THESIS

AUDITORY SENSORY PROCESSING IN CHILDREN WITH SENSORY PROCESSING DISORDER AND AUTISM SPECTRUM DISORDER

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

Fall 2016

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ABSTRACT

AUDITORY SENSORY PROCESSING IN CHILDREN WITH SENSORY PROCESSING DISORDER AND AUTISM SPECTRUM DISORDER

Sensory processing has long been a topic of interest in the field of occupational therapy. This study sought to replicate the results of Davies and Gavin (2007) which examined differences in auditory sensory processing between children with sensory processing disorder (SPD) and typically developing (TD) children as well as expand the results to a sample of children with high functioning autism spectrum disorder (ASD). Additionally, this study sought to relate the neurophysiological measures of sensory processing to a behavioral assessment measuring sensory processing. We hypothesized that the results of Davies and Gavin (2007) would be replicated and expanded to include children with ASD and measures from the Sensory Profile (SP) would relate to the participants' neurological measures of sensory processing. 62 TD children, and 21 children each with SPD and ASD were recruited as part of a convenience sample. Participants' brainwaves were recorded through electroencephalography (EEG) while they watched a silent movie and listened to a sensory gating paradigm consisting of two paired clicks and a sensory registration paradigm consisting of 4 tones of varied intensity and frequency. From the sensory gating paradigm P50 amplitudes were obtained. From the sensory registration paradigm amplitudes and latencies for N100, P200, N200, and P300 were obtained. Analyses revealed that while the results of Davies and Gavin (2007) were partially replicated, in that sensory gating was able to be significantly predicted from sensory registration the same

pattern of sensory hyper and hypo-responsivity was not observed. Results indicate that the Sensory Profile does in part relate to the neurophysiological measures of sensory processing. This study confirmed that auditory sensory processing does differ between children with SPD, children ASD, and TD children. It contributes to occupational therapy's understanding of sensory processing in children and also towards increased understanding of how the SP relates to underlying neurological mechanisms.

ACKNOWLEDGEMENTS

I am grateful to Dr. Patti Davies for her kind and patient mentoring over the course of my thesis. I would also like to thank Dr. Gavin and Dr. Blyth Lagasse for serving on my committee and giving me excellent feedback, ideas, and encouraging me to think outside the box throughout this process.

I would also like to thank Jewel, Brittany, and Mei for their help, for taking the time to review my work, and for making the lab a fun place to be!

Thanks to my friends, family, and husband for their support!

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CHAPTER ONE

Sensory integration has been a prevalent topic in the field of occupational therapy since Jean Ayres introduced it in the 1970s. She defined sensory integration as "the neurological process that organizes sensation from one's own body and from the environment and makes it possible to use the body effectively within the environment" (Ayres, 1989). Researchers and occupational therapy practitioners continue to use sensory integration to describe the neurophysiological process originally outlined by Ayres but the term has also evolved to reflect a variety of behaviors thought to be related to one's ability to organize oneself within a sensory environment. Occupational therapists also commonly and interchangeably utilize the term sensory processing to describe similar neurophysiology and behavior. Sensory integration theory has been the subject of a great deal of research, the basis of many intervention techniques, and also a source of great controversy within the field. While occupational therapists frequently employ sensory integration based therapy in practice many of the underlying assumptions of sensory integration have yet to be extensively validated. For instance, while work has begun to explore differences in neural processing between children with and without sensory processing difficulties (Brett-Green, Miller, Schoen, & Nielsen, 2010; Davies, Chang, & Gavin, 2009; Davies & Gavin, 2007; Schoen, Miller, Brett-Green, & Nielsen, 2009) very little work has been conducted that tests the assumption that sensory integration therapy effectively impacts the way sensory information is organized and processed in the brain. This paper will seek to expand upon the knowledge base upon which occupational therapists can draw to understand the neurophysiological underpinnings of sensory processing.

This research study will replicate and expand upon the work of Davies and Gavin (Davies & Gavin) which utilized electrophysiological and behavioral measures to examine sensory integration or processing patterns in children with Sensory Processing Disorder (SPD) and neurotypical children. An exploration of the same measures in children with Autism Spectrum Disorders (ASD) will also be conducted. Further replication and expansion of the work of Davies and Gavin (2007) will provide information which can be used to assess the validity of assumptions underlying sensory integration theory and intervention. For instance, this study will validate the assumption that children who experience difficulties with planning and organizing behavior thought to stem from challenges in integrating sensory input do indeed have neurophysiological differences in how their brains process sensory information (Bundy & Murray, 2002). Additionally, the results from this study will provide foundational information upon which further studies examining brain processing both before and after a sensory integration intervention may be based. This will allow testing of the assumption of neuroplasticity upon which sensory integration intervention is based (Bundy & Murray, 2002).

The History of Sensory Integration Theory

Sensory integration theory attempts to explain the relationship between various behaviors and the brain. Ayres' early work sought to explain learning difficulties in children. Her theory proposed that children with learning or behavioral difficulties were not able to adequately take in and organize sensory information from their environment which in turn was needed to learn to interact effectively within the context of the experience (Fisher & Murray, 1991).

In order to further refine her theory of sensory integration Ayres utilized data from the Southern California Sensory Integration Tests and later the Sensory Integration and Praxis Tests to perform factor analyses in order to determine typologies of sensory integration dysfunction

(Smith Roley, Mailloux, Miller-Kuhaneck, & Glennon, 2007). Some of these early typologies included somatosensory processing deficits, poor bilateral integration, impaired somatopraxis, poor praxis on verbal command, visuopraxis, and generalized sensory integrative dysfunction (Fisher & Murray, 1991).

Ayres' sensory integration theory also establishes assumptions about the nature of sensory integration and the relationship of the brain and behavior (Bundy & Murray, 2002). Firstly, that the brain is plastic, leading to the belief that sensory integration intervention is effecting changes within the brain. Secondly, sensory integration follows a developmental trajectory in which a disruption can interfere with normal development. Thirdly, the brain functions as an integrated whole with both cortical and subcortical structures contributing towards normal sensory integration. Fourth, adaptive interactions are critical to sensory integration. When a child has an adaptive response to sensory input they are able to utilize that sensory input to interact effectively within their environment. Lastly, that people are innately driven to perform activities which contribute towards sensory integration. This is most evident in children who understand their world through a variety of sensorimotor experiences (Bundy & Murray, 2002).

The Evolution of Modern Sensory Integration Theory

The foundation which Ayres established has been expanded upon and has changed rapidly over time. Currently within the field of occupational therapy there is a lack of a clear consensus about one specific model of understanding sensory integration or sensory processing. Additionally, different practitioners and researchers will utilize a variety of language both around labeling sensory integrative dysfunction and the interventions that are being utilized (Schaaf & Davies, 2010). Based upon the work of Ayres there are now considered to be two main types of

sensory integration dysfunction: sensory modulation dysfunction and dyspraxia. Dyspraxia represents sensory integration dysfunction which leads to motor impairment (Bundy & Murray, 2002). Sensory modulation dysfunction is the type of sensory integration difficulty which is relevant to this paper and will be explored in greater depth below.

Sensory Modulation

A component of sensory integration is sensory modulation, which is defined by Schaaf, Schoen, et al. (2010) as "one's ability to respond adaptively to sensation over a broad range of intensity and duration". Sensory modulation dysfunction can often lead to behaviors such as sensation seeking or increased distractibility (Bundy & Murray, 2002). A great deal of work has been done to further identify and classify the behaviors that may be related to sensory modulation dysfunction. One such effort was conducted by Dunn. Dunn proposes that there are four main types of sensory modulation dysfunction which can be classified into four quadrants based upon an individual's threshold and their responding strategies (Dunn, 2001; see figure 1). Threshold is defined by how much of sensory input it takes for a response; a low threshold means that it does not take very much sensory information in order for a person to recognize the input whereas a high threshold means much more sensory input is required for recognition to occur (Dunn, 2001). In turn, a person's respond strategy is how they react in the presence of sensory input over a given threshold, this response can be either active or passive (Dunn, 2001). Those who have a high threshold and passive responding strategies are classified as having low registration, while those with high threshold and active responding strategies are classified as sensory seeking. Those with low threshold and passive responding strategies are sensory sensitivity while those with active responding strategies and low threshold are sensory avoiding (Dunn, 2001).

	Behavioral Response/Self-Regulation Continuum	
Neurological Threshold	PASSIVE	ACTIVE
High Threshold (habituation)	**Registration**	**Seeking**
Low Threshold (sensitization)	**Sensitivity**	**Avoiding**

Figure 1. Depiction of Dunn's Model of Sensory Processing

These quadrants have been used to explain a wide variety of behaviors in children. For instance, having low registration can explain a child who often does not notice when people are calling his or her name, it is not that he or she is distracted or does not care but rather that they require significantly higher levels of sensory input to respond (Dunn, 2001). Besides clinical observations from therapists and educators Dunn's model has been validated through physiological measures. For instance, Brown et al. (2001) found that those who have low threshold patterns have a greater skin conductance response to auditory stimuli than those with high threshold patterns but those who are classified as sensory seeking or sensory sensitive took longer to habituate to the auditory stimuli than those from the other two quadrants. These findings provide validation to Dunn's model as each individuals from each of the quadrants responded distinctly on the physiological measures indicating that they do indicate different patterns of sensory processing. Additionally, the responses to the physiological measures align with what would be expected based upon the behaviors of each quadrant as measured by the sensory profile.

Another modern theory of sensory processing is the work of Miller and colleagues which suggests that rather than four quadrants those with sensory modulation disorder (SMD) fall into three categories (Miller, Anzalone, Lane, Cermak, & Osten, 2007). These categories are sensory over-responsivity, sensory under-responsivity, and sensory seeking/craving (Miller et al., 2007). Children with sensory over-responsivity have responses to stimuli that are either quicker or more intense than would be expected and due to this may act out or withdraw behaviorally. Children with sensory under-responsivity are similar to those classified by Dunn as having low registration in that they often have a lower response to stimuli or seem to not notice stimuli. Children who are sensory seeking often engage in behaviors which provide them with greater amounts of sensory input and may be constantly moving, touching, or spinning (Miller et al., 2007). Miller's model has also been validated by physiological evidence such as electrodermal activity (McIntosh, Miller, Shyu, & Hagerman, 1999 & Hagerman, 1999).

Clinical Relevance of Sensory Integration Theories

Sensory integration theory is utilized by occupational therapists to develop interventions aimed at treating various disorders. It has frequently been utilized in treating children with ASD, but also with children with motor impairments, behavioral difficulties, and even infants in the NICU (Koomar & Bundy, 2002). Interventions based upon sensory integration (SI) theory include the use of swings, deep pressure, vibration, brushing, weighted vests, and blankets, and many other tactile, auditory, and visual modalities (Parham & Maillous, 2015). SI intervention has been found to be an effective treatment for children for children with ASD and Sensory Modulation Dysfunction with improvements being shown in motor, cognitive, self-care, and social performance (Parham & Maillous, 2015; Pfeiffer, Koenig, Kinnealey, Sheppard, &

Henderson, 2011; Schaaf et al., 2014). However, more research about the efficacy of SI intervention is needed with a variety of populations.

ASD and SPD: An Introduction to Relevant Clinical Groups

Sensory integration or sensory processing is a topic of interest for occupational therapists who work with many different clinical populations. Explorations of sensory processing in both a neurophysiological and behavioral sense have been conducted in many populations of children including those with Attention Deficit Hyperactive Disorder (ADHD), Autism Spectrum Disorders (ASD), and Fetal Alcohol Syndrome (FAS) (Franklin, Deitz, Jirikowic, & Astley, 2008; Ghanizadeh, 2011; Tomchek & Dunn, 2007). A population which poses an interesting challenge is the group of individuals who experience sensory processing or integration dysfunction but have not received a formalized diagnosis of any disorder. Currently there is controversy among the field of occupational therapists about how to label these individuals (Schaaf & Davies, 2010). Some therapists and researchers prefer to utilize the terminology sensory integration dysfunction while others utilize a more recently coined label of sensory processing disorder (SPD). SPD is not specifically recognized as a disorder in the Diagnostic and Statistical Manual of Mental Disorder fifth edition (DSM-5) but continues to be recognized amongst clinicians and is gaining recognition among the general public (Miller, 2014). For the purposes of this paper SPD will be utilized to describe the group of children who experience sensory integration difficulties.

Sensory Processing Disorder (SPD) Information and Prevalence

SPD is a condition in which sensory information is not interpreted correctly within the brain, which in turn leads a child to behave abnormally in the presence of certain sensory stimuli (Miller, 2014). SPD can impact every aspect of a child's life (Dunn, 1997). An estimated 5-10%

of children without disabilities and 40-88% of children with another disability have SPD (Ahn, Miller, Milberger, & McIntosh, 2004 & McIntosh, 2004), As mentioned earlier, Miller and colleagues proposed a nosology for sensory processing disorder as being divided into three categories, sensory modulation disorder (SMD), sensory-based motor disorder (SBMD), or sensory discrimination disorder (SDD) (Miller, Anzalone, Lane, Cermak, & Osten, 2007 Cermak, & Osten, 2007). SMD is the specific type of SPD most relevant to this study and it as previously discussed has been preliminarly validated through both neurophysiological and behavioral measures (Ben-Sasson et al., 2008; McIntosh et al., 1999).

SPD and auditory sensory processing. Abnormalities in sensory processing have been investigated through a variety of means in children with SPD. Nuerophysiological and behavioral assessments have found that children with SPD have abnormal responses to auditory stimuli (Davies et al., 2009; Davies & Gavin, 2007; Miller, Nielsen, & Schoen, 2012; Schoen et al., 2009). Electroencepholography studies examining auditory processing in children with SPD have revealed differences in peak amplitudes and latencies as compared to typically developing children (Davies et al., 2009; Davies & Gavin, 2007).

Autism Spectrum Disorders Information and Prevelance

ASD is a prevalent disorder which has gained a great deal of interest over time. Occupational therapists frequently work with children and adults of ASD, and may address difficulties related to sensory processing (Case-Smith & Arbesman, 2008). The Centers for Disease Control and Prevention (CDC) estimates that 1 in 68 children have ASD (2014).The prevalance of ASD has increased over time, however this is likely explained by a combination of factors including changes in the diagnostic criteria and increasing awareness of the disorder (Wing, 2002).The DSM-5 specifies 5 diagnostic criteria for ASD which are:

- Persistent deficits in the areas of social communication and social interaction across multiple contexts
- Restricted or repetitive patterns of behavior, interests, or activities
- Symptoms which present in the early developmental period
- Symptoms cause clinically significant impairment in functioning
- Symptoms are not better explained by intellectual disability or global developmental delay (American Psychiatric Association (APA), 2013).

ASD and auditory sensory processing. The APA includes sensory processing deficits as an example of the restricted or repetitive patterns of behavior in the DSM 5 where it is noted that children with ASD frequently have hyper or hypo-responsivity to sensory input or an unusual interest in sensory aspects of the environment (2013). Auditory sensory processing is the most common sensory deficit in children with ASD (Tomchek & Dunn, 2007). Children with ASD are reported to have differences in auditory sensory processing compared to typically developing peers on both behavioral and neurophysiological measures of sensory processing (Cheung & Siu, 2009; Orekhova et al., 2008; Schoen et al., 2009; Tomchek & Dunn, 2007; Crasta, Gavin, & Davies, 2016). For instance, several electroencephalography (EEG) studies have found that children with autism have abnormal early peak latencies and amplitudes in response to auditory tones (Bruneau, Roux, Adrien, & Barthélémy, 1999; Ferri et al., 2003; Martineau, Garreau, Barthelemy, & Lelord, 1984).

Introduction to Measures Relevant to this Paper

Sensory processing has traditionally been explored using a variety of neurophysiological and behavioral measures. Neurophysiological measures which have been commonly utilized include EEG, magnetoencephalography (MEG), and functional magnetic resonance imaging

(fMRI) (Marco, Hinkley, Hill, & Nagarajan, 2011). There are also a wide variety of behavioral assessments which have been utilized to examine sensory processing including the sensory profile (Dunn, 1997), the Sensory Integration and Praxis Test (SIPT) (Ayres, 1989), the Sensory Processing Measure (SPM) (Ahn et al., 2004; Miller-Kuhaneck, Henry, Glennon, & Mu, 2007), as well as many others. The sensory profile is the behavioral measure which will be utilized for this study; it will be introduced in greater depth in the methods section.

Neurophysiological Measurement Technique

EEG is the neurophysiological measurement technique which will be utilized in the current study. EEG utilizes electrodes placed on the scalp to record the electrical activity from the cortex of the brain. It collects information about brain processing with excellent temporal resolution. EEG is a useful and well validated measurement tool for understanding both typical and atypical brain activity (Teplan, 2002). One method of utilizing EEG to understand brain activity is the use of event related potentials (ERPs). ERPs are obtained by segmenting the running EEG around the onset of a specific event and the segments are averaged together. Averaging the time-locked segments is assumed to eliminate background electrical activity in the brain that is unrelated to the stimulus being presented and thus the averaged ERP represents the brain's response to a particular stimulus (Teplan, 2002).

ERP waveforms consist of several peaks which are commonly thought to represent different aspects of brain processing. The amplitude of the peaks as well as the timing (latency) can be measured to better understand how the brain processes a particular stimuli (Davies & Gavin, 2007). These peaks are typically named in a way that reflects their direction and timing. For instance, one such component is the P50 which is named due to being a positive peak approximately 50 milliseconds (Lincoln, Courchesne, Harms, & Allen) after the stimulus onset.

Another such peak is the N100 (or N1) which is a negative peak approximately 100ms post stimulus onset.

ERPs have been extensively utilized to investigate sensory processing in a variety of clinical populations including schizophrenia, ASD, and ADHD (Marco et al., 2011; Nazari et al., 2010; Niznikiewicz et al., 1997). ERP studies provide an important view into what is happening within the brain of an individual during the presentation of sensory information and can contribute to our understanding of how sensory processing may be different in various clinical populations. This information may better inform intervention approaches and help us to understand typical behaviors in clinical populations.

Neurophysiological Measures

Sensory gating. Sensory gating is a neurological process through which the brain's response to a repeated stimuli is suppressed and is typically examined through a paradigm consisting of two auditory clicks separated by 500 ms. Sensory gating is examined by comparing the P50 component of an event related potential (ERP) of the first click (conditioning or C click) to the second (test or T click); a decrease in amplitude of the P50 for the second click compared to the first represents successful sensory gating (Davies, Chang & Gavin, 2009; see figure 2). The extent of sensory gating can be measured through the use of a T/C ratio calculated by dividing the peak-to-peak P50 amplitude of the T click by the peak-to-peak P50 amplitude of the C click; larger T/C ratios represent less sensory gating while smaller T/C ratios represent greater sensory gating (Davies & Gavin, 2007). Sensory gating is impaired in many clinical populations including children with SPD and low functioning autism (LFA) (Davies et al., 2009; Orekhova et al., 2008). It is thought that impaired sensory gating may explain some of the behavioral manifestations of sensory processing difficulties due to the fact that the brain does not filter or

"gate out" irrelevant sensory information and instead continues to process it repeatedly. Alternatively, some believe that impaired sensory gating may be a result of impaired registration of the first click or an inability to "gate in" important information from a novel stimulus (Hazlett et al., 2015). The research literature has demonstrated that sensory gating typically matures with age with adults having improved gating when compared to children although this has not been demonstrated among children with SPD (Brinkman & Stauder, 2007; Davies et al., 2009; Marshall, Bar-Haim, & Fox, 2004).

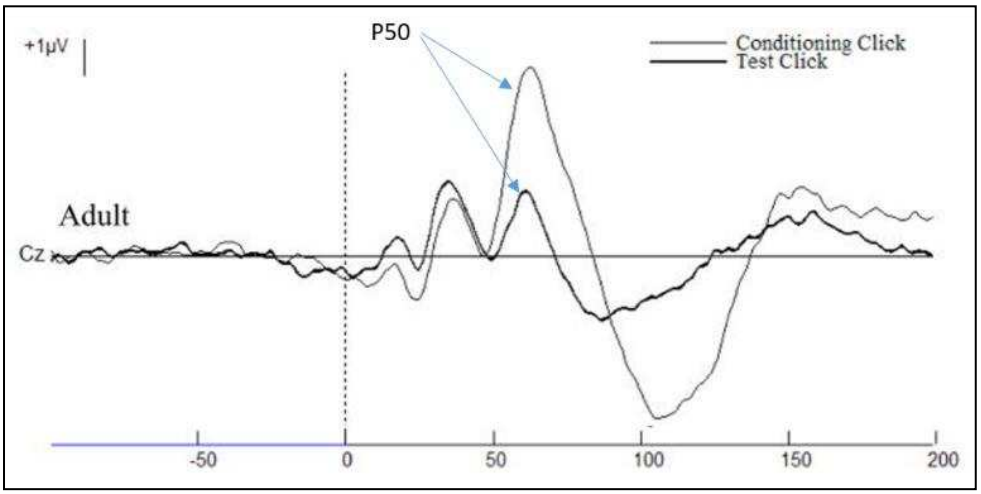

Figure 2. Depiction of Sensory Gating. Reprinted from Davies, Chang, & Gavin, 2009).

Sensory registration. The sensory registration EEG paradigm modified from the work of Lincoln, Courchesne, Harms & Allen (1995) by Davies and Gavin (2007) examines the brain's response to four auditory tones which are presented at varying frequencies and intensities. In typical processing each of these four tones elicits a unique response in the brain indicating that a tone has "registered" (Davies & Gavin, 2007; see Figure 3). Children with SPD demonstrate less organized brain responses in a sensory registration paradigm (Davies & Gavin, 2007). While sensory registration in children with ASD has not been widely explored in the literature existing data suggests that registration may be impaired in children with high functioning ASD (Crasta, 2015). Other research which presented auditory tones of various frequencies has found that

children with ASD demonstrate some latency differences compared to typically developing children (Bruneau et al., 1999; Lincoln et al., 1995).

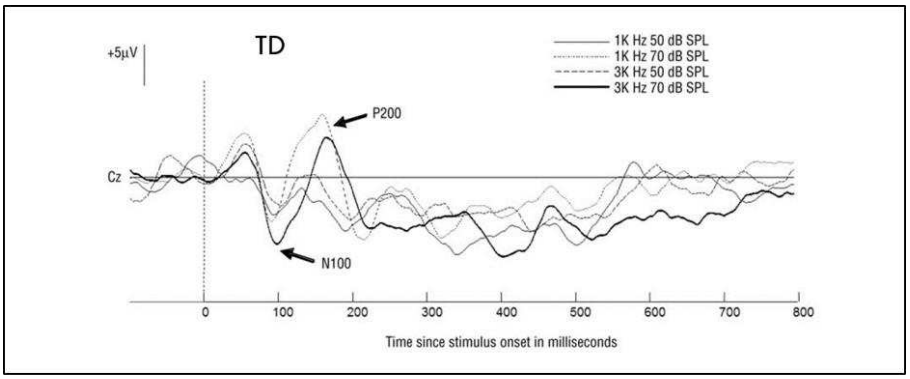

Figure 3. Depiction of Sensory Registration Reprinted from Davies and Gavin 2007.

Purpose of the Current Study

This paper seeks to address two main aims. The first aim of the current study is to replicate the work of Davies and Gavin (2007) with a new sample. The study that is being replicated will be described in detail below. The second aim of this study is to better understand the relationship between the brain and behavior by examining correlations between the neurophysiological and behavioral measures which will be utilized. Occupational therapists frequently utilize assessments to measure aspects of behavior, many of which are thought to relate to brain processing. However, little has been done to validate this assumed relationship. This paper will correlate measures of neurophysiological auditory processing with a behavioral measure of sensory processing.

Introduction to the Paper to be Replicated: Davies and Gavin (2007)

Davies and Gavin (2007) examined sensory processing in children with SPD and age-matched typically developing peers utilizing a sensory gating and sensory registration paradigm as well as the behavioral measure of the SP. The 2007 study found that children with SPD demonstrated less P50 sensory gating than typically developing children although the difference

did not reach statistical significance. Children with SPD did not differ significantly from typically developing children in the sensory registration paradigm although a visual inspection of ERPs found that children with SPD had less organized responses to auditory stimuli than typically developing children. In order to examine the impact of individual differences Davies and Gavin (2007) developed a regression model which predicted a child's sensory gating (P50 T/C ratio) from age, and a child's sensory registration (N100 from loud intensity stimuli and P200 from loud intensity stimuli). This model was developed upon the belief that a child's ability to perform sensory gating effectively is based upon both brain maturation (age) and also their brain's ability to organize auditory stimuli. Davies and Gavin (2007) found that this regression model was statistically significant for typically developing children but not for children with sensory processing disorder. In order to understand the brain processing in children with SPD more effectively Davies and Gavin used the unstandardized coefficients derived from the regression analysis found to be significant for typically developing children to develop a prediction equation for P50 T/C ratios. In this method P50 T/C ratios were calculated for all children in the study. Predicted T/C ratios were then subtracted from the child's actual P50 T/C ratio to obtain a difference score (see figure 4). Davies and Gavin found that when these difference scores were plotted as a function of their actual P50 T/C Ratio the children with SPD fell into two groups, one which can be classified as being hyper-responsive in sensory gating and one which can be classified as being hypo-responsive in sensory gating. This result supports the division of sensory processing dysfunction into two types, hyper-responsivity and hypo-responsivity.

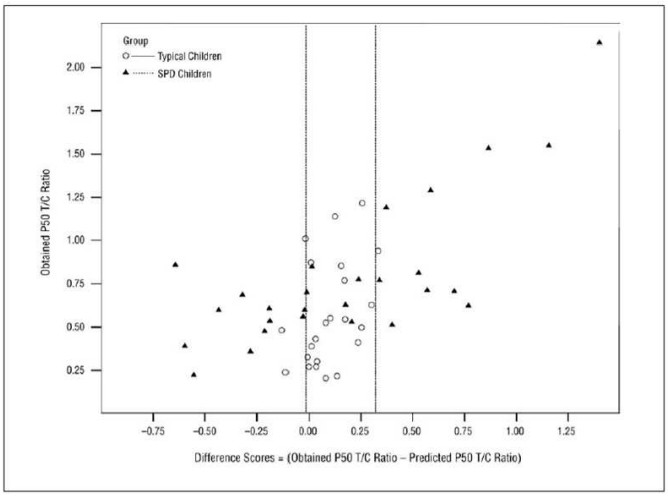

Figure 4. Difference scores plotted against actual P50 T/C ratio scores for TD children and children with SPD. Reprinted from Davies and Gavin (2007)

The current paper will contribute towards knowledge about sensory dysfunction among children with SPD and children with high functioning ASD. Additionally this paper seeks to validate theories of sensory integration and sensory typologies which have been proposed in the literature by examining the neurophysiological correlates of behavior. This will contribute to understanding the relationship between the brain and behavior and how individuals differ in their sensory processing. There is some evidence in the literature to support the idea of various categories of sensory processing dysfunction but more evidence is needed to support the idea of varying biological bases underlying the varied behavioral typologies (Brett-Green et al., 2010; James, Miller, Schaaf, Nielsen, & Schoen, 2011; Mulligan, 1998; Reynolds & Lane, 2008; Schaaf & Davies, 2010). The research questions and corresponding hypotheses of this study are as follows:

1. Question 1: Can the results of Davies and Gavin (2007) be replicated with a new sample of children with SPD and typically developing children?
    - Hypothesis 1: When examining individual differences between predicted T/C scores (derived from regression model based upon typically developing children)

and actual T/C scores, children with SPD from this new sample will fall into two groups, one of which represents hyper-responsiveness to stimuli and one of which represents hypo-responsiveness to stimuli.

- Children with SPD from the new sample, when examining individual differences between predicted T/C scores (derived from regression model based upon typically developing children) will fall into two groups, one of which represents hyper-responsiveness to stimuli and one of which represents hypo-responsiveness to stimuli.

2. Question 2: Will the sensory pattern of hyper-responsivity or hypo-responsivity in children with high functioning ASD be similar to that in children with sensory processing disorder found by Davies and Gavin (2007)?
    - Hypothesis 2: When examining individual differences between predicted T/C scores (derived from regression model based upon typically developing children) and actual T/C scores, children with ASD will fall into two groups, one of which represents hyper-responsiveness to stimuli and one of which represents hypo-responsiveness to stimuli.
    - Children with ASD, when examining individual differences between predicted T/C scores (derived from regression model based upon typically developing children) will fall into two groups, one of which represents hyper-responsiveness to stimuli and one of which represents hypo-responsiveness to stimuli.
3. Question 3: What is the relationship between the behavioral indicators of sensory dysfunction as measured by the Sensory Profile and the neurophysiological indicators are measured by the ERP components in the sensory gating and registration paradigms?

- Hypothesis 3: Children who are predicted as being hyper-responsive based upon their T/C difference scores will be more likely to be classified as having sensory sensitivity or sensory avoidance on the SP.
- Hypothesis 4: Children who are predicted as being hypo-responsive based upon their T/C difference scores will be more likely to be classified as having low registration or being sensory seeking on the SP.

CHAPTER TWO

Sensory integration or sensory processing has been a topic of interest and a specialty area for occupational therapists since A. Jean Ayres introduced it in the 1970s. Ayres' sensory integration purports several assumptions about the way sensory information is processed in the brain and in turn how this processing can directly contribute to the way an individual interacts meaningfully in their everyday lives. The first of these assumptions is that the brain possesses neuroplasticity and therefore can be altered by intervention. Secondly, sensory integration is a developmental process. Thirdly, cortical and subcortical structures within the brain function as an integrated whole in typical sensory integration. Fourth, adaptive interactions in the environment are critical towards the development of sensory integration. Lastly, that individuals have an innate motivation to participate in activities which contribute towards sensory integration (Bundy & Murray, 2002). Modern sensory integration theory still relies heavily upon these assumptions and they are also used as a basis for intervention (Bundy & Murray, 2002). Today, sensory integration as understood by occupational therapists can be conceptualized representing both a neurophysiological process of taking in and interpreting sensory information in the brain, the behavioral responses to sensory information and also a means for intervention. Occupational therapy using a sensory integrative approach (OT-SI) is gaining more recognition by the public in recent years and as a result is becoming one of the more frequently reported types of therapy by parents whose children have an autism spectrum disorder (ASD, Green et al., 2006). Additionally, increasing public recognition of the conditions of ASD and sensory processing disorder or sensory processing difficulties (SPD) have led to an increase in parental awareness of and demand for OT-SI. As such, the importance of evaluating the assumptions

underlying SI therapy and the clinical utility are of upmost importance in order for OT to meet its centennial vision of being an evidence based and ethical profession (American Occupational Therapy Association, 2007).

Clinical Populations and Sensory Integration

Autism Spectrum Disorders

Children with autism spectrum disorders (ASD) and children with sensory processing disorder or sensory processing difficulties (SPD) are recipients of OT-SI and are the clinical populations that are relevant to this paper. 1 in 68 children are estimated to have an ASD by the CDC (CDC, 2014). Symptoms of ASD under the DSM-5 include persistent deficits in social communication and interaction and restricted or repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2013). Sensory hyper or hypo-responsivity is also recognized in the DSM-5 as a possible manifestation of restricted or repetitive patterns of behavior (American Psychiatric Association, 2013). Children with ASD are frequently reported to experience sensory difficulties the most common being auditory processing difficulties (Tomchek & Dunn, 2007). These auditory processing difficulties have been explored in the literature through both behavioral and neurophysiological measures (Cheung & Siu, 2009; Crasta, Gavin, & Davies, 2016; Orekhova et al., 2008; Schoen, Miller, Brett-Green, & Nielsen, 2009; Tomchek & Dunn, 2007). There have been mixed results regarding the nature of auditory processing differences between children with ASD and typically developing (TD) children (Cheung & Siu, 2009; Crasta et al., 2016; Orekhova et al., 2008; Schoen et al., 2009; Tomchek & Dunn, 2007).

Sensory Processing Disorder

Sensory processing disorder or (SPD) is not officially recognized by the DSM-5 however it is included as a diagnosis in the *Diagnostic Manual for Infancy and Early Childhood* (ICDL-DMIC; Greenspan & Wieder, 2005) and the *Diagnostic Classification of Mental Health and Developmental Disorders of Infancy and Early Childhood. Diagnostic Classification: 0-3* (DC:0-3R; Wieder, 1994). This disorder is thought to impact 5-10% of children without another disability and up to 40-88% of children with another identified diagnosis (Ahn et al., 2004). There are three main proposed types of SPD which are sensory modulation disorder (SMD), sensory-based motor disorder (SBMD) and sensory discrimination disorder (SDD) (Miller et al., 2007).

Sensory modulation disorder. SMD is the subtype of SPD that is most relevant to the current paper and has begun to be validated through a variety of neurophysiological and behavioral measures (Ben-Sasson et al., 2008; McIntosh et al., 1999). There are several proposed subtypes of SMD, one of which was proposed by Dunn (2001). Dunn proposed that sensory modulation can be represented as four distinct subtypes which are determined by a persons' neurological threshold and behavioral response. A person can have either a high or low threshold; a high threshold indicating that it takes a larger degree of a particular stimulus to elicit a response and a low threshold indicating that it takes a lower amount for the same response. Dunn proposes that once an individual's threshold is reached their response to that stimulus can be either active or passive. These two variables (threshold and response strategy) combine to produce four quadrants of sensory processing (see figure 5).

	Behavioral Response/Self-Regulation Continuum	
Neurological Threshold	PASSIVE	ACTIVE
High Threshold (habituation)	**Registration**	**Seeking**
Low Threshold (sensitization)	**Sensitivity**	**Avoiding**

Figure 5. Depiction of Dunn's Model of Sensory Processing

Electrophysiological Measures

Researches in OT and other disciplines have begun to use brain imaging techniques to examine underlying neurophysiological differences in sensory integration in a variety of clinical populations including those with ASD and SPD; however much of this work is preliminary or has generated conflicting results. One such brain imaging technique is electroencephalography (EEG). EEG records electrical activity from the brain's cortex through electrodes placed on the scalp and is a valuable tool for understanding brain activity (Teplan, 2002). EEG data is frequently transformed into an event related potential (ERP) as a way of understanding the brain's response to a particular stimulus. ERPs are generated by averaging together a segment of time around each presentation of a particular event or stimulus. By averaging, background activity in the brain that is unrelated to that particular stimulus is canceled out and therefore the averaged waveform represents a pure indication of the brain's response to a particular stimulus. ERPs are broken into components (or peaks) which are labeled using either a P or N (representing whether the peak is in the positive or negative direction) and a number which

represents how far after the onset of the stimulus the peak occurs. For instance, the N100 (or N1) peak is a negative deflection which occurs approximately 100 ms after the stimulus is presented.

Examining Sensory Processing Using ERPs

As ERPs can be used to understand how the brain responds to a particular stimulus in the environment it is an ideal tool through which sensory processing can be understood on a neurological level. Among the types of sensory processing, auditory sensory processing has a rich history in the EEG literature and a variety of paradigms have been used to explore auditory sensory processing in a variety of clinical populations. Two such paradigms include the sensory gating and sensory registration paradigms which were utilized in the current study.

Sensory gating. Sensory gating is studied using a pair of identical auditory clicks presented 500ms apart. Successful sensory gating occurs when the brain's response to the second click (test or T click) is suppressed when compared to the first click (conditioning or C click; see figure 6). Sensory gating is thought to reduce the likelihood of the brain being "flooded" by a series of repetitive stimuli (Hazlett et al., 2015). Sensory gating is often measured in the P50 component as a T/C ratio; that is taking the ratio of the amplitude of the P50 component of the second click to the amplitude of the same component of the first click (Davies, Chang, & Gavin, 2009; Davies & Gavin, 2007). A larger T/C ratio represents less successful gating while a smaller one represents more successful gating (Davies & Gavin, 2007). Sensory gating has been found to be impaired in children with SPD and low functioning ASD (LFA; Davies et al., 2009; Orekhova et al., 2008). Two possible mechanisms for this impairment in sensory gating have been proposed. One suggests that "gating out" or supression of the second click is impaired

while in the other "gating in" or registration of the first click is impaired so that the overall reduction in amplitude from the first to the second tone is lessened (Hazlett et al., 2015).

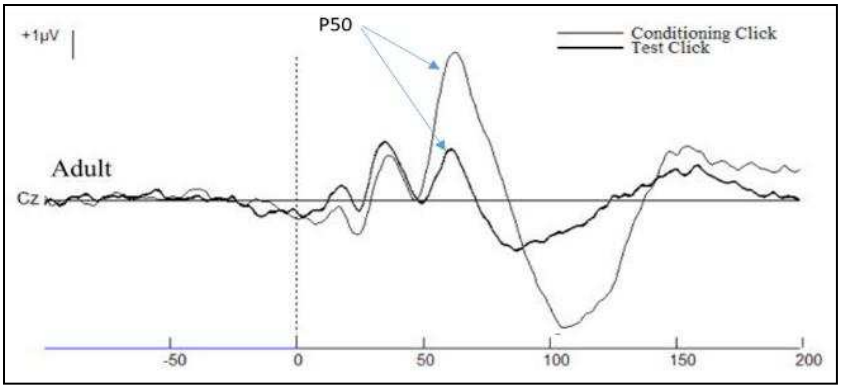

Figure 6. Depiction of Sensory Gating. Reprinted from Davies, Chang, & Gavin, 2009).

Sensory registration. Sensory registration is studied using a paradigm which presents four auditory tones at various frequencies and intensities (Davies & Gavin, 2007; Lincoln et al., 1995). Typical processing elicits four unique ERPs for each tone indicating that that each tone has been "registered" uniquely and distinguished from the other three (see figure 7; Davies & Gavin, 2007). Children with ASD and SPD have been found to have differences in registration compared to TD children (Bruneau, Roux, Adrien, & Barthélémy, 1999; Crasta, 2015; Davies & Gavin, 2007; Lincoln et al., 1995).

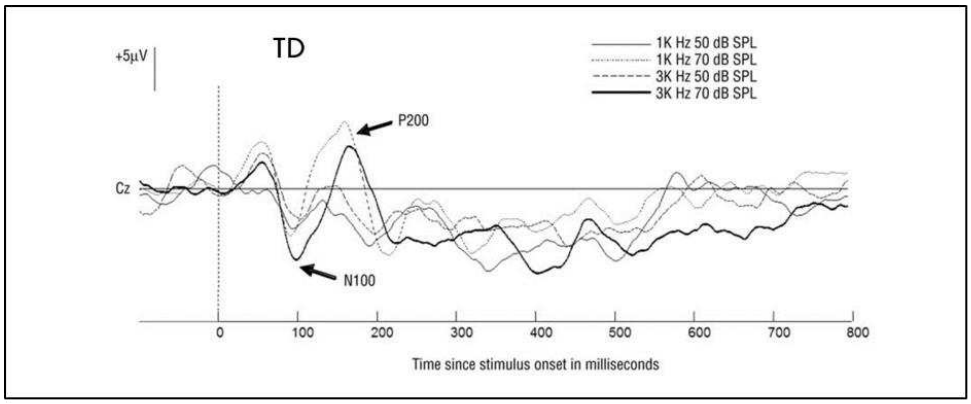

Figure 7. Depiction of Sensory Registration Reprinted from Davies and Gavin 2007.

Current Study

The purpose of the current study was to better understand auditory sensory processing in children with ASD and SPD and how it compares to children who are typically developing. This was done in two main ways. Firstly, this paper sought to replicate the findings of Davies and Gavin (2007) which examined sensory processing in children with SPD and TD children and found that the children with SPD tended to be either hyper or hypo responsive to auditory tones compared to TD children. This was determined by utilizing data from TD children on the registration paradigm to derive an equation by which a child's T/C ratio on the sensory gating paradigm could be predicted. A predicted T/C ratio was then derived from the equation for each child and a difference score was obtained by subtracting the predicted T/C ratio from the observed T/C ratio. Davies and Gavin (2007) found that TD children had little smaller difference scores than children with SPD, whose difference scores were either significantly below what would be expected or above, indicating that the children with SPD were hyper-responsive or hypo-responsive respectively (see figure 8).

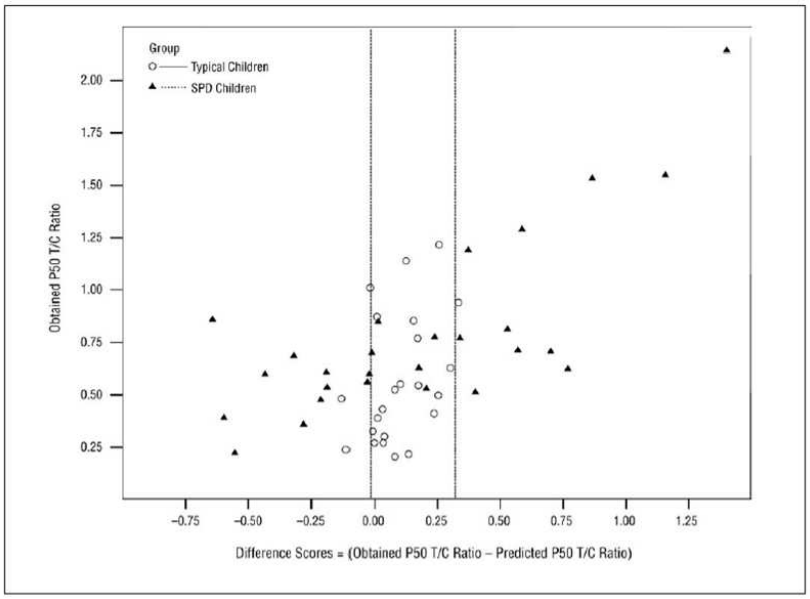

Figure 8. Difference scores plotted against actual P50 T/C ratio scores for TD children and children with SPD. Reprinted from Davies and Gavin (2007)

Data from new samples of TD children and children with SPD were analyzed and additionally the same analyses were conducted on a sample of children with high functioning autism (HFA). The second main purpose of this study was to explore the relationship of neurophysiological measures of sensory processing and behavioral measures of sensory processing. Specifically, the relationship between the child's ERPs from the sensory gating and registration paradigms and the child's quadrant scores from the Sensory Profile were examined. Understanding the brain behavior relationship is particularly important for occupational therapists who utilize assessments to understand underlying neurological mechanisms such as sensory processing.

Research Questions and Hypotheses

Question 1. Can the results of Davies and Gavin (2007) be replicated with a new sample of *children with SPD* and typically developing children?

Hypothesis 1: *Children with SPD* from the new sample will exhibit a pattern of sensory hyper or hypo-responsivity as compared to the TD children as determined by differences between their expected sensory gating and their observed sensory gating.

Question 2. Will the sensory pattern of hyper-responsivity or hypo-responsivity in children with *high functioning ASD* be similar to that in children with sensory processing disorder found by Davies and Gavin (2007)?

Hypothesis 2: *Children with ASD* from the new sample will exhibit a pattern of sensory hyper or hypo-responsivity as compared to the TD children as determined by differences between their expected sensory gating and their observed sensory gating.

Question 3. What is the relationship between the behavioral indicators of sensory dysfunction as measured by the Sensory Profile and the neurophysiological indicators are measured by the ERP components in the sensory gating and registration paradigms?

Hypothesis 3: Children who are predicted as being hyper-responsive based upon their T/C difference scores will be more likely to be classified as having sensory sensitivity or sensory avoidance on the SP.

Hypothesis 4: Children who are predicted as being hypo-responsive based upon their T/C difference scores will be more likely to be classified as having low registration or being sensory seeking on the SP.

Methods

Participants

Data were collected from 104 children ages 5-12; 21 children with sensory processing disorder (SPD), 21 children with high functioning autism spectrum disorder (HFA), and 62 age matched typically developing peers. All participants were recruited as part of a convenience samples. Children with a diagnosis of HFA had their diagnosis confirmed using the Asperger Syndrome Diagnostic Scale (ASDS; Myles, Bock, & Simpson, 2001). Demographics for each sample can be seen below (see Table 1).

Participants were seated comfortably in a chair with the support of pillows or footstools if necessary during data collection. Following a brief introduction the EEG cap and electrodes were placed and children were trained on reducing artifacts such as eye blinks and muscle tension. Three EEG paradigms were collected across the two sessions. During the first session the sensory gating and sensory registration paradigms were collected.

Table 1

Demographics by Group

Group	Age		Gender		ASDS Score[1]			Registration[2]		Seeking[2]		Sensitivity[2]		Avoiding[2]	
	Mean	SD	Males	Females	1	2	3	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Typically Developing (*n* = 62)	7.47	1.42	35	28				66.00	10.35	105.87	18.69	85.10	13.60	117.08	19.15
Sensory Processing Disorder (*n* = 2	7.00	1.62	13	6				47.81	14.038	78.10	27.95	64.95	18.36	95.81	24.63
High Functioning Autism (*n* = 21)	9.04	2.19	18	3	9	7	1	50.71	13.94	80.48	23.16	64.10	15.87	93.14	20.65

Note.

1. An ASDS score of 1 indicates a very likely diagnosis of Aspergers, a score of 2 indicates a likely diagnosis, 3 indicates a possible diagnosis
2. Quadrant scores from the Supplement to the Sensory Profile

During the second session an orientation/habituation paradigm was collected, the data from which will not be utilized in this study. Following each EEG session, behavioral tests were administered and included the Test of Everyday Attention for children (TEA-Ch) during the first session and the Wechsler Abbreviated Scale of Intelligence (WASI) and the Clinical Observation of Motor and Postural Skills (COMPS) during the second session. Data from these assessments were not be utilized for the current study.

EEG/ERP data recording. The running EEG was recorded with a 32-channel BioSemi Active Two EEG system with electrodes placed in accordance with the American Electroencephalographic Society nomenclature guidelines (1994). Two bipolar electro-oculograms (EOGs) were measured by electrodes placed on the left and right outer canthus to measure horizontal movements and on the left supraorbital and infraorbital regions to measure vertical movements. Two additional electrodes were placed on the earlobes to serve as a reference. Two electrodes were also placed on the mastoids. EEG signals were sampled at an analog-to-digital rate of 1024 Hz with a bandwidth of 268 Hz. Auditory stimuli were presented through earbuds using E-Prime software (Psychological Software Tools, Pittsburgh, PA, USA). Prior to the administration of either the sensory registration or gating paradigms the participant's hearing threshold was assessed using a 3 ms click stimulus and a stepping procedure (Levitt, 1971).

Sensory registration paradigm. To understand children's response to auditory stimuli a sensory registration paradigm was used to evoke an ERP. The paradigm consists of four types of pure tones which are 50 ms in duration with a 10 ms rise/fall time. Two of the tones are low frequency (1000 Hz) and two are high frequency (3000 Hz). Each frequency of tone is played at both a low intensity (50 dB SPL) and high intensity (70 dB SPL). Stimuli were presented in

blocks of 100 with 25 trials of each stimuli presented randomly with a 2-second inter-stimulus interval (Ferri et al.) between each. Four blocks total were presented with each block taking about 3.5 minutes with a 30 second break given at the conclusion of each block. During the stimulus presentation children watched a silent animated film.

Sensory gating paradigm. To understand children's ability to suppress irrelevant sensory stimuli a sensory gating paradigm was used to evoke an ERP. The paradigm consisted of 120 pairs of clicks presented at 60 dB above hearing threshold. Each click was 3 ms in duration and were presented at mixed frequencies. Clicks were separated by a 500 ms ISI and click pairs were separated by an 8 second inter-trial interval (Year & Investigators). During the stimulus presentation children watched a silent animated film.

Data Processing

The software Brain Vision Analyzer 2 by Brain Products (Munich, Germany) was used to filter, segment, and remove artifacts for both paradigms. A customized software written in MatLab (Mathworks Inc., Natick, Massachusetts) was used to identify peaks representing ERP components and data were visually inspected afterwards to ensure accuracy.

Sensory registration. Data from the sensory registration paradigm were filtered using a .23-30 Hz band pass (Davies & Gavin, 2007). Data were segmented around each of the four tones from 200 ms pre-stimulus onset to 800 ms post-stimulus onset. Each segment was baseline corrected using EEG data from 200 ms prior to the stimulus onset. A regression approach was used to remove artifacts caused by eyeblinks (Segalowitz, 1996). Additional segments containing artifacts were then removed using EOG artifact rejection (+/- 100 µV). Baseline correction was performed again relative to a baseline of -100 ms to 0 ms for the non-rejected segments. Then the segments were averaged to create a separate ERP for each of the four tones. The N100

component was scored as the most negative peak between 80 and 120ms post stimulus onset. Its amplitude was measured peak to peak as the difference in µV between the N1 peak amplitude and the P1 peak amplitude. The P100 amplitude was defined as the most positive peak between 20 and 80 ms post stimulus onset. The P200 component was scored as the most positive peak between 180 and 240 ms post stimulus onset. Its peak to peak amplitude was calculated as the difference in µV between the N1 peak and P2 peak. Data were analyzed at site Cz.

Sensory gating. Data from the sensory gating paradigm were filtered using a 10-200 Hz band pass (Chang, Gavin, & Davies, 2012). Data were segmented from 100 ms before the click onset through 500 ms following the click offset. Each segment was baseline corrected using EEG data from 100 ms prior to the stimulus onset. Additional segments containing artifacts were then removed using EOG artifact rejection (+/- 100 µV). Baseline correction was performed again relative to a baseline of -100 ms to 0 ms for the non-rejected segments. Averaged ERPs for both the test click (T) and the conditioning click (C) were obtained. The peak of P50 was measured as the highest peak from 40-80ms post stimulus onset and N45 was measured as the most negative peak from 30-60ms post stimulus onset. Latencies of the P50 peak for the T and C clicks were compared to ensure that peaks were no further than 20ms apart. 4 subjects had latency differences of more than 20ms but upon a second visual inspection the peaks were confirmed by a second observer. The decision was made to retain data from these 4 participants. One subject was excluded due to an unscorable P50 component. Peak-to-peak amplitude was calculated by subtracting the amplitude of N45 from the amplitude of P50. Data were analyzed at site Cz.

Behavioral Measures

Sensory Profile. The Sensory Profile (SP) is a 125 item instrument which is completed by caregivers and indicates a level of sensory dysfunction (Dunn, 1999). The SP has been found

to have good reliability and validity as an instrument and consists of 7 sections which are Tactile, Taste/Smell, Visual/Auditory, and Movement Sensitivity, Under-responsive/Seeks Sensation, Auditory Filtering, and Low Energy/Weak (T. Brown, 2008; Tomchek & Dunn, 2007). Scores from the SP can be converted utilizing the Supplement to the Sensory Profile into 4 quadrant scores. The four quadrants are registration, seeking, sensitive, and avoiding. Each quadrant represents a combination of a child's level of threshold (high or low) which represents the level of a stimuli that must be presented for it to be recognized by the child, and their response when an above threshold stimulus is encountered (active or passive). Children who have high scores on the registration or seeking quadrants have a high threshold and therefore require a higher level of input for a stimulus to be recognized. Children with a high score on registration therefore require much greater levels of input for a stimulus to be recognized and also have a passive response to that input which may lead to them missing important information within their environment. Children who score highly on seeking also require more input but they take an active role in seeking that information out and may have participation difficulties as a result of excessive seeking of sensory input. Children who score highly on the sensitivity or avoiding quadrant are more likely to recognize a stimulus at a lower level. Children scoring highly on the sensitivity quadrant recognize the stimulus at a low level and respond to it passively but may find the sensory information so overwhelming that it prevents them from engaging in the task at hand. Children scoring highly on the avoiding quadrant also recognize information at a low level but take an active role in avoiding that sensory information and may become too overwhelmed by the environment to participate (Dunn, 2006).

Data Analysis

In order to test hypotheses one and two, a 3 step regression analysis was performed using the data from typically developing children. The predicted dependent variable was the P50 T/C ratios from the sensory gating paradigm. The predicting independent variables were age, the N100 amplitudes and latencies of the two loud intensity auditory stimuli from the sensory registration paradigm, and the P200 amplitudes and latencies of the two loud intensity auditory stimuli which were entered in the first, second, and third steps respectively. From this regression, a prediction equation for P50 T/C ratios using the unstandardized coefficients obtained for each variable of the regression equation was developed. The predicted T/C ratios were then calculated for each child in the other two groups, SPD and ASD. From there the predicted T/C ratio were subtracted from their actual T/C ratio to obtain a difference score. These difference scores were then plotted against their obtained P50 T/C ratios.

In order to test hypotheses three and four, scores from the SP were first converted into quadrant scores using the Supplement to the Sensory Profile (Dunn, 1997, 2006). Next, a linear regression was conducted using the obtained T/C difference scores as the predicted dependent variable and the total subscores for registration, seeking, sensitivity, and avoiding as the predicting independent variables.

Results

In order to determine the prediction equation for a child's P50 T/C ratio to test hypotheses 1 and 2, a 3 step regression analysis was performed using the data from only the typically developing children. The predicted dependent variable was the P50 T/C ratios from the sensory gating paradigm. The predicting independent variables were age, the N100 amplitudes and latencies of the two loud intensity auditory stimuli from the sensory registration paradigm,

and the P200 amplitudes and latencies of the two loud intensity auditory stimuli which were entered in the first, second, and third steps respectively. Analyses revealed that age, N100 amplitudes and latencies, and P200 amplitudes and latencies explain a significant amount of the variance in P50 T/C ratio, R^2 = .35 (Adj. R^2 = .23), $F_{(9, 47)}$ = 2.86, p = .009. Of the variance in P50 T/C ratios age accounted for 15.6% (F Change$_{(1, 55)}$ = 10.18, p = .002), N100 amplitudes and latencies for 13.3% (F Change$_{(4, 51)}$ = 2.39, p = .063), and P200 amplitudes and latencies for 6.4% (F Change$_{(4, 47)}$ = 1.17, p = .336, See Table 2). Of the variables only age was found to be a significant predictor (t = -2.72, p = .009).

After the regression equation was derived from the data from the TD children it was used to calculate a predicted P50 T/C ratio for the children with SPD and ASD. A difference score was then calculated by subtracting the predicted P50 T/C ratio from the child's actual ratio. These difference scores were then plotted against the child's actual (or obtained T/C ratio (see Figure 9 and Figure 10). Data from 7 children were excluded due to missing data on one or more variables (1 ASD, 2 SPD, and 4 TD).

In order to test hypotheses three and four, scores from the SP were first be converted into quadrant scores using the Sensory Profile Supplement (Dunn, 2006). Next, a multiple linear regression was conducted using the obtained T/C difference scores (derived from the first regression analysis) as the predicted dependent variable with age and the total subscores for registration, seeking, sensitivity, and avoiding as the predicting independent variables entered in steps 1 and 2 respectively. The regression was conducted for each group separately. For typically developing children, age and the sensory profile quadrant scores were found to explain a significant amount of variance in the P50 T/C ratio difference score, R^2 = .21 (Adj. R^2 = .14), $F_{(5, 51)}$ = 2.76, p = .028.

Table 2

Regression Analysis Predicting Sensory Gating from Sensory Registration

Variable	B	SE B	β	t	p
Constant	1.744	.508		3.432	.001
Age	-.093	.034	-.359	-2.718	.009
Low, loud tone N100 latency	.006	.003	.346	1.761	.085
Low, loud tone N100 amplitude	-.007	.018	-.079	-.387	.701
High, loud tone N100 latency	-.005	.004	-.279	-1.503	.139
High, loud tone N100 amplitude	.033	.016	.322	2.013	.050
Low loud tone, P200 latency	-.003	.002	-.256	-1.409	.165
Low loud tone, P200 amplitude	-.017	.014	-.244	-1.194	.239
High loud tone, P200 latency	.000	.002	-.012	-.065	.948
High loud tone, P200 amplitude	.022	.014	.288	1.592	.118

Notes. $R^2 = .35$, R^2 adj. = .23, (p =.009)

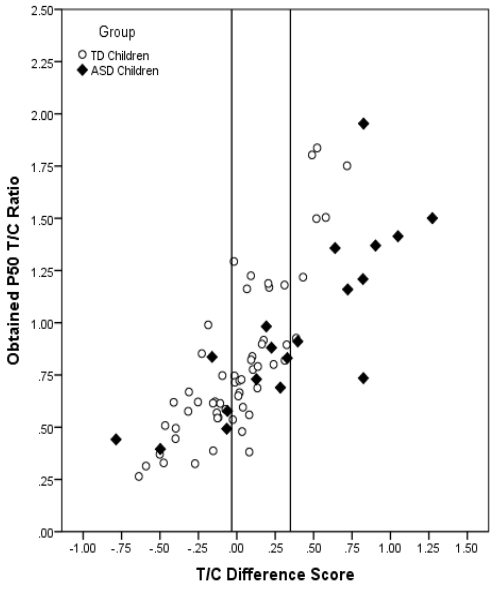

Figure 9. Difference scores against actual P50 T/C Ratio Scores for TD children and children with ASD.

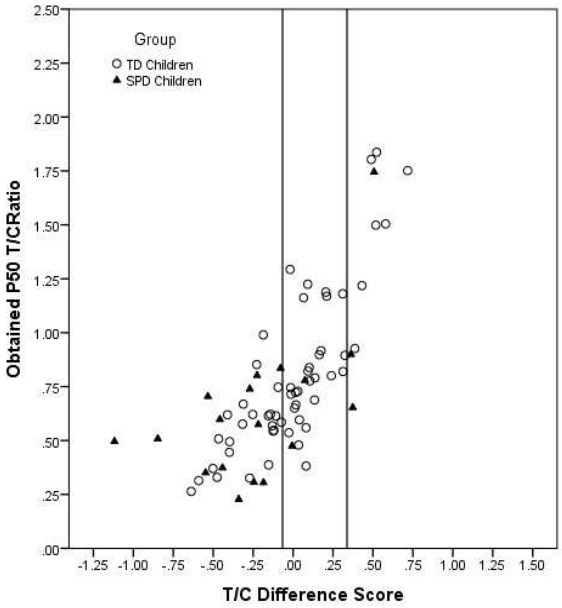

Figure 10. Difference scores against actual P50 T/C Ratio Scores for TD children and children with SPD.

However, the regression was not significant for the children with SPD, R^2 = .33 (Adj. R^2 = .07), $F_{(1, 17)}$ = 1.26, p = .339 or for the children with ASD, R^2 = .23 (Adj. R^2 = -0.04), $F_{(5, 14)}$ = .847, p = .539, see Table 3 for the regression for TD children.

Table 3

Regression Analysis Predicting T/C Ratio Difference Score from SP Quadrants

Variable	B	SE B	β	t	p
Constant	-.071	.332		-.213	.832
Age	.017	.027	.082	.643	.523
Registration	.005	.009	.172	.564	.575
Seeking	-.004	.004	-.230	-.879	.383
Sensitivity	.021	.008	.993	2.605	.012
Avoiding	-.015	.005	-1.023	-3.292	.002
Notes. R^2 = .21, R^2 adj. = .14 (p =.028)					

For the TD children, age explained 0% of the variance in P50 T/C difference score (F Change$_{(1, 55)}$ = .00, p = 1.00) while the SP quadrant scores explained 21.3% (F Change$_{(4, 51)}$ = 3.44, p = .014). For the TD children, the subscores for the sensitivity quadrant (t = 2.61, p = .012) and the avoiding quadrant (t = -3.29, p = .002) were significant predictors.

Post Hoc Analyses

Results for the first regression analyses (to predict gating from registration) revealed a positive linear trend in the residuals (or difference scores) of the TD children. As this indicates that at least one unknown variable exists to explain this additional variance, two additional regression analyses were conducted to explore potential third variables.

In order to determine possible 3rd variables a 4 step regression analysis was performed using the data from only the typically developing children. The first three steps were identical to the earlier regression model predicting gating from registration with the predicting independent variables of age, the N100 amplitudes and latencies of the two loud intensity auditory stimuli from the sensory registration paradigm, and the P200 amplitudes and latencies of the two loud intensity

auditory stimuli entered in the first, second, and third steps respectively. In both alternate regression models a fourth step was added. In the first alternate regression model P300 peak to peak amplitude and N200 latencies from the two loud intensity auditory stimuli from the sensory registration paradigm were included. Analyses revealed that age, N100 amplitudes and latencies, P200 amplitudes and latencies, P300 amplitude, and N200 latency explain a significant amount of the variance in P50 T/C ratio, R^2 = .43 (Adj. R^2 = .23), $F_{(13, 39)}$ = 2.23, p = .027. Of the variance in P50 T/C ratios age accounted for 16.7% (F Change$_{(1, 51)}$ = 10.20, p = .002), N100 amplitudes and latencies for 12.9% (F Change$_{(4, 47)}$ = 2.16, p = .088), P200 amplitudes and latencies for 7.2% (F Change$_{(4, 43)}$ = 1.23, p = .314), and P300 amplitude and N200 latency for 5.8%, (F Change$_{(4, 39)}$ = 0.98, p = .430, see Table 4). Of the variables only P2 latency for the low frequency high intensity tone was found to be a significant predictor (t = -2.05, p = .047). After the regression equation was derived from the data from the TD children it was used to calculate a predicted P50 T/C ratio for the children with SPD and ASD. A difference score was then calculated by subtracting the predicted P50 T/C ratio from the child's actual ratio. These difference scores were then plotted against the child's actual (or obtained) T/C ratio (see Figures 11 and 12). Data from 12 children were excluded from these analyses due to missing data on one or more variables (1 ASD, 3 SPD, and 8 TD).

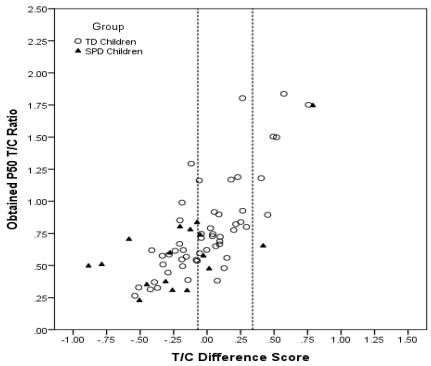

Figure 11. Difference scores for TD children and children with SPD (inclusion of P3 and N2)

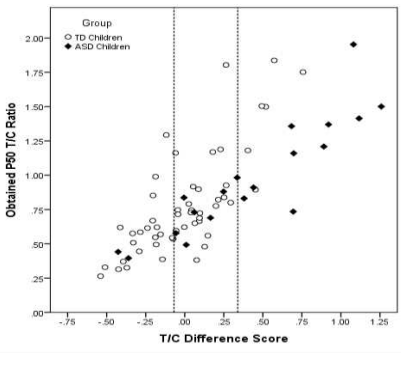

Figure 12. Difference scores for TD children and children with ASD (inclusion of P3 and N2)

Table 4

Regression Analysis Predicting Sensory Gating from Sensory Registration Including P300, N200

Variable	B	SE B	β	t	p
Constant	1.333	.708		1.88	.067
Age	-.075	.042	-.286	-1.80	.079
Low, loud tone N100 latency	.006	.003	.366	1.75	.089
Low, loud tone N100 amplitude	.000	.019	.002	.011	.99
High, loud tone N100 latency	-.005	.004	-.279	-1.38	.177
High, loud tone N100 amplitude	.027	.021	.244	1.31	.198
Low loud tone, P200 latency	-.005	.003	-.421	-2.05	.047
Low loud tone, P200 amplitude	-.013	.015	-.195	-.90	.376
High loud tone, P200 latency	.001	.003	.040	.19	.853
High loud tone, P200 amplitude	.009	.015	.113	.57	.572
Low loud tone, N200 latency	.002	.001	.272	1.71	.095
Low loud tone, P300 amplitude	-.006	.013	-.068	-.48	.637
High loud tone, N200 latency	-8.036E-5	.001	-.010	-.07	.947
High loud tone, P300 amplitude	.011	.014	.126	.78	.441
Notes. R^2 = .43, R^2 adj. = .23 (p =.027)					

A second alternate regression was then conducted which maintained the first three steps of the previous regression but included the four quadrant scores from the sensory profile as a fourth predictor. Analyses showed that age, N100 amplitudes and latencies, P200 amplitudes and latencies, the sensory profile quadrant scores explain a significant amount of the variance in P50 T/C ratio, R^2 = .51 (Adj. R^2 = .36), $F_{(13, 43)}$ = 3.38, p = .001. Of the variance in P50 T/C ratios age accounted for 15.6% (F Change$_{(1, 55)}$ = 10.18, p = .002), N100 amplitudes and

latencies for 13.3% (F Change$_{(4, 51)}$ = 2.39, p = .063), P200 amplitudes and latencies for 6.4% (F Change$_{(4, 47)}$Se = 1.17, p = .336, and the SP quadrant scores for 15.2%, (F Change$_{(4, 43)}$) = 3.30, p = .019. Age (t = -2.31, p = .026), N100 latency for the low frequency high intensity tone (t = -2.13, p = .039), P200 amplitude for the high frequency high intensity tone (t = 2.41, p = .020), the sensitivity quadrant score (t = 2.51, p = .016), and the avoiding quadrant score (t = -3.22, p = .002) were significant predictors (see Table 5).

After the regression equation was derived from the data from the TD children it was used to calculate a predicted P50 T/C ratio for the children with SPD and ASD. A difference score was then calculated by subtracting the predicted P50 T/C ratio from the child's actual ratio. These difference scores were then plotted against the child's actual (or obtained) T/C ratio (see Figure 13 and Figure 14). Data from 7 children were excluded from these analyses due to missing data on one or more variables (1 ASD, 2 SPD, and 4 TD).

Discussion

The original aims of this study included to replicate and expand the results of Davies and Gavin (2007) to a new sample and to increase understanding of brain behavior relationships by examining the relationship between measures of neurological sensory processing with behavioral measures of the same concept. The first aim of this study was partially achieved. For the new sample of typically developing children and children with sensory processing disorder sensory gating was able to be significantly predicted from sensory registration. However, in the new sample much less of the variability in sensory gating was able to be explained by the child's performance in the sensory registration paradigm. The second aim was also achieved as a child's score on the sensory profile did contribute significantly to explaining how well that child's registration predicted their gating.

Table 5

Regression Analysis Predicting Sensory Gating from Sensory Registration Including Sensory Profile Quadrant Scores

Variable	B	SE B	β	t	p
Constant	1.583	.552		2.864	.006
Age	-.074	.032	-.285	-2.306	.026
Low, loud tone N100 latency	.007	.003	.403	2.131	.039
Low, loud tone N100 amplitude	-.019	.018	-.210	-1.054	.298
High, loud tone N100 latency	-.005	.003	-.267	-1.496	.142
High, loud tone N100 amplitude	.032	.016	.310	1.974	.055
Low loud tone, P200 latency	-.003	.002	-.248	-1.446	.155
Low loud tone, P200 amplitude	-.017	.013	-.250	-1.329	.191
High loud tone, P200 latency	.000	.002	-.014	-.082	.935
High loud tone, P200 amplitude	.032	.013	.408	2.410	.020
Registration	.003	.010	.092	.307	.760
Seeking	-.003	.005	-.141	-.589	.559
Sensitivity	.023	.009	.883	2.508	.016
Avoiding	-.017	.005	-.933	-3.219	.002
Notes. R^2 = .50, R^2 adj. = .36 (p =.001)					

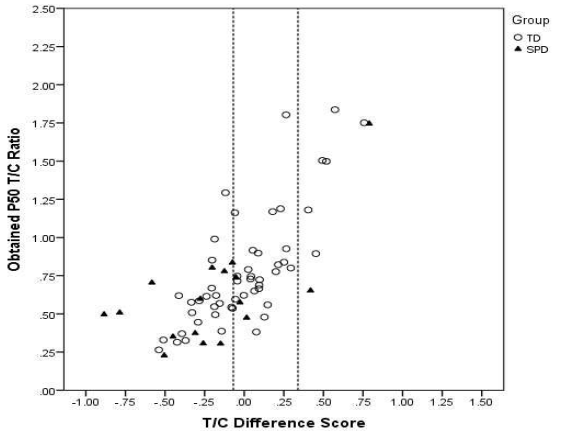

Figure 13. Difference scores against actual P50 T/C Ratio Scores for TD children and children with SPD (inclusion of SP)

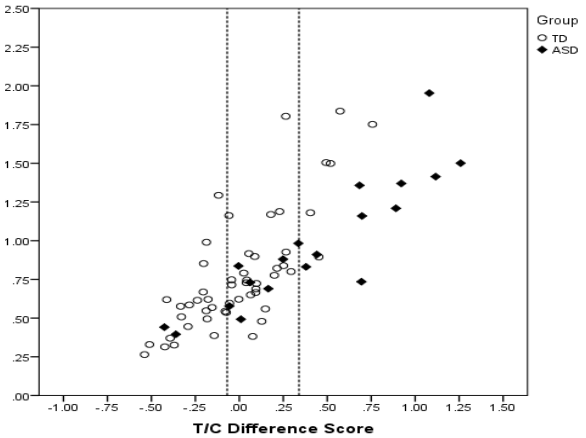

Figure 14. Difference scores against actual P50 T/C Ratio Scoresfor TD children and children with ASD (inclusion of SP)

Patterns of Auditory Sensory Processing in Children with SPD and ASD

SPD. The first hypothesis, that children with SPD from the new sample, when examining individual differences between predicted T/C scores (derived from regression model based upon typically developing children) will fall into two groups, one of which represents hyper-responsiveness to stimuli and one of which represents hypo-responsiveness to stimuli was not supported by the results. While a regression was able to be determined that predicted a child's sensory gating (T/C ratio) from their registration the children with SPD did not split cleanly into two different groups based upon how well the model predicted their data. Children with SPD tended to have consistently better sensory gating than expected as their difference scores tended to be negative. Additionally, the TD children in the sample had much more variation in their difference scores than in the original sample. Davies and Gavin (2007) were able to predict 84% of the variance in T/C ratios using age and measures from the sensory registration paradigm while in the current study only 35% of the variance in gating was explained by age and registration. This could be due to several reasons. Firstly, this study was not a true replication as there were a few methodological differences between Davies and Gavin (2007) and the current study. Additionally, the participants in Davies and Gavin (2007) were slightly older on average than those participants in the current study (8.34 years old compared to 7.47 years old for TD children, and 7.71 years old compared to 7.00 for the children with SPD). Secondly, during the original study the children viewed a fixation point during the sensory registration paradigm while in the current study they watched a silent film. This may have impacted the children's attention to the stimuli which could change the way their brain processed the auditory information (Coull, 1998; Woldorff & Hillyard, 1991). Additionally, this study had a larger sample of TD children utilizing data from 57 children compared to 25 in Davies and Gavin (2007). Having a larger

sample tends to create more normally distributed data and therefore the results of this study may be more reflective of the population as a whole.

Children with SPD did demonstrate neurophysiological differences in their auditory sensory processing as compared to TD children (Davies et al., 2009; Davies & Gavin, 2007; Miller, Nielsen, & Schoen, 2012; Schoen et al., 2009). The children with SPD were overall more hyper-responsive to the auditory stimuli than the typically developing children demonstrating more sensory gating than predicted as they tended to have negative T/C ratio difference scores, indicating they were better sensory-gaters than expected. This is similar to the finding of Schoen et al. (2009), McIntosh et al. (1999) and Miller et al. (2012) in that children with SMD (one subtype of SPD) had greater physiological reactivity overall as measured by galvanic skin response (GSR) to an aversive auditory stimuli than TD children.

ASD. The second hypothesis, that children with ASD, when examining individual differences between predicted T/C scores (derived from regression model based upon typically developing children) will fall into two groups, one of which represents hyper-responsiveness to stimuli and one of which represents hypo-responsiveness to stimuli was also not supported by the data. Children with ASD had a wide variance in how well the model was able to predict their sensory gating and did not cluster on either side of the TD children. However, as noted above the TD children also had much more variability in their difference scores than in the original sample.

This study also found that children with ASD demonstrated a different pattern of auditory sensory processing than TD children as demonstrated by their residuals falling along a different slope than the TD children's. This mirrors existing evidence in the literature for early auditory evoked potentials (Bruneau et al., 1999; Ferri et al., 2003; Martineau, Garreau, Barthelemy, & Lelord, 1984). While the children with ASD did not demonstrate a significant hyper or hyper-

responsivity as compared to TD children their residuals seem to fall along a different slope than those of the TD children, indicating that their pattern of processing is being impacted by another variable. Schoen et al.'s (2009) findings support this study's result that children ASD did not demonstrate considerable hyper- or hypo-responsiveness as compared to TD children. Schoen et al. (2009) found that children with ASD had similar reactivity to an auditory stimulus to TD children and less overall reactivity than children with SMD.

Relatedness of Neurophysiological and Behavioral Measures of Auditory Processing

The third hypothesis, that children who are predicted as being hyper-responsive based upon their T/C difference scores will be more likely to be classified as having sensory sensitivity or sensory avoidance on the SP was partially supported. A significant amount of the variability in TD children's difference score (or residual) was explained by age and the child's scores on the sensory profile. Of the four quadrants sensitivity and avoiding were significant predictors. Additionally, sensory sensitivity had a positive unstandardized coefficient which indicates that children who score higher on this quadrant are more likely to have a higher difference score or in other words are more likely to be worse sensory-gaters than expected. This makes sense as children who are poorer gaters may be more likely to be overwhelmed by repeated auditory input in their environment and therefore be sensitive to loud and chaotic environments a finding which was supported in adults by Kisley, Noecker, and Guinther (2004). However, sensory avoiding had the opposite relationship in that children who had more avoidance were less likely to have higher difference scores. That is children who were more likely to avoid sensory input were more likely to be better sensory gaters than expected. It is important to note that each sensory profile quadrant takes into account children's behavioral responses from a variety of sensory areas (tactile, auditory, visual, etc) and therefore children scoring highly on each quadrant may not

necessarily be avoiding or sensitive to auditory stimuli but rather another type of input (Dunn, 2006).

Hypothesis four, that children who are predicted as being hypo-responsive based upon their T/C difference scores will be more likely to be classified as having low registration or being sensory seeking on the SP was not supported by the data. Registration and seeking were not found to be significant predictors of a child's residuals.

The results of this study were similar to those of Brown, Tollefson, Dunn, Cromwell, and Filion (2001). Brown et al. (2001) found that adults scoring highly on the sensitivity or avoiding quadrants had higher overall GSR responsivity to auditory stimuli than those who scored highly on the low registration or sensation seeking quadrants. This is similar to the result that children who scored higher on the sensory avoiding quadrant were more likely to be better gaters (or hyper-responsive) as opposed to those who scored lowly on that quadrant. Additionally, Brown et al. (2001) found that those who scored highly on the sensory avoiding were faster to habituate than those in the sensory sensitivity quadrant. Sensory gating can be thought of as habituation over a quick duration. This aligns with the results of the current study in that children who were avoiding were more likely to be better gaters and children who were more sensory sensitive were more likely to be worse gaters.

Post Hoc Analyses

The initial analyses showed a linear trend in the residuals for the TD children. This indicates that a third variable was explaining some of the variability in children's sensory gating. Two additional post hoc analyses were conducted to explore possible third variables through the addition of a fourth step to the original regression model. The first post hoc analyses included the addition of the P300 amplitude and N200 latencies of the two loud intensity auditory stimuli

from the sensory registration paradigm. These variables were selected as late components (including N200 and P300) are thought to represent attention and the methodological difference between the current study and Davies and Gavin (2007) of the silent movie was suspected to impact attention. For instance, Gavin, Dotseth, Roush, Smith, Spain, and Davies (2011) found that children with SPD had smaller P300 amplitudes compared to TD peers while Davies et al. (2010) found that children with SPD had larger P300 amplitudes compared to TD peers. Davies et al. (2010) utilized the same methodology as Davies and Gavin (2007) as children gazed at a fixation point during the sensory registration paradigm while in Gavin et al. (2011) children watched a silent film. The differences in the results of these two studies suggest that movie watching may alter attention to the auditory stimuli and suggested that investigation of the impact of attention was relevant to the current study. This regression model predicted a significant amount of the variability in sensory gating although only P200 latency for the low frequency high intensity tone was found to be a significant predictor. P200 as well as other early components such as the N100 and N200 have been found to be associated with attention (Lijffijt et al., 2009). Overall, this model explained 43% of the variance in sensory gating indicating that attention is likely a third variable that can account for some of the variability in difference scores among TD children.

The relationship between attention and auditory processing has also been explored in the literature and supports the idea that attentional manipulations may impact early auditory processing. Early components such as the P50, and N100 have been shown to be impacted by attentional manipulations in typical adults (Coull, 1998; Parasuraman, 1980; Woldorff & Hillyard, 1991). Additionally, children with attention deficit hyperactivity disorder (ADHD) have been shown to demonstrate abnormalities in early ERP components during an auditory task

(Jonkman et al., 1997; Oades, Dittmann-Balcar, Schepker, Eggers, & Zerbin, 1996). As impaired attention is a central feature of ADHD these results lend support to the idea that early auditory evoked potentials may be impacted by attention.

The second post hoc analysis sought to explore the relationship between neurophysiological measures and behavioral measures of sensory processing in an alternate way. The linear trend in the residuals for TD children could additionally be explained by individual differences in the processing of auditory sensory information some of which could be examined based upon how the children responded to sensory information in their environment as measured by the sensory profile. In this analysis the quadrant scores from the SP were added as the fourth step. This model significantly predicted 51% of the variability in sensory gating. Similar to the analyses for hypotheses three and four (see above) sensitivity and avoiding were the quadrant scores which significantly predicted sensory gating. This second analyses provided additional support for the relationship between behavioral and neurophysiological sensory processing.

Limitations

The current study was limited by the methodological differences between it and Davies and Gavin (2007). This prevented the study from acting as a true replication but did provide an opportunity to examine how the data may have been impacted by altering the delivery of the auditory stimulus. Additionally, it would have been ideal to have higher numbers of participants with SPD and ASD included to increase the generalizability of data to these two samples. Comparisons between the TD children and children with ASD must also be interpreted with caution as the children with ASD were slightly older than the TD children.

Clinical Utility

This study is of utility for clinicians because it not only helps to understand auditory sensory processing in children with ASD and SPD but it also begins to explore how the brain and behavior are linked in the processing of sensory information. Information of this sort can be utilized by practitioners to gain a better understanding of the challenges faced by their clients, to provide education to those in the client constellation, to provide more targeted intervention, and potentially to develop tools to monitor progress from intervention. This study also lends credibility to the diagnosis of SPD.

This study provides support for the diagnosis of SPD in two main ways. Firstly, it along with previously existing literature demonstrates that children with SPD do have a neurophysiological difference in the manner in which they process auditory sensory information distinct from both TD children and children with ASD (Davies et al., 2009; Davies & Gavin, 2007; Miller et al., 2012; Schoen et al., 2009). This lends support to the validity of SPD as a diagnostic group. Secondly, this study partially validates a behavioral questionnaire, the SP, which is utilized by clinicians to make inferences about a child's processing and may be utilized as part of a comprehensive evaluation to diagnose SPD. This study demonstrated that there is a relationship between the way a child processes sensory information in their brain and how they respond accordingly behaviorally.

Future Directions

Further work is needed to understand underlying differences in sensory processing between children with ASD, SPD, and TD children in a variety of sensory domains including tactile, visual, and olfactory. Additionally, more research is necessary to understand how neurophysiological sensory processing relates to behavioral measures of sensory processing.

Many clinicians utilize assessments of sensory processing which could be further validated and understood if these measures were correlated with physiological measures.

Moving forward, research of this nature could also be utilized to monitor progress through interventions by measuring actual changes of the neurophysiological processing of sensory information in the brain. This would provide powerful evidence for the efficacy of sensory integration interventions and also allow for clinicians to target outcomes more specifically.

CHAPTER 3

Centennial Vision

Research of this nature is crucial to the field of occupational therapy (OT). AOTA's Centennial Vision states that "We envision that occupational therapy is a powerful, widely recognized, science-driven, and evidence-based profession with a globally connected and diverse workforce meeting society's occupational needs" (American Occupational Therapy Association, 2007). In order to meet the tenants of this Centennial Vision OT as a profession must commit itself to becoming not only a consumer of research but also an avid producer.

Firstly, in order to be science-driven and evidence-based OT must be producing research that answers the questions specific to the field. OT has a unique viewpoint and while information can be drawn from many disciplines to information OT practice efforts should be made to produce evidence which specifically informs how occupational therapists practice and understand the clients they serve. For instance, OT has been key in the formation and beginnings of recognition for the diagnosis of SPD. As a profession we need to be producing research that further validates this diagnosis and also explores the impact that occupational therapists (Gavin et al., 2011) can have in reducing the participation limitations which are experienced by those with this disorder (Dunn, 1997).

This study demonstrates one possible way that research in the field can begin to address these topics. Research of a similar nature to this study helps OTs to make more informed decisions in their practice because it increases their understanding of the clients they serve. Being able to pinpoint specific differences in sensory processing could help a practitioner to create more specifically targeted interventions and be more efficient in helping their clients to

begin engaging in meaningful and age appropriate occupations. For instance, this study demonstrated that children with sensory processing disorder may be more hypersensitive to auditory stimuli than a typically developing child. This finding could be utilized by therapists to begin formulating a treatment plan which includes gradual desensitization to stimuli or making recommendations about the child's environment in order to maximize their performance and participation. Additionally, this study demonstrated that children with ASD demonstrated both hyper-sensitivity and hypo-sensitivity of their responses to auditory stimuli. This informs therapists that they need to include information from observations or other assessments to determine whether a child with ASD has hyper-responsivity or hypo-responsivity in order to begin to make treatment plans.

Another key to being a science-driven and evidence-based profession is to utilize research throughout every step of the OT process (American Occupational Therapy Association, 2014). This includes using well validated and reliable assessments as part of the evaluation process. As technology advances and we have better tools through which to evaluate assessments utilized by OT it is important whenever possible to connect behavioral assessments back to their underlying physiological cause. This ensures that assessments have construct validity and are actively measuring what they report to measure. Comparing the results of an assessment to a biological measure provides an additional layer of construct validity beyond just comparing it to other measures of similar behavior.

This study takes steps to validate a well-used measure in occupational therapy, the Sensory Profile. Results indicated that some of the scores on this measure do correlate with underlying neurophysiological measures of sensory processing. Scores on the avoiding and sensitivity quadrants were significant predictors of the brain's processing of auditory

information. Additionally, they predicted the brain's response in a way that correlates with the description of how children scoring highly in those quadrants is outlined in the assessment. This provides validation that at least two of the quadrants of the Sensory Profile are measuring the construct that they claim. Not only does this provide validation that the Sensory Profile is in many ways tapping directly into sensory processing but it also suggests ways in which the assessment has not been as successful at directly measuring underlying mechanisms that create sensory driven behaviors. Information such as this could be taken to improve and modify assessments to help OTs obtain the most complete picture of their clients upon which they can develop and implement interventions.

In addition to having evidence based assessments, science-driven and evidence-based OT must make decisions based upon well-supported and researched theories. Sensory integration theory as proposed by Ayres is a widely utilized theory among occupational therapy practitioners (Bundy & Murray, 2002) however, there is still work to be done to validate its basic principles. For instance, while neuroplasticity has been investigated in detail by other fields little work has been done directly within occupational therapy to validate neuroplasticity as a mechanism of behavioral change (Lane & Schaaf, 2010). It is important for OT as a field to take responsibility to generating research which can be utilized to evaluate and improve upon theories which direct practice. The current study provides an underlying basis from which work investigating OT interventions role in facilitating neuroplasticity could be further explored.

Research can also contribute to OT becoming powerful, and widely recognized as a profession. As interest in disorders such as SPD and ASD grow among the general public research produced by OTs has the potential to reach a wider audience and therefore begin to be recognized as leaders in understanding and treating these conditions. Additionally, research is

important for OT to be able to prove its efficacy in today's healthcare system. Currently, the "Triple Aim" of healthcare calls for care which improves the individual experience, improves the health of populations as a whole, and reduces costs (Lamb & Metzler, 2014). To meet the Triple Aim OT must be able to prove that it provides effective care which contributes towards overall engagement and well-being of those it serves.

This study takes initial steps towards establishing a basis from which OT can demonstrate its efficacy at addressing sensory processing difficulties among children. For one, it contributes towards the establishment of baseline information about how those with sensory impairments process auditory information. This provides a basis from which practitioners can begin to better understand their clients and gives them tools to provide education to families, educators, and community stakeholders who may interact with their clients. Research of this sort may be useful in validating or explaining the experiences of parents of children with SPD and ASD who see that their child interacts with the world in a different way than other children. Additionally, once the underlying differences in various populations are understood OT practitioners may be able to move towards utilizing measures such as EEG or other neurophysiological measurement techniques to demonstrate actual changes in the body's response prior to and following intervention. This would give OTs a powerful tool to monitor progress and alter interventions to more specifically target a specific child's abilities and challenges. This strongly aligns with OT as a client centered profession (American Occupational Therapy Association, 2014) and would also provide empirically measurable evidence that could be provided to doctors, insurance providers, and policy makers who make decisions about the provision of and reimbursement for healthcare services.

Client Centeredness and Understanding Individual Differences

While being client centered is not a direct part of the Centennial Vision it has been and remains a key philosophy which underlies occupational therapy practice (Law et al., 1996). Occupational therapists collect information from many sources to gain a complete picture of their client and what impacts their ability to perform and participate in their occupations (American Occupational Therapy Association, 2014). Research such as this study provides another potential source of information which can be utilized to understand the incredibly complex factors which impact occupational performance and participation. Research that taps into the underlying neural mechanisms that drive behavior is a valuable resource to understand what contributes towards a person's interaction with their environment and the tasks in which they engage. For instance, directly measuring neurophysiological processing of sensory information may help to determine whether a child who becomes upset and cries in a loud and stimulating environment is engaging in that behavior due to an underlying impairment in the way they perceive sensory information in their environment or perhaps if it is a behavior which stems from feeling overwhelmed by attentional demands of the task at hand. Knowing whether a behavior is driven by an underlying sensory difficulty or whether it has another cause can help a therapist to more effectively address that child's needs without engaging in a process of intervention, progress monitoring, and then re-evaluation.

Understanding Participation Limitations

Occupational therapy's role is to facilitate the occupational performance and participation of humans in everyday contexts across the lifespan (Colorado State University Occupational Therapy, n.d.). Sensory processing difficulties can create a variety of barriers to performance and participation for individuals of all ages (Bar-Shalita, Vatine, & Parush, 2008; Schaaf, Toth-

Cohen, Johnson, Outten, & Benevides, 2011). Understanding the root cause of these barriers and being able to address it will enable occupational therapists to better serve their clients. Additionally, the creation of research which facilitates increased understanding of sensory processing difficulties among the general public will help to create motivation to change environments. Already, some movie theaters, zoos, and museums are hosting sensory friendly events to promote the ability of those with sensory processing difficulties to attend and engage in occupations which may normally be inaccessible to them. OTs can play a role in generating research and then implementing strategies determined from the results to advocate for the needs of their clients in the community.

Conclusion

Overall, research of this type is critical for OT as a profession to remain true to its work and to strive towards the goals of the Centennial Vision. OTs should make every effort to contribute towards research whether that be as a producer or an educated consumer in order to best serve their clients and communities.

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