expression, gesture, and any reference to third parties, objects or events (Belmonte, 2000). For example, when children engage in a social group activity, the nervous system requires participants to switch their attention effortlessly between numerous concurrent stimuli, specifically in the production of efficient neural responses to select stimuli such as voice and gesture while simultaneously inhibiting neuronal responses to other stimuli (Courchesne et al., 1994) in order to create a successful response.

Ayres (1979) described the highest level of functioning when a child is able to display adaptive responses including the organization of self-esteem, self-control and self-confidence. Yet for children with auditory processing difficulties, social-emotional behavioral manifestations include attention seeking, low self-confidence, and distractibility with increased activity (Bellis, 2002; Bundy & Murray, 2002; Burleigh, McIntosh & Thompson, 2002). This subtype of attention is most complex, and children with SPD can display behaviors that indicate difficulty with this processing ability. In our current study it is hypothesized that behavioral measures provided in two of the TEA-Ch subtests, Creature Counting and Opposite Worlds, will confirm that children with ASD and SPD do have difficulties with the attentional control/shift subtype of attention.

Selective Attention

Several studies suggest that individuals with ASD have difficulties with selective attention (Belmonte & Yurgelun-Todd, 2003; Burack, 1994; Chan et al., 2011; Goldstein, Johnson, & Minshew, 2001), the ability to select a particular relevant target and disregard any irrelevant stimuli (Manly et al., 2001). Further, several studies suggest that executive dysfunctions, including repetitive or stereotyped behaviors that are often seen in persons with ASD, could be caused by the deficits in these selective attention and inhibitory controls (Burack, 1994; Goldstein, Johnson, & Minshew, 2001). For children with SPD, challenges with attention are linked to poor modulation of sensory input (Stackhouse et al., 2014) and the correlating behavioral manifestations include distractibility with increased stimuli, irritability, hyperactivity or impulsivity can imply difficulties the ability to inhibit responses to sensory stimuli, including sound (Bellis, 2002; Bundy & Murray, 2002; Burleigh, McIntosh & Thompson, 2002; Stackhouse et al., 2014). These reported difficulties are likely connected to difficulties in selective attention abilities. In our current study, it is hypothesized that subtests of the TEA-Ch, Sky Search and Map Mission, will confirm that children with ASD and SPD have greater difficulties with tasks that require selective attention when compared with the control group.

Sustained Attention

Sustained attention in children with ASD has been previously studied. Johnson et al. (2007) examined the responses of 23 children with ADHD, 21 children with HFA and 18 control children using the Sustained Attention to Response Task (SART). The SART requires participants to withhold responses to infrequent targets while responding to all other stimuli, placing great demand on the sustained attention system. This study used a fixed- and random-sequence versions of the SART, with the Fixed SART placing larger demand over sustained attention system due to the predictability of the stimuli presentation (Johnson et al., 2007). The results of Johnson et al. (2007) showed that with regard to sustained attention, the children with HFA performed similar to the control group, suggesting that children with HFA have intact sustained attention (Johnson et al., 2007). In our current study, it is hypothesized that subtests of the TEA-Ch, Score, Walk, Don't Walk, Sky Search DT, Score DT, and Code Transmission, will confirm this inference. Further, due to behavior manifestations of distractibility with increased stimuli (Bundy & Murray, 2002), irritability, hyperactivity or impulsivity (Bellis, 2002; Burleigh, McIntosh & Thompson, 2002; Stackhouse et al., 2014) it is also hypothesized that children with SPD will also show increased difficulty with TEA-Ch subtests that address sustained attention, including Score, Score DT, and Code Transmission when compared to the TD group.

Attention Differences in Children with HFA and SPD using a Neurophysiological Approach

The complex and heterogeneous phenotypes of ASD and SPD conditions were discussed above. To more fully understand these phenotypes, researchers are beginning to uncover neurophysiological underpinnings of these behavioral phenotypes. This will allow for more discrete explanations for the different behavioral phenotypes. One neurological approach that is being used is to analyze these behavioral phenotypes of attention is through the study of event-related potentials (ERP), which originate from electroencephalography (EEG) recordings.

Electroencephalography (EEG) is a non-invasive technique that allows for analysis of brain processing in real time. Specifically, EEG measures electrical activity of the brain by means of electrodes that are precisely positioned on the scalp (Davies, Chang & Gavin, 2010) and can efficiently monitor spatio-temporal brain activation during sensory, cognitive, affective, attentional and motor information processing (Banaschewski & Brandeis, 2007). EEG can reliably be reproduced amongst diverse groups of people, including infants and children, during both wake and sleep levels of arousal, and eliminate the demand of providing a motor or verbal response (Banaschewski & Brandeis, 2007). Together, these factors support the use of EEG as an optimal tool for studies of brain functioning of normal and atypical child development (Banaschewski & Brandeis, 2007; Key, Dove, & Maguire, 2005). Other neuroimaging techniques include functional magnetic resonance imaging (fMRI) and positron emission tomography (PET), both of which provide spatial resolution allowing for accurate analysis of neurological structures and localization. However, EEG provides precise temporal resolution from milliseconds to fractions of milliseconds, which is why it remains the optimal device for measuring attentional variations (Key, Dove & Maguire, 2005). In fact, for decades EEG has been used as a tool to accurately record changes in physiological responses in various auditory and visual attention tasks (Luck, Woodman & Vogel, 2000). Courchesne, Kilman, Galambos & Lincoln (1984) believes EEG is the most favorable tool to study information processing in individuals with ASD.

Methods are currently being established that provide successful EEG data collection in children, even those with disabilities (Gavin & Davies, 2008). For example, during EEG data collection, researchers can create positive environments for participants that can minimize any anxiety and fear in children, which can provide for a means of maintaining compliance while simultaneously reducing fatigue (Gavin & Davies, 2008). Creating a positive environment allows for participants to take breaks, and to sit in a comfortable seated position among the researchers and parents (Gavin & Davies, 2008). This can be less intimidating than that of other methods such as an fMRI where participants are asked to remain entirely still while they are placed into a very small space with loud banging noises that could be frightening both for children or anyone who fears claustrophobia.

Components of an Event Related Potential

A running EEG accounts for various sensory-cognitive input being presented to the participant. When the running EEG is time locked to the stimulus, event related potentials (ERPs) are produced (Yordanova & Kolev, 2008). ERPs are described as a transient, subsequent series of changes in the brain's electrical activity to the event (Jeste & Nelson, 2009). These components are recorded immediately following any event or stimulus presented in the external or internal environments. Single trial ERPs are time-locked to the stimulus presented and are averaged together to produce an averaged ERP. This averaging aids in the reduction of noise or other background brain processing, and yields more concise ERP components relative to the specific stimulus provided in the paradigm (Banaschewski & Brandeis, 2007; Luck, 2005; Segalowitz & Davies, 2004; Stern, Ray & Quigley, 2001). Generally, it is the averaged ERP that is used when scoring and interpreting ERP components (Luck, 2005), and has even been used previously when studying adults using an orientation and habituation paradigm that assess attentional measures (Luck, Woodman, & Vogel, 2000; Ritter, Vaughan & Costa, 1968). Another ERP study looked at the ability of attention and its role in modulating multisensory integration in adults with HFA (Magnee, Gelder, van Engeland & Kemner, 2011). The averaged ERP components can be analyzed through a variety of characteristics including topography, polarity (P for positive and N for negative), amplitude (in μV), or latency from stimulus onset (in ms); and are associated with certain sensory or cognitive functions (Banaschewski & Brandeis, 2007; Davies, Chang & Gavin, 2010; Trainor, 2008).

ERP components are labeled according to the sequence of when the peak occurs, also referred to as latency or time from stimulus onset, and to its polarity. For example, P50, also known as P1, refers to a positive peak that is displayed at 50 milliseconds after the stimulus. Similarly, the N1 or N100 refers to a negative peak that is displayed at 100 milliseconds after the stimulus and the P2 or P200 refers to the positive peak displayed at 200 milliseconds after the stimulus (Key, Dove & Maguire, 2005; Segalowitz & Davies, 2004). See Figure 1.1 for an example running ERP waveform with labeled components. To reiterate, ERP components record very fine temporal resolutions that warn of even the slightest change in patterns of brain activation (Key, Dove & Maguire, 2005) which makes this method of data retrieval optimal for collecting measures related to attention.

During a running EEG, it is pertinent to acknowledge that the initial ERP components are recorded in response to a stimulus as reflections of the automatic or sensory processing (i.e.

auditory processing), while later components are more reflective with the cognitive processing of the stimulus such as determining if a response to the stimulus is required (Banaschewski & Brandeis, 2007; Stern, Ray & Quigley, 2001). For example, the P50 and N1 are greatly influenced by the parameters of the stimulus, in contrast, the P3 is known to reflect cognitive processing and has been shown to be larger when participants are told to respond to a stimulus than when they are told to ignore the stimulus (Stern, Ray & Quigley, 2001).

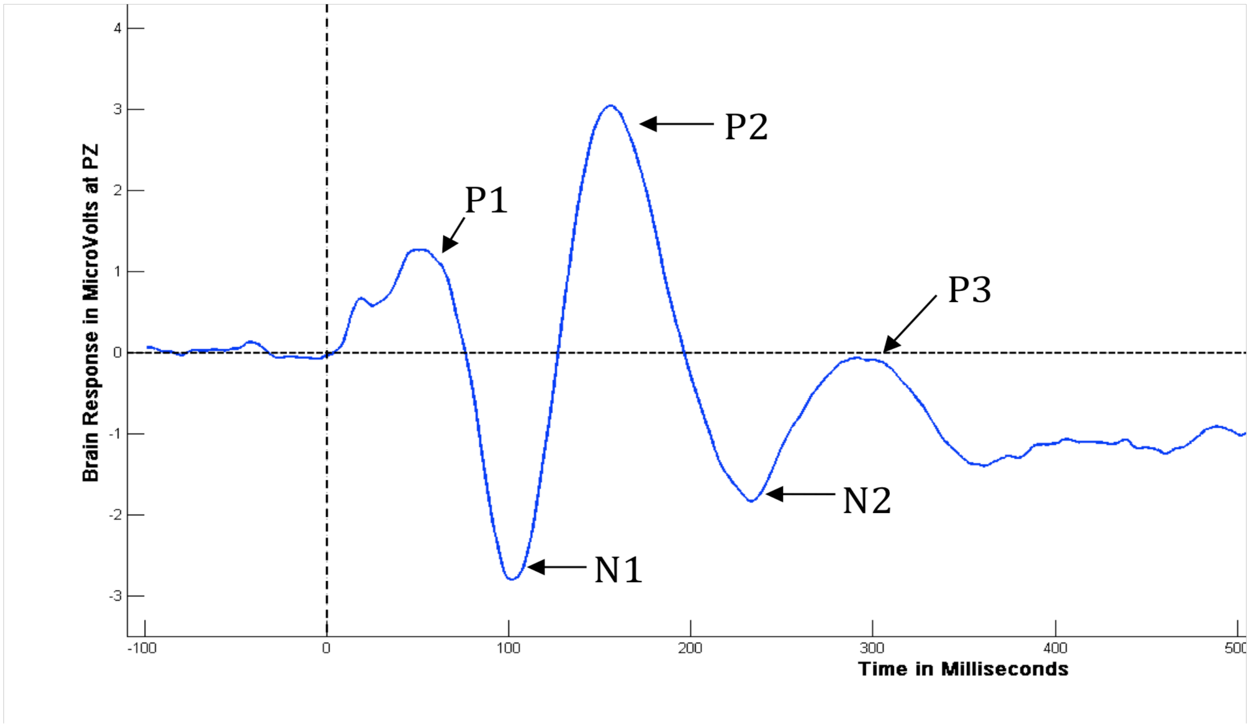


Figure 1.1: Running ERP of brain response to an auditory tone

Individual ERP paradigms are uniquely designed to examine distinct aspects of brain processing. Previously, Luck, Woodman & Vogel (2000) published a review of literature article that looked specifically at ERP studies that evaluate various cognitive subsystems of attention. Our current study incorporates two functional aspects of neural sensory processing within the brain that include sensory gating and habituation. In our paradigm for example, our first train (see figure 2.1 for a visual representation of the orientation/habituation paradigm) has eight identical tones where sensory gating is measured from P50 (also referred to at P1) to N1 and habituation can be measured during this first train, beginning at N1 and measured throughout tones 2 through 8. Since there is limited evidence on sensory gating and habituation paradigms in children with ASD or SPD it will be interesting to see if our findings will confirm what evidence has already been published and whether or not it will support the previous results.

Sensory gating paradigms

The auditory P50 has been reported to have the greatest peak at the central electrode cite which is Cz, and is associated with auditory inhibition (Key, Dove, & Maguire, 2005). As previously mentioned, sensory gating looks at the auditory P50 when paired clicks are administered within short interstimulus intervals (ISIs) (Rosburg et al., 2004). The amplitude of the average ERP to the second click is reduced when compared to the average ERP of the first click. This decrease in amplitudes is what is referred to from a neurophysiological standpoint as sensory gating (Key, Dove, & Maguire, 2005; Rosburg et al., 2004, Seri et al., 2007). In our paradigm, sensory gating can be measured as the reduction in amplitude of N1 of tone 2 to amplitude of N1 of tone 1. Gating can also be measured as a reduction of N2 amplitude of tone 2 compared to tone 1. These are the neurophysiological aspects of an ERP recording that can provide us with the fundamental understanding of attention required to draw sound conclusions both among and between children with and without ASD or SPD.

Kemner, Oranje, Verbaten, & van Engeland (2002) used a P50 sensory gating paradigm to analyze sensory filtering in children with ASD. While this study had only 12 children with ASD and 11 controls, the results failed to demonstrate a difference in sensory gating between the groups. Kemner and colleagues concluded that children with ASD present with typical orientation to the sensory input followed by typical inhibitory process related to P50 gating (Kemner, Oranje, Verbaten, & Engeland, 2002). Another study by Oranje, Lahuis, Engeland, Gaag, & Kemner (2013) looked at P50 inhibition in 13 children with ASD, 14 children with multiple complex developmental disorders, and a control group of 12 children, with participants between 9 and 14 years of age. Findings here also failed to show differences in P50 inhibition between the groups (Oranje, et al., 2013).

Orekhova et al. (2008) also looked at P50 sensory gating in younger children aged 3 to 8 years old. The three participant groups in this study included: 10 children with high-functioning autism (HFA), 11 children with low-functioning autism (LFA), and 21 typically developing (TD) control group. This study found supporting evidence that children with HFA have similar gating of P50 amplitude when compared to their TD peers. Additionally this study suggests that P50 gating improves with age. These researchers attribute this finding to brain maturation that occurs during brain development that includes an increased ability to inhibit auditory stimuli (Orekhova et al., 2008).

Sensory gating has also been studied among 18 TD adults, in 25 TD children, and in 28 children with SPD (Davies, Chang, & Gavin, 2009). These researchers found measurable differences in gating among typical adults, typically developing (TD) children and children with SPD. First, they documented that children (both TD and children with SPD) have more difficulty gating when compared to TD adults, and TD children have smaller brain responses when compared to TD adults (Davies, Chang, & Gavin, 2009). They also declared that children with SPD have significantly less sensory gating abilities (more difficulty suppressing brain responses to repeated auditory stimuli) and with more variability when compared to TD children (Davies, Chang, & Gavin, 2009). Further these researchers declared that children with SPD are unable to inhibit a response to repeated auditory input (Davies, Chang, & Gavin, 2009). Another study by Davies and Gavin (2007) also assessed sensory gating in 28 children with SPD and 25 TD children. In this study, they also found that children with SPD were less able to demonstrate sensory gating when compared to the TD group. Similar to the Orekhova et al. (2008) study, the Davies and Gavin (2007) and the Davies, Chang, & Gavin (2009) studies each provide an understanding that maturation of sensory gating does occur among TD children, which was not evident between the SPD group. Most notably, Davies and Gavin (2007) were able to distinguish children with and without SPD with 86% accuracy using EEG technology by using a prediction equation. The children in the SPD group displayed either hyperresponsive or hyporesponsive in their sensory gating abilities when compared to the TD group, validating that children with SPD have distinguished neuronal processes from that of TD children (Davies & Gavin, 2007).

Habituation paradigms

Habituation relates to cognitive processing and is reflective of the later ERP components typically beginning with N1. Habituation is observed as a decrease in the ERP response amplitude to subsequent components over time (Rosburg et al., 2006). Measuring habituation in this manner may reflect how attention to a stimulus continues or tapers off over time. Previous habituation studies including Rosburg, et al. (2004), assess habituation by using short trains of stimuli with longer intervals of silence between trains. Our current study provides similar assessment of habituation. During a person's activities of daily living, habituation can be described more vividly as a person's ability to attend to one stimulus while simultaneously inhibiting attention to another repeated stimulus (Burack, 1994; Hillard, Hink, Schwent, & Picton, 1973; Ohman & Lader, 1972; Maclean, Ohman, & Lader, 1975; Rosburg et al., 2004). For example, picture children sitting in a classroom and listening to the teacher explain how to solve a mathematics equation. Now imagine within this context, a steady humming sound coming from the classroom radiator. Many children sitting in the classroom are able to habituate; they successfully listen to the teacher while simultaneously ignoring the irrelevant stimulus that is the radiator noise. These children inhibit a response to the constant radiator noise. Again, habituation can be observed in ERP data after sensory gating occurs (the suppression of brain response to the second tone compared to the first tone), when the N1 and later ERP components are shown to gradually taper off, with each repeated tone. Children with ASD are thought to have difficulties with this ability to habituate (Burack, 1994) and children with SPD might also have difficulties with habituation of auditory stimuli.

As mentioned previously, Rosburg et al. (2004) were able to summarize that the function of sensory gating is displayed with a clear decrease in the P50 amplitude from tone one to tone two. However, during a habituation study, the N1 is analyzed since it is known to produce larger amplitudes to tones (Rosburg et al., 2004). N2 is also analyzed because this component provides larger amplitudes when deviants are presented within a habituation study (Luck, 2005). Below a few ERP studies that assess habituation are presented. By taking into consideration these studies findings can help create an understanding of why we established our habituation study the way we did.

There are many factors that need to be accounted for when considering a habituation paradigm. In one of the earlier ERP studies on habituation, Ohman & Lader (1972) report the importance of the interstimulus interval (ISI) factor and its role in attending and making a response. By analyzing the averages of the ERPs in two different tasks, one where a response was given to attending to a task and the other when a response was given to visual stimuli while ignoring a task, they found that when looking at P1-N1 and N1-P2, amplitudes were greater when participants were attending to the stimuli, rather than the latter (Ohman & Lader, 1972). Additionally they found long ISI's correlate with larger responses (Ohman & Lader, 1972). In our paradigm we use a 500 ms ISI that has been used in a previous habituation study by Rosburg et al. (2004) and allows for the P3 cognitive processing to be displayed.

In another study, Maclean, Ohman & Lader (1975) report on three separate experiments, each with varying experimental conditions of attention looking at the activation of stimulus regularity on habituation. In one of their experiments they found that when attention was directed away from the stimulus, a more defined slope was displayed among the averaged evoked responses (Maclean, Ohman & Lader, 1975). This is one of the reasons why, in our current study, we play a soundless Shaun the Sheep movie while the tones are being played, allowing us to direct the child's attention to the movie, while simultaneously allowing the opportunity for habituation to occur among each train of tones.

The information presented in this chapter provides and understanding of the prevalence, core diagnostic criteria and/or behaviors and theories that describe children with HFA and SPD. This chapter also introduced the relationships between the three subtypes of attention with the behavioral phenotypes seen within these groups and was followed by a review of the literature of the attentional differences in children with HFA and SPD first from a behavioral approach and then from a neurophysiological approach. This knowledge serves as the foundation upon which the intention for this thesis was based. Chapter 2 provides an understanding of attentional and neuronal differences and relationships, which could inform therapeutic approaches chosen by practitioners.

CHAPTER 2

Attentional measures of N1 and N2

The ERP components N1 and possibly N2 can provide meaningful information about the role of sensory processing and attention required for sensory gating and habituation in children with HFA and SPD. Ceponiene et al. (2002) studied ERPs in children and found that P1 and N2 components to be the most prevailing and specifically with N2 being the largest amplitude of the auditory evoked potentials. Several other studies have shown N1, generally the most easily identified ERP component (Key, Dove, & Maguire, 2005) to be related to selective attention by producing larger amplitudes when attending to a tone (Hillyard, Hink, Schwent, & Picton, 1973; Luck, Woodman, & Vogel, 2000; Paavilainen, Jiang, Lavikainen, & Naatanen, 1993).

One study that examined the effects of attention on the latency and amplitude of the N1 component comparing children with ASD and aged matched peers was Oades, Walker, Geffen, & Stern (1988). In this study, participants were asked to respond to auditory stimuli by pressing a button to infrequent targets, to ignore higher pitched infrequent targets and frequent non-targets. This study found shorter N1 latencies and larger N1 amplitudes in the ASD group to the deviant stimuli compared to the control group. In contrast, when the stimuli were later presented passively, requiring no response, N1 amplitudes were larger in the control group when compared with ASD participants (Oades, Walker, Geffen, & Stern, 1988). They attributed the larger N1 amplitudes to an increased responsiveness to rare stimuli, and shorter N1 latencies to shorter reaction times in the ASD group (Oades et al., 1988). However, the Oades et al. (1988) study only included seven children with HFA and nine age matched peers, which limits the ability to generalize these results.

In contrast, Lincoln, Courchesne, Harms, & Allen (1995) looked at children with ASD and found that the N1 component did not increase in amplitude to increased auditory stimulus intensity. Lincoln et al. (1995) also found that children with ASD displayed similar N1 amplitudes to both rare and frequent auditory stimuli (Lincoln et al., 1995). Again, the Lincoln et al. (1995) study also only included ten children with ASD and ten TD controls limiting the generalizability of the results. Davies, Chang, & Gavin (2009) analyzed the N1 component as part of a sensory gating paradigm in adults, typically developing children and children with SPD. Their findings agree with the notion that the N1 corresponds to distinct aspects of sensory processing, and further that N1 may represent more complex processing than that of the P50 component (Davies, Chang, & Gavin, 2009). It would be interesting to analyze the N1 component in our current study to add to this growing but limited and controversial body of knowledge.

Similar to the ERP component N1, for the N2 to emerge a person must also be attending to a stimulus (Key, Dove, & Maguire, 2005). However, the functional interpretation of the N2 component and specifics on how it relates to attention is less certain. For example, some researchers believe that N2 reflects tasks demand (Ducan et al., 1994), while others hypothesize that this component may be associated with target selection (Donchin, Ritter & McCallum, 1978) or with a discriminative process (Bernal et al., 2000). Since there are so few studies with children with ASD or SPD using a series of tones, or that analyze the N2 component of and ERP, in the present orientation/habituation paradigm it would be interesting to compare N2 to that of the previous negativity, N1, in relation to both novel tones presented at low frequency (1 kHz) and deviant tones presented at a higher frequency (3 kHz).

Purpose

The purpose of this study is to understand relationships between neurological components of auditory processing and behavioral measures of attention among typically developing (TD) children, children with HFA, and children with SPD. First, we analyze differences in performance on tasks that require various subtypes of attention, as measured by the TEA-Ch between children with HFA, SPD, and age matched peers. We will then take a more focused neurological approach and look at specific ERP components of these children that were measured while the children completed an orientation/habituation paradigm. Specifically, we wanted to more clearly understand, and add to a conflicting body of knowledge, any differences in gating and habituation performances by comparing N1 or N2 amplitudes among our three groups. Additionally, we examined if children with HFA and SPD showed different responses, compared to TD children, to novel or deviant stimuli by again assessing N1 and N2 brain responses to tones occurring in different positions within our EEG paradigm. Along with this, we sought to determine if the three groups differed on habituation of brain responses (i.e., N1 and N2) to the series of tones. Last we strove to discover if relationships between neurophysiological measures of attention at N1 and N2 amplitudes and behavioral measures of attention among the three groups existed.

Understanding the attentional differences among children with special needs could help inform therapeutic approaches chosen by practitioners. For children with HFA results of this study may contribute to deeper understanding and further examination of the DSM-5 core criteria in children with ASD, particularly the social communication and social interaction as well as sensory processing of auditory stimuli. Similarly, understanding the attentional difficulties of children with SPD may also contribute to better understanding the levels of SPD as described by Ayres (1979), and theories presented by Bundy & Murray (2002), Stackhouse et al. (2014), and Dunn (1997), specifically with these children's abilities to process auditory stimuli and difficulties with modulating attention. Differences in a child's neuronal makeup can shed light on behavioral differences and may provide opportunities for increased awareness of how to best set up therapeutic environments. This may also play a role in a therapist's decision making about which type of intervention to employ with correlating groups. With an increased understanding, therapists might be better able to challenge the child's auditory processing abilities and as a result create more frequent opportunities for the child to achieve an adaptive response, a key component of sensory integration therapy (Ayres, 1979) discussed previously. Since processing of auditory stimuli is modulated by attention, and this study could provide evidence that there are relationships between the two, perhaps the therapist setting up the environment mindfully controls or scaffolds the demands (working on repeatedly triggering the just right challenge) by implementing a cognitive approach onto the attention system, this may allow for improved processing of auditory stimuli. This also brings awareness to the potential benefits of therapists using multiple approaches during treatment. While some therapists may use sensory-based intervention strategies more frequently, others may continually use cognitive approaches. Understanding the role of sensory and attention in behavioral manifestations might help guide which types of intervention may be more effective.

Research Questions and Hypotheses

Question 1: From a behavioral perspective, will there be differences in performance on tasks that require attention among typically developing (TD) children, children with HFA, and children with SPD?

Hypothesis 1.1: TD children and children with HFA will have similar performance on tasks requiring sustained attention, as measured by the TEA-Ch.

Hypothesis 1.2: Tasks that require selective attention and attentional control/shift will be significantly more difficult for children with HFA and SPD when compared to the control group, as measured by the TEA-Ch.

Hypothesis 1.3: Children with SPD will have more difficulty on tasks that require sustained attention than children with HFA & TD, as measured by the TEA-Ch.

Question 2: From a neurophysiological perspective, will TD children and children with HFA or SPD show differences in sensory gating and habituation performances in the train of tones without a deviant?

Hypothesis 2.1: TD children and children with HFA will show similarities in gating as shown when comparing reduction in N1 or N2 amplitudes from tone 1 to tone 2.

Hypothesis 2.2: TD children will show greater abilities in gating than children with SPD as shown when comparing reduction in N1 or N2 amplitudes from tone 1 to tone 2.

Hypothesis 2.3: TD children will show greater abilities to habituate than children with HFA when comparing N1 or N2 amplitude from tone 2 to tone 8.

Hypothesis 2.4: TD children will show greater abilities to habituate than children with SPD when comparing N1 or N2 amplitude from tone 2 to tone 8.

Question 3: From a neurophysiological perspective, will children with HFA or SPD show different brain responses to a novel or deviant stimulus?

Hypothesis 3.1: At tone 1 in a train with no deviant, the N1 and N2 responses will be larger among TD children when compared with children with HFA.

Hypothesis 3.2: At tone 1 in a train with no deviant, the N1 and N2 responses will be larger among TD children when compared with children with SPD.

Hypothesis 3.3: During the second and third trains with deviants at the 4th and 5th positions respectively, the N1 and N2 amplitudes will be significantly different between TD & HFA groups when compared to the amplitudes for N1 and N2 prior to the deviant.

Hypothesis 3.4 During the second and third trains with deviants at the 4th and 5th positions respectively, the N1 and N2 amplitudes will be significantly different between TD & SPD groups when compared to the amplitudes for N1 and N2 prior to the deviant.

Question 4: Is there a relationship between the neurophysiological measures of attention displayed at N1 and N2 amplitudes and behavioral measures of attention among groups, as measured by the TEA-Ch?

Hypotheses 4.1: In TD children, there will be a relationship between both the N1 amplitudes of tone 1 or the deviant tones and attention scores as measured by subtests of the TEA-Ch.

Hypotheses 4.2: In children with HFA, there will be a relationship between both the N1 amplitudes of tone 1 and the deviant tones and attention scores as measured by subtests of the TEA-Ch.

Hypotheses 4.3: In children with SPD, there will be a relationship between both the N1 amplitudes of tone 1 and the deviant tones and attention scores as measured by subtests of the TEA-Ch.

Hypotheses 4.4: In TD children, N2 amplitudes of tone 1 will display a relationship with the attention control/shift scores as measured by the TEA-Ch.

Hypotheses 4.5: In children with HFA, N2 amplitudes of tone 1 will display a relationship with the attention control/shift scores as measured by the TEA-Ch.

Hypotheses 4.6: In children with SPD, N2 amplitudes of tone 1 will display a relationship with the attention control/shift scores as measured by the TEA-Ch.

Methods

Participants

Colorado State University's Institutional Review Board (IRB) approved all recruitment procedures. Participants recruited include 51 children between the ages of 5 and 12 years of age, 70% male. The inclusion of 10 participants with high functioning autism (HFA), 6 participants with sensory processing difficulties, and 9 control participants were taken from a previous study conducted at the Brainwaves lab at Colorado State University (CSU) that used identical procedures, behavior tests and electroencephalograph paradigm. The additional 26 participants were recruited as part of a convenience sample throughout the state of Colorado. Graduate students at CSU recruited participants by connecting with local therapy clinics and parent groups within Colorado communities. In addition, the IRB approved recruitment flyer was posted to CSU Today web mail contacts and community social network sites. Inclusion criteria included the following: between the ages of 5 and 12, normal or corrected hearing, normal or correction vision, no past history of significant brain injury, and no past history of conditions of epilepsy, schizophrenia, bipolar, or depression.

A total of 20 children with diagnoses of autism spectrum disorder (ASD; 15 male and 4 female) between 5 and 12 years of age (M=8.94; SD=2.03) were included in this study. For this group, the children had to have received a diagnosis from a medical or psychological professional of ASD or Aspergers' to be included. Once contact with the family was made, HFA was confirmed by completion of the Aspergers' questionnaire form. The second group consisted of 9 children with SPD (7 male and 2 female) also approximately between 5 and 12 years of age (mean age 6.57 ± 1.26 years). Children in the SPD group were referred to our study by therapists who were treating the child for sensory integration challenges. Lastly, the control group of 22 typically developing (TD) children was also recruited with both gender and age matched participants in either HFA or SPD groups. All control participants were also between 5 and 12 years of age (mean age 8.46 ± 2.39 years) and without any physical, neurological, or behavioral disorders. All participant caregivers were requested to complete the Sensory Profile (Dunn, 1999) prior to participation in this study.

Data Collection

Procedures

Once contact with a participant was established, parents were sent an information packet and scheduled for two visits at local university. The information packet included a letter to the parents with details of the appointment, two maps one with directions to CSU and a second map of the CSU Brainwaves Research lab, a child tip sheet for what to expect (get a good nights sleep, dress in layers, bring a snack, etc.), a consent form, a child demographic form, and the Sensory Profile (Dunn, 1999). The second visit was scheduled within 2 weeks of the first visit, and if possible on the same day of the week and time. This was done in an attempt to control for confounding performance factors such as fatigue/alertness, or arousal levels that can change depending on the time of day. On the first visit, a member of the Brainwaves research team at CSU obtained parent permission and child assent. Child assent was presented with the parents in the room but directed towards the child to ensure that they were willing volunteers of the research and had the choice to stop the study at any time.

The EEG data was collected while having each participant sit in a comfortable seated position, with pillows and footstools if applicable. Once the EEG cap and electrodes were positioned the researchers then lead the participant through brief artifact reduction training. This artifact reduction training taught the child the importance of reducing eye blinks, teeth grinding or other muscle activity as a way to maintain a calm and relaxed muscles of the face. The artifact reduction training was provided in an attempt to control for cleaner EEG data but was abbreviated or skipped if the child showed a lack of interest or inability to attend to the explanation. This time was also simultaneously used for building rapport with the children, allowing for questions and answers, and for sharing photos of previous child participants wearing the EEG cap and electrodes. Each visit was scheduled to last approximately two hours with the first half of each visit spent collecting EEG data and the second half administration of the behavioral assessments.

Each participant completed a series of three EEG paradigms. During the first visit each participant was seen for the sensory registration paradigm and sensory gating paradigm. Prior to starting these paradigms a threshold was attained for the purposes of confirming parental report of no hearing problems and to note the child's range of hearing. During the second visit, the participants were administered the orientation and habituation paradigm, the only paradigm analyzed in this thesis study. The other half of each visit participants completed behavioral testing. During the first visit, participants completed each of the 9 subtests of the Test of Everyday Attention for Children (TEA-Ch) version A, with auditory components of the assessment provided through speakers attached to a nearby portable laptop. On the second visit, participants were administered the vocabulary and matrix reasoning subtests of the Wechsler Abbreviated Scale of Intelligence that could serve as a control for cognitive functioning of the participants between groups. In addition on the second visit, the Clinical Observations of Motor & Postural Skills were also administered. Neither the Wechsler Abbreviated Scale of Intelligence nor the Clinical Observations of Motor & Postural Skills was analyzed in this study.

Behavioral Measures & Psychometrics

The Test of Everyday Attention for Children (TEA-Ch), a standardized and normed assessment, provides raw scores and correlated standard scores for each of its nine subtests. Each of the nine subtests also correlates with one of the three subtypes of attention. Standardization of the TEA-Ch was conducted on a normative sample of 293 children and adolescents aged 6 to 16 years old residing in Australia (Manly et al., 1999). Each child was administered version A of the TEA-Ch and 55 of these children were retested a second time, 6 to 15 days later, for establishment of reliability of test-retest correlation coefficients (Manly et al., 1999). For all but two of the nine subtests, correlation coefficients range from 0.57 to 0.87 (Manly et al., 1999). For subtests Score, Score DT, and Walk, Don't Walk, correlations were unrealistic due to ceiling effects, percentage of agreement was found to be within 1 standard deviation for 1st and second test administered, and ranged from 71.0% to 76.2% (Manly et al., 1999). Validity of the TEA-Ch shows that each of the subtypes of attention (selective, sustained, and control/shift), or latent variables, has distinct performance patterns (Manly et al., 1999). Scores on the TEA-Ch and the latent variables were reviewed in a Structural Equation Model with a Comparative Fit Index of 0.973, Normed Fit Index of 0.913, and Non-Normed Fit Index of 0.96, each of which are above the 0.9 threshold, representing a good fit (Manly et al., 1999). In our study, the TEA-Ch was administered and later scored according to the procedures outlined in the manual. Descriptions of each of the subtests that correlate with the elements of attention were mentioned briefly in the introduction. Below they are described more thoroughly in addition to how they are each scored. For children who could not perform the practice problems provided in each of the subtests or if the examiner made the decision that the child could not perform the subtests, the child received a score of 0.

Attentional control/shift. Measuring attentional control/shift in the TEA-Ch is done within two of the nine subtests. In the first subtest referred to as Creature Counting, children are asked to count aliens in their burrow while responding to arrows that notify them when to switch the direction they are counting. For example, when they come to an arrow that points up, they must count in a positive direction verses when they come to an arrow that points down they must then switch the direction they are counting and begin to count in a negative direction. Another subtest, Opposite Worlds, has the children follow a path lined with the numbers 1 and 2. In this task the child reports either the same as what is shown or the opposite of what is shown, so if in the opposite world when a child sees a 1 on the path they must say "two" and when they see a 2 on the path they must say "one." Both of these subtests will allow us to evaluate a child's ability to shift or adjust their attention to the corresponding designated target. Creature Counting records the child's accuracy and speed while Opposite Worlds records differences in time between the two "worlds."

Selective attention. In the TEA-Ch there are two subtests that measure selective attention. Sky Search is one of these subtests where children are asked to find matching pairs of space ships while ignoring pairs that do not match. Following this they then perform the same task without the distracting or spaceships that do not match. In this way, Sky Search controls for differences in motor speed so that the results only reflect attentional demands. To do this the total attention score is calculated as time per target and then subtracts out the motor score. The second selective attention task, Map Mission, has children search a map to locate as many identified symbols (fork and spoon) as possible within a period of one minute, while ignoring non-target symbols. In the Map Mission subtest, the score given is the number of symbols correctly identified within one minute. Manly et al. (1999) state that both of these tasks "examine the efficiency with which information can be filtered to detect relevant information and reject or inhibit irrelevant or distracting information" (p. 26).

Sustained attention. In the TEA-Ch, sustained attention is measured in five different subtests, Score, Score DT, Code Transmission, Walk, Don't Walk, and Sky Search DT. In the subtest Score, performance is measured by the child's ability to count the number of sounds that are played from a tape. There is little being done to entertain the child, which makes it a good task to test the child's ability to self-sustain their attention to the sounds. Another subtest, the Score Dual Task (DT), the child must count the number of scoring sounds on an audio clip (just like in the subtest Score!) but simultaneously they must also listen for an animal mentioned in a news broadcast. In the instructions they are asked to "concentrate most on the counting. If you concentrate too much on the news, the counting is very difficult" (Manley et al., 2001). Duration of this sustained attention task is 5 minutes and 40 seconds. Another subtest, the Code Transmission subtest requests the child to sustain their attention to a sequence of verbally reported numbers. The child listens closely for two number fives in a row and when they hear two fives in a row to state the number that was presented immediately before the two fives. The duration of the Code Transmission task is about 12 minutes, notably the longest task on the TEA-Ch, and a total of 40 targets are presented. Each of these subtests requires the participant to sustain attention to the task. For calculating the score for these sustained attention subtests, the total number of targets correctly reported serves at the total raw score.

The final two subtests that assess sustained attention include Walk, Don't Walk, and Sky Search DT. The Walk, Don't Walk measure was modified from the Sustained Attention to Response Test mentioned previously (Manly et al., 2001). In this task, the child is provided a sheet with 14 square walking paths or columns. Children are instructed to listen to an audio tape that plays two sounds, a go sound (walk) and a no go sound (don't walk). While keeping up with the sounds on the tape they need to make a mark on the sheet when the go sound is played and inhibit a mark when the no go sound is presented. The duration of this task is just over 6 minutes. The Walk, Don't Walk score is calculated by the number of trials they correctly inhibit a response to the no go sound while keeping up with the audio. Lastly, the Sky Search DT task is a dual task where the participant has to perform the identical task described in Sky Search (to visually search and circle matching space ships) while simultaneously counts the number of scoring sounds on the audio clip. The duration of this task is dependent on the child's ability to find the matching space ships. A total score for Sky Search DT was computed by calculating time taken to find the visual targets and totaling the number of counting sounds that were correct. Performance was calculated by this time (in seconds) divided by proportion of counting sounds correct. Last visual search performance was taken out of this subtest by subtracting the time-per-target score from the Sky Search task from the value, which provided a score for Sky Search DT.

EEG/ERP Data Recording

EEG data obtained in the current study was collected using a BioSemi ActiveTwo EEG/ERP Acquisition System (BioSemi, Wg-Plein 129, 1054 SC Amsterdam, Netherlands). This system has 32 channels, with 8 additional electrodes (one was attached to each earlobe and each mastoid, and four others accounted for movements of the eyes located above, below and to the side the left eye and one above the right eye). These 8 additional electrodes are important for controlling muscle activity such as eye blinks. For the orientation and habituation paradigm, tones were administered in both ears through earphones (Etymotic Research) connected to the E-Prime Software (Psychological Software Tools, Pittsburgh, PA, USA).

Orientation and habituation paradigm. The orientation and habituation paradigm used for the present study has three trains of 8 tones. The first train consists of 8 identical 1 kHz tones, each tone with duration of 50-milliseconds (ms). The second train consists of 7, 1 kHz tones, each with 50 ms duration and includes a deviant tone located in the 4th position. This deviant was presented as 3 kHz (higher frequency) and maintained the 50 ms duration. The third train is similar to that of the second train, which consists of 7 1kHz tones, and one deviant tone of a 3 kHz tone in the 5th position. All tones, standard and deviant, are presented with the same intensity. In addition, each tone in the train of 8 has a Stimulus Onset Asynchrony (SOA) of 500 ms and between each train has a random inter-trial interval (ITI) or 8 – 10 seconds, an average of 9 seconds. See Figure 2.1 below for a visual representation of the individual auditory tones and group trains used in the orientation and habituation paradigm. Throughout the paradigm each train was administered in a predetermined random order 80 times, and required about one hour to complete. While the participants listened to the tones presented through the headphones, they simultaneously watched a silent film, Shaun the Sheep, on a computer monitor directly in front of them.

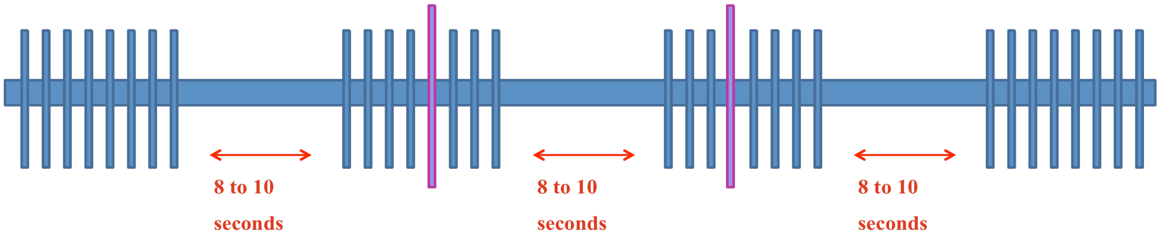


Figure 2.1: A visual representation of the trains of tones used in the orientation and habituation paradigm. All tones were presented for 50ms duration. The blue, standard tones presented at 1kHz and the purple, deviant tones, at 3 kHz. There was 8 to 10 seconds duration between each train/group of tones.

ERP Waveform and Component Analysis

Brain Vision Analyzer 2 (Brain Products GmbH, Gilching, Germany, 2002) and Matlab softwares (The MathWorks, Inc, Natick, Massachusetts, USA) were used for the analysis of the EEG and ERP data. Averaged ERP's were composed from the running EEG data. In order to create averaged ERP, data were segmented from 200 ms before a stimulus until 500 ms after the stimulus was presented for each tone. Each of the waveforms then were baseline corrected and artifacts such as blinks and muscle movement were eliminated. Averaged ERP waveforms were created for each series by averaging the segments for each tone separately.

The ERP waveforms were assessed using the PeakPicker program (Gavin, BrainwavesResearch Lab, Fort Collins, CO, 2009). The Peak Picker program automatically recorded the amplitudes and latencies of chosen peaks, P50, N1, P2, and N2, into Microsoft Access. These peaks were then individually confirmed manually by visual inspection of the grand averages. Time windows were determined for each of the ERP components for the purpose of appropriate scoring thereafter. P50 amplitudes were recorded as the highest peak within a 40 - 90 ms latency window, N1 amplitudes were recorded as the highest peak within a 80 - 150 ms latency window, P2 amplitudes were recorded as the highest peak within a 110 - 210 ms latency window, N2 amplitudes were recorded as the highest peak within a 200 - 310 ms latency window, and P3 amplitudes were recorded as the highest peak within a 280 - 420 ms latency window. Again each peak was visually assessed and confirmed or chosen based on the greatest amplitude and latency window. If peaks did not fall within the latency windows these peaks were chosen while considering overall ERP morphology and rarely when a slope was displayed with absolutely no peak available, a "no peak" was recorded. If the specific peak was required for analysis (for example N1 or N2 of tone 2 or tone 8 in the habituation analysis) and a "no peak" was recorded this participant was not included in that specific analysis.

Following the confirmation of P50, N1, P2, and N2 peaks, peak-to-peak amplitudes for the N1 and N2 components were computed. The peak-to-peak amplitude of N1 was determined by measurement of the difference in μV between the N1 (80 - 150 ms) peak amplitude and the P50 (40 - 90 ms) peak amplitude. The peak-to-peak amplitude of N2 was determined by measurement of the difference in μV between the N2 (200 - 310 ms) peak amplitude and the P2 (110 - 210 ms) peak amplitude.

T-maps were created from the averaged ERP waveforms in order to determine which of the 32 channels would be utilized for statistical analysis. Peak amplitudes were scored at Fz, Cz, Pz, T7, and T8 sites. The channel with the greatest amplitude, Cz was chosen and is consistent with previous literature (Key, Dove, & Maguire, 2005) and in studies measuring sensory gating in children with ASD (Davies, Chang, & Gavin, 2009; Kemner, Oranje, Verbaten, & van Engeland, 2002; Oranje, Lahuis, van England, van der Gaag, & Kemner, 2013; Orekhova et al., 2008).

Data Analysis

Dependent measures

The dependent measures used for the behavioral Test of Everyday Attention for Children (TEA-Ch) were the raw and scaled scores of all nine subtests. These include attention control/shift subtests Creature Counting and Opposite Worlds; selective attention subtests Sky Search and Map Mission; and sustained attention subtests Score, Code Transmission, Walk, Don't Walk, Score DT, and Sky Search DT. Generally, higher raw scores reflect better attention abilities, except for the subtests Sky Search, Sky Search DT, Creature Counting and Opposite

Worlds where lower raw scores reflect better attention ability due to quicker timing to complete these tasks. Each of the scaled scores results ranged from 0 – 19. Higher scaled scores for the subtests Score, Map Mission, Score DT, Walk, Don't Walk, and Code Transmission indicated better attention abilities. Conversely, smaller scaled scores on subtests including Sky Search, Sky Search DT, Creature Counting and Opposite Worlds indicated better attention abilities also due to timing taken to complete tasks.

The dependent measures of sensory gating include N1 and N2 peak amplitudes of tone 1 and tone 2 among all trains without a deviant tone throughout the paradigm. The dependent measures of habituation include N1 and N2 amplitudes of tone 2 and tone 8 again in the trains without a deviant tone. For trains without deviant tones, dependent measures include orientation at the beginning of the train at tone 1 by measuring amplitudes of N1 and N2. N1 and N2 amplitudes are also measures of dependent variables in trains with a deviant in the 4th and 5th positions that measure orientation to deviant tones. For the train with the deviant in the 4th position, N1 and N2 amplitudes were measured at tone 3 and tone 4. The train with the deviant in the 5th position, N1 and N2 amplitudes were measured at tone 4 and tone 5.

To bring the behavioral and neurophysiological data together, regression analyses were conducted. The dependent measures included ERP component N1 and N2 amplitudes and the behavioral measures of attention among groups as measured by the TEA-Ch served as independent measures.

Statistical analysis

Descriptive statistics were performed for behavioral data as well as the neurophysiological data. As expected for analysis of children with heterogeneous conditions, the statistical frequencies did not always display a bell curve representing normally distributed data.

Accordingly when the data were not normally distributed the non-parametric statistics were used such as the Mann-Whitney *U* test. Likewise, when the data were normally distributed t-tests were used. Differences in raw and standard score means and standard deviations in the behavioral data were also reviewed and implications are presented in the results section. Children younger than 6 years of age (9 in total) were removed from the scaled score behavioral analysis because the TEA-Ch is only standardized for children ages 6 – 16 and a scaled score cannot be computed for children less than 6 years of age.

Hypotheses that correlate with research question 1 assessing behavioral subtypes of attention among groups, a Mann-Whitney *U* test was computed to compare groups based on their raw and standard scores for each of the nine TEA-Ch subtest. For all analyses, children in the HFA group were compared to the correlating age and gender matched peers, and similarly children within the SPD group were compared to selected age and gender matched peers in the TD group. Each of the nine TEA-Ch tasks were analyzed parallel to the correlating attentional subtypes. For example, the TEA-Ch tasks that assess selective attention, Sky Search and Map Mission, analysis were computed using the Mann-Whitney *U* test and compared scores of HFA and TD groups and again between SPD and TD groups.

For analysis of research question 2, in trains without a deviant tone, gating was first measured at the Cz site by first computing the peak-to-peak amplitudes of N1 and N2 and then compared the amplitudes of tone 1 to the amplitudes of tone 2. For gating, two way ANOVAs included a between factor of groups (TD and HFA or TD and SPD) and within factor parameters of tone 1 and tone 2. The ANOVAs were performed among 20 children with HFA and 16 age matched peers, and also between 8 children with SPD and 7 age matched peers. Similarly for hypotheses on habituation, trains without a deviant were also assessed at the Cz site also using two way ANOVAs with similar between factor parameter but within factors of tone 2 and tone 8, to determine the difference between tone 1 and tone 2 for both the N1 and N2 peak-to-peak amplitudes. Participants included 20 children with HFA and 15 age matched peers, and 9 children with SPD and 7 age matched peers. For the gating and habituation analyses that produced an interaction between groups, follow up Post Hoc test using Tukey's ratio using error mean squared values from the AONVA were conducted (Kirk, 1994).

For testing hypothesis for research question 3, hypothesis 3.1 required the analysis of the Mann-Whitney *U* test for TD and HFA and *t*-test for TD and SPD groups. These analyses were computed for measurement of brain responses including N1 and N2 to novel and deviant auditory stimuli. Within this ERP data, some participant peak-to-peak amplitude measures were lost which affected the number of participants within a given hypotheses, which will be reflected by the degrees of freedom for each analysis. For hypotheses 3.1 and 3.2 we compared the ERP component amplitudes at tone 1 in a train without a deviant between groups using the Mann-Whitney *U* test for TD and HFA groups and *t*-test for TD and SPD groups. ANOVAs were run for hypothesis 3.3 and 3.4. These ANOVAs measured the difference between the deviant tone and to the tone just prior to the deviant tone for both N1 and N2 amplitudes. For example, the train with the deviant in the 4th position compared the amplitude response to tone 3 to the amplitude of tone 4. For hypothesis 3.3 that assesses trains with deviants in 4th and 5th positions, participants included during the analysis of the train with the deviant in the 5th position included 20 children with HFA and 13 TD peers. For the train with the deviant in the 4th position, 20 children with HFA and 14 TD peers were included in the analysis. For hypothesis 3.4 that assessed children with SPD in comparison with TD peers and also comparing brain responses of N1 to trains with deviants, 7 children with SPD and 5 TD peers were analyzed within a *t*-test.

For identical measures of N2, 9 children with SPD and 6 TD peers were included in the analysis. Post hoc analyses were also computed in the same manner as presented above in question 3 for any significant interaction between tone and group.

For analysis of question 4, Hiearchial Regression was computed for analysis of possible relationships between ERP brain responses of tone 1 for N1 and N2 at Cz site and behavioral subtypes of attentions measured on the TEA-Ch. The number of children within each regression analysis was dependent on the number of participants that were able to complete the TEA-Ch subtests themselves. As mentioned previously, a few a participants were unable to demonstrate understanding with the practice rounds or if the examiner understood the child was not able to complete a task; a score of 0 was recorded.

Results

Question 1: Behavioral Measures of Attention

The Test of Everyday Attention for Children (TEA-Ch) provides justification that indeed there are differences among the subtypes of attention in children with high functioning autism (HFA), children with sensory processing difficulties (SPD) and neurotypically developing (TD) children. Below Table 2.1 provides TEA-Ch score descriptive statistics among children with HFA and TD groups and table 2.2 provides TEA-Ch score statistics among children with SPD and TD groups.

For analysis of hypothesis 1.1, Mann-Whitney *U* tests were performed for each of the five subtests measuring sustained attention (Score, Code Transmission, Walk, Don't Walk, Score DT and Sky Search DT) to assess whether children with TD and HFA will show similar performance on tasks requiring sustained attention. However, four of the five subtests did not confirm this hypothesis. For the subtest Score, significant differences in raw scores of $z = -2.16$, *p* = .031 and scaled scores approached significance at *z* = -1.62, *p* = .105; subtest Code Transmission, significant differences in raw scores of *z* = -3.13, *p* = .002 and scaled scores of *z* = -3.15, *p* = .002; subtest Walk, Don't Walk, significant differences in raw scores of *z* = -2.81, *p* = .005 and scaled scores of *z* = -2.17, *p* = .03; and subtest Score DT, significant differences in raw scores of *z* = -3.39, *p* = .001 and scaled scores of *z* = -2.97, *p* = .003. These subtests did not support the hypothesis 1.1, instead TD participants performed significantly better on these sustained attention tasks. Hypothesis 1.1 was only supported by the subtest Sky Search DT that showed no significant difference between groups, raw scores of *z* = -.44, *p* = .661 .

For hypothesis 1.2, Mann-Whitney *U* tests were also performed to analyze whether tasks that require selective attention and attention control/shift were significantly more difficult for children with HFA when compared to the control group. For subtests that assessed attention control/shift the hypothesis was supported by a significant difference shown in the scaled score results of the subtest Creature Counting, *z* = -2.22, *p* = .027. The selective attention subtest Map Mission also showed significant differences in the raw scores, *z* = -2.18, *p* = .03 between HFA and TD groups. The selective attention subtest Sky Search did not show significant differences between HFA and TD groups.

Table 2.1: Descriptive information for the maximum number for the TD children (n = 22) and HFA children (n = 16) for each of the TEA-Ch subtests, for scaled score there are fewer participants due to age or if they were unable to complete task

TEA-Ch Subtests	Mean		Median		Mean Rank	
	TD	HFA	TD	HFA	TD	HFA
Sustained						
Score!						
Raw Score	7.93	5.35	8.00	6.00	20.27	13.18
Scaled Score	9.46	7.24	9.00	6.00	17.81	12.72
Code Transmission						
Raw Score	32.80	16.13	33.00	21.00	21.23	11.09
Scaled Score	8.46	3.50	9.00	3.50	19.73	9.97
Walk, Don't Walk						
Raw Score	11.47	5.56	10.00	3.50	20.70	11.59
Scaled Score	6.23	3.56	7.00	3.00	18.08	11.40
Score DT						
Raw Score	14.93	9.13	16.00	10.00	21.70	10.66
Scaled Score	10.00	5.38	11.00	6.00	19.42	10.23
Sky Search DT						
Raw Score	13.55	47.66	1.41	0.16	15.77	14.38
Scaled Score	7.33	7.63	7.00	9.50	12.58	15.13
Selective Attention						
Sky Search						
Raw Score	6.00	5.57	4.56	4.11	17.07	16.00
Scaled Score	9.23	7.76	9.00	9.00	15.62	14.50
Map Mission						
Raw Score	33.40	23.18	32.00	23.00	20.33	13.12
Scaled Score	9.00	7.35	10.00	7.00	17.31	13.13
Attentional Control/ Shift						
Creature Counting						
Raw Score	4.76	4.35	4.27	4.71	16.43	16.56
Scaled Score	8.00	4.88	10.00	5.00	18.85	11.88
Opposite World						
Raw Score	5.00	3.59	5.00	4.00	18.63	14.62
Scaled Score	8.23	7.31	9.00	7.50	17.50	11.90

Note. TD = typically developing participants; HFA= high functioning autism participants

Table 2.2: Descriptive information for the TD children (n = 22) and SPD children (n = 9) for each of the TEA-Ch subtests, for scaled score there are fewer participants due to age or if they were unable to complete task

TEA-Ch Subtests	Mean		Median		Mean Rank	
	TD	SPD	TD	SPD	TD	SPD
Sustained						
Score!						
Raw Score	8.43	5.44	8.00	5.00	11.00	6.56
Scaled Score	12.25	9.00	12.50	7.00	6.88	4.58
Code Transmission						
Raw Score	25.43	15.00	24.00	19.00	10.43	7.00
Scaled Score	7.14	4.17	8.00	3.50	6.88	4.58
Walk, Don't Walk						
Raw Score	7.86	5.33	9.00	6.00	10.07	7.28
Scaled Score	5.00	4.67	5.00	4.00	5.25	5.67
Score DT						
Raw Score	12.29	8.78	13.00	8.00	10.79	6.72
Scaled Score	11.50	7.50	13.00	6.50	7.38	4.25
Sky Search DT						
Raw Score	27.01	65.11	0.84	10.80	6.86	9.00
Scaled Score	9.00	2.17	9.00	1.00	8.00	3.83
Selective Attention						
Sky Search						
Raw Score	8.12	9.58	7.16	8.53	7.86	9.00
Scaled Score	9.00	8.83	9.00	8.00	6.25	5.00
Map Mission						
Raw Score	22.00	17.00	21.00	15.00	9.93	7.39
Scaled Score	8.00	8.33	9.00	8.50	6.75	4.67
Attentional Control/ Shift						
Creature Counting						
Raw Score	4.57	3.31	3.98	0.00	9.43	7.78
Scaled Score	9.75	2.83	10.00	2.00	8.38	3.58
Opposite World						
Raw Score	5.29	3.33	6.00	2.00	10.07	7.28
Scaled Score	11.00	7.67	10.00	8.00	6.88	4.58

Note. TD = typically developing participants; SPD= sensory processing difficulties participants

In children with SPD, subtests that measured attention control/shift, Mann-Whitney *U* tests did show significant differences between groups. The Creature Counting subtest provided scaled score between TD group and SPD group yielding values of z = -2.59 and *p* = .01. The selective attention subtest Sky Search scaled scores reached significance, *z* = -2.42, *p* = .015. For TEA-Ch subtests measuring selective attention and attentional control/shift, Mann-Whitney *U* tests yielded significant differences between SPD & TD groups, which supports hypothesis 1.2.

For hypothesis 1.3, Mann-Whitney *U* tests were used to confirm whether or not children with SPD had more difficulty than TD children when performing tasks that require sustained attention. While results did not yield significant differences, two subtests provided results that approached significance. Sustained attention subtest Score DT approached significance with scaled scores of *z* = -1.79, *p* = .073, and raw scores approached significance on Score resulted in *z* = -1.89, *p* = .059.

Grand Averages of the Brain Responses during the Orientation/Habituation Paradigm

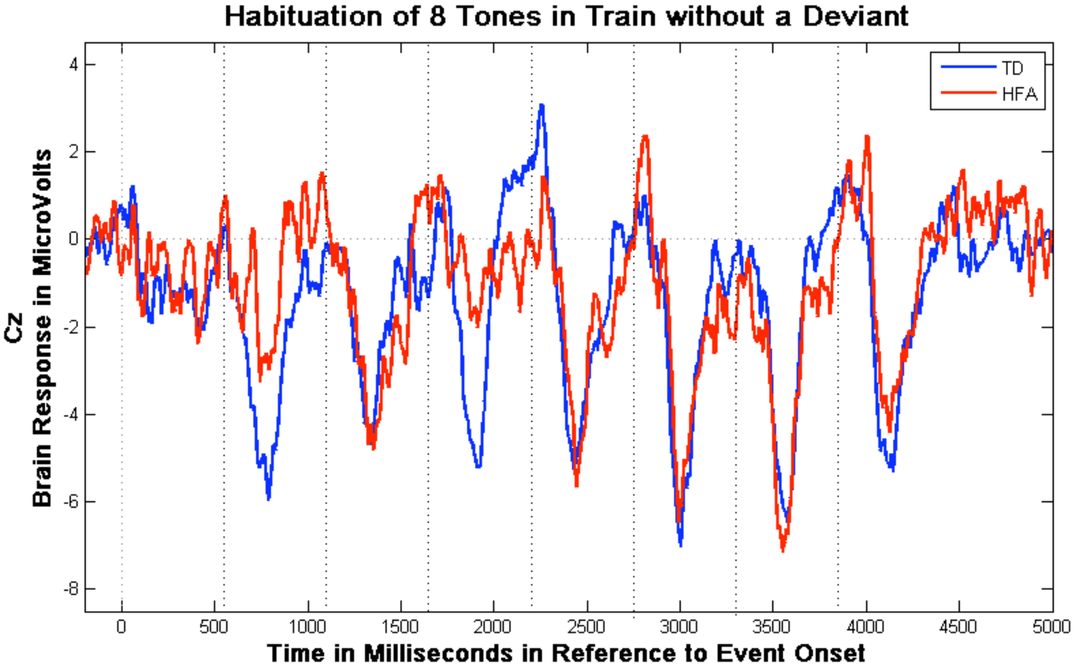
Prior to presenting the results of the ERP measures, we will present the ERPs in visual form and provide descriptive information. Figures 2.2 and 2.3 below display each of the 8 tones (represented by a black vertical line every 500 milliseconds apart), in the train without a deviant, the train with the deviant in the 4th position (represented by a solid red line), and the train with the deviant in the 5th position (also represented by a solid red line), respectively.

Figure 2.2 presents three ERP grand averages, one for each of the three trains used in this paradigm, between children with HFA (n = 15) and TD (n = 15) groups. In Figure 2.2 A, the train with eight standard tones, it is noticeable that the TD group has larger negativities following the second and fourth tone while children with HFA do not produce these mirroring responses (while the do seem to mirror each of the other negativities in this train in a similar manner). One explanation for the greater negativity following the second tone in the TD group but not in the HFA group could be that the TD group has cognitively registered that a train has started, while the children with HFA have a delay in this process until the third tone is presented. Interpretation of the large negativity of the TD group following the fourth tone could be the response that they were expecting a deviant to occur (despite the fact that this is the train without a deviant). This could represent hyporeactivity to auditory stimuli of children with the HFA group.

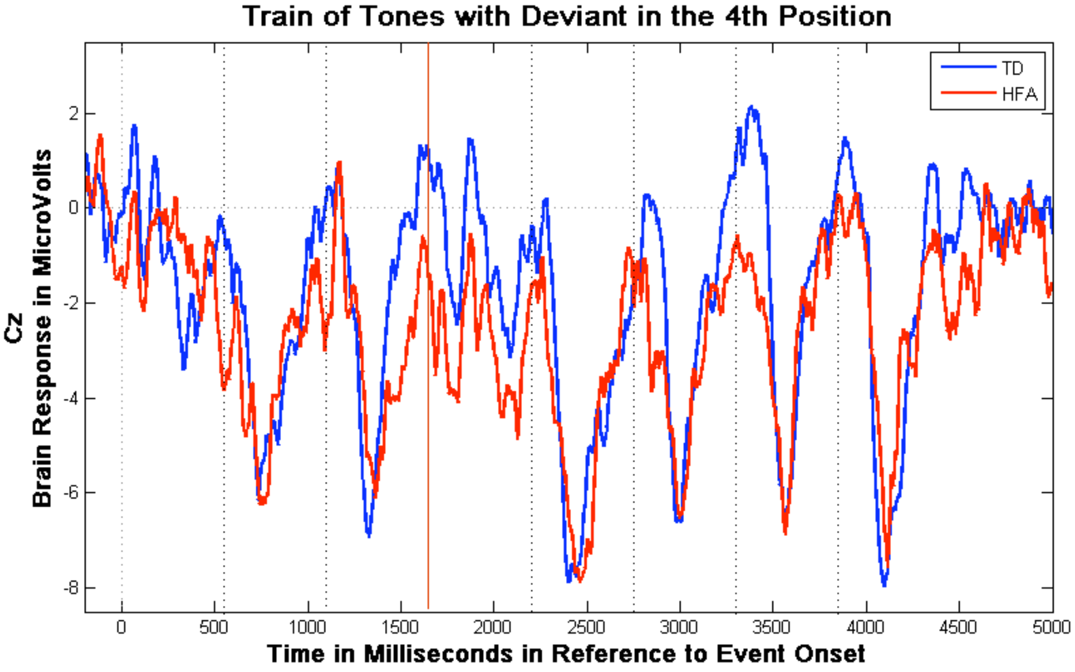
Figure 2.2 B represents the grand average of the train of tones with the deviant in the 4th position in children with HFA and TD groups. In this grand average it is depicted both groups begin to show similar responses after the second tone is presented. Both HFA and TD groups have comparable negativities in this train while the TD group consistently displays larger positive responses. From tone 5 through tone 8 both groups seem to follow a similar rhythm or pattern, with the HFA group producing smaller positive amplitudes compared to the TD group. This is consistent of the responses just following the deviant in the 4th position; the responses between groups are similar in regards to latency, but with smaller positive and larger negative amplitudes between the HFA group.

Figure 2.2 C represents the grand average of the train of tones with the deviant in the 5th position in children with HFA and TD groups. In these grand average children with HFA display somewhat more difficulty maintaining a pattern similar to the TD group, with more variability in the responses of the HFA group. For example, during the first half of the train the TD group shows similar responses to tone 2 and tone 3, yet the HFA group has more noise and variability. This noise and variability is seen in the HFA group also from tone 6 through the end of the train. After the deviant is presented, both groups display smaller positive and negative amplitudes until the next standard tone is presented in the 6th position, the TD group displayed a greater negativities and it isn't until the 8th tone is presented that the HFA group displays a similar increased negative amplitude. This grand average can also imply hyporesponsitivity of auditory stimuli of the HFA group.

A


Habituation of 8 Tones in Train without a Deviant
TD
HFA
Cz
Brain Response in MicroVolts
4
2
0
-2
-4
-6
-8
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Time in Milliseconds in Reference to Event Onset

B


Train of Tones with Deviant in the 4th Position
TD
HFA
Cz
Brain Response in MicroVolts
2
0
-2
-4
-6
-8
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Time in Milliseconds in Reference to Event Onset

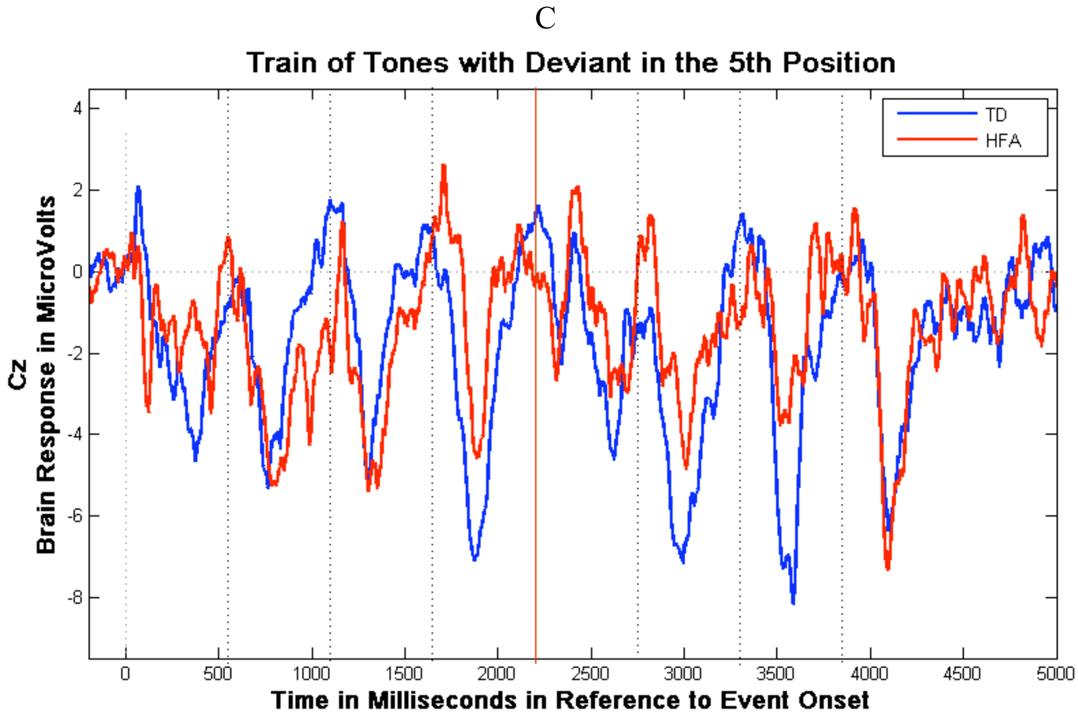
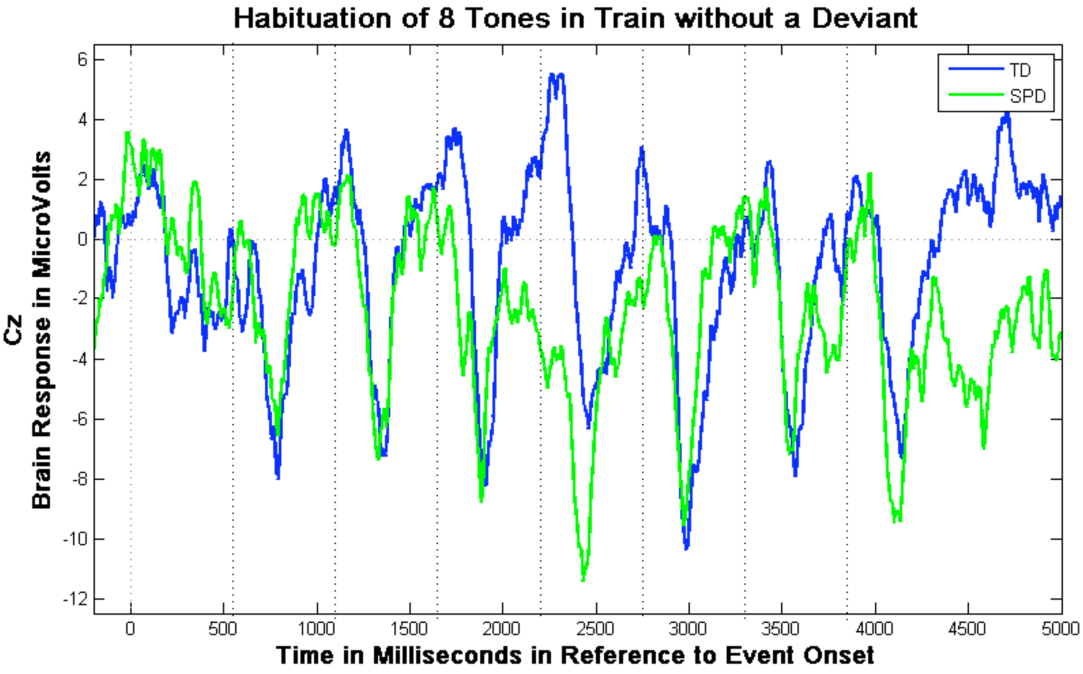


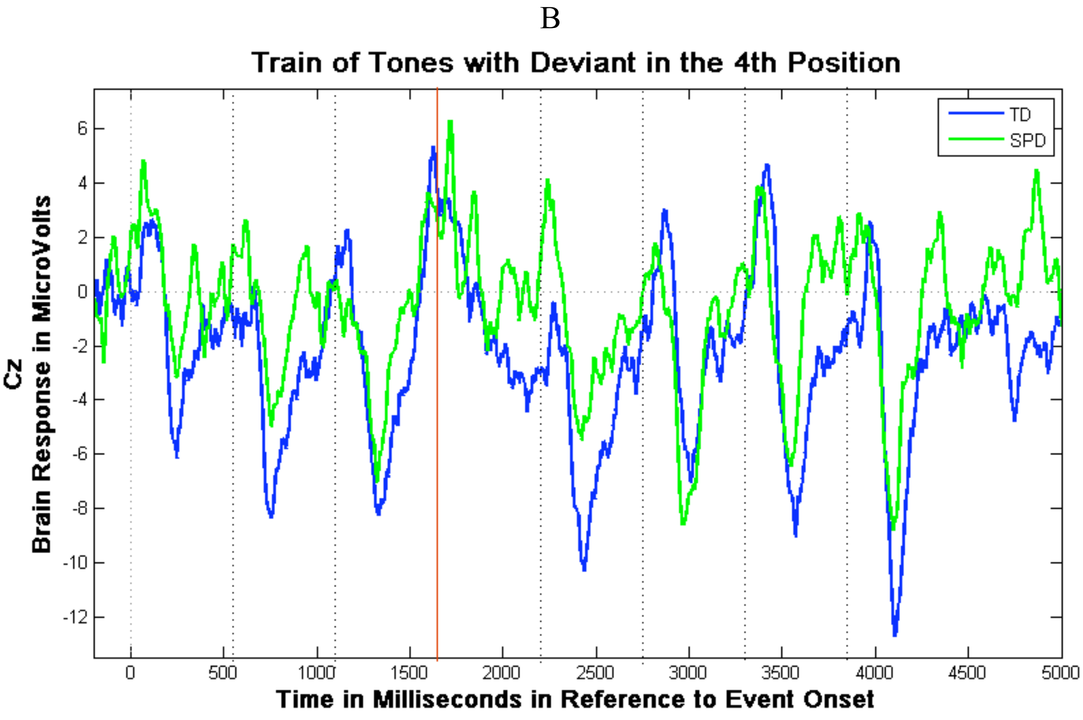
Figure 2.2: Grand Averages of children with HFA (n=15) and TD (n=15) of the Orientation/Habituation ERP paradigm, graph A depicts the train without a deviant, graph B depicts the train with a deviant in the 4th position, and graph C depicts the train with the deviant in the 5th position. Vertical dashed lines represent presentation of a standard tone and vertical red line represents presentation of a deviant tone.

Figure 2.3 depicts three ERP grand averages, one for each of the three trains used in this paradigm, between children with SPD (n = 7) and TD (n = 7) groups. With a smaller sample size in these grand averages, the amplitudes are accordingly larger (when you have a large sample size they average out and become smaller) this is evident in the Microvolt's scale on the y-axis when compared to the grand averages presented in Figure 2.2 where the number of participants was twice as large. Due to the small sample size of these grand averages they should be interpreted with some caution and fewer interpretations will be provided.

For all three of the grand averages comparing SPD and TD groups, for the most part the TD group is able to produce a somewhat consistent pattern when responding to standard tones, especially in the train without a deviant. The SPD group in comparison does not follow this pattern with the same consistency. Instead, there is more variability in brain response of the SPD group, especially in the trains with the deviant tones the children with SPD have much larger positive amplitudes in comparison to the TD group. Another noticeable difference between SPD and TD groups is presented at the end of the trains of tones. In the train without a deviant, the SPD group has more negative responses, and in the trains with the deviants, the SPD group has more positive responses, because the TD responses are nearer to baseline in all three trains, this could suggests that the SPD group is still cognitively processing the tones even after the train has ended while the TD group amplitudes are more closer to baseline. Last, in the train without a deviant in the middle of the train following the 4th tone, the TD and SPD responses are opposite; the TD group has a large positivity while the SPD group displayed a larger negativity and more latency. This could suggest that the SPD group is processing the middle of the train (similar to the TD group in figure 2.2 A) while the TD group is not. Children in the SPD group may be more hyperreactive to the tones presented in this paradigm.

A





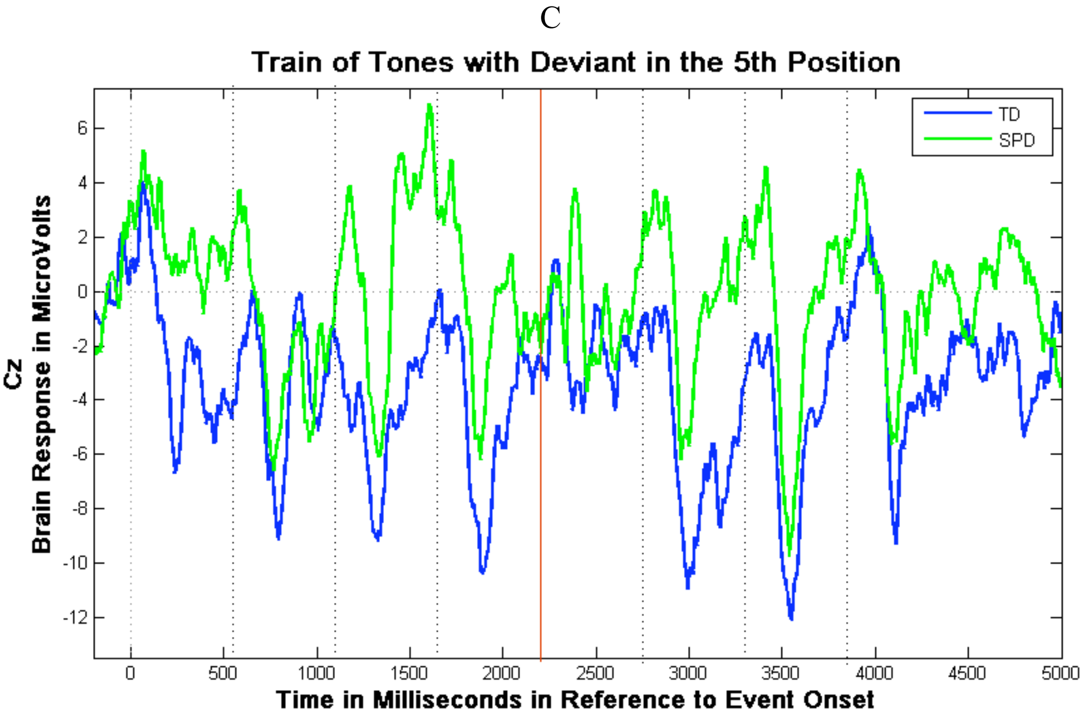


Figure 2.3: Grand Averages of children with SPD (n=7) and TD (n=7) of the Orientation/ Habituation ERP paradigm, graph A depicts the train without a deviant, graph B depicts the train with a deviant in the 4th position, and graph C depicts the train with the deviant in the 5th position. Vertical dashed lines represent presentation of a standard tone and vertical red line represents presentation of a deviant tone.

Question 2: Sensory Gating and Habituation Performance

To address hypotheses 2.1 and 2.2, two way ANOVAs were performed to determine whether sensory gating ability was present among groups. To review, sensory gating was measured by a significant reduction of N1 and N2 amplitudes from tone 1 to tone 2. The more negative amplitude of N1 or N2 is equivalent to a larger brain response while a smaller negativity would be a smaller brain response. Results are displayed in Figure 2.4. For HFA and TD groups, the ANOVA showed that there are no significant N1 amplitude differences regardless of group or tone. For the HFA and TD groups, the N2 amplitude was significantly larger for tone 1 (M = -9.19, SD = 3.7) compared to tone 2 (M = -5.73, SD = 3.43), F (1,33) = 25.46, $p < .0005$ regardless of the group.

Similar to the HFA and TD groups, for SPD and TD groups the ANOVA also showed that the difference of N1 amplitudes are not significant, regardless of group or tone. While not significantly different, the children with SPD produced larger N1 amplitudes to the second tone, this resulted in an interaction between groups that could suggest that children with SPD have some difficulty with sensory gating. For SPD and TD group differences between tone and group also did not reach significance at N2 amplitude.

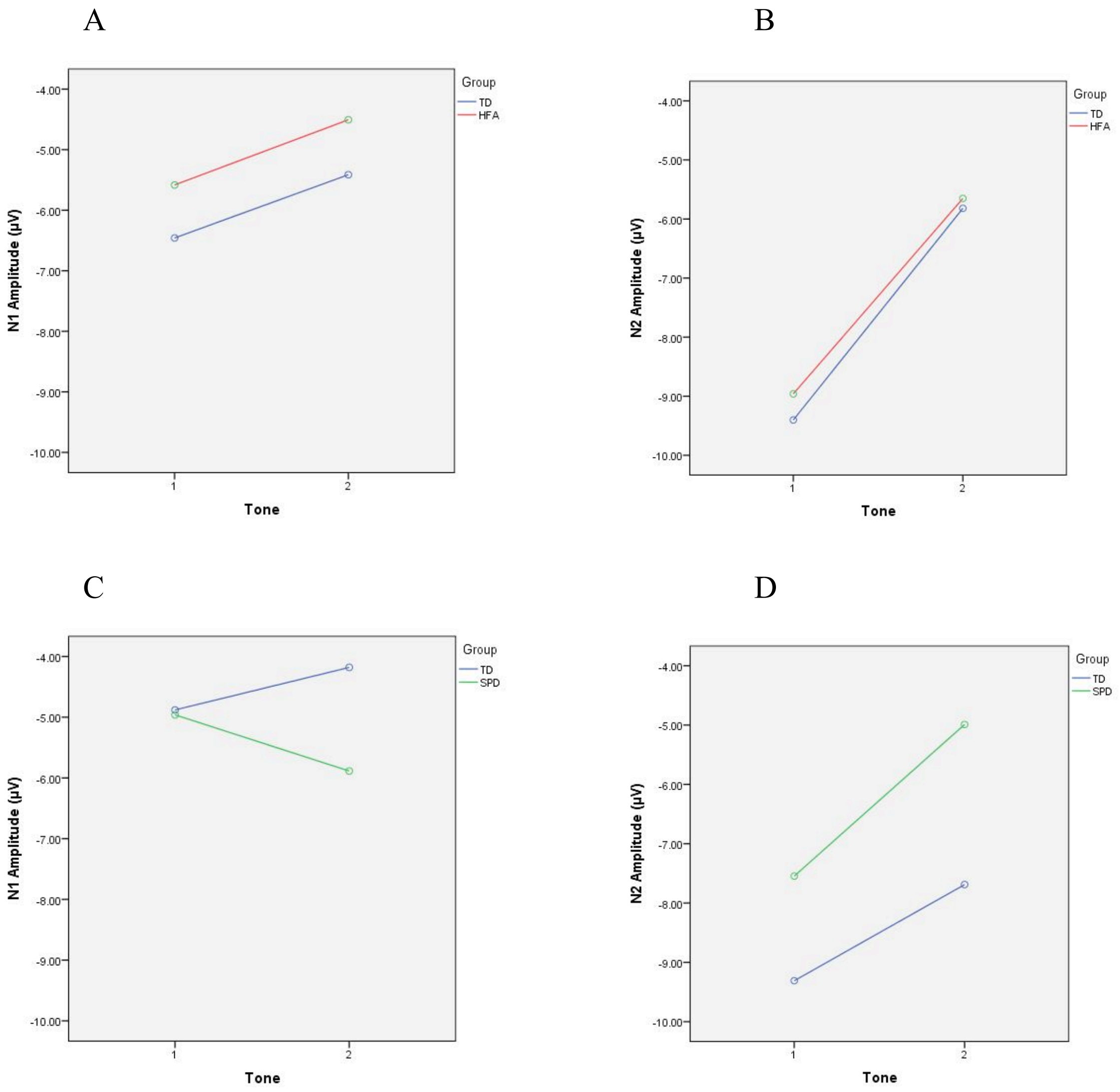


Figure 2.4: Gating of N1 (A and C) and N2 (C and D) amplitude responses from tone 1 to tone 2 in trains without a deviant. A and B compare TD and HFA groups and C and D compare TD and SPD groups. Sensory gating is not displayed for SPD group at N1 amplitude response (graph C).

Hypotheses 2.3 and 2.4 assess habituation from tone 2 to tone 8 also required repeated ANOVAs for analysis see Figure 2.5 for illustration of these habituation effects. Children with HFA and age matched TD peers showed no significant differences between tone 2 and tone 8 at N1. However, the N2 amplitude was significantly larger for tone 8 (M = -8.81, SD = 4.19) compared to tone 2 (M = -5.8, SD = 3.41), F (1,33) = 15.35, $p < .0005$ regardless of the group. While there was not a significant interaction between groups, follow up Post Hoc analysis revealed significance between tone 2 and tone 8 in the HFA group, *t* (1,33) = -8.02, *p* = < .01, and the TD group, *t* (1,33) = -3.42, *p* = < .05.

When comparing SPD and TD groups, the TD group N1 amplitudes at tone 8 (M = -7.34, SD = 4.33) is significantly larger than the N1 amplitude at tone 2 (M = -4.18, SD = 4.30), *F* (1,6) = 67.83, *p* < .0005. The SPD group had no significant difference between N1 amplitudes at tone 2 and tone 8. The interaction between tone and group is significant for N1 amplitude *F* (1,14) = 8.54, *p* = .011. The TD group follow up Post Hoc analysis resulted in a significant difference between tone 2 (M =-4.18, SD = 4.3) and tone 8 (M = -7.34, SD = 4.32), *t* (1,14) = -4.05, *p* = < .05. The SPD group follow up Post Hoc analysis resulted in a significant difference between tone 2 (M = -6.39, SD = 3.16) and tone 8 (M = -3.47, SD = 3.0), *t* (1,14) = 4.24, *p* = < .01.

SPD and TD group N2 amplitude of tone 8 (M = -9.71, SD = 4.58) is significantly larger than the N2 amplitude at tone 2 (M = -6.01, SD = 3.75), *F* (1,14) = 10.75, *p* = .005 regardless of the group. The interaction between tone and group analysis significant effect for the SPD and TD groups at N2, *F* (1,14) = 8.28, *p* = .012. The TD group follow up Post Hoc analysis did not demonstrate a significant difference between tone 2 (M = -7.69, SD = 3.8) and tone 8 (M = -8.1, SD = 5.67), *t* (1,14) = -0.54. The SPD group follow up Post Hoc analysis resulted in a significant difference between tone 2 (M = -4.71, SD = 3.34) and tone 8 (M = -10.96, SD = 3.34), *t* (1,14) = -8.22, *p* = < .01.

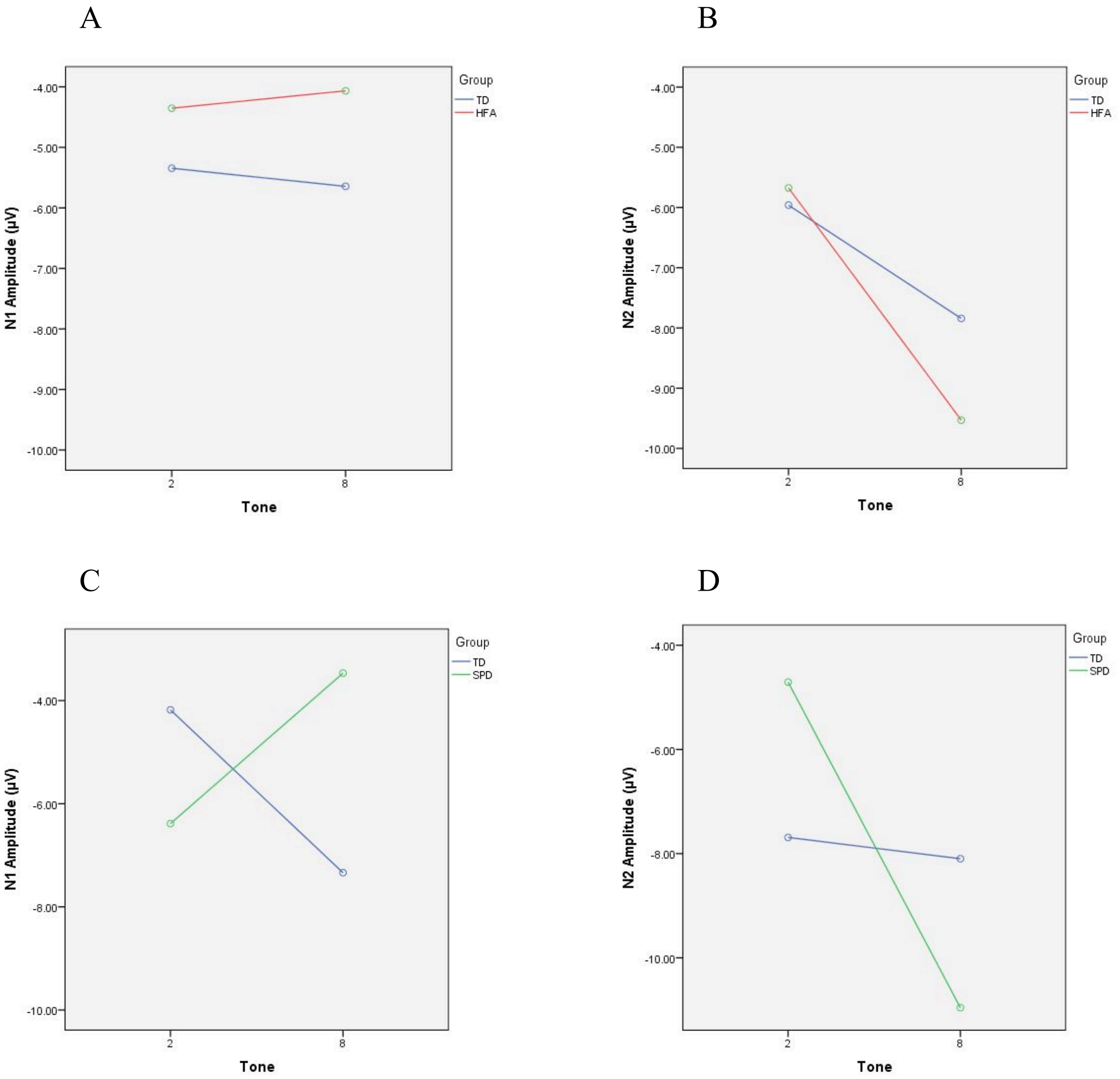


Figure 2.5: Habituation of N1 (A and C) and N2 (B and D) from tone 2 to tone 8. The comparison between TD and HFA are displayed in A and B and the comparison between TD and SPD are shown in C and D.

Question 3: Response to Novel and Deviant Stimuli

Hypothesis 3.1 assessed tone 1 in the train without a deviant and compared N1 and N2 amplitude responses among TD children and children with HFA. Likewise, hypothesis 3.2 assessed similar factors among TD children and children with SPD. The results of these analyses (Mann-Whitney *U* test for TD and HFA and *t*-test for TD and SPD groups) showed no significant difference between groups for tone 1 in a train with no deviant for either N1 or N2 amplitudes. Further, although not significant, it is worth noting that the mean ranks for the children with HFA were larger than the mean ranks for the control group, which it the opposite of what was hypothesized. These results suggest that all participants responded to tone 1 with similar amplitudes at N1 and N2.

Hypotheses 3.3 and 3.4 evaluated the response to the deviant tones in comparison to the prior standard tone in the second (deviant tone in the 4th position) and third (deviant tone in the 5th position) trains of tones. An ANOVA compared the amplitude of the deviant tone to the amplitude of the tone presented prior to the deviant, for both N1 and N2 in the train with the deviant in the 5th position for the HFA and TD groups. See table 2.3 for comparison of this descriptive information for children with HFA and TD groups. This comparison revealed there was not a significant main effect between HFA and TD groups. However, there was a significant main effect for tone, $F\ (1, 31) = 15.65$, $p < .0005$ for N1 amplitudes. This demonstrates a larger brain response to the deviant tone when compared to the standard tone presented prior to the deviant. However, this significance was not demonstrated to the deviant tone in the 4th position. As illustrated in Figure 2.4 there is a greater difference between the amplitude of the tone prior to the deviant and the deviant tone when the deviant was in the 5th position (Figure 2.6, A) compared to when the deviant was in the 4th position (Figure 2.6, B).

For N2 amplitude, an ANOVA was used to compare the tone prior to the deviant with the deviant in the 5th position (Figure 2.6, C) and there were no significant differences. Of interest, while not significant, the children with HFA actually displayed smaller amplitudes to the deviant tone than to the standard tone presented just prior to the deviant. The direction of this change is opposite of that which we hypothesized and resulted in a non-significant interaction between the groups. There were no significant differences for tone or between groups for N2 amplitude.

Table 2.3: Descriptive information for the TD children (n = 14) and HFA children (n = 20) for the ERP comparison of brain response to deviant tone when compared to prior standard tone. Number of participants varied whether or not all of their ERP components could be scored.

Component Amplitude	Mean		Standard Deviation	
	TD	HFA	TD	HFA
Peak-to-peak N1				
Tone 43	-6.83	-5.48	2.95	4.23
Tone 44	-7.76	-6.13	3.45	2.82
Tone 54	-4.51	-4.04	2.04	3.04
Tone 55	-7.45	-7.11	3.51	3.83
Peak-to-peak N2				
Tone 43	-6.50	-6.43	2.92	3.56
Tone 44	-6.44	-6.26	3.34	3.84
Tone 54	-6.61	-7.51	2.21	3.82
Tone 55	-6.78	-6.41	3.67	2.18

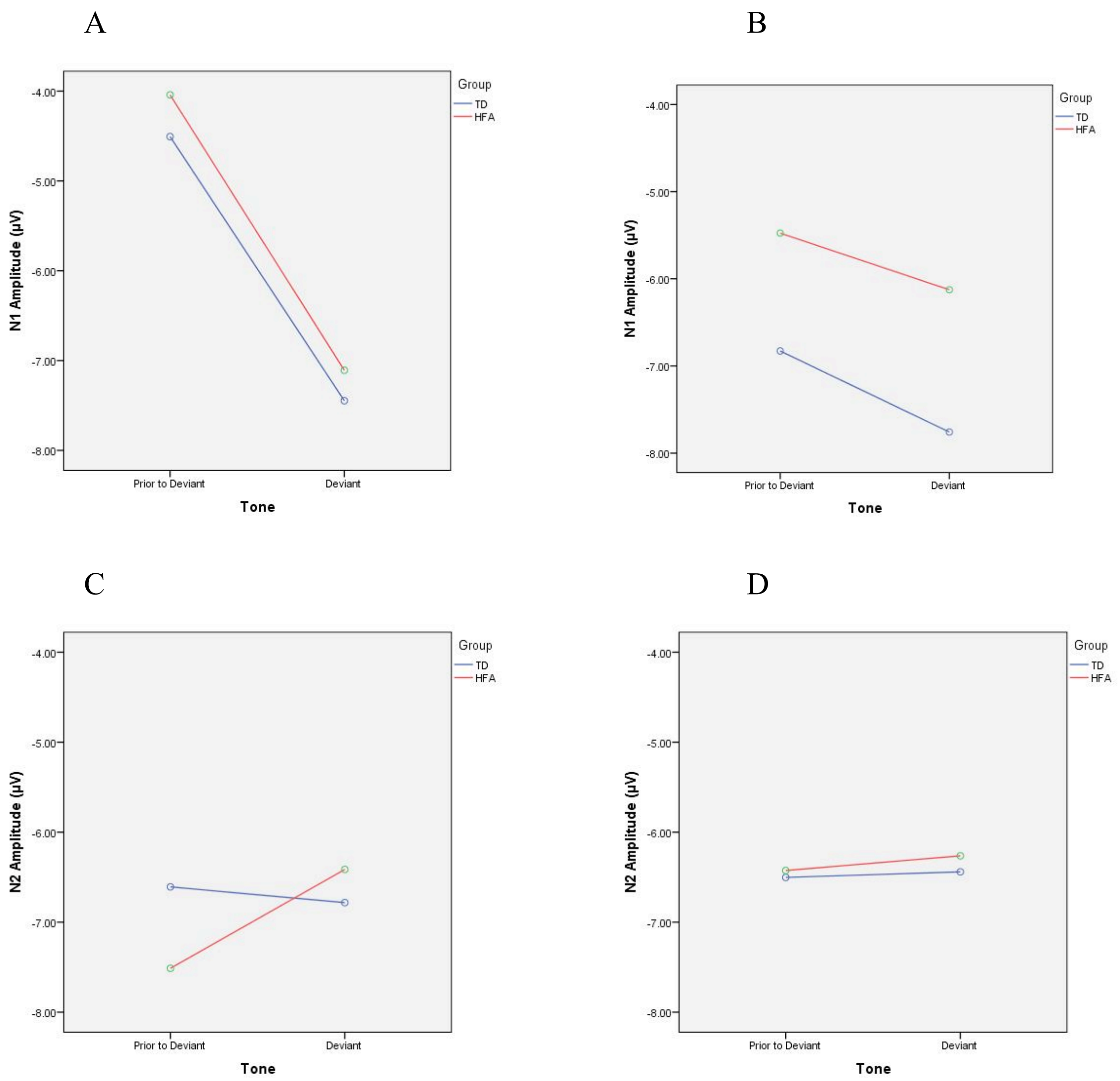


Figure 2.6: Changes in amplitude response of standard and deviant tones in the 5th position (A and C) and in the 4th position (B and D), between HFA and TD groups.

Hypothesis 3.4 investigated the differences the amplitudes to the tone prior to the deviant and the deviant for both SPD and TD groups for both N1 and N2 (see table 2.4 for descriptive information). Similar to the above comparison for the HFA and TD groups, N1 amplitudes were significantly different to the deviant tone in the 5th position than to the standard tone presented prior to the deviant *F* (1,10) = 12.06, *p* = .006 (see Figure 2.7, A). The TD group follow up Post Hoc analysis resulted in a significant difference between tone 4 (M =-3.75, SD = 1.55) and tone 5 (M = -9.82, SD = 4.85), *t* (1,10) = -5.95, *p* = < .01. The SPD group follow up Post Hoc analysis resulted in a significant difference between tone 4 (M =-3.31, SD = 1.7) and tone 5 (M = -6.57, SD = 3.5), *t* (1,10) = -3.76, *p* = < .05.

In addition, a significant difference was also found between the deviant tone in the 4th position compared to the standard tone presented prior to the deviant for N1 amplitude, *F* (1,10) = 12.71, *p* = .005 (Figure 2.7, B). For N2 amplitudes in the train with the deviant in the 5th position there was a significant difference between the two tones, *F* (1,13) = 11.35, *p* = .005. However, opposite from the hypothesis, here both groups actually display reduced responses to the deviant compared to the prior tone, similar to HFA group presented above.

There was a significant interaction between tone and group for amplitudes N2 when the deviant was in the 4th position, *F* (1,10) = 7.76, *p* = .019 (See Figure 2.7, D), where there is an interaction in amplitudes to the deviant tone and prior standard tone for each group. The TD group follow up Post Hoc analysis resulted in a significant difference between tone 3 (M = -9.85, SD = 2.96) and tone 4 (M = -7.27, SD = 3.9), *t* (1,10) = 3.36, *p* = < .05. The SPD group follow up Post Hoc analysis resulted in a significant difference between tone 3 (M = -5.42, SD = 2.11) and tone 4 (M = -8.45, SD = 2.85), *t* (1,10) = -4.67, *p* = < .01. As expected the Children with SPD respond with greater N2 amplitudes to the deviant tone when compared to the standard tone presented previously, while the control group responded with reduced amplitude, or smaller amplitude to the deviant tone compared to that of the prior standard tone.

Table 2.4: Descriptive information for the TD children (n = 6) and SPD children (n = 9) for the ERP comparison of brain response to deviant tone when compared to prior standard tone. Number of participants varied whether or not all of their ERP components could be scored.

Component Amplitude	Mean		Standard Deviation	
	TD	HFA	TD	HFA
Peak-to-peak N1				
Tone 43	-2.99	-4.14	1.74	2.08
Tone 44	-5.16	-7.80	4.27	2.38
Tone 54	-3.75	-3.31	1.55	1.71
Tone 55	-9.82	-6.57	4.85	3.50
Peak-to-peak N2				
Tone 43	-9.85	-5.42	2.96	2.11
Tone 44	-7.27	-8.45	3.90	2.85
Tone 54	-9.66	-8.62	3.73	3.52
Tone 55	-6.50	-6.04	4.47	2.94

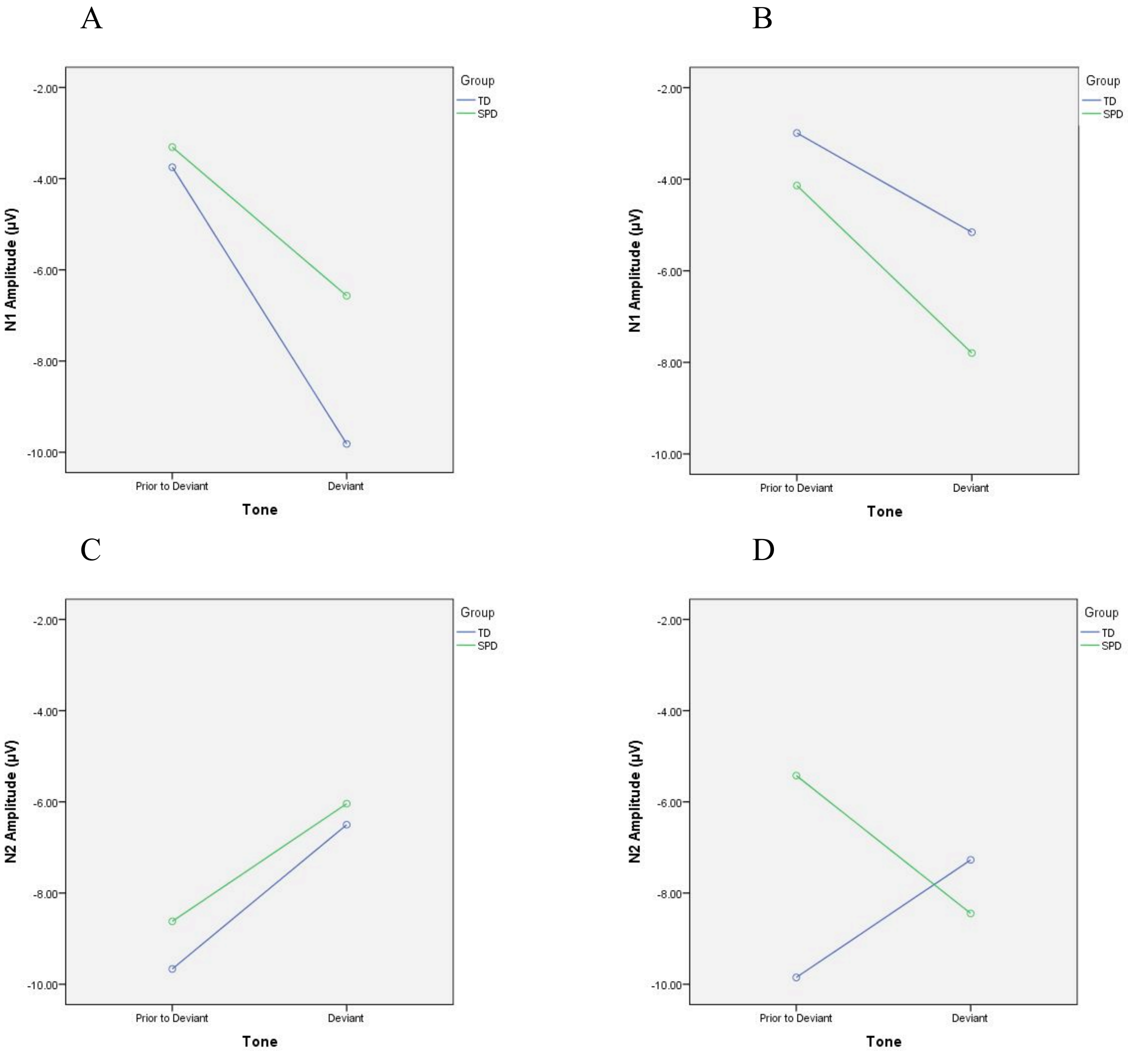


Figure 2.7: Changes in amplitude response of standard and deviant tones in the 5th position (A and C) and in the 4th position (B and D), between SPD and TD groups.

Question 4: Relationships between ERP Measures of Attention and Behavioral Measures

As mentioned previously in the statistical analysis section, exploration analyses of a larger model of attention predicting of N1 and N2 measures were conducted. Results of a Hierarchical Regression analysis for children in the TD group did not suggest a significant relationship between N1 amplitude and the subtypes of attention. Continuing to assess possible brain and behavior relationships of the TD group, the Hierarchical Regression analysis for hypothesis 4.4, a significant relationship between N2 amplitude and the attention control/shift

Creature Counting measure was identified. The attention control/shift measure, Creature Counting, was a significant predictor and accounted for about 39% of the variance of the N2 amplitude at tone 1 (see table 2.5). In this model, performance on Opposite Worlds was not a significant predictor of N2 amplitude. No other relationships were predicted between TD attention subtypes and ERP N1 or N2 components.

Table 2.5: Results of the Hierarchical Regression for TD children for the N2 at Cz of the first tone for the series of tones without a deviant.

TEA-Ch subtest	Coefficients			Model Summary			
	t	*p*	β	*F*	*df*	*p*	Adj. R^2
Attention Control/Shift							
Overall model				5.168	2, 13	.026	.391
Creature Counting	2.903	.014	.712				
Opposite Worlds	-.145	.888	-.035				

For children with HFA (hypothesis 4.2) Hierarchical Regression analysis confirmed a relationship between attention control/shift subtest scores of the TEA-Ch and N1 amplitudes of tone 1. Specifically the attentional control/shift subtest Opposite Worlds accounted for approximately 38% of the variance of the N1 amplitude at tone 1 in the train without a devaint. Review Table 2.6 for these regression results. For children with HFA, no other significant relationships were indicated between attention subtypes and ERP N1 or N2 components.

Table 2.6: Results of the Hierarchical Regression for HFA children for the N1 at Cz of the first tone for the series of tones without a deviant.

TEA-Ch subtest	Coefficients			Model Summary			
	t	*p*	β	*F*	*df*	*p*	Adj. R^2
Attention Control/Shift							
Overall model				5.199	2, 14	.024	.375
Creature Counting	.951	.360	.212				
Opposite Worlds	3.223	.007	.719				

Children with SPD, the Hierarchical Regression revealed significant relationships between the selective attention measures and the N1 amplitudes. The model was significant in predicting N1 using the selective attention subtest scores of the TEA-Ch (see table 2.7). Specifically, the Sky Search subtest was the significant predictor accounting for about 77% of the variance of N1 amplitude at tone 1 in the train without a deviant.

Table 2.7: Results of the Hierarchical Regression for SPD children for the N1 at Cz of the first tone for the series of tones without a deviant.

TEA-Ch subtest	Coefficients			Model Summary			
	t	*p*	β	*F*	*df*	*p*	Adj. R^2
Selective Attention							
Overall model				12.757	2, 7	.011	.771
Sky Search	-5.046	.004	-.988				
Map Mission	-2.144	.085	-.420				

Discussion

Using the orientation/habituation paradigm of electroencephalography technology, this study extends prior literature regarding the neuronal brain processes of auditory stimuli in children with HFA or SPD and age matched TD peers. Correlating these neurological underpinnings with behavioral measures of attention using the Test of Everyday Attention for Children (TEA-Ch) allows us to understand the impact that neuronal processing has on performance on different subtypes of attention. The orientation/habituation paradigm allowed for analysis of brain responses of sensory gating and habituation, as well as brain responses to novel and deviant tones, while the TEA-Ch provided a basis for measuring performance on the different subtypes of attention. The purpose of this study was to first build a solid understanding of these measures separately and once this was established to bring the information together to understand relationship and interactions between the auditory neural responses and the behavioral patterns of attention. The knowledge obtained in this study may be used by therapists to inform their clinical reasoning by guiding the selection of a therapeutic approach, or in applying the just right challenge and to better target therapeutic outcomes they aspire for their clients with HFA and SPD who have challenges in attention related to interpretation of incoming auditory stimuli.

Behavioral Measures

This study evaluated three subtypes of attention that were originally described by Posner and Petersen (1990) and later by Manley et al. (2001). To review, attentional control/shift is defined as a change or shift in attention to a particular stimulus. Selective attention is the selection of a particular stimulus and inhibition of an irrelevant stimulus. Sustained attention is the ability to sustain vigilance and performance of a task over time (Posner & Petersen, 1990; Manley et al., 2001).

It is interesting that with regards to sustained attention, children with HFA demonstrated unexpected significant behavioral performance differences from that of the control group. Accordingly, our present study yielded contrary results presented by Johnson et al. (2007), upon which hypothesis 1.1 was based. To review, the Johnson et al. (2007) assessed 21 children with HFA and 18 controls on the Sustained Attention to Response Task (SART) that provided similar performances in the task among groups. A closer look at the SART task itself may provide some insights. In the SART children were required to withhold responses to an infrequent target and to respond to all other stimuli. The authors Johnson et al. (2007) use and describe the SART task as a measure of sustained attention. Walk, Don't Walk, a subtest of the TEA-Ch that measures sustained attention was adapted the SART task (Manly et al., 2001). The Walk, Don't Walk task requires participants to mark on a path to a go tone and inhibit a mark on the no-go tone. Yet in our study, children had significant differences in raw and scaled scores of the Walk, Don't Walk subtest, suggesting difficulties with this sustained attention ability in children with HFA, which is opposite to what was found in the Johnson, et al. (2007) study.

Further justification that children with HFA have difficulties with sustained attention was also supported by their performances on the subtests including Code Transmission and Score DT in our study. In Code Transmission, for example, children are asked to listen to a sequence of verbally presented numbers. For this task, the child listens for two number fives in a row and then reports the number that came just before the two number fives. This task lasts about twelve minutes total, which proved to be highly difficult for children with HFA. In the Score DT task, the child counts the number of scoring sounds on an audio news clip while simultaneously listening for an animal name to be mentioned in a simulated news story. This is one of the most complex sustained attention tasks on the TEA-Ch because the child is requested to provide two answers, the number of scoring sounds in addition to the animal name at the end of each of 10 trials. For children with HFA, performance on this subtest also yielded significant findings indicating that TD children perform significantly better on this task than children with HFA. With this evidence, it is understood that Score DT and Code Transmission were significantly more difficult for children with HFA when compared to age matched controls. Not surprisingly, for children with SPD, performance on these two exact subtests, Score DT and Code Transmission, were the only two subtests that approached significant differences when compared to children in the TD group. With a larger SPD and TD aged-match sample size, it is likely that significance in these sustained attention measures could be reached as well.

In Grandin and Panek's (2013) book, The autistic brain: Thinking across the spectrum, Grandin mentions the strengths of some individuals with autism spectrum disorders (ASD) in their highly developed abilities to pay close attention to detail. Grandin, an adult with HFA, describes herself as seeing the world in smaller details before she is able to make sense of the bigger picture. She also writes that some children with ASD display greater performances than neurotypically developing children on embedded-figure tasks (Grandin & Panek, 2013) such as Where's Waldo, a popular children's book that provides page after page of challenges in finding the main character Waldo hidden within a highly visually distracting scene. In thinking about why children with HFA in the present study performed similarly to children in the TD group, rethinking the subtests themselves can provide insight.

The only sustained attention subtest of the TEA-Ch that did not show significant differences between the HFA group and the TD group was the Sky Search DT subtest. This is a complex dual task subtest since it requires participants to attend to two different tasks simultaneously. First the participants must visually scan and find matching spaceships on a sheet (a modified embedded-figure task) while at the same time count the number of scoring sounds on an audio clip. Since this subtest of sustained attention required them to use visual skills of finding matching space ships, a skill that Grandin & Panek (2013) describe as being particularly easy for some children with ASD, helps justify how some children with HFA would perform similarly to the control group for this subtest.

The subtest of the TEA-Ch that is most similar to an embedded-figure task is the Map Mission subtest. In this task participants were asked to circle as many small symbols that match the displayed target that they could find within one minute on a visually distracting map. Raw scores between HFA and TD groups provided significant differences, with HFA participants having more difficulty with the task. An examination of the variance of performance on this subtest revealed SD = 14.787 for children with HFA while the control group had a SD = 9.504.

With a higher standard deviation among children with HFA this can suggest that performance on this task is more variable for this group. This makes sense that some children in this group did better or comparable to the TD group, supporting Grandin & Panek's (2013) observations of high levels of visual spatial skills in some, not all, children with ASD.

As hypothesized, TEA-Ch tasks that required participants to activate attentional control/shift performances, Creature Counting and Opposite Worlds, also provided significant differences between children with HFA and TD groups. When thinking back to the core diagnostic criteria for children with HFA, deficits in communication such as social-emotional reciprocity are a key factor because similarly, this requires attentional control/shifting among social partners in order to create a functional and meaningful response. In this way, it makes sense that children with HFA would have more difficulty with attentional control/shift performance measures.

Bundy & Murray (2002) described behavioral manifestations of SPD as distractible with increased activity. For children with SPD, our results also showed significant differences on Creature Counting, a task requiring attentional control/shift performance. Selective attention subtest Sky Search, also resulted in significant difficulty for SPD group when compared to age matched peers. The measures of central tendency on these tasks suggest that the children with SPD do not perform at the level of the children in the TD group, and since behavioral manifestations include being distractible with increased activity, it is understood that children with SPD have more difficulty than the TD group on tasks that require the attentional control/shift and selective attention performance.

Selective attention measures did not provide significant differences between SPD and TD groups. Behavioral characteristics of children with SPD can include difficulties modulating attention that can present as hyper or hyporeactive to sensory input. Hyperactivity to sensory input could entail reacting to specific non-relevant sounds, like the sound of a radiator for example, while hyporeactivity to sensory input could be not responding to the sound of his or her name being called. There are qualifying behaviors of children SPD conditions that may interfere with selective attention, it was thought at the onset of the study that there would be a significant difference in performance on these tasks between the SPD group and the children in the control group. The behavioral measures did not demonstrate that performance on these tasks were different between the groups. However, a unique aspect of this study was to include measure of neuronal processing of auditory stimuli along with behavioral measures. The results of the neurological data discussed next will help in understanding the neurological processes better, specifically the data that assesses responses to deviant tones. Future research is needed and encouraged to better understand selective attention among these groups and the relationship between performance on tasks that require selective attention and behavioral manifestations of over- and under-responsivity to sensory stimuli in the environment for children with HFA and SPD.

Sensory Gating Performance

In our study we analyzed sensory gating abilities by the decrease of N1 or N2 amplitude response from sequential tone 1 and tone 2 at the Cz location in the series of tones without a deviant. Our findings demonstrated, that for both children with HFA and TD displayed sensory gating abilities for the N2 amplitude. The amplitude of N1 also decreased from tone 1 to tone 2 for children with HFA, however the decrease was not significant. Our results, as expected support the findings of sensory gating among children with HFA and TD groups found within the literature (Kemner, Oranje, Verbaten, & Engeland, 2002; Orekhova et al., 2008; Oranje, Lahuis, Engeland, Gaag, & Kemner, 2013). Prior literature also states that in children, N2 amplitudes are the most distinguishable ERP component (Ceponiene et al., 2002). Our sensory gating results provide clear support of this statement with more defined decrease in amplitude between tone 1 and tone 2 for N2. Results for children with SPD should be interpreted with caution due to a small sample size, however, our results did not show a significant reduction in amplitude between tone 1 and tone 2 for N1 or N2 for the group of children with SPD or their age-matched peers.

Children with SPD showed inconsistent results in sensory gating abilities and interpretation of these results require several considerations. While not significant, N1 amplitudes from tone 1 to tone 2 increased in the SPD group, which suggests auditory sensory gating might be difficult for children with SPD. This increase in N1 amplitude from tone 1 to tone 2 in the SPD group resulted in an interaction between responses with the age-matched peers. Significance of this interaction might be achieved with a larger sample size of SPD and age-matched peers. For the N2 amplitudes, children with SPD surprisingly displayed a similar decrease in sensory gating abilities to that of the control group, however this decrease was not significant for either group. It is also important to note that N2 is known to respond with greater amplitudes in children (less maturation of neurological processes have developed). The children within the SPD group and the age-matched TD peers in our study were younger than the comparison of the HFA and TD groups (SPD mean age 6.57 ± 1.26 years; HFA mean age 8.94 ±2.03), yet neither the age-matched TD group for the children with SPD and the SPD group showed significant gating. Further, it has also been reported that sensory gating improves with age Orekhova et al. (2008). At this time, our mixed results can be interpreted by suggesting that children with SPD have more difficulty with sensory gating abilities when compared to age matched peers, who displayed gating at both N1 and N2 amplitudes. To further justify this interpretation, sensory gating has been previously analyzed among children with SPD and TD controls. Results of Davies et al. (2009) publication documented that children with SPD had more difficulty with sensory gating abilities of auditory stimuli when compared to TD children. This study had a sample size of 28 children with SPD yielding more powerful results than that of our current study. Yet Davies et al. (2009) primarily analyzed the N1 amplitudes and did not report gating among N2 amplitudes. It would be interesting if these researchers could revisit these data to assess sensory gating abilities of N2 components among children with SPD to provide more power to this research area.

Habituation Performance

Habituation relates to automatic processing and within the ERP waveform can begin as early as 100 milliseconds after the presentation of a stimulus (N1), and thereafter in which the brain responses or amplitudes become smaller with each subsequent presentation (Rosburg et al., 2006). While this is what we would expect habituation to look like according to neuronal activity within the brain, it has been described in reference to attention as a person ability to attend to one stimulus and at the same time inhibit a response or attention to any other stimuli occurring within the person's environment. Likewise, habituation has also been described as response to a single stimulus, for example when a person first puts a shirt on in the morning and after a few seconds or minutes the person does not feel the shirt on at all.

Habituation as measured by neuronal responses in this study was measured by a decrease in N1 and N2 amplitudes from tone 2 to tone 8 in the series of tones without a deviant. Results of repeated ANOVAs provide some interesting yet understandable significant main effects and interactions. Habituation performance between children with HFA and age-matched peers showed both groups had a lack of habituation for N1, the amplitudes for tone 2 and tone 8 did not show significant decreases, and responses were similar for both groups. Yet since we understand that in children, N2 provides a larger amplitude response to that of the previous negativity (i.e. N1) it is understandable that the responses of N2 amplitude provided different results. Habituation performance at N2 amplitudes between children with HFA and TD groups significantly larger amplitudes for tone 8 compared to tone 2. While the N2 amplitude performances were more significant than the N1 amplitude performances, because there was a larger response to tone 8 these results suggest much difficulty with habituation performance between both HFA and TD groups.

Interesting, when comparing the SPD and TD groups there were significant interactions (group x tone) for both N1 and N2 amplitudes. For N1, the TD group had a significant increase at tone 8 and the SPD group had significant decrease of amplitudes to tone 8. However, the results were opposite for the N2 amplitude, where the children in the TD group displayed similar amplitudes for tone 2 and tone 8, and the children in the SPD group displayed a significant increase in amplitude from tone 2 to tone 8. It is clear that for the SPD group differences of N1 amplitude responses and N2 amplitude responses are inconsistent (they display opposing results). These results should be interpreted with some caution due to small sample size of the SPD and age-matched TD groups. It is important to remember that this same analysis was performed above with TD children with a larger sample size and large N1 amplitude at tone 8 was not evident.

Upon further investigation, figure 2.8 was created to visually inspect N1 peak amplitudes from tone 2 through tone 8 in the train without a deviant among children with HFA and TD groups. This graph provides additional insight in the possible differences of auditory processing between the two groups. In visual examination of the TD group, larger N1 amplitude responses are displayed at tone 2 which could be interpreted as the TD participants orienting at the beginning of the train of tones. The TD group N1 amplitudes then decrease by tone 4 followed by another increased amplitude by tone 5. This increase of N1 amplitude in the middle of the train could suggest that they were expecting a deviant to occur in the middle of the train location (even in the train without a deviant). Additionally, the N1 amplitudes then decrease again by tone 7. If we had measured habituation from tone 2 to tone 7, instead of tone 2 to tone 8, results for the TD group may have demonstrated that the habituation phenomena is present. Visual examination of the N1 amplitude response of the TD group to tone 8 displays another increase in amplitude and when comparing this to the amplitude of tone 2 did not yield results to suggest habituation over time. The increased amplitude at tone 8 might suggest that the TD participants recognize that the train of tones is complete. In comparison, the children with HFA processed every tone presented with somewhat similar amplitudes from tone 2 through tone 6 and then displayed reduced amplitudes to tone 7 and tone 8, although habituation phenomena was not significant in results presented previously. In comparing the TD and HFA groups in this graph, it is notable the differences between the two groups, and can help provide understanding of the difficulties that children with HFA experience when processing auditory stimuli. This graph was not created for the SPD and TD comparison due to small sample size (TD n = 5, SPD n = 7) that would make it difficult to interpret.

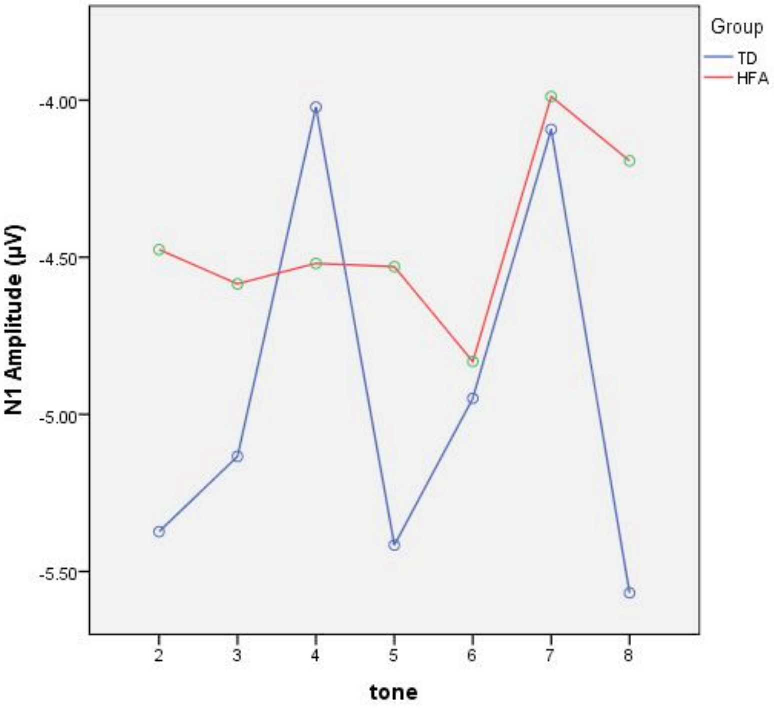


Figure 2.8: N1 amplitude habituation in a train without a deviant from tone 2 through tone 8

Response to Novel and Deviant Stimuli

To review, Question 3 first looks at how children in each of the three groups respond to the first standard tone presented in the train without a deviant. It assesses the child's response to tone 1 by measuring the N1 and N2 amplitudes. The second part of this question then looks at the same components, N1 and N2 amplitudes, in response to the deviant tone when compared to the prior standard tone. For example, in the train with the deviant in the 4th position, N1 and N2 amplitudes were measured and compared to the standard tone presented just before the deviant tone so that any significant differences between the standard and deviant tones could be established.

In the literature, a few studies have already assessed this phenomenon but yielded conflicting results. To briefly review, the Lincoln et al. (1995) study assessed N1 amplitudes among children with ASD and TD (with ten participants in each group) and reported similar N1 amplitudes to rare and frequent targets between both groups. In our study, this was supported by hypothesis 3.1 and hypothesis 3.2. We found that when looking at N1 and N2 responses to the first tone presented in the train without a deviant, there was no significant differences found between HFA and TD groups or between SPD and TD groups.

Oades, Walker, Geffen, & Stern (1988) studied children with autism spectrum disorder (ASD) with seven participants and age matched peers and found that N1 amplitudes were larger in the ASD group to deviant stimuli when compared to the TD control group when participants were required to press a button to infrequent target tones. However, when the auditory stimuli were administered passively and no response was required, the control group produced larger N1 amplitudes compared to the ASD group. Results between children with HFA and TD groups in this thesis study did not reveal a main effect for groups. However, in the train with the deviant in the 5th position, asignificant main effect for tones was found. The N1 amplitudes to the deviant tone were significantly larger when compared to the amplitude of the prior tone the N1 amplitude, regardless of the group. Since the tones presented in our study were presented passively, not requiring a cognitive or motor response, the results of our study showed similar responses between groups which is contrary to the results presented by Oades, Walker, Geffen, & Stern (1988). Similarly no significant differences were found among the N2 amplitudes between children with HFA and TD groups when compared deviant tones in the 4th or 5th positions with that of the prior standard tone. While our study supports the findings of Lincoln et al. (1995) it presents conflicting evidence with the Oades, Walker, Geffen, & Stern (1988) findings. This brings awareness to the need for more research in this area of auditory processing within the brain.

Hypothesis 3.4 assessed N1 and N2 amplitude response to deviant tones when compared to the prior standard tone among children with SPD and their age matched peers. For SPD and TD groups there was neither a group main effect difference nor an interaction of N1 or N2 amplitudes to a novel tone 1 in the train without a deviant. SPD and TD group analyses resulted in a significant main effect for tone regardless of the group. However there was not a main group effect for tone. This was consistent in both trains with the deviant in the 4th and 5th positions. The comparison between SPD and TD resulted in significant differences in larger N1 amplitudes to the deviant tones. However, N2 amplitudes provided different results that were somewhat similar to the HFA results (regarding the train with the deviant in the 5th position) presented above. At N2 when the deviant tones were compared to the prior standard tone, children in SPD and TD groups responded with reduced amplitudes to deviant tones in the train with the deviant in the 5th position. TD groups also responded this way in the train with the deviant in the 4th position while SPD children did not, resulting in an interaction of the N2 amplitudes of the train with the deviant in the 4th position between children with SPD and TD. This interaction consisted of SPD children responding with increased N2 amplitudes to the deviant tone while the TD group responded with decreased N2 amplitudes to the deviant tone. There is no literature that assesses the N2 component to novel and deviant tones that makes it difficult to provide justifiable conclusions to these results, which again should be interpreted with caution due to small sample sizes. Continued research to assess these measures is needed.

Relationships between ERP Measures of Attention and Behavioral Measures

In order to bring the behavioral data of attention subtypes and the neurological responses of auditory processing data together, relationships among the two were assessed using Hierarchical Regression analysis. Discussion of these results in a systematic flow will begin by a review of the findings among the TD groups followed by the HFA group and SPD group respectively.

Previous thesis study conducted at the Colorado State University Brainwaves Lab by Phelan (2012) also analyzed N1 and N2 amplitudes using two ERP paradigms including the sensory gating paradigm and the focused attention paradigm. Phelan (2012) also compared her ERP data with attentional measures using the TEA-Ch among TD children. Phelan's (2012) study found that N1 amplitude components in TD children related to attentional control/shift subtest Creature Counting, $\beta = -.651$, $t = 2.824$, $p = .009$. Phelan's (2012) study found that the N2 amplitudes were a significant predictor of the control/shift attentional abilities, Creature Counting, $\beta = -.668$, $t = -2.479$, $p = .021$ and Opposite Worlds, $\beta = -.612$, $t = 2.404$, $p = .024$.

In this thesis study, hypothesis 4.1 analyzed the TD group to assess relationships between the N1 amplitude of tone 1 or the deviant tones and attention scores of the TEA-Ch. It was predicted (hypothesis 4.1) that there would be a relationship between these measures. Unfortunately, results in our study did not confirm a relationship between N1 amplitude at tone 1 in the non-deviant train with the attentional control/shift subtests on the TEA-Ch.

Hypothesis 4.4 looked at the TD group to assess relationship between N2 amplitudes of tone 1 and the attentional control/shift subtype. Since a relationship was demonstrated among these measures in the Phelan (2012) study, it was also hypothesized that our study would yield similar a relationship. Regression analysis resulted in N2 amplitudes were a significant predictor of the Creature Counting attentional control/shift subtype abilities. Not only does this finding support the findings of Phelan (2012) study, it also brings awareness to the brain behavior connection among TD children. To review, the attentional control/shift subsystem could be a leading contributing factor in the behavioral manifestations of children with HFA and SPD. It is significant that there is a relationship between attentional control/shift measures and N2 amplitudes at tone 1. Since N2 is more reflective of a cognitive process, this suggests that the children in the TD group are able to register tone 1 cognitively but that they are also able to drop their attention to that tone and shift off of it to the next incoming stimuli. By understanding that the TD group's performance demonstrated this relationship can provide understanding when assessing children with neurodevelopmental diagnoses or challenges. We would not expect to see the same relationship among children with HFA or SPD because their behaviors suggest that they have difficulties with this process.

An interesting relationship was discovered among children with HFA. Similar to the TD group, the HFA participants also had a significant relationship with the attentional control/shift subtype, but the subtests for the HFA group correlated with the sensory processing of the N1 component. With what we know about the diagnostic criteria of ASD, this finding could push for validation of the sensory N1 amplitudes are significantly hypo or hyperreactive to tone 1. In testing hypothesis 3.1 previously we discovered that although not statistically significant, children with HFA had larger mean ranks than the TD group when responses to tone 1 were assessed. These larger mean ranks could suggest more hypo or hyperresponsive to the sensory input of tone 1. In understanding this relationship, sensory-based approaches may be viable for improving this neuronal sensory pathway or conversely, a cognitive approach may be useful in strengthening the child's neuronal connections in hopes of new pathways that would lead to a relationship similar to the TD group presented previously.

Our results also provide a significant brain and behavior relationship among children with SPD. The regression analysis for the SPD participants provided a significant relationship between the selective attention subtest Sky Search and the N1 amplitudes at tone 1. Similar to what was discovered with the HFA group, the SPD group relationship involved the sensory N1 measure. To review, the behaviors manifestations that are used to describe children with SPD that have difficulties with disinhibition of auditory stimuli include distractibility with increased stimuli, irritability, hyperactivity, and impulsivity. The Sky Search subtest is an embedded figure task in that they have to find matching spaceships while ignoring the spaceships that do not match. The Mann-Whitney *U* tests for children in the SPD group did result in significant difficulty when compared to the TD group. The SPD group also was not able to display sensory gating abilities at N1 amplitudes when compared to the TD group that could suggest the continued difficulty inhibiting a response and indicate irregular processing of the auditory stimuli, which would make tasks requiring selective attention skills very difficult.

Limitations

One limitation of this study is the smaller sample size and younger ages of the children with SPD and their correlating age matched-peers. While ERP studies that assess auditory processing or attention in children with neurodevelopmental diagnoses are published with small sample sizes, sometimes with ten or less participants in each group (Courchesne, Kilman, Galambos & Lincoln, 1984; Lincoln, Courchesne, Harms & Allen, 1995; Oades, Walker, Geffen & Stern, 1988) we are fairly certain that our results would benefit from more power and would help in producing results free from type II error. In addition, when viewing the grand average ERP waveforms, more participants in the SPD group would strengthen this output data.

A second limitation of our study is that the TEA-Ch was designed for children aged 6 to 16 years of age. However, in our study, participants were recruited starting as young as age 5. In fact our five-year-old participants included: 2 TD males and 3 TD females, 1 five-year-old male with HFA, 2 five-year-old males with SPD and one 4 years and 11 months old female with

SPD. A total of 9 participants in our study were under the age of six. To protect the internal validity of the behavior results these 9 participants they were only included in the raw score analyses and removed from the scaled score analyses. Unfortunately, removing these participants had negative effects on the power of the TEA-Ch data; specifically for the SPD group by further decreasing the number of subjects even more for the scaled score analysis. While it is uncertain why our recruitment provided our study with several five-year-olds, a few hypotheses could be that there are increased demands on attention in kindergarteners or that not all children attend preschool so some children may only have been evaluated until starting kindergarten. Another option would be to use a different behavioral assessment; unfortunately there is not currently another measure that looks at attention in the way the TEA-Ch provides. At this time, there is not a measure of attention that evaluates the three subtypes of attention for children less than 5 years of age. Future studies could instead limit their participants to 6 years-of-age and older.

Conclusions

Studying neurological brain processing of ERPs in relation to the behavioral manifestations of attention subtypes can be informative in the way we understand and treat individuals who have difficulties with performance and participation in daily life. The major relationships found in this study assess ERP components of the N1 and N2 amplitude responses using EEG technology. Our results suggest a few key relationships among each group. In the TD group, a significant relationship was found between the discriminative N2 amplitudes at a standard tone (tone 1 in the train without a deviant) and the attentional control/shift subtype of attention. Children with HFA displayed a relationship between sensory N1 also at tone 1 in the train without a deviant with attentional control/shift subtype. Children with SPD displayed significant relationship of the sensory N1 at tone 1 in the train without a deviant with selective attention measures. The control group provides a basis for understanding for what typical auditory processing of neurological measures should look like for optimal performance and participation. While the experimental groups ERP data provides insight to where the difficulties are occurring, or where the lack of a relationship fails to exist.

The benefits of understanding the neurological underpinnings of auditory processing and relationships these brain processes have with attentional subsystems could be helpful informants of therapy modalities and frame of references chosen by practitioners. The data presented in this thesis study provides understanding to some of the core diagnostic criteria in children with HFA as well as the behavioral manifestations that contribute to attention difficulties in children with SPD. The TEA-Ch results demonstrated that both children with HFA and SPD had difficulties with some of the attention subtypes including attentional control/shift, sustains and selective subtypes, while TD children did not. Our study also examined abilities of children in our three groups to orient to a stimuli, allowed for opportunities for sensory gating, habituation as well as analysis of brain processing to deviant tones. As expected, our results showed that sensory gating is more difficult in children in the SPD group and that children with HFA are able to perform more closely to their TD peers. In the habituation analysis, the HFA group had significant differences between tones as well as some difficulty with habituation of the N2 amplitudes while children with SPD data provided differences among groups and significant interactions of N2 from tone 2 to tone 8. Further while all participants in each group responded similarly at N1 and N2 to a standard tone 1, the responses were much different to for deviant tones. These differences among groups can provide opportunities for more informed clinical reasoning when providing interventions to individuals with HFA or SPD.

CHAPTER 3

The American Occupational Therapy Association's (2008) Practice Framework reports play as a primary occupation. For children, play is not only how they spend the majority of their time but also the means by which they experience and participate in the world. It is through active engagement in play that children learn (Knox, 2010). Yet for children who have high functioning autism (HFA) or for those who have sensory processing difficulties (SPD), experiencing the world as it is can be overwhelming or discouraging. Families are often referred to occupational therapists for guidance in better enabling their children to engage more optimally in activities of daily life. Pediatric occupational therapists have access to a variety of treatment models and theories to guide clinical reasoning and inform occupation based, client centered treatments. Play and developmental theories are a starting point, but occupational therapists should also incorporate clinical experience, knowledge of both the child and family priorities and concerns when making treatment decisions (Case-Smith et al., 2010). After an understanding of these factors have been considered, occupational therapists might turn to a certain practice model, or frame of reference, to help guide their clinical reasoning and offer interventions based on these factors. Additionally, when treating children with neurodevelopmental disorders such as ASD and SPD, it can be especially helpful if the therapist has an understanding of the neurological underpinnings of the behaviors the child displays. For example, knowing that children with SPD have more difficulty with processing of sensory and discrimination of auditory stimuli along with difficulties of control/shift and selective attention measures, therapists might better target these areas of difficulty by implementing a sensory or cognitive approach. When considering each of these factors, client-centered occupational therapy practice is brought to life.

Case-Smith and Arbesman (2008) produced a systematic review of effective interventions used in OT for children with autism. These researchers found that occupational therapists working with children with autism most frequently create goals and treatment plans that focus on improvement of sensory processing difficulties, sensorimotor performance, social and behavioral performance, self-care, and participation in play. In addition, Case-Smith and Arbesman (2008) provide a variety of intervention strategies that occupational therapists can access that are appropriate for working with children with autism. Among others, these intervention strategies discussed by Case-Smith and Arbesman (2008) included the sensory integration theory as described by Ayres (1979) and social-cognitive skill training. Next a closer look at two treatment strategies that could help children with HFA or SPD improve neuronal processes of auditory stimuli and improve behaviors related to attentional measures will be described.

The first treatment area Case-Smith and Arbesman (2008) listed was improvements with sensory processing difficulties, which is an occupational therapy treatment plan often used to benefit children with both HFA and SPD. Stackhouse (2014) provides an understanding of the necessary components within sensory (SI) integration intervention as well as advances in science that further enhance the SI theories since they were first described. As previously mentioned in Chapter 1 of this thesis, foundational to the A. Jean Ayres (1979) SI approach is the repeated triggering of an adaptive response. An adaptive response results from improved connections of the actual neurons themselves within the brain (Ayres, 1979). When the adaptive response is exercised within the context of an intrinsically motivating activity where the child role is that of an active participant, more optimal functioning can result. Current research attributes neuroplasticity as the key to what makes the adaptive response possible (Stackhouse, 2014). The adaptive response is achieved through setting up the environment to provide the child with the just right challenge (Ayres, 1979; Stackhouse, 2014). This can be accomplished when the therapist applies moment-by-moment grading in the amounts of sensory input while simultaneously scaffolding and providing encouragement to ensure a successful experience. If the activity is novel or not yet mastered, this type of experience could provide opportunity for neural adaptive responses and can be used to target a variety of motor (discriminative processes) or modulation processes, which among others includes regulation of attention (Stackhouse, 2014).

Another approach that is appropriate for occupational therapists to utilize when providing interventions to children with HFA and SPD is the use of a cognitive approach. Cognitive approaches focus on assisting the child in identifying, developing and using cognitive strategies to perform occupations of daily living (Case-Smith et al., 2010) and may be useful in improving the attention system. With this approach, the therapist should be aware of the cognitive strategies and subtypes of attention that child has difficulty with and create opportunities for the child to build on these cognitive processes. With this approach, therapists apply questions as prompts to help lead the child in the right direction without giving direct instruction. The underlying idea of the cognitive strategy is to create skills that will later be generalized to other experiences for improved performance and participation (Case-Smith et al., 2010). While using this strategy children can improve their self-efficacy and confidence. Next an example of what an occupational therapy intervention could look like for a child with HFA or SPD.

During occupational therapy interventions, therapists can weave in opportunities to work on improving attention modulation within a variety of therapy contexts. Two ways of doing this are through the use of a sensory or cognitive approach as describes above. Having the child change and perform an appropriate response after a direction or agreed upon cue is given can stimulate the attention control/shift processes. For example, imagine a child you have worked with previously enjoys pretend sword fights, shooting sea urchins at a pirate ship target while suspended from a platform swing (pretend boat), or loves jumping on a trampoline. Any of these contexts will work for providing opportunities for utilizing a cognitive approach for stimulating any of the attentional subtypes. I first will expand on the pirate ship and sea urchin example. For this activity the therapist could set up the environment for the child, designating where the pirate ship will be stationed (perhaps it is a bucket or a nearby bean bag). The therapist could also include the child for other obstacles to set up, some "non-targets" such as a bolster standing up for the lighthouse, etc. The game could evolve in many directions but the therapist could provide some guidelines in order to stimulate the attentional control/shift measure. The therapist could have the child count the number of sea urchins that the child successfully hit at the pirate ship, and when throwing out a code word like "the pirates are coming" the child must then switch the direction they are counting so the pirates will see less sea urchins on deck. Then the therapist might say "all clear" and the child must then switch to count in an upward direction as they toss the sea urchins. In this way, the therapist is implementing a cognitive approach by allowing manipulation of the subtypes of attention within a favorite activity chosen by the child. For success with this activity, the child must sustain attention to the therapist or mode of cueing, but must also shift his attention to his motor tasks and direction of counting while shooting at a designated target while continuing to listen for the next cue. This example that can help provide insight when thinking about the results of the data gathered in this research study. Another example of how the results from this study can help inform therapist that work with children with HFA or SPD is provided next.

With regards to sensory gating, opposite to the desired effect in our study the N1 amplitudes from tone 1 to tone 2 actually increase which suggests that sensory gating phenomena is challenging to children with SPD. Similarly, it could be interpreted that children with SPD did not habituate but instead continued to process every standard tone that was administered throughout the hour-long paradigm. These children also provided larger N1 and N2 amplitudes to deviant tones. Understanding these brain responses can be very informative for therapist in their knowledge of auditory processing in children with SPD. It can also allow the therapists to modify their own interactions with the child. The therapist should think about the auditory demands being placed on a child at any given time, this could be in the form of limiting the number of words they themselves produce, their tone of voice, speed with which they are providing verbal demands, or the auditory stimuli within the environment such as loud radiators or other conversations, etc. This research provides understanding that children with SPD processed every tone we presented in our highly controlled environment; think of how much these children are challenged to process in the uncontrolled environments of their homes and schools. It is then understood why children with SPD would display behaviors such as difficulty sitting still, or following verbal instructions, irritability, hyperactivity, impulsivity or oppositional behaviors (Bellis, 2002; Burleigh, McIntosh & Thompson, 2002; Stackhouse et al., 2014).

In order for a child to be successful in play, they must continually rely on the attention system and auditory processing of the brain for optimal performance. Yet because attention is multidimensional, it may be difficult in determining the root of the child's unique difficulty. For success in play environments, children must be able to sustain attention to the task for the duration it takes for it to be completed, they must inhibit responses to irrelevant stimuli that unexpectedly occur, and at other times they must be able to switch their attention from one stimulus to the next while effectively processing relevant meaningful stimuli and forming appropriate responses along the way. For many children with HFA and SPD, these processes can be difficult but there are also differences in attention abilities between these two diagnoses themselves. Understanding the different subtypes of attention helps to understand the behaviors that can be triggered as a result. In our study, children with HFA had significant difficulty among each subtype of attention (including attentional control/shift, selective, and sustained) when compared to the age-matched controls. Children with SPD also had significant difficulty with attentional control/shift and selective attention subtypes. Understanding these differences in behaviors of attention is the first area of knowledge that this thesis presents. This area of knowledge can help in deciding which subtype of attention to target in therapy sessions.

The second area of knowledge that the results of this study provide is an understanding of the differences in brain processing of auditory stimuli among groups. The results that are provided in this study allow for the understanding that there are differences in how children with HFA process auditory stimuli and similarly there are also differences in how children with SPD process the same auditory stimuli in comparison with age-matched peers. If the brain responses of the children with special needs were similar to the control group (for example, children with HFA showed similarities in sensory gating to age-matched peers in this study), then the difficulty could be in how the child attends to the stimuli presented in the environment and might indicate that a cognitive approach could be more efficient. Yet if the differences are evident within the underlying brain processing, this can provide explanation for the behavioral manifestations that child a with HFA and SPD display. Our results provide insight for whether the child is having more difficulty in the discrimination aspects of sensory processing (earlier brain processing), or if the children are not cognitively processing the auditory stimuli in a similar way (later brain processing). While this study does not provide evidence for the most effective therapeutic interventions for improving auditory processing, based on the results, one could hypothesize that depending on what phase of brain processing the child is having difficulty, certain interventions could be selected that might directly influence the aspect of the neural processing difficulties (attending to certain stimuli or discrimination certain stimuli). For example, this study suggested that children with SPD have difficulty with registration and discrimination aspects of processing (i.e. N2). If an individual with SPD has these difficulties then the therapist might provide interventions through play where the child must make decisions about the incoming auditory stimuli and respond accordingly. This type of intervention, through the ideas of neuroplasticity, might improve the neural processing of sensory stimuli in everyday activities. Another example displayed in this study is that children with HFA showed similarities to the TD group in sensory gating and in their response to deviant tones (i.e. N1). This suggests that taking a sensory approach might not be necessary for improving this aspect of auditory processing as it is already comparable to their age-matched peers.

The final area of knowledge that this study provides is insight to relationships between neural processing and performance on everyday tasks that require attention. In understanding relationships among children of typical development, helps in thinking about the differences of children with neurodevelopmental disabilities. At this time, more research is needed to fully understand the implications of these relationships. Yet understanding these neuronal processes are one way that therapists can better understand the behavioral manifestations displayed among children with HFA and SPD.

In the field of occupational therapy practice, it is critical that therapists can justify the purpose of intervention they utilize. For this to happen, the clinical reasoning behind each activity should be understood. For children with HFA and SPD, understanding the relationships between the neurological processes and behavior can be vital in helping improve the behaviors themselves. Both sensory integration and cognitive strategies can be beneficial but knowing when to use one over the other takes thought and understanding. In the future a study such as this one, where there is a comparison of neurological brain responses and behavioral data might be able to provide further understanding of brain behavior relationships and aid in directly targeting desired outcomes. For adults who work alongside, or live with children with HFA or SPD understanding these relationship can allow for greater patience and compassion.

In theory, EEG/ERP measures such as those examined in this thesis study, could eventually serve as a pre/post measure for showing changes in the auditory processing abilities of children before and after receiving therapy that simulates the specific area of attention modulation difficulty. In this way, the use of EEG/ERP measures in treatment effectiveness studies would serve to show if the treatment impacted the neuroplasticity of the brain. Some interventions or approaches suggest that the interventions will have lasting effects by facilitating changes in brain processing. However, very few studies have been conducted to provide evidence for such hypotheses.

Understanding the underlying neurological differences that correlate with behavioral manifestations is key to clinical reasoning and likewise, providing interventions that improve neuronal functioning is key to improvements in behavior. Since occupational therapists work directly with children with neurodevelopmental difficulties, often there is a focus on improving behavior as a means for more optimal function of performance and participation in play. It is encouraged that future research continue to provide connections between behavior and neurology. By providing evidence of relationships between behavior and brain response as we have done in this study, we are better informed and our theories about the brain behavior connection are better supported.

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