THESIS

ASSESSING THE IMPACT OF A MUSIC THERAPY PROGRAM ON ATTENTION IN CHILDREN WITH AUTISM USING BEHAVIORAL AND NEUROPHYSIOLOGICAL MEASURES

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 2021

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ABSTRACT

ASSESSING THE IMPACT OF A MUSIC THERAPY PROGRAM ON ATTENTION IN CHILDREN WITH AUTISM USING BEHAVIORAL AND NEUROPHYSIOLOGICAL MEASURES

Children with Autism Spectrum Disorders (ASD) are known to have difficulty with auditory sensory processing. Music therapy is a common intervention approach for children with autism to address numerous behavioral and sensory challenges using auditory stimuli. Auditory processing capabilities have also been linked with attention skills and with attentional challenges often observed in children with ASD. This study seeks to understand the differences between children with ASD and their typically developing peers in auditory processing and attention. An additional study goal is to evaluate impacts of a music therapy protocol on those constructs.

Baseline measurements were collected for 10 children with ASD using the Test of Everyday Attention in Children (TEA-Ch) and EEG under a sensory registration paradigm. These data were compared to those of age- and sex-matched typically developing peers (n = 10). The children with ASD participated in biweekly music therapy over 5 weeks for a total of 10 sessions and then completed the same assessments during a post-test. The sensory registration paradigm measured passive responses to four auditory tones at two different intensities (50 and 70 dB) and two different frequencies (1 and 3 kHz). The resultant event related potentials (ERPs) were averaged into a waveform for each child at each tone and amplitudes and latencies were calculated for N1, P2, N2 and P3 components. The TEA-Ch resulted in an overall attention score and a score for each of three subdomains of attention: sustained, selective and switching.

Results indicated that children with ASD performed more poorly on the TEA-Ch with significantly poorer scores in overall attention, selective attention, and sustained attention. A series of independent sample t-tests on ERP components revealed few significant differences but a trend of increased latency at N1, P2, and N2 in children with ASD for each of the four tones. Children with ASD had lower amplitude of N1 components and greater amplitude P2 components compared with the typically developing children. Following the music therapy intervention, children with ASD improved significantly in selective attention and showed a trend of improvement in switching and total attention compared to pre-testing scores. The music therapy did not result in statistically significant changes in EEG results, but a trend of increased latency was noted for N1, P2, and N2. Amplitude of the P3 component decreased following the music therapy intervention in response to the high and loud tone when age was used as a covariate. Some significant associations were found between the latency of N1, P2, and N2 and sustained and selective attention in response to the 1kHz 70dB tone across all participants at baseline (TD children and children with ASD before music therapy).

In conclusion, this study shows that children with ASD have different neural processing of simple auditory tones and reduced performance in multiple domains of attention. The music therapy intervention is a promising approach to improving attention skills. The intervention did not appear to alter neural processing in the expected way of children with ASD performing more like their typically developing peers. Further research at this foundational level of neural processing may help clarify the differences in processing between children with ASD and their typically developing peers and may provide a way of monitoring interventions which seek to alter neural processing to target attentional skills and behaviors.

ACKNOWLEDGEMENTS

I am grateful to everyone who has supported and guided me through the process of creating this thesis project. I am immensely grateful for the guidance of Dr. Patti Davies. She has shared her wisdom and offered endless encouragement throughout this process. I am fortunate to have had such a gifted researcher mentor me. I would also like to also thank Dr. William Gavin for his input and assistance especially with technology challenges. Dr. Blythe LaGasse has provided invaluable knowledge and skill related to music therapy and the intervention under study in this project. Dr Emily Merz has helped as a committee member through her unique perspective on child development from psychology. Dr Jaclyn Stephens has offered constructive and helpful feedback to craft high quality research.

I would like to acknowledge the Brainwaves Research Lab as a whole – students, staff, and gracious participants– for being resources and sounding boards and affirming that this work can be hard and tedious but ultimately a rewarding challenge.

I am eternally indebted to every other thesis student in the occupational therapy class of 2021 for weathering the COVID storm with me as we all stayed dedicated to doing the best work we could in difficult circumstances. I am proud of all of us for the work we have done and the place at which we have arrived.

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CHAPTER ONE

Introduction

Overview of Autism Spectrum Disorder

Description and Prevalence

Autism Spectrum Disorder (ASD) is an increasingly well-known disorder and has grown in prevalence in recent years. According to the Centers for Disease Control, in 2014 approximately 1 in 59 children were diagnosed with ASD compared to 1 in 150 in 2000 (Centers for Disease Control and Prevention, 2019). It is more prevalent in males than females but does occur in both sexes (Tick et al., 2016). The DSM-5 characterizes ASD through two main criteria: (1) consistent challenges in social interaction/communication with other people across several settings and (2) restricted, repetitive patterns of behavior, interests, and activities (American Psychiatric Association [APA], 2013). ASD is considered a spectrum because it covers a wide range of symptom severity levels (Autism Spectrum Disorder, 2018; Marco et al., 2011). In order for a diagnosis of ASD to be applied, the symptoms must present in the early stages of development, must cause a functional or occupational impairment and cannot be better explained by a different developmental disorder. Social interaction challenges include inconsistent eye contact, unusual facial expressions, not responding to their name being called, and tone of voice that may be sing-song or flat and robotic (American Psychiatric Association, 2013). Restricted behavior patterns manifest as repeating words, intense interest in one topic to the exclusion of others, being upset by changes in routine and abnormal reactions to sensory input (American Psychiatric Association, 2013). Sensory issues are a new addition from the DSM-IV to the DSM-5 adding further relevance to studying sensory processing in the population of children with ASD

(Grapel et al., 2015). Sensory symptoms have long been associated with ASD, but the DSM-5 is the first version to include them as diagnostic criteria (Brett, et al., 2016). These abnormal responses to sensory input can include hyposensitivity, hypersensitivity, sensory attractions, or sensory aversions across any or all sensory domains including auditory, visual, tactile, vestibular, and proprioception (Marco et al., 2011).

Continued refinement of diagnostic criteria has paralleled continued research to understand the origins of the disorder. Autism has been shown to be hereditary. A child with a sibling with ASD is more likely to have ASD themselves (Tick et al., 2016). Twin studies have demonstrated that monozygotic twins have a higher likelihood of both having ASD than do dizygotic twins. While an environmental, non-genetic, component could be one factor, current evidence points toward genetics being more significant (Tick et al., 2016). The specific genetic etiology is far from fully understood.

Several studies have demonstrated evidence of physiological and structural abnormalities in the brains of children with ASD (Ha et al., 2015). These studies demonstrate that ASD has a neurological basis and point toward specific treatment approaches to support children with ASD (Silva, et al., 2013). Structural magnetic resonance imaging (MRI) and functional MRI (fMRI) have been common tools used to show structural abnormalities and changes in the blood oxygenation level dependent (BOLD) response in the brain during some tasks, respectively (Salmond et al., 2003). There are volumetric and morphological differences between the brains of individuals with ASD and neurotypical controls (Ha et al., 2015). Electroencephalogram (EEG) studies already provide information about neurophysiology in the brains of individuals with ASD in response to stimuli (Dinstein, et al., 2012; Marco et al., 2011). Continued research using EEG will broaden our understanding of neurological responses to auditory stimuli.

Sensory Processing in ASD

Sensory processing refers to the neurological events that take place in the mind as a person perceives a sensory stimulus, organizes it, categorizes it, and decides what to do about it (Tomcheck & Dunn, 2007). Early sensory integration frameworks include a linear continuum from over-responsiveness to under-responsiveness (Schaaf & Davies, 2010). However, the linear model fails to capture the true diversity of sensory processing. Further research is warranted to add additional subtypes and further understand sensory processing in clinical populations (Lane, 2020). Those within the scholarly community of occupational therapy can continue to lead the investigation of sensory processing by "being systematic, rigorous, and open minded" in the approach (Schaaf & Davies, 2010, p. 365).

Each sensory system contributes to an individual's understanding of the world around them and their position within it (Dunn, 2001). Auditory sensory processing is composed of hearing the auditory stimulus in the ears, registering the stimulus in the brain and subsequent processing of the stimulus (Marco et al., 2011). Due to the constant bombardment of sensory information coming into the various sensory receptors on the body, the nervous system is also responsible for modulating responses by balancing inhibition and excitation (Dunn, 2001). Many factors influence how the brain modulates sensory input and how successful and functional the modulation is. Factors include genetics, experience, and environment (Dunn, 2001). Genetic differences underlie brain structure and function at base level. Experience and practice in modulating sensory responses develop over time and with exposure to ranges of sensations. Environments vary in regard to variety and intensity of input across the domains. Individual variations to sensory experiences are expected, but the presence of neurological and neurodevelopmental disorders can create maladaptive processing patterns that impact daily functioning (Weitlauf et al., 2017).

The common feature of ASD relevant to this research is atypical reactions to sensory stimuli (LaGasse et al., 2019; Lane, 2020; Liss et al., 2006). Commonplace auditory stimuli, such as the sound of a vacuum cleaner, can provoke strong behavioral reactions (Liss et al., 2006; Marco et al., 2011). Research has established that individuals with ASD have altered processing of stimuli at the neural level (Brett, et al., 2016; Kown et al., 2007; Marco et al., 2011; Whitehouse & Bishop, 2008). One functional impact of these abnormalities could be in relation to language development delays common to children on the autism spectrum (Marco et al., 2011). One study using event-related potentials (ERPs) discovered an atypical neural activation response to speech sounds in children with ASD but reactions to non-speech sounds did not appear abnormal (Whitehouse & Bishop, 2008). There is mixed evidence from EEG studies looking at latency of various components in response to auditory stimuli (Marco et al., 2011). The wide range of symptoms, severity levels, ages and cooccurring disorders of research participants likely contribute to such inconsistencies. Furthermore, different paradigms used by these researchers contributes to the mixed findings (Marco et al., 2011).

It is essential to understand more about sensory processing contributions to the symptom cluster of ASD (Lane, 2020). For occupational therapists treating children with ASD, sensory deficits are often a priority due to the impact on daily functioning especially performance in school, social difficulties, and language acquisition (Weitlauf et al., 2017). Hypersensitivity is correlated with overfocused and overselective attention (Liss et al., 2006). Meaning children with ASD often are unable to shift attention off a particular stimulus or attend to a cuing stimulus in the presence of other distractors. In Liss et al. (2006)'s research, overfocusing traits cooccurred with more severe social deficits.

Research remains limited in the efficacy of various sensory interventions by occupational therapists (Lane, 2020). There remain no clear guidelines for which types of sensory interventions will be most effective for various clinical populations. The body of evidence for interventions targeting sensory dysfunction in children with autism can be strengthened by using well defined and replicable interventions, incorporating standardized measurement tools, and discussion of possible harms as well as benefits of interventions (Weitlauf et al., 2017). Such research would benefit multiple clinical populations including children with ASD as well as other diagnoses such as sensory processing disorder.

Sensory processing disorder (SPD) shares some features with ASD but lacks the social and behavioral components. Children with SPD do show similar brain abnormalities in areas associated with sensory processing compared to children with ASD (Chang et al., 2014). The two groups also show similar behaviors in reactivity to sensory stimuli (Chang et al., 2014). Thus, it is reasonable to draw on sensory processing research from both populations to inform further studies. However, Lucker (2013) found that hypersensitivity to auditory stimuli in children with ASD was not based in the auditory system but rather was a conditioned behavioral response. Children with ASD were less able to tolerate the loudest sound range compared to children without ASD who were identified as having hypersensitivities to sounds. The result of this study may indicate that for children with ASD, a behavioral response to avoid loud sounds is an emotional response more so than it is in children with SPD. Combined with work in the neurophysiological field the behavior patterns seen in children with ASD in response to auditory stimuli may be a mixture of underlying neural abnormalities, conditioned responses, emotional responses, and environmental influences (Crasta, et al., 2016; LaGasse et al., 2019; Lincoln et al.,1995; Lucker, 2013; Marco et al., 2011).

Sensory Dysfunction Implications for Daily Performance

Abnormalities in sensory processing and reaction to sensory stimuli have significant implications for daily functioning. For individuals without sensory processing difficulties, the brain can register environmental inputs, appropriately attend to ones that are important and disregard those that are irrelevant without interrupting functional activities (Chang, et al., 2014). Noises that are loud, unique, or unexpected may receive conscious attention. Sounds that are mundane or are part of background noise can be ignored without distracting from task performance. However, some typically developing children do demonstrate abnormal sensory reactions. For example, across a sample of typically developing school-aged children, hyper-reactivity to various sensory modalities including auditory was associated with anxiety and with selective eating patterns (Lane, 2020). Although, in individuals with atypical sensory processing, there may be overreactions, underreactions, or other unusual responses to sensory inputs (Dunn, 2001).

Children with ASD may be overall overresponsive or under-responsive to stimuli (Liss et al., 2006). They often struggle to filter out background noise or to attend to novel noises that are important. Children who are overresponsive to auditory stimuli may avoid certain noises or react poorly in noisy environments. These children may also avoid or dislike speech which may further delay social skill acquisition and remove them from various other learning contexts (Cromwell et al., 2008). Evidence suggests that children with ASD do not process language via the same neural pathways or at the same speed as neurotypical children (Silva, et al., 2013). Language development is an essential part of early childhood. Children learn language through hearing, repeating, and striving to communicate orally with others. A disinterest or aversion to hearing language may stunt development in multiple realms (Whitehouse & Bishop, 2008).

Sensory Processing and Attention

Impaired sensory processing abilities affect multiple kinds of cognitive performance including attention (Bailliard & Whigham, 2017; Schauder & Bennetto, 2016). Attention is the ability to orient and stay attended to specific stimuli in appropriate patterns (Marco et al., 2011). Three kinds of attention are relevant to this research: selective, sustained, and switching (Heaton et al., 2001). Selective attention is the ability to focus on a target stimulus among an array of distracting stimuli. Sustained attention is the process of maintaining focus on a target over an extended period of time. Switching attention involves fluidly moving focus from one stimuli to another as needed by the task and environmental demands. In order to complete a task, neural resources must be recruited and used for cognitive processing (Liss et al., 2006). In a typical task environment, there are external stimuli from multiple domains constantly activating sensory receptors in the nervous system: the feel of clothing on skin, the slight flicker of a light, the steady hum of appliance, the smell or someone eating lunch nearby, or the chatter of other people. Appropriate attention involves filtering unnecessary environmental inputs while attending to ones that are relevant – a complex neural process (Marco et al., 2011).

An inability to filter stimuli, or a maladaptive pattern of neural response to stimuli may detract from the brain's ability to stay attended to a task. As of yet there is a lack of definitive linkage between abnormal auditory sensory processing and attentional skills deficits in individuals with ASD (O'Connor, 2012). However, it is known that attentional difficulties and sensory processing are both frequently observed in children with ASD (Butera et al., 2020; Crasta et al., 2020). Individuals with ASD may overfocus on a single stimulus to the exclusion of others which could lead to difficulty in shifting attention from one task to another (Liss et al., 2006). Liss and colleagues (2006) found that overreactive, overselective, and overfocused attention traits correlated with one another in a study of children with mild ASD.

Music Therapy: History and Overview with ASD

Music therapy (MT) began in the 1940's as part of a shift toward a holistic treatment model for individuals with ASD (Reschke-Hernandez, 2011). Evidence for the efficacy of music therapy for children with ASD is limited but promising (LaGasse et al., 2019; Simpson & Keen, 2011). Small scale studies have reported a positive impact of MT on some symptoms of ASD such as communication and social interaction (Geretsegger et al., 2012). MT has been used to address a variety of skills including socialization, sensory exploration, behavioral management, self-expression, rapport building, attention, and body awareness (Reschke-Hernandez, 2011). Improvisational MT, developed in the late 1970's, is a more flexible approach which accommodates a child's individuals needs and strengths (Reschke-Hernandez, 2011). In public schools, MT is a sanctioned treatment for ASD drawing on principles from speech language pathology, psychology, and special education (Reschke-Hernandez, 2011).

Current findings from research into ASD and MT indicate that children with ASD engage longer with musical auditory stimuli than with stimuli from other sensory domains (Simpson & Keen, 2011). Two challenges of current research are the generalizability of study conditions and whether the benefits of of MT persist over time (Reschke-Hernandez, 2011). There is also a need to establish physiological measurements that can complement behavioral measures to evaluate efficacy of MT interventions for children with ASD (LaGasse et al., 2019; Pasiali et al., 2014). Electroencephalography (EEG) is emerging as one such physiological measure (LaGasse et al., 2019; Pasiali et al., 2014).

Electroencephalography: An Introduction

Electroencephalography (EEG) are recordings of voltage variation in the brain as read through electrical leads placed on the scalp (Coles & Rugg, 1995). EEG has excellent temporal resolution allowing researchers to monitor brain processing in milliseconds following a stimulus (Remijn et al., 2014). This approach enables researchers to understand individual brain processing and make comparisons between groups of individuals with certain demographics or backgrounds. However, EEG has poor spatial resolution and does not indicate which brain structures are creating the response, nor how many structures might be involved. EEG is therefore, best used to understand the timing and sequence of processing.

In response to an external or internal stimulus, neurons change their electrical potential and when clusters of similar neurons change together, electrical potentials can be detected in the running EEG recorded at the scalp (Coles & Rugg, 1995). In order to reduce the noise and isolate the signal – the neural response of interest – a researcher can conduct multiple trials and average the results to generate an averaged event-related potential (ERP) representing the neural response to the specific stimulus (Remijn et al., 2014). Background neurological noise which is not related to the stimulus response averages to zero. The resultant ERP waveform following the stimulus is composed of components representing the brain processing phases in response to that specific stimulus (Otten & Rugg, 2005; Polich, 1993). Remijn et al. (2014) defines an ERP as a "scalp-recorded activity generated by a specific neural or physiological process, which in turn produces a certain polarity, latency, and scalp distribution" (p. 35). ERP components can be measured by their polarity (positivity or negativity), amplitude (degree of deviation from baseline) and latency (time between the onset of the stimulus and the peak of the component). Peak-to-peak amplitude is a measure of the difference from the previous peak to the peak of interest. An ERP in response to a sensory stimulus results in a series of peaks that correspond to different phases of sensory processing. The components of stimulus response occur at unique latencies, so researchers can compare an atypical response to a typical response and discriminate between difficulties registering the stimulus, or evaluating the stimulus, or deciding what action to take in response to the stimulus (Otten & Rugg, 2005).

Certain components have been identified and named (Polich, 1993). These components can be compared across various studies and used to understand the origin of the component (Otten & Rugg, 2005). Components are conventionally named by a P or N to denote positivity or negativity and the approximate latency of the peak of the component or the order in which it occurs; the first positivity is then the P1, the second negativity is the N2 (Polich, 1993). Some sources name the components with the typical latency at which they occur so the N1 is named the N100, the P2 is called the P200, etc.

Components that are more sensitive to changes in stimulus quality are considered exogenous because they are related to external processes (Chennu, et al., 2013). Components that are representative of internal cognitive processing are termed endogenous (Chennu, et al., 2013). In general, earlier components are more exogenous and later components are more endogenous. However, this dichotomous categorization is overly simplistic, and most components are combinations of both types of processing. Early ERPs which are more exogenous tend to have more consistent latencies across the neurotypical populations (Remijn et al., 2014). Later, more endogenous ERPs show greater variability in their latency because cognitive processing is unique to individuals and the variability compounds with each subsequent component (Remijn et al., 2014).

EEG Paradigms and the Sensory Registration Paradigm

EEG studies of auditory processing use various paradigms or presentations of specific stimuli in specific patterns with or without an associated response task or attention direction. The use of standard paradigms allows for better comparisons between studies and aggregation of findings. Three auditory paradigms will be discussed here: the oddball paradigm, the sensory gating paradigm, and the sensory registration paradigm, the latter being the paradigm used in this study.

The Oddball Paradigm. The oddball paradigm consists of a specific tone that is repeated regularly with random intrusions of a stimuli that differ in pitch or duration or intensity (Remjin et al., 2014). This paradigm has passive variations, where the subject is not asked to make any response, and active variations where a response is required to the oddball or target tone. In a classic oddball paradigm, there are two stimuli: a frequent/standard stimulus and a rare/oddball/target stimulus. The oddball paradigm is often used to elicit a strong P3 component for the rare/oddball/target stimulus that corresponds to changing mental representation of the stimulus environment (Polich, 1993).

The Sensory Gating Paradigm. The sensory gating paradigm measures the ability to suppress the neural response to repeated stimuli (Cromwell et al., 2008). Sensory gating is a critical process to protect the brain's sensory processing capacities from being overwhelmed by constant input of sensory stimuli (Davies et al., 2009). Pairs of stimuli (often clicks) are presented with the two clicks separated by 500ms. Pairs are separated by 8 to 10 seconds. Robust sensory gating is observed when the neural response to the second stimulus is reduced compared to the response to the first stimulus. When sensory gating occurs typically, a person is able to filter out irrelevant sensory information allowing the brain to devote processing resources to more important stimuli (LaGasse et al., 2019). Functional sensory gating enables selective attention by preventing a person from being distracted by background stimuli (Freedman, 1987).

The Sensory Registration Paradigm. The study described here used a sensory registration paradigm based on Lincoln et al. (1995). In this paradigm, tones of two different frequencies and two different intensities (four total tones) are presented randomly while subjects listen passively (Lincoln et al., 1995). The resulting EEG recordings and ERP component latencies and amplitudes can be examined for differences between subject groups, between responses to the frequencies and between responses to the intensities or any combination of those factors. The ERP components of interest, the P1-N1-P2-N2-P3 complex (discussed below), is known to be sensitive to the pitch and volume of a tone. The N1, P2, N2 component complex corresponds to the sensory processing of an auditory stimulus in the auditory cortex (Polich, 1993). The P3 component represents the beginning attentional engagement with the stimulus (Remjin et al., 2014). Previous studies have shown mixed results about the differences in amplitude and latency of the peaks between subjects with ASD and typical controls (Marco et al., 2011). Individuals with ASD do show higher variabilities in peak latencies (Lincoln et al., 1995).

ERP Components in the Sensory Registration Paradigm

The following are components of the ERP resulting from an auditory stimulus in the sensory registration paradigm. The P1 is the first positive peak following the stimulus onset. Delays in the P1 can indicate a processing deficit (Polich, 1993). P1 is primarily an exogenous component.

The N1 is the first significant negativity after the onset of an auditory stimulus. It is thought to represent selective attention (Polich, 1993). It typically has a peak latency of 50 to 150 ms (Remijn et al., 2014). It is often evoked by a sudden change in auditory environment such as a new tone. The N1 is thought to be affected by the suddenness of the stimulus onset and the intensity of the sound (Remijn et al., 2014) and may be connected to attention switching during passive listening (LaGasse et al., 2019). Although considered a sensory component, the N1 can change depending on if a person is directing conscious attention to the task. N1 can be considered endogenous and exogenous due to the mixed nature of the component (Remijn et al., 2014).

The P2 occurs approximately 200 ms after stimulus onset and follows the N1 (Remijn et al., 2014). The P2 typically indicates registration of the stimulus. It is the brain beginning to categorize and define the stimulus. It reliably occurs across individuals and varies with characteristics of the sound's intensity and frequency (Remijn et al., 2014).

The N2 is a negative deflection that typically appears between 180 and 325 ms (Remijn et al., 2014). The N2 has subcomponents including the mismatch negativity which arises when a stimulus differs from the background context (Coles & Rugg, 1995). It can be sensitive to the intensity and other characteristics of a sound having a larger amplitude with a greater intensity sound.

The P3 is the third positive deflection and occurs between 250ms and 500ms after stimulus onset (Polich, 1993). It is thought to be linked with memory updating due to changes in the stimulus environment such as when a different tone is presented (Polich, 1993). Others have characterized it as reflecting "attentional engagement" with a stimulus (Remijn et al., 2014, p. 232). The difference between the current stimulus and the prevailing or previous stimuli can impact the P3 especially in an oddball paradigm (Remijn et al., 2014). The P3 is commonly studied because, as a later occurring component, it is more closely associated with higher level thinking and is thought to reflect voluntary or involuntary attentional engagement to a stimulus (Remjin et al., 2014). It is also a large peak compared to some earlier components which can be easier to study (Luck, 2005). In children with ASD, the inability to control attention shifts to a stimulus can be a cause of challenging behaviors (Marco et al., 2011). Most of the studies using the P3 have shown a decrease in amplitude for children with ASD compared to neurotypical controls.

EEG Results in Children with ASD

EEG has been used to study various sensory related disorders including sensory processing disorder and autism spectrum disorder (Davies & Gavin, 2007; O'Connor, 2012). Behavioral measures can show evidence of external change following interventions for such populations; EEG can show neural changes. When simple auditory stimuli are presented, previous EEG studies have revealed atypical latencies for early ERP components in children with ASD (Marco et al., 2011). The P3 has also received significant attention from previous literature (Ferri, et al., 2003). Ferri et al., (2003) found that N1 had a shorter latency in adolescent boys with ASD in response to a variety of stimuli at different frequencies compared to age-matched controls and that the mismatch negativity – which occurs in the same timeframe as N2 – had a larger (more negative) amplitude in boys with ASD compared to typical controls (Ferri, et al., 2003). An earlier study for ERPs related to auditory stimuli also reported shorter latencies for P1, N1, P2, and P3 and greater amplitude of the P3 to a habituation series of tones (Martineau et al., 1984). In contrast, other studies have shown increased latency of the N1 (Roberts, et al., 2010). The mixed evidence tends to show differences between control groups and groups with ASD however, the direction of that difference is not conclusively established. These inconsistent results may be a consequence of varied paradigm approaches and the heterogeneity of ASD which encompasses numerous presentations and severities of symptoms. Additionally, children with ASD are known to fall along a spectrum from hyporesponsive to hyperresponsive to auditory input which may predict a range of above average to below average ERP amplitudes and latencies. Averaging results may obscure the unique responses of individuals with ASD.

Previous Feasibility Studies

A previous study established feasibility of this study protocol (LaGasse et al., 2019). Recruitment of children with ASD is difficult but possible. Retention for repeated EEG and treatment sessions was good. Furthermore, the protocols of this study are suited to children with ASD (LaGasse et al., 2019). Children with ASD can become more anxious in novel situations such as those of a research laboratory. Care must be taken to reduce a child's anxiety so stress does not contribute to changes in the physiological data (Gavin & Davies, 2008). The Brainwaves Research Lab has had success managing clinical populations of children through EEG testing procedures (Crasta et al., 2016; Davies & Gavin, 2007; Davies et al., 2010; LaGasse et al., 2019). EEG can differentiate between children with sensory processing disorder (SPD) and children without SPD using the registration paradigm (Davies et al., 2010). Given some similarities between the auditory processing in children with SPD and children with ASD (Chang, et al., 2014), it is reasonable to attempt a similar comparison in the latter group.

Purpose of the Study

The purpose of the present study is to investigate auditory processing in children with and without autism spectrum disorder as it relates to attention in comparison with typically developing children. The study also evaluates the impact of a music therapy intervention on attention and auditory processing in children with ASD. This study examined neural differences that may underly dysfunctional behavioral responses that characterize autism. A secondary aim evaluated this specific music therapy treatment protocol for its impact on neural processing as measured by electroencephalography.

The sensory registration paradigm will be used in this study and is a passive listening task to 4 tones of high/low frequency and loud/soft volume. This paradigm allows for examination of early neural responses to sensory input without any task demands which helps establish foundational differences of auditory processing in children with ASD compared to their typically developing peers. Previous neurophysiological studies have shown that with simpler tasks, individuals with ASD can perform at the same speed and accuracy as typically developing individuals but the neural processes are different. When the tasks increase in difficulty, the individuals with ASD perform more poorly than the typical peers (Marco et al., 2011). Although the sensory registration paradigm is not a functional task performance, it does reveal information about different neural processing to simple tasks which may underly functional difficulties to more challenging tasks.

Attention will be measured by the Test of Everyday Attention in Children (TEA-Ch) (Manly et al., 2001). Attentional scores at baseline will be compared between the children with ASD and their TD peers. Attentional scores will also be compared before and after the MT intervention in children with ASD. Neurophysiological measures will include the ERP components: P1, N1, P2, N2, and P3. The music therapy intervention is an individualized protocol administered by a board-certified music therapist (LaGasse et al., 2019).

Previous studies have provided promising results of the impact of music therapy on sensory differences and attentional deficits in children with ASD (LaGasse et al., 2019). LaGasse and colleagues examined data from the sensory gating paradigm which evaluates the ability of the brain to filter out irrelevant stimuli. The addition of the sensory registration paradigm will further increase our understanding of the neurophysiological differences and potential changes after a music therapy intervention by expanding the phases of brain processing (N1, P2, N2, P3) that might be affected in children with ASD. Comparing ERP results with performance on an attention task will also strengthen the link between observable behavior and neural processing.

Research Questions and Hypotheses

Question 1: How will children with ASD before the music therapy intervention compare to age and sex matched TD children on the attention task?

> ***Hypothesis 1:*** Children with ASD will have poorer scores on the attention task compared with TD children at baseline.

Question 2: How do scores on the attention task compare in children with ASD before and after a music therapy intervention?

> ***Hypothesis 2:*** Children with ASD will have improved scores on the attention task after a music therapy intervention compared to before the music therapy intervention.

Question 3: How do ERP component magnitudes and latencies compare between children with ASD before the music therapy intervention and typically developing children?

> ***Hypothesis 3.1:*** Children with ASD will have delayed latencies in N1, P2, N2, and P3 compared to TD children

> ***Hypothesis 3.2:*** Children with ASD with have reduced amplitudes of N1, P2, N2, and P3 compared to TD children.

Question 4: How do ERP components N1, P2, N2, and P3 from the sensory registration paradigm compare in children with ASD before and after a music therapy intervention?

> ***Hypothesis 4:*** Children with ASD post music therapy will more closely resemble TD children compared to the pre music therapy scores in amplitude and latency of N1, P2, N2, and P3.

Question 5: How do scores on the attention task associate with variations in EEG magnitude and latency in the sensory registration paradigm in children with ASD and TD children?

> ***Hypothesis 5*:** Amplitude measures of N1, P2, N2, and P3 components in the sensory registration paradigm to high frequency tones will be significantly associated with attention scores.

CHAPTER TWO

Autism Spectrum Disorder, Sensory Processing, and Attention

Autism Spectrum Disorder (ASD) is a common developmental disorder affecting approximately one in 59 children as of 2014 (Centers for Disease Control and Prevention, 2019). The DSM-5 characterizes it through two criteria: (1) consistent challenges in social interaction/ communication with other people across several settings and (2) restricted, repetitive patterns of behavior, interests, and activities (American Psychiatric Association, 2013). Sensory symptoms have long been associated with ASD, but the DSM-5 is the first version to include them as diagnostic criteria as a form of restricted behavior patterns (Brett, et al., 2016; Grapel et al., 2015). Several studies have demonstrated physiological and structural abnormalities in brains of children with ASD and point toward neurologically informed research approaches to enable children with ASD to succeed (Ha et al., 2015; Silva, et al., 2013). Electroencephalogram (EEG) studies are one way to study sensory processing in individuals with ASD (Dinstein, et al., 2012; Marco et al., 2011).

Sensory processing is the neurological events which occur as a person perceives a sensory stimulus, organizes it, categorizes it, and decides what to do about it (Tomcheck & Dunn, 2007). A common feature of ASD is atypical behavioral reactions to sensory stimuli (LaGasse et al., 2019; Lane, 2020; Liss et al., 2006). Such children may have overreactions, underreactions or other unusual responses to sensory inputs (Dunn, 2001). Sensory processing deficits are a priority treatment area for children with ASD due to the impact on daily participation especially related to school, social difficulties, and language acquisition (Weitlauf et al., 2017). Research remains limited in the efficacy of various sensory interventions used by

OTs (Lane, 2020). The evidence for interventions targeting sensory dysfunction can be strengthened by using well defined and replicable interventions, incorporating standardized measurement tools, and discussion of possible harms as well as benefits of interventions (Schaaf et al., 2014; Weitlauf et al., 2017).

Impaired sensory processing abilities affect multiple kinds of cognitive performance including attention (Bailliard & Whigham, 2017). Three kinds of attention are relevant to this research: selective, sustained, and switching (Heaton et al., 2001). Selective attention is the ability to focus on a target stimulus among an array of distracting stimuli. Sustained attention is the ability to maintain focus on a target over an extended period. Switching attention is fluidly moving focus from one stimulus to another as demanded by the task. An inability to filter stimuli, or a maladaptive pattern of neural response to stimuli may detract from the brain's ability to stay attended to a task (Liss et al., 2006). Currently, there is a lack of definitive linkage between abnormal auditory sensory processing and attentional skills deficits in individuals with ASD (O'Connor, 2012). However, it is known that attentional difficulties and sensory processing are both frequently observed in children with ASD, so a link is suspected (Butera et al., 2020).

Music Therapy: History and Overview with ASD

Music therapy (MT) for ASD began in the 1940's as part of a shift toward a holistic treatment model (Reschke-Hernandez, 2011). Evidence for the efficacy of music therapy for children with ASD is limited but promising (Geretsegger et al., 2012; LaGasse et al., 2019; Reschke-Hernandez, 2011; Simpson & Keen, 2011). Music is engaging to children with ASD and previous studies have shown that engagement with music improves attention control and selective attention (Pasiali et al., 2014). Physiological measurements to complement behavioral measures to evaluate MT interventions will add more and novel evidence for the efficacy of MT

(LaGasse et al., 2019; Pasiali et al., 2014). Electroencephalography is emerging as one such physiological measure (LaGasse et al., 2019; Pasiali et al., 2014).

Electroencephalography (EEG)

EEG is a recording of voltage variation in the brain as read through electrical leads placed on the scalp (Coles & Rugg, 1995). EEG studies of auditory processing use various *paradigms* or presentations of specific stimuli in specific patterns with or without an associated response task or attention direction. The sensory registration paradigm used in this study is a passive presentation of four tones of high/low intensity and high/low frequency (Lincoln et al., 1995). Multiple responses to the same tone are averaged to reduce background noise and create an event related potential (ERP). The ERP components of interest, the P1-N1-P2-N2-P3 complex (discussed below), correspond to sensory processing in the auditory cortex and early categorization/recognition of the tones (Polich, 1993).

The N1 is thought to represent selective attention and is often evoked by a sudden change in auditory environment (Polich, 1993). It is thought to be affected by the suddenness of the stimulus onset as well as the intensity of the sound and may be connected to attention switching (LaGasse et al., 2019; Remijn et al., 2014). The P2 varies with sound intensity and frequency and typically indicates registration of the stimulus as the brain begins to categorize and define the stimulus (Remijn et al., 2014). The N2 is also sensitive to sound characteristics like intensity (Remijn et al., 2014). The P3 is linked with memory updating due to changes in the stimulus environment such as when a different tone is presented (Polich, 1993). Others have characterized it as reflecting "attentional engagement" with a stimulus (Remijn et al., 2014, p. 232).

Individuals with ASD have altered processing of stimuli at the neural level (Brett, et al., 2016; O'Connor, 2012; Crasta et al., 2020; Kown et al., 2007; Marco et al., 2011; Whitehouse &

Bishop, 2008). Results, however, are inconsistent and do not create a clear picture of neurologic sensory processing. These inconsistent results may be a consequence of varied paradigm approaches and heterogeneity of ASD which has diverse symptom presentations and severities. In response to simple auditory stimuli, children with ASD have atypical latencies for early ERP components (Marco et al., 2011). Ferri et al. (2003) found a shorter N1 latency in boys with ASD and a larger amplitude mismatch negativity compared to typical controls. A different study reported shorter latencies for P1, N1, P2, and P3 and greater amplitude of the P3 to a habituation series of tones in children with ASD (Martineau et al., 1984). In contrast, some studies have shown increased latency of the N1 (Roberts, et al., 2010). The mixed evidence shows differences between children with ASD and typical controls, however, the degree and direction of those differences are not established. Therefore, the purpose of this study is to continue adding to understanding of neural auditory processing in children with ASD as it relates to attention and examining the impact of a music therapy intervention on both auditory neural processing and attention.

Previous Feasibility Studies

A previous study established feasibility of this study protocol (LaGasse et al., 2019). Recruitment of children with ASD was possible; retention for repeated EEG and treatment sessions was satisfactory; the protocols are suited to children with ASD (LaGasse et al., 2019). Children with ASD can be anxious in novel situations such as those of a research laboratory, but adjustments can reduce a child's anxiety so stress does not impact physiological or behavioral data (Gavin & Davies, 2008). The Brainwaves Research Lab has success managing pediatric clinical populations during EEG testing (Crasta et al., 2016; Davies & Gavin, 2007; Davies et al., 2010; LaGasse et al., 2019). EEG can differentiate between children with sensory processing disorder (SPD) and children without SPD using the registration paradigm (Davies et al., 2010). Given some similarities between the auditory processing in children with SPD and children with ASD (Chang, et al., 2014), it is reasonable to attempt a similar comparison in the latter group.

Research Questions

Question 1: How will children with ASD before the music therapy intervention compare to age and sex matched TD children on the TEA-Ch.

Question 2: How do scores on the TEA-Ch compare in children with ASD before and after a music therapy intervention.

Question 3: How do ERP magnitudes and latencies compare between children with ASD and typically developing children?

Question 4: How do ERP components N1, P2, N2, and P3 from the sensory registration paradigm compare in children with ASD before and after a music therapy intervention?

Question 5: How do measures of attention on the TEA-Ch scores associate with variations in EEG magnitude and latency in the sensory registration paradigm in children with ASD and TD children?

Methods

Participants

A total of ten children ages six to twelve years with mild ASD were recruited for this study. Children with ASD having additional diagnoses such as down syndrome, epilepsy, hearing loss, or psychological disorders were excluded from the study. A convenience sample of typically developing children were recruited from the community. From the group of typically developing children who completed the sensory registration paradigm and behavioral testing, age and sex matched peers were selected to compare with the children with ASD (Table 1). Parents provided consent and children were asked to assent to the study procedures prior to data collection. Children were compensated with a commemorative T-shirt, mug, option for a $15 cash and parents were given $25 in cash for travel expenses.

Table 1.

Age and sex of study participants

Children with ASD		Paired TD Children
Age (years)	Sex of pair	Age (years)
4.63	Male	5.09
5.42	Male	5.74
6.51	Male	6.75
6.92	Female	7.37
8.40	Male	8.47
9.56	Female	9.42
10.09	Female	10.30
11.38	Male	9.30
11.48	Male	9.85
12.61	Male	10.50

Procedures

All procedures were approved by the IRB of Colorado State University. Children with ASD participated in two pretest and two posttest testing sessions including behavioral measures (TEA-Ch) and neurophysiological measures (EEG recordings). All children with ASD participated in an individual music therapy intervention between the pre and post testing sessions (described below). TD children participated in a single data collection session for the behavioral and EEG measures and did not participate in the music therapy intervention. The TD children served as a comparison group.

Data collection occurred at the Brainwaves Research Lab at Colorado State University. Behavioral measures and EEG testing was conducted by Brainwaves Research Lab faculty and research assistants representing members from the Occupational Therapy department, music therapy program, and neurosciences program at Colorado State University. Each of the testing sessions lasted two hours. During testing sessions, the child performed passive listening activities for EEG data to be gathered lasting about one hour and completed behavioral testing lasting about one hour. The first music therapy intervention occurred within two weeks of the pre-testing sessions. The music therapy intervention occurred biweekly over five weeks for a total of ten sessions. After completion of the music therapy program, children returned for an additional two testing sessions.

Music Therapy Intervention

The music therapy intervention (ten 35-min sessions biweekly for five weeks) was designed and conducted by a board-certified music therapist. Parents were present for music therapy sessions but did not participate. The protocol was based on a neurodevelopmental framework to target neural networks involved in attention. Sessions included musical activities targeting attentional skills focusing on selective attention and switching attention. Children played instruments while ignoring distracting stimuli to target selective attention. Switching/attention control was targeted with activities that required the child to continue with melodic sequence while attending to other stimuli and by playing different sequences in response to changes by the music therapist. Each session was adjusted by the interventionist to be appropriate for the child's age and cognitive abilities and adjusted to actively engage the child. Sessions progressed in difficulty throughout the intervention to maintain a 'just-right challenge'. Despite alterations to the specific activities, the goals and principles were held sufficiently consistent by the interventionist for fidelity to the study protocol.

EEG Set Up

During EEG data collection, the child was briefed about the EEG recording process. Research assistants applied the EEG cap. Water based gel is used to conduct electrical signals from the brain through metal sensors in the EEG stretch cap. Research assistants ensured proper conductance through each channel before proceeding. Children were fitted with in-ear headphones. Children were positioned in a chair in front of the computer. The chair height was adjusted to an appropriate height for each child. Footstools were used to support the child's feet in a comfortable position. Research assistants provided children strategies to reduce movement and blinking and thus reduce artifacts during the recording. Children practiced staying still while watching the EEG tracing to better understand how to reduce unwanted artifact.

A silent video of *Wallace and Gromit* played during the listening activities to help the child stay calm and quiet. Children participated in two passive listening paradigms: sensory registration and sensory gating. Each paradigm lasted approximately twenty minutes and was followed by a three minute break. The sensory registration paradigm data are addressed in this paper. The sensory gating paradigm data were written up in a previous publication from the Brainwaves Research Lab (LaGasse et al., 2019).

Measures

Sensory Registration Paradigm

The sensory registration paradigm used in this study is adapted from Lincoln et al. (1995) and previous work by the Brainwaves Research Lab (Davies et al., 2010; Davies & Gavin, 2007). The registration paradigm aims to examine neurological reaction to stimuli of varying frequency and intensity. This paradigm is a passive listening activity in which four total tones are presented through in-ear headphones in random order. The auditory stimuli were presented with E-prime software (Psychological Software Tools, Pittsburgh, PA, USA) in both ears. A total of four blocks of stimuli were presented with 100 stimuli per block. Interstimulus interval (ISI) was two seconds. Stimulus duration was 50-ms with 10-ms rise and fall times. The four tones were 1 kHz at 50 dB SPL, 1 kHz at 70 dB SPL, 3 kHz at 53 dB SPL and 3kHz at 73 dB SPL. Each block of 100 stimuli lasted 3.4 minutes. Participants were given a 30 second rest between blocks to blink and shift in the chair.

EEG Data Acquisition

EEG recordings were obtained with BioSemi Active Two EEG Acquisition system. Thirty-two Ag-AgCl sintered electrodes were placed based on the American Electroencephalography Society guidelines (American Electroencephalographic Society, 1994). The common mode sense (CMS) and the driven right leg (DLR) electrodes were used to generate a reference voltage (http://www.biosemi.com/faq/cms&drl.htm). Flat electrodes were placed on the left and right earlobes, left and right outer canthus of the eye – for horizontal electrooculograms (EOGs), and left supraorbital and infraorbital regions – for vertical EOGs. Data were sampled at a rate of 1024 Hz.

ERP Component Analysis and Scoring

Raw data from the EEG recordings was processed with the Brain Vision Analyzer software. The average channels on the earlobes were used for the off-line The EEG was filtered using a .23 –.30 Hz band pass. The EEG was segmented (separately for each of the four tones) from 200ms pre stimulus onset to 800 ms post stimulus onset. The segments were baseline corrected from the average voltage of 200 ms preceding the stimulus onset. Eye movement artifacts were removed using a regression approach based on the VEOG channel using customized MATLAB code (Segalowitz, 1996) then baseline-corrected again using the period of 200 ms preceding the stimulus onset. Segments were rejected if they showed deviations greater than 100 μV. For each participant, averaged ERPs were created for each of the four tones.

The averaged ERP data was imported into software created in the Brainwaves Research Lab for automated peak picking while allowing for visual inspection and adjustment of the peak. The software selected the P1, N1, P2, N2 and P3 peaks for each of the Fz, Cz, and Pz channels. Visual inspection by author confirmed the correct selection of peaks within defined windows for each channel and to ensure appropriate peak choice and adjustments were made as needed. Final peak selection and scoring was reviewed and confirmed by lab director. Latencies and polarities used to identify ERP components are presented in Table 2.

Table 2.

ERP Component polarity and latency window for selecting peaks

Component	**Polarity**	**Latency Window (ms)**
P1	Positive	20 to 80
N1	Negative	70 to 170
P2	Positive	130 to 270
N2	Negative	200 to 375
P3	Positive	250 to 450

Note. ms = millisecond

Following peak picking, the MATLAB program stores individual amplitudes and latency of peaks in an ACCESS database for each participant for each of the four tones. Peak-to-peak amplitudes were calculated as the difference between the previous peak and the peak being calculated. For instance, the amplitude of the P3 is defined as the difference in amplitude between the N2 and the P3. A topographical map of the voltage distribution across the scalp was used to select the best electrode site for each component (Figure 1). The Cz channel demonstrated maximal peak intensity for the N1, P2, and N2. The Pz channel was chosen for P3 due to the more posterior distribution of electrical activity during that window.

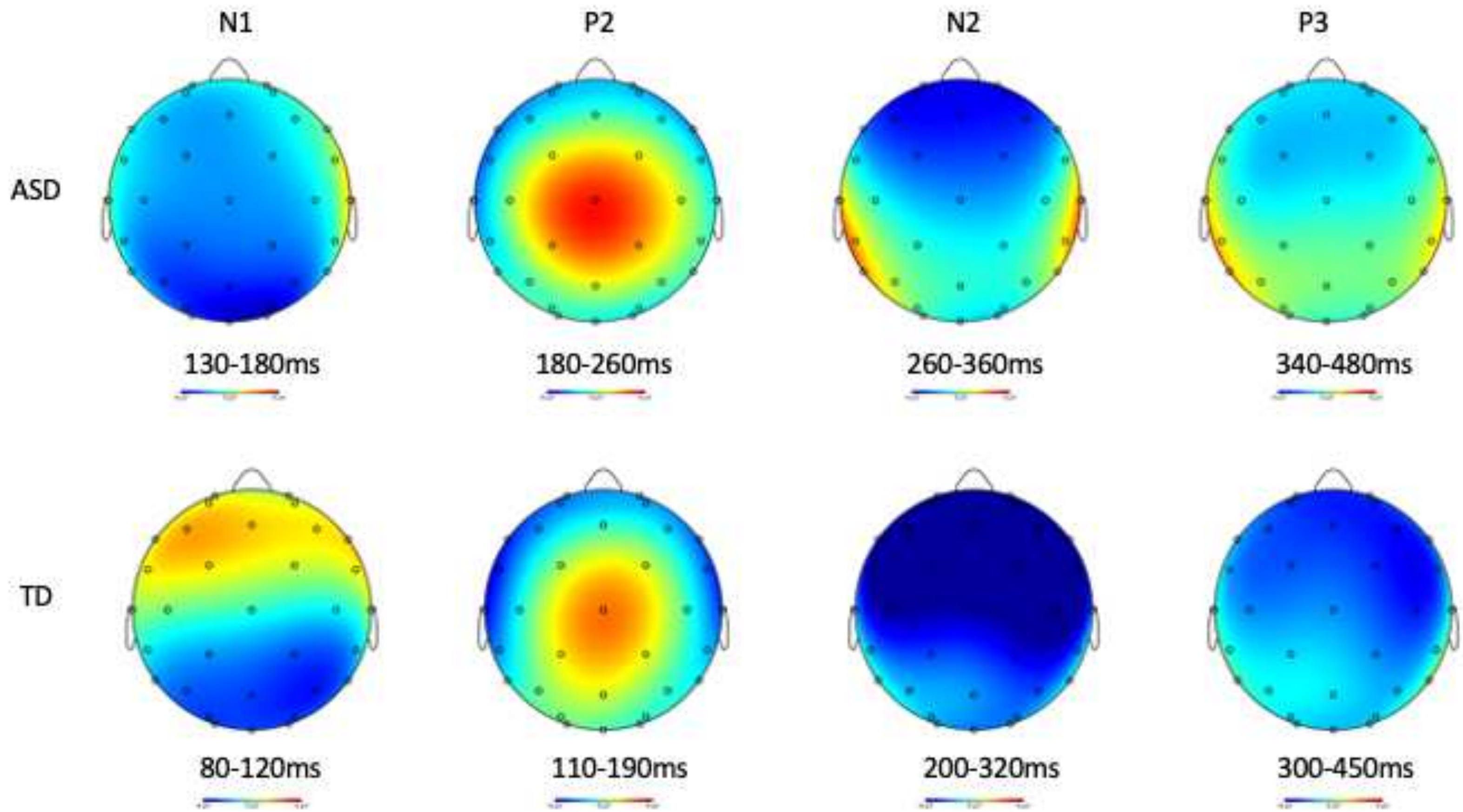

Figure 1.
Scalp topography for ERP components in children with ASD (top row) and TD children (bottom row) in response to 3kHz 73dB tone over indicated time period. Selection windows were adjusted for children with ASD to account for increased latency and capture grand averaged peaks. Cz was chosen as the best site for N1, P2, and N2 components. Pz was chosen as the best site for P3 component.

TEA-Ch

The Test of Everyday Attention for Children (TEA-Ch) is a measurement tool consisting of nine subtests addressing several components of attention: selective attention, sustained attention, and attentional control/switching (Manly et al., 2001). The TEA-Ch has 9 subtests designed like games each addressing one of the three types of attention**.** Five subtests measure sustained attention. Two subtests measure selective attention. Two subtests measure attentional control/switching. The TEA-Ch requires approximately one hour to complete. Two versions exist to allow retesting without learning effects. Validity measures, reliability measures and normative data has been collected from children of all ages (Manly et al., 2001). Test-retest reliability ranges from 0.57 to 0.87 across the nine subtests. The TEA-Ch has adequate concurrent validity with other attentional measures including the Stroop Task, Trails Test, Matching Familiar Figures Test (Manly et al., 1999). Each subtest begins with ensuring the child understands the instructions through practice. If a child is unable to perform the task during the practice or is unable to understand the instructions, the subtests can be skipped. Raw scores on each subtest are converted into scaled scores ranging from one to twenty with higher scaled scores indicating better performance. The conversion from raw to scaled score factors in the child's age and sex. Scaled scores for subtests are added together to create an overall scaled score for each attention domain and for a total attention score.

The five subtests of the TEA-Ch which measure sustained attention are *Score!, Score DT, Code Transmission, Walk Don't Walk,* and *Sky Search DT*. The two subtests that measure selective attention are *Sky Searc*h and *Map Mission.* The two subtests that measure attentional control/switching are *Creature Counting* and *Opposite worlds*. A description of each subtest is available in Appendix 1.

Statistical Analysis

To answer the first research question, independent sample *t*-tests were used to compare TEA-Ch scores of children with ASD at baseline to TD children. For the second research question, paired *t*-tests were used to compare pre and post scores of children with ASD. Tests were conducted for overall scores as well as the three sub-scores. Scaled scores were used for all statistical testing of TEA-Ch data.

For the third research question, independent *t*-tests were performed to compare both latencies and amplitudes of ERP components across all four tones and all four components between children with ASD and baseline and TD peers. For the fourth research question, paired *t*-tests were conducted to compare EEG data before and after the music therapy intervention for both amplitude and latency across the four tones and four components. Age was used as a covariate in an ANOVA for pre/post testing for the P3 component which does vary with age.

For the fifth research question, correlation matrices were created for the latencies of the N1, P2, N2, and P3 at each of the four tones with each measure of attention (selective, switching, sustained, and total). From the resultant correlation matrix, the variables with the most significant correlations were selected for further regression analysis. ERP component latencies were input as dependent variables and attention measures were input as independent variables. Age was also included as an independent variable. Also for the fifth research question, a linear regression analysis was conducted to predict P3 amplitude by total attention as well with selective attention. A bivariate correlation and a partial correlation using age as a covariate was done with the P3 component and with the attention scores at the 3kHz 73dB tone. All analyses were conducted using IBM SPSS v26. Significance thresholds were set at 0.05 and not corrected despite the multiple statistical tests conducted due to exploratory nature of this research.

Results

Behavioral Performance Measures

Baseline Comparisons of Attention Between ASD and TD groups

Baseline scores on the TEA-Ch are presented in Table 3. Comparisons were made using the scaled scores in the three subdomains of attention (selective, switching, sustained) as well as overall (or total) attention between the two groups. Data were determined to violate assumptions of normality and so a *t*-test and a nonparametric Mann-Whitney U test were both performed to compare differences between groups. Both the *t*-test and the Mann-Whitney U test showed the same pattern of significant differences between the two groups thus parametric statistics are reported with effect sizes (Table 3). Children with ASD had overall poorer performance than TD peers prior to the music therapy intervention. Significant differences were found in selective, sustained, and total attention. Children with autism did perform more poorly in switching attention as well but the difference was not statistically significant. Large effect sizes are seen in selective (d = 1.34), sustained (d = .1.46), and total attention (d = 1.44), indicating these differences may be clinically important for diagnosis, intervention, and assessment.

Table 3.

Comparison of Behavioral Measures of Attention at Baseline Between ASD and TD Groups

	Children with ASD (n=10)	TD Children (n=10)	Results of *t*-test			
TEA-Ch scaled scores	*M (SD)*	*M(SD)*	*t* value	*df*	*p*-value	*d*
Selective	14.1 (4.2)	19.0 (3.0)	2.97	18	.009**	1.34
Switching	14.9 (6.6)	17.1 (3.5)	0.93	18	.370	.416
Sustained	25.7 (13.8)	42.7 (9.0)	3.26	18	.005**	1.46
Total	54.7 (19.8)	78.7 (12.7)	3.24	18	.005**	1.44

Note. *M* = mean; *SD* = standard deviation; *d* = effect size.
* $p<0.05$. ** $p<0.01$

Efficacy of Intervention on Measures of Attention in ASD Group

A paired *t*-test was used to compare the scaled scores of children with autism before and after the intervention in the three attention domains and the total attention. Scaled scores and results of *t*-test are presented in Table 4.

Table 4.

Within Subjects Comparison of Attention Before and After Music Therapy

	Children with ASD Pre MT (n=10)	Children with ASD Post MT (n=10)	Results of t-test			
TEA-Ch scaled scores	*M (SD)*	*M(SD)*	*t* value	*df*	*p*-value	*d*
Selective	14.1 (4.23)	19.60 (7.52)	-2.64	9	0.027 *	0.84
Switching	14.90 (6.64)	15.90 (7.97)	-0.87	9	0.409	0.27
Sustained	25.70 (13.81)	25.90 (13.53)	-0.12	9	0.911	0.04
Total	54.70 (19.81)	61.40 (22.58)	-1.49	9	0.171	0.47

Note. M = mean; *SD* = standard deviation; *d* = effect size.
* $p<0.05$. **$p<0.01$

The children with ASD showed improved performance on the TEA-Ch assessment following the music therapy intervention. A significant difference was found only in the domain of selective attention. In all other domains and in total attention, there was a mean improvement in attention scores, however, it did not rise to the level of significance. Effect sizes were large for selective attention (*d*=0.84), medium for total attention (*d*=0.47) and small for switching attention (*d*=0.27). These effect sizes indicate that despite the lack of significance for switching attention and total attention, the degree of improvement in attention scores overall as a result of the music therapy intervention may be clinically important and warrants further investigation.

Neurophysiological Measures

Descriptive statistics for amplitudes and latencies of the N1, P2, N2, and P3 components are presented in Table 6 for children with ASD and the typically developing group at baseline as well as children with ASD following the music therapy intervention for all four tones in the sensory registration paradigm. Grand average ERPs for TD children, children with ASD pre-MT and children with ASD post-MT are shown for the Cz and Pz sites in Figures 2 and 3 respectively. As illustrated in Figure 2 grand averages at Cz shows larger amplitude responses at N1 and P2 to the higher volume tones compared to the lower volume tones for all three groups. Additional visual inspection shows delayed latencies of components in children with ASD compared to the TD group at baseline.

Comparisons using *t*-tests were made to explore significant differences both at baseline and at pre/post measures. Few significant results were found in these comparisons at $p<0.05$ significance level. In baseline comparisons (children with ASD before music therapy and TD children), a significant result was longer latency of the P2 component in children with ASD at the 1kHz 70dB tone ($t_{(18)} = -2.885$, $p=.01$) and the 3kHz 53dB tone ($t_{(18)}=-2.09$, $p=.05$) tones. The N2 component also had a significantly longer latency in children with ASD for 1kHz 70dB ($t_{(18)}=-2.25$, $p = .04$).

Based on previous results from this lab and visual inspection of grand averaged ERPs, an ANOVA was used to examine the amplitude of the P3 component at the loud high frequency tone (3kHz, 73 dB) from pre to post test in children with ASD (Davies et al., 2010; Gavin et al., 2011). Using age as a covariate there was a significant decrease in the amplitude of the P3 from pre to post testing. There was a main effect of group ($F_{(1,8)}=5.96$, $p= .041$) and an interaction effect of group X age ($F_{(1,8)}=10.79$, $p = .011$). Effect sizes for this comparison were large for both the main effect ($\eta^2=0.43$) and for the interaction effect ($\eta^2=0.57$). No additional significant results were found using paired *t*-tests with pre and post data for children with ASD.

Because of apparent trends in latency, a correlation matrix was run with ERP component latencies at each tone and each measure of attention. The most significant correlations from the matrices were chosen for further regression analysis. All significant correlations were found in relation to the 1kHz 70 dB tone. The most significant correlations, and the variables chosen for further analysis were: N1 latency with selective attention, P2 latency with selective attention, P2 latency with sustained attention, and N2 latency with selective attention. The latency measure was put in the first model and age was added in the second model. The results for these regression analyses are shown in table 5. Age was not a significant predictor for any of the regression analyses, so only the first model for each regression is reported here. N1 latency for the 1kHz 70dB tone accounted for 21.1 percent of the variance of selective attention, $R^2 = 0.211$, adj $R^2 = 0.165$, $F(1,17) = 4.549$, $p = 0.480$. P2 latency for the 1kHz 70dB tone accounted for 21.1 percent of the variance of selective attention, $R^2 = 0.211$, adj $R^2 = 0.165$, $F(1,18) = 3.693$, $p = 0.071$. P2 latency for the 1kHz 70dB tone accounted for 22.0 percent of the variance of sustained attention, $R^2 = 0.220$, adj $R^2 = 0.177$, $F(1,18) = 5.074$, $p = 0.037$.N2 latency for the 1kHz 70dB tone accounted for 31.4 percent of the variance of selective attention, $R^2 = 0.314$, adj $R^2 = 0.276$, $F(1,18) = 8.234$, $p = 0.01$.

Based on previous lab findings and the significant ANOVA test reported above, the P3 component was chosen as the most likely to have a significant correlation with attention measures. A correlation of the P3 amplitude with total attention and with selective attention were run both in the baseline groups and in the post MT group with no significant findings ($p>0.05$). Using age as a covariate did not change the results.

Table 5.

Summary of regression models comparing measures of attention with latency of ERP components at 1kHz 70dB tone

			Model Statistics			**Standardized Coefficient of the latency variable**
Dependent Variable	**Independent Variable**	R^2	***Adjusted R***	F	p	β
N1 Latency	Selective Attention	.211	.165	4.549	.048*	-.459
P2 Latency	Selective Attention	.170	.124	3.693	.071	-.413
P2 latency	Sustained Attention	.220	.177	5.074	.037*	-.469
N2 Latency	Selective Attention	.314	.276	8.234	.010*	-.560

Note. * $p<0.05$.

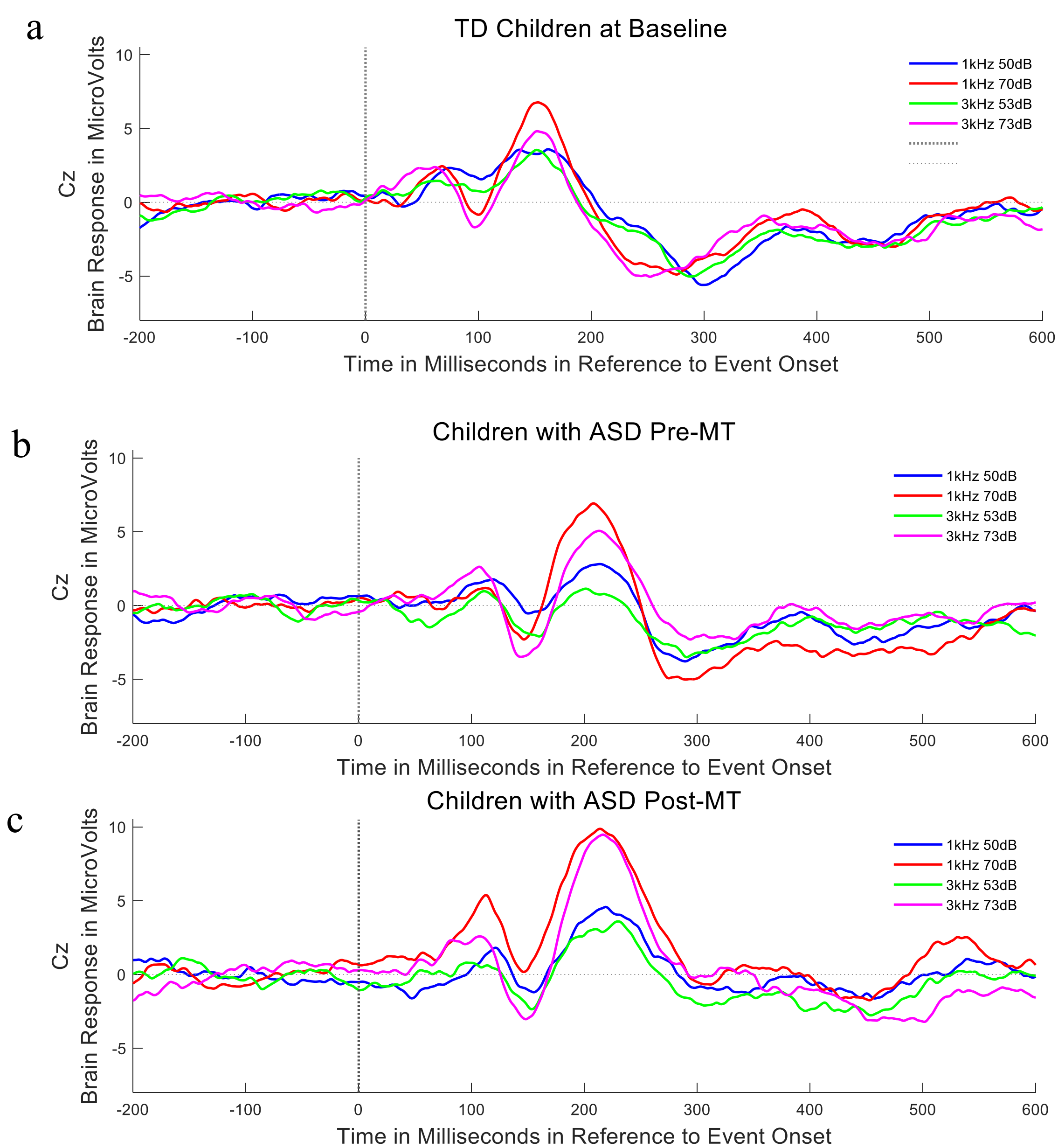

Figure 2.

Plots of Grand Averaged ERPs from Cz Sensor Site: (a) TD Children at Baseline; (b) Children with ASD at Baseline Period Before Music Therapy Intervention; (c) Children with ASD Post Music Therapy Intervention. Each line corresponds with one of the 4 tones.

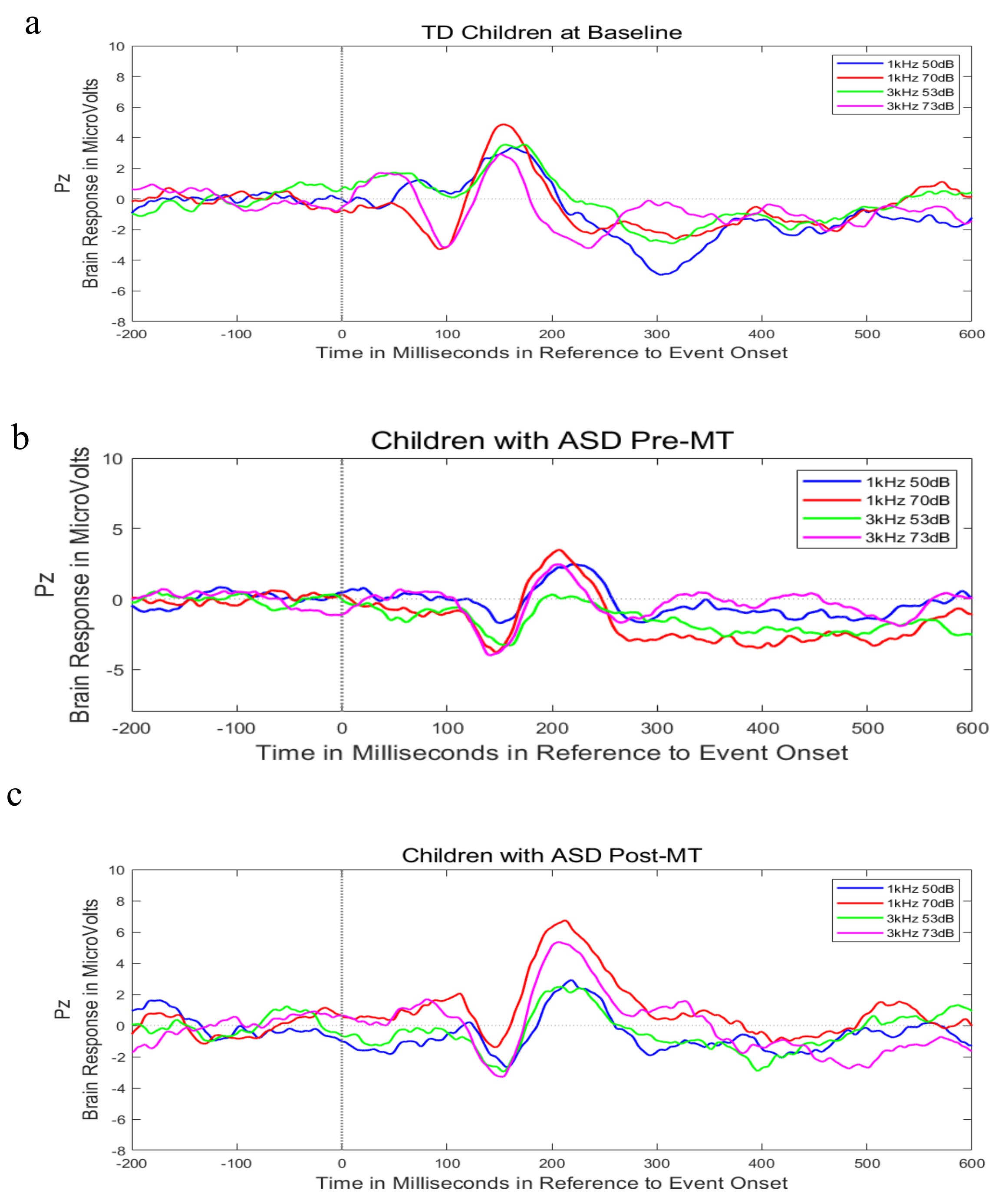

Figure 3.

Plots of Grand Averaged ERPs from Pz Sensor Site: (a) TD Children at Baseline; (b) Children with ASD at Baseline Period Before Music Therapy Intervention; (c) Children with ASD Post Music Therapy Intervention. Each line corresponds with one of the 4 tones.

Table 6

Average Amplitudes and Latencies of each ERP component at each tone in all three groups

	Tone	1 kHz at 50 dB SPL		1 kHz at 70 dB SPL		3 kHz at 53 dB SPL		3kHz at 73 dB SPL	
		Amplitude	Latency	Amplitude	Latency	Amplitude	Latency	Amplitude	Latency
		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)	
N1	TD Children	-4.07 (2.57)	113.93 (26.81)	-6.77 (6.42)	104.81 (21.02)	-3.40 (2.16)	99.12 (25.36)	-7.53 (4.90)	106.44 (24.33)
	ASD Pre MT	-4.90 (2.64)	119.63 (41.47)	-6.92 (3.66)	121.68 (32.79)	-6.00 (4.21)	123.34 (43.30)	-9.87 (5.11)	128.17 (34.49)
	ASD Post MT	-4.59 (2.25)	135.55 (45.47)	-6.41 (3.76)	114.06 (37.88)	-5.47 (2.52)	143.46 (15.90)	-9.39 (3.76)	145.14 (8.72)
P2	TD Children	6.31 (4.44)	160.35 (29.44)	11.92 (15.89)	153.32 (28.91)	5.80 (3.69)	158.50 (27.75)	10.30 (11.29)	158.5 (27.75)
	ASD Pre MT	9.39 (3.48)	187.50 (41.66)	14.29 (8.44)	196.29 (37.17)	8.41 (4.41)	187.30 (45.05)	14.10 (7.53)	187.30 (45.05)
	ASD Post MT	9.56 (3.24)	198.93 (45.14)	14.20 (7.92)	184.47 (48.60)	8.13 (3.37)	208.60 (26.71)	12.42 (3.58)	208.59 (26.71)
N2	TD Children	-12.24 (5.70)	291.02 (37.70)	-15.87 (9.42)	270.61 (35.51)	-11.23 (3.95)	276.56 (27.92)	-15.00 (8.34)	269.82 (53.20)
	ASD Pre MT	-12.14 (4.36)	305.27 (33.57)	-16.79 (9.78)	310.16 (42.77)	-10.05 (5.95)	309.57 (47.43)	-12.99 (6.06)	295.02 (59.73)
	ASD Post MT	-9.73 (4.86)	298.24 (53.91)	-15.49 (6.54)	347.95 (80.13)	-9.32 (5.50)	325.49 (65.99)	-15.24 (6.63)	339.75 (65.88)
P3	TD Children	7.50 (2.35)	423.14 (87.93)	7.73 (3.50)	411.23 (123.02)	6.05 (1.98)	462.70 (86.67)	8.39 (2.42)	404.59 (88.81)
	ASD Pre MT	6.50 (2.85)	435.64 (82.34)	6.10 (2.72)	402.83 (86.28)	6.24 (2.61)	432.71 (91.74)	7.57 (3.11)	418.55 (77.50)
	ASD Post MT	6.29 (3.01)	422.66 (73.71)	7.41 (2.98)	463.18 (101.41)	6.54 (3.23)	458.40 (93.33)	5.58 (2.26)	394.53 (74.34)

Note: SD=standard deviation

Discussion

The purpose of this study was (1) to investigate differences in children with ASD and typically developing peers in behavioral and neurophysiological measures of attention and auditory processing and (2) to examine the impact of a music therapy intervention on those measures in children with ASD. Findings from this study demonstrated that children with ASD performed significantly more poorly in most attention domains. Attention scores significantly improved in the domain of selective attention following therapy music therapy intervention in children with ASD. Comparing neurophysiological measurements at baseline between groups demonstrated that children with ASD had longer latencies at P2 and N2 in response to some of the tones compared with TD peers. Following the music therapy intervention, children with ASD showed a significant decrease in the amplitude of the P3 in response to the 3kHz 73dB tone when age was used as a covariate suggesting that music therapy had an impact on how the children with ASD processed that auditory stimulus.

Behavioral Measures

Baseline Comparisons of Attention between TD and ASD Groups

As expected, children with ASD did perform significantly more poorly on measures of attention at baseline compared to TD children. The results of this current study included data from three additional participants who were not included the analysis of LaGasse et al. (2019) which performed the same testing. LaGasse et al. (2019) found significant differences in selective and total attention but not in sustained nor switching attention. In addition to selective attention and total attention score, this current study found an additional significant difference in sustained attention between the groups. The large effect sizes found in the comparisons indicate that the difference in attentional abilities between the two groups at baseline is clinically significant. It is known that children with ASD have difficulty with attention (Butera et al., 2020). These attentional difficulties can cause challenging behaviors in childhood occupations especially in school (Weitlauf et al., 2017). These baseline differences were expected and confirm that the TEA-Ch is sensitive to the differences in attention skills between the groups and thus a useful tool to measure improvements as the result of intervention.

Sustained Attention. Children with mild ASD are often described as having above-average ability to focus on preferred tasks for extended periods of time without being distracted – i.e., sustained attention (APA, 2013). However, their attentional abilities are highly dependent on their interest in the task. We found that children with ASD performed significantly more poorly on the standardized assessment of sustained attention. Although the authors of the TEA-Ch designed the tasks to be engaging and appropriate for children, they may not fit with restricted interests of a child with ASD (Liss et al., 2006). Typically developing children were more able to sustain their attention on the activities required by the TEA-Ch in order to complete the tasks more accurately and quickly.

Selective attention. Children with ASD had significantly poorer performance in selective attention than their TD peers. This observation aligns with knowledge that children with ASD have less ability to filter out irrelevant stimuli during task performance unless they are highly engaged and interested in the task (Liss et al., 2006). The published study of this protocol found less robust sensory gating in children with ASD indicating that they have greater difficulty filtering stimuli during early neurological processing (LaGasse et al., 2019). That finding and the known traits of ASD predict the differences in selective attention that were found in this analysis.

As with many standardized assessments, the TEA-Ch may not capture true performance in a natural context. For children with ASD, attention is influenced by individual preference for the activities and stimuli around them. Their scores on selective attention may have been greater if the assessment used preferred activities or interest areas. But occupational performance in childhood roles is not limited to preferred activities. Children are expected to sustain focus and attend to tasks that they do not enjoy especially in school. However, the results observed in this study align with what is known about children with ASD and attentional skills and deficits. The differences in baseline performance between the two groups on this measure do support its use as a progress measure of overall and specific domains of attentional skills.

Switching attention. A characteristic common to children with ASD is difficulty changing focus from one task to another. We would expect to find significantly poorer scores for children with ASD in switching attention compared to the TD peers. However, this sub-score was not significantly different between the two groups. This finding is counter to what was expected. It may be the case that children with ASD struggle to shift their attention only when performing a preferred activity, instead of performing during a standardized assessment. The lack of significance in this domain of attention as measured by the TEA-Ch is an indicator that attention measured by this standardized assessment may not necessarily reflect a child's ability to perform tasks requiring attentional switches in daily occupations or natural contexts.

Efficacy of Intervention on Measures of Attention in ASD Group.

Children with ASD only improved significantly in selective attention scores. This lack of significance across the other domains may be due, in part, to the large standard deviations and small sample size. The wide age range of the participants could have introduced some additional variability, however scaled scores are calculated based on age and sex normed data which should reduce the variability due to age. Comparison of scaled scores within subjects does fail to capture improvements in the lowest and highest ends of the score range. Raw score comparisons were attempted in order to capture smaller differences in performance than scaled scoring. However, the sub-tests of the TEA-Ch are not uniform in scale, nor unit, nor in which direction (smaller or larger scores) a change indicates an improvement in performance. Scaled scores must first be calculated and then summed to produce scores on the three domains of attention and the overall attention score. Comparing scaled scores may fail to capture all important improvements. Scaled scores are calculated based on a child's age with age blocks spanning a two-year window. One child with ASD moved into a higher age block from pre- to post-testing; improved raw scores resulted in lower scaled scores due to the higher age group. In some cases, children with ASD improved their raw score but not enough to move into a different scaled score due to raw-score cutoffs for the lowest scaled score. A scaled score of 1 – indicating performance at or below the bottom 5th percentile requires a larger gain in raw score performance to increase to the next scaled score. A child who performs significantly below the norms can receive a scaled score of 1 during their pre and post-test despite a large improvement in the raw score for the subtests.

Despite the limitation of the small sample size and use of scaled scores, the children with ASD did show improvement in all domains even though it was not statistically significant. These results indicate that with a larger sample size and with more complex statistical analysis to overcome the challenge of using scaled scores there may be additional statistically significant improvements in the attention scores.

Selective attention was specifically targeted by the music therapy intervention. The interventionist tasked children with play instruments while ignoring extraneous stimuli intended to be a distraction. The significant improvement in selective attention as measured by the TEA-Ch could indicate that the approach taken in the music therapy sessions successfully targeted selective attention skills which are important for all manner of occupational tasks in natural contexts. It is a promising finding that practice with selective attention in a specific context (playing and listening to music) may translate to general skill with this type of attention.

Neurophysiological Measures

Baseline Comparisons of Neurophysiologic Measures Between ASD and TD Groups

Few significant differences were found between the typically developing children and the children with ASD at baseline in neurophysiological measures. All statistically significant differences were in comparisons of latencies and not amplitudes. Across all 4 tones, children with ASD had greater latencies for the N1, P2, and N2 components, although these differences with TD group were not significant. The consistent delayed latency of components observed in response to the sensory registration paradigm indicate that children with ASD may take longer to process and recognize a simple auditory stimulus in passive listening tasks. Due to the lack of significant results, and small sample size, further research is warranted using this paradigm and a larger and more diverse sample. If such a delay is reflective of true differences found in children with ASD, the processing of auditory environmental stimuli not under conscious attention is delayed.

These results do align with previous results from studies using EEG in children with ASD (Marco et al., 2011; O'Connor, 2012). Previous findings have shown mixed results of increased or decreased latency of early components and appear dependent on the paradigm and circumstances of testing. Shorter latencies have been observed to the N1 under oddball paradigms (Ferri et al., 2003). The oddball paradigm, however, is a more active task in comparison with the sensory registration paradigm used here. Children with sensory processing disorder (SPD) have similar trends of increased latency at the N1 and P2 to the sensory registration paradigm (Davies & Gavin, 2007). Children with SPD can have similar behavioral challenges related to attention and auditory processing as children with ASD (Chang et al., 2014). The increased latency of processing may indicate that a simple stimulus consumes neurological resources for a longer time which could lead to more difficulty processing stimuli of greater complexity or within a stimulus-rich environment.

Children with ASD generally had a reduced N1 amplitude and then an increased P2 amplitude. This finding could indicate that neural processing is shifted toward the later components with less energy devoted to the earlier components. The N1 is often described as an initial orientation to the stimulus (O'Connor, 2012). The P2 occurs as the brain begins more work classifying and defining the stimulus (Remjin et al., 2014). The reduction of N1 and enlargement of the P2 in children with ASD indicates these children have less orienting response and then a greater processing response. An initial, more automatic, and unconscious, processing is reduced requiring greater processing in the later stages where it is more conscious and could interfere more with cognitive processes and behavior including attention. This could also relate to the possible slower neural responses that may be seen in children with ASD.

The P3 component did not reveal any consistent patterns across the 4 tones and between the two groups at baseline in either latency or amplitude. In the visual inspection verification of peak-picking for the P3, it was noted that children with ASD had far less organized ERPs at the later time-points. The P3 was not sharp or well-defined for most children for most of the tones. As a later peak, it is more endogenous meaning it is more influenced by the internal processing and less representative of automatic reaction to stimuli (Remjin et al., 2014). The sensory registration paradigm used in this study did not require a response from the child and thus may not have provoked a strong P3. Previous studies using different paradigms to examine the P3 in children with autism have shown a decreased amplitude compared with typically developing children (Marco et al., 2011).

An additional consideration is that in this study, a silent movie was shown while the child passively listened to the tones. In previous studies where a movie was not shown, children had a greater response at the P3 (Davies et al., 2010, Gavin et al., 2011). The use of a movie may act to reduce the P3 peak-to-peak amplitude during passive listening. The P3 is the beginning of attentional engagement with a stimulus. For children watching a silent movie, attention is directed to visual stimuli as well as the auditory of the listening task that could result in decreased engagement with the auditory stimuli.

Comparisons of neurophysiological measurements at pre and post testing in ASD Group

The amplitude of P3 in response to the loud, high frequency tone significantly reduced from pre to post intervention testing when age was used as a covariate. The P3 associates more with processing and conscious attention. A reduction in amplitude may indicate that music therapy improved the children's ability to disregard an irrelevant stimulus and not put as much though toward categorizing or understanding. In this way, music therapy could be improving a child's ability to inhibit neural processing of simple auditory tones when they are participating in a passive task.

Besides the change in P3 amplitude, other component amplitudes from before to after the music therapy intervention have no observable or consistent trends. Slight reductions in amplitudes are seen at the N1 and P2 across all four tones but the amount of change is insignificant even through the lens of exploratory analysis. The high degree of variability between subjects may obscure any changes in individual component amplitudes resulting from the intervention. As discussed previously, age is a known factor in the amplitude of these ERP components. The age range of participants in this study is quite broad given the small sample size which introduces substantial variability.

We had hypothesized that following the music therapy intervention, neurophysiological measurements of children with ASD would change to approximate more closely their typically developing peer group. However, latency trends indicate a change in the opposite direction. The increased latencies are a surprising result as one would expect that practice and therapeutic intervention guided at processing auditory stimuli would reduce the latency of the early processing components. It is possible that the intervention acted on later aspects of neurological processing and not the components associated with stimulus registration which are measured by this ERP paradigm and protocol. It is also possible that for children with ASD, more adaptive processing of auditory stimuli requires slowing down the response.

Given that the direction of change for the latencies was unexpected, it is an interesting result and worthy of continued study. Music therapy is an accepted and research-validated therapy for children with ASD (Reschke-Hernandez, 2011). We would expect that following music therapy, auditory processing improves. This study has been predicated on the assumption that children with ASD will have improved occupational performance and participation when their foundational neural functions more closely approximate their typically developing peers. However, we see a change in the attentional performance as measured by the TEA-Ch in a direction toward the TD peers because of the music therapy simultaneous with a change away from the TD group in the latency of neurological processing. Change in the direction of typical performance of neurophysiological measurements is thus not necessarily a marker of functional improvement for children with ASD. Given that there are structural differences in brain structure of children with ASD, it is possible that a different neurological processing pattern will result in the most adaptive responses to stimuli than the neurological processing patterns seen in typically developing individuals.

Associations between neurophysiological and behavioral measures

This study had hoped to find relationships between the change in behavioral expression of attention and auditory neural processes to better understand the mechanism of interventions like music therapy. However, small sample size and large between subject variability made such correlation analysis difficult. A correlation matrix revealed trends which were further explored for possible significant associations. While this process may result in increased likelihood for type 1 errors, it was a reasonable approach due to exploratory nature of this research. Across both groups of children, it appears that the latency of the N1, P2 and N2 components for the 1kHz 70dB tone significantly predict attention scores. Thus, future studies may want to focus on the effects of the 1kHz 70dB tone related to attention scores.

Limitations

This study was limited by a small sample size that represented a single and homogenous geographic region. All participants were recruited from the northern Colorado area which is predominantly white, non-hispanic as is the sample of children who participated. The sample of typically developing children and of children with ASD was a convenience sample. The impact of the COVID-19 pandemic prevented collection of additional participants for the intervention protocol as well as of a control group of children with ASD which would have completed pre- and post-testing in the same timeframe but without the music therapy intervention. We are therefore unable to determine if the changes in performance of children with ASD were a result of the music therapy intervention or of maturation processes or increased comfort with the testing procedures. The relatively few significant results may be due to the small sample size and wide age range. Use of scaled scores instead of a raw score tool in comparing pre- and post-testing scores may further obscure changes in performance due to lack of test sensitivity.

Recommendations for Future Studies

The Brainwaves Research Lab intends to continue with these study protocols and recruit more participants for the research study. A control group of children with ASD who do not complete the music therapy intervention, or who complete the testing over the same interval while on a waitlist for the program will add validity to the study. With the addition of more participants, further analysis should attempt to control for age of the participants. It is known that there are maturation effects on sensory registration during the age range represented by participants. Controlling for age may increase the power of the study by explaining variation in neurophysiologic measures. An additional factor to examine in future studies is the severity of ASD. All of the participants of this study have mild autism which limits the applicability of the results to that subset of children with ASD. Recruiting children with a broader severity range of ASD and then understanding of impact of the severity on performance and efficacy of the MT intervention would help clinicians make choices about music interventions that are appropriate for specific clients.

With additional participants, further discriminant analysis and regression analysis could be done. Previous studies from this lab used discriminant analysis to determine which ERP components discriminate between adults, typically children and children with SPD (Davies et al., 2010). A similar procedure could be used to potentially discriminate between children with ASD who undergo a music therapy intervention, children with ASD who are a control group, and TD peers with EEG and TEA-Ch measures as the potential discriminants. Additional regression analysis with more participants could help understand which variables in the EEG results are predictive of variables in the TEA-Ch results: i.e. how does neurophysiological data predict behavioral performance.

In order to maintain consistency in study protocols, using a silent movie may need to be retained for this study. However, in future research, it will be important to consider if viewing the movie interferes with the amplitude or latency of the P3 component.

Future research can investigate further some trends noted in this project. One notable result that should receive more attention is the increase in latency of many components following the music therapy intervention particularly to the 1kHz 70dB tone. The other interesting result is the variation in response to tones of different intensities in both groups of children. With tones of just two intensities, it is difficult to establish here any definitive pattern. Auditory ERPs are sensitive to the quality of the sound and it would be interesting to understand if that sensitivity occurs in the same pattern for children with ASD as it does for typically developing individuals.

Conclusions

Together, these findings demonstrate that children with ASD perform more poorly on a standardized assessment of attention and may have different neurological processing of simple auditory stimuli compared to their typically developing peers. Specially, children with ASD have poorer performance on sustained and selective attention. They have a trend of delayed latency of early ERP components to all tones and processing occurs more strongly in later stages compared with typical children and that early processing is not as efficient at recognizing and registering simple tones. Both groups of children did show greater amplitude responses to the louder tones compared with equivalent frequency tones at lesser intensities. The pattern of change in amplitude between the two intensities was very similar between children with ASD and the TD children for N1, P2, and N2 components. At this time, few relationships can be demonstrated between attention and ERP component latency or amplitude in this paradigm. In this study latencies for N1, P2, and N2 of the 1kHz 70dB tone significantly predicted either selective and sustained attention.

The music therapy intervention has evidence of preliminary efficacy regarding attention with significant improvement in selective attention between pre and post testing. A decrease in amplitude of the P3 component to the louder and higher pitched tone following music therapy warrants further investigation. The P3 component may also be the best candidate for further research linking behavioral measures and neurophysiological measures and this should be one emphasis for the data analysis following the data collection of more participants. A trend of further increasing latency of early processing components was noted following the intervention. Perhaps these results indicate that improvement in outward expression of constructs like attention are not necessarily dependent on changes at the neurological level of early processing. Further research is warranted to continue exploring differences in processing between children with and without ASD as well as to investigate changes in neurological processing as the result of intervention targeting neural processes.

CHAPTER THREE

Sensory Processing and Occupational Therapy

Interventions to address sensory processing have long been a part of occupational therapy's scope of practice (Dunn, 2001; Kilroy et al, 2019; Lane et al., 2019; Schaaf & Davies, 2010). In the 1970's Ayres, an occupational therapist, began to describe difficulties some children with learning disabilities experienced when confronted with sensory inputs. Her sensory integration theory arose from these observations combined with the current body of knowledge of neuroscience (Lane, et al., 2019). Children with autism spectrum disorder (ASD) often experience sensory processing challenges (Grapel et al., 2015). Such children, and children with other sensory processing disorders, often experience occupational performance challenges because they do not respond adaptively to sensory inputs. Individuals with ASD are often overwhelmed in highly stimulating environments and feel bombarded by sensory input, particularly of auditory inputs (National Institutes of Mental Health, 2018). Autism spectrum disorders are increasing in prevalence and along with them are children with ASD who experience sensory processing difficulties A study aiming to assess what treatments are being utilized by children with ASD found that 85% of children with autism had or were currently being seen by an occupational therapist (Goin-Kochel, 2007). Additionally, 62% of the children either had received or were currently receiving sensory integration-based treatments.

The term sensory integration, as used by occupational therapists, "refers to the neural organization of sensory information for functional behavior" (Parham & Mailloux, 2020, p.516). Sensory integration allows a person to make sense of the sensory environment and take in relevant information without becoming overwhelmed. A specific protocol of sensory treatment in occupational therapy is Ayres Sensory Integration (ASI). ASI techniques, require active participation by the child and use purposeful activity and play (Kilroy et al., 2019). It is thought that "active engagement in individually-tailored sensorimotor activities, contextualized in play, at the just-right-challenge, promotes adaptive behaviors via neuroplastic changes that occur in response to these experiences." (Lane, 2019, p 7). Adaptive responses, often the goal of sensory interventions, allow children to successfully interact with their environment to accomplish goal-directed tasks (Parham & Mailloux, 2020). ASI is just one of the approaches to treating sensory challenges. Other approaches are used by occupational therapists as well as by other disciplines including music therapy (Weitlauf et al., 2017).

As part of the push toward a more evidence-based style of practice, occupational therapists continue to seek empirically validated treatment approaches and evaluations methods (American Occupational Therapy Association [AOTA], 2020). Toward that end, more research is warranted to validate treatments for sensory processing difficulties in children with occupational challenges resulting for dysfunctional sensory responses (Schaaf & Davies, 2010). One specific area of need is to examine neurological change as a result of intervention which could support interventions that are predicated on principles of neuroplasticity (Marco et al., 2011). It is important for occupational therapists and other allied health professions to show efficacy of interventions but also to explain the mechanism of change (Reed, 1987). The music therapy intervention used in this study targeted specific neurological pathways connected with attention to auditory stimuli and evaluation methods addressed the behavioral expression of attention and the neurological processing of auditory processing in a dual approach that could be a model for evaluation of other sensory-based interventions (LaGasse et al., 2019).

Rehabilitation Science Perspectives

Rehabilitation science is a relatively new field in allied health dedicated to resolving performance problems in clients experiencing disability. In its infancy, the field focused on body structures and functions within an individual (Seelman, 2000). As a result of changing social and research perspectives, the focus of rehabilitation science–initially bodily impairments–broadened to include environmental factors, the role of assistive technology, and the meaning of participation. The field now exists as a means to study the full continuum from function to disfunction, all processes by which disability develops and improves, and numerous factors influencing these movements (Brandt & Pope, 1997). Related to ASD, it is known that there are body function and structure differences in children with ASD compared to typically developing peers and that those differences may result in functional challenges (Ha et al., 2015).

This research focuses on factors related to disability at the body functions and structures level of the International Classification of Functioning, Disability and Health (ICF) model (WHO, 2002). While rehabilitation science has shifted toward a more complete view of person and environment factors related to enabling and disabling process, there is still merit in research to understand brain processes and functions. According to Baum (2013) "science must be developed at all levels if we are to have knowledge to translate findings that will inform interventions to improve participation, health, and well-being" (p. 172). From the early origins of sensory integration treatment, a knowledge of foundational neuroscience and the differences between typically and atypically developing children has allowed practitioners to address higher levels of participation (Lane, 2020).

Initial TEA-Ch scores demonstrated lower attentional skills in children with ASD which is a measure of performance. Those changes were reduced after the music therapy intervention;

the children improved their attentional skills and more closely resembled the typically developing peers. This study also confirms that there are differences in how the brain processes in auditory tones in children with ASD – this is a measure of body functions. Prior to the intervention, children with ASD showed increased latency of most components in response to many of the tones compared to their TD peers. Delayed latency of these components could indicate more difficulty processing stimuli or that more time is required to complete successful auditory processing. Children with ASD also had reduced amplitudes at the N1 and greater amplitude at P2. These results indicate that more neural processing happening later in children with ASD than their typically developing peers. This study also shows that there some are neurological changes related to that auditory processing as a result of a music therapy intervention, notably a reduction in amplitude of the P3 component. Children with ASD after music therapy demonstrated even longer latencies compared with the pre-testing EEG. While unexpected, the shift in neural processing away from the TD children accompanied by the shift in attentional performance toward the TD children indicates that adaptive auditory processing for children with ASD may require more time. Neural processing in children with ASD may be most efficient – and result in the best performance – when it occurs more slowly than in TD children.

From this study, we gain another example of neurological differences, which are responsive to change via intervention, and associate with a change in behavioral expression. While a small addition to the rehabilitation science research base, continued interdisciplinary work between occupational science, neuroscience, and other complementary therapies will further elucidate how best to support children with autism.

Rehabilitation science can benefit from additional measurement tools and new uses of existing measurement tools to strengthen research designs and demonstrate positive outcomes of interventions (Seelman, 2000). Findings from this study and similar work being done by the Brainwaves research lab additionally support the use of EEG in working with children with sensory processing difficulties. EEG can be used to discriminate between children with and without SPD (Davies et al., 2010). EEG could potentially become a tool use to discriminate between children with and without ASD. EEG is being studied as a potential diagnostic tool for autism (Bosl et al., 2018). Bosl and colleagues showed that using a combination multiple signatures from resting EEG could discriminate between children with ASD and typically developing children. A future aim of this research project is to recruit enough participants and determine which ERP components discriminate between children with ASD and TD peers.

Occupational Science Perspectives

Occupational therapy as a profession continues to strive toward rigorous use of evidence and research to support practice. Some of the research draw on by occupational therapists is generated in the field of occupational science (Yerxa et al., 1990). The centennial vision of the American Occupational Therapy Association (AOTA), issued to commemorate the professions one-hundred-year anniversary, included that the profession is both “science driven” and “evidence-based” (AOTA, 2007, p. 613). Given the prevalence of sensory strategies in use for children with autism by OTs, it is essential that they are supported by research specific to occupational outcomes. Sensory treatments draw from multiple disciplines including neuroscience (Lane, 2019). Research such as the present study provides foundational knowledge and precedence for the use of neurophysiological tools alongside behavioral measurements in occupational science research and perhaps in practice.

The practice of occupational therapy can be informed by various models which represent people as occupational beings. One such model is the Person-Environment-Occupation (PEO) model which considers the transactions and interactions of a person, their environment, and their occupations (Law et al., 1996). A client's personal factors interact with their environmental contexts to result in ability or inability to participate and perform in their desired occupations (AOTA, 2020). Occupational science, as a basic science underlying occupational therapy practice, must consider all components of this model. The present study fits with occupational science research of person-factors. This study examined sensory processing and attention skills, both of categorized as body functions which is a part of client factors in the occupational therapy practice framework (AOTA, 2020).

However, occupational therapy is meant to be practiced with a 'top down' approach wherein occupational performance and participation are kept central to all interventions and evaluations and the client is considered in context of their environment (Fisher & Marterella, 2019). Research on client factors, such as the present study, is informative and valuable when combined with additional occupational science research of how client factors fit into occupational performance. Translational research can provide a link the neurological and body functions knowledge to occupational therapy practice. For example, a retrospective analysis of parent-identified goals for their children with ASD at the start of an occupational therapy intervention determined that sensory processing difficulties were an underlying cause of poor occupational performance across multiple OTPF domains (Schaaf, et al., 2015). The measurement tools used in the present study could be combined with measures of occupational performance to further understand how the client factors of attention and auditory processing impact occupational performance.

I conclude by restating that this research, and all research addressing neurological and behavioral relationships, makes a valuable contribution to our understanding of how to best serve clients with ASD. This research draws on both rehabilitation and occupational science to understand sensory dysfunction more clearly in children with autism and study intervention approaches which could improve occupational outcomes. However, the results cannot be viewed in isolation; they must be combined with an understanding of how environment and context influence occupational performance as well as a holistic understanding of individual clients. Good rehabilitation and occupational science include consideration of context, environment, and task which all interact with client-factors. Most importantly, best practice in occupational therapy requires an understanding and appreciation of physiological differences which may influence occupational performance and participation in any given context. Future best practice for children with ASD will draw from research such as this within occupational and rehabilitation science to understand and support wellbeing and occupational performance.

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APPENDIX 1

Subtests of the Test of Everyday Attention in Children (TEA-Ch)

Subtests Measuring Sustained Attention

Score!: Children count the number of auditory tones presented during an interval silently and without using their fingers. Between 9 and 15 tones are presented during each of 10 trials with ISI varying between 500 and 5000 ms.

Score DT: Children complete the same tone-counting aspect of Score! But with an added auditory distraction of a recorded news bulletin. The children were asked to count tones as before but also listen for the mention of an animal during the bulletin.

Code Transmission: Children listen to a string of digits read aloud with 2 second intervals listening for a particular sequence and the must indicate the digit that occurred immediately before the target sequence.

Walk Don't Walk: Children listened to a tape which played tones corresponding to "go" or "no go" instructions and marked progress along a path by dotting squares with a marker. The child was to make a dot in the next square if the "go" tone occurred and to make no mark if the "no go" tone played. The ISI was consistent within each trial but decreased incrementally from 1500 ms to 500 ms by the 20^{th} trial.

Sky Search DT: This is a dual performance task where the child is asked to complete the Sky Search (see below) while counting presented auditory tones.

Subtests Measuring Selective Attention

Sky Search: Children a presented with a sheet of paper with rows of paired of paired spacecrafts. There are 4 total types of spacecraft and children are required to locate the matching pairs. 20 target pairs are distributed among 108 distractors. Children mark a box in the corner when they have finished searching. Prior to this test, children complete a test page with no distractors to control for differences in motor function. Children are scored by accuracy and by the time using the control time to adjust for motor slowness.

Map Mission: Children are given a sheet of paper representing a map with various symbols. 80 target symbols (knife and fork representing restaurants) are distributed among distractor symbols. Children are given 1 minute to circle as many targets as possible.

Subtests Measuring Switching Attention

Creature Counting: Children are given a booklet depicting creatures in burrows. Arrows are interspersed with the creatures. Children must count the creatures moving along the burrow from top to bottom but change the direction of their count as indicated by the arrows. Children are scored by time and by accuracy.

Opposite worlds: Children are presented with two kinds of game boards with an array of 1's and 2's displayed in a path. In the "same world" condition, children are asked to read the digits as they appear. In the "opposite world" condition children are asked to say "two" when they encounter a 1 and to say "one" when they encounter a 2.