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Electrodermal Activity as an Indicator of Sensory Processing in Typically Developing Children and Children with Autism Spectrum Disorders

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ELECTRODERMAL ACTIVITY AS AN INDICATOR OF SENSORY PROCESSING IN TYPICALLY DEVELOPING CHILDREN AND CHILDREN WITH AUTISM SPECTRUM DISORDERS

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Dedication

This work is dedicated to my son Ethan who has taken me on a personal journey into the world of Sensory Processing Disorder. Your struggle to cope with the daily discomfort in your own skin inspired me to learn all I could to help you and all children who struggle with this condition. Ethan I am so proud of your tremendous achievements in overcoming this struggle and living a happy, healthy life. I love you.

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ELECTRODERMAL ACTIVITY AS AN INDICATOR OF SENSORY PROCESSING IN TYPICALLY DEVELOPING CHILDREN AND CHILDREN WITH AUTISM SPECTRUM DISORDERS

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Chair: Dr. Genevieve Pinto-Zipp

Objective: The purpose of this study was to test the reliability of the Sensory Challenge Protocol (SCP), a laboratory procedural tool that has been used to discriminate differences in sensory processing between typically developing (TD) children and children with Autism Spectrum Disorder (ASD).

Method: Electrodermal activity (EDA) during rest and in response to sensation was measured using skin conductance. Skin conductance measures were used to calculate ICC (Intraclass Correlation Coefficient) reliability in 14 children with ASD and 18 TD children.

Results: ICC reliability during rest phase (tonic) for both groups was good to moderate (.65 - .73). ICC reliability during response to sensation (phasic) was good to moderate for amplitude (.60 - .81) and magnitude (.50 - .75) of response measures. In addition, high to moderate reliability (.51 - .93) for Non-specific response (NSR) measures were found.

Conclusion: This study supports the SCP as a reliable tool to measure response to sensation in TD children and children with ASD.

Chapter I

INTRODUCTION

Sensory Integration therapy is the most widely used therapy among pediatric occupational therapists to treat sensory processing disorder (SPD) [Lane & Schaaf; Leong & Carter, 2008; Miller, Coll & Schoen, 2007], the most frequently requested treatment for SPD among parents of children with Autism Spectrum Disorder (ASD) [Lane & Schaaf], and the most investigated frame of reference in occupational therapy practice (Lane & Schaaf, 2010). The theoretical framework underlying SPD is known as Sensory Integration (SI) theory and was developed forty years ago by A. Jean Ayres to explain disorganized behavior in children (Ayres, 1979; Hoehn & Baumeister, 1994; Leong & Carter, 2008; Miller, Anzalone, Lane, Cermak, Osten, 2007). The theory of Sensory Integration introduces the construct sensory processing. In this model sensory processing (also known as sensory integration) is defined as the ability of the brain to receive and organize sensations from the environment and generate an appropriate response (Ayres; Bundy, Lane & Murray, 2002). Difficulty with direct, tangible measurement of sensory integration or sensory processing within the central nervous system (CNS) has relegated the constructs of SI not able to withstand the rigors of scientific inquiry. Therefore, sensory integration therapy is categorized as an

experimental treatment in a significant segment of the medical and scientific community (Hoehn & Baumeister, 1994; Lane & Schaaf, 2010; Leong & Carter, 2008; May-Benson & Koomar, 2010).

During the last decade, scholars have developed a diagnostic taxonomy in an attempt to describe and distinguish patterns of response to sensation (Miller, Anzalone, Lane, Cermak, & Olsen, 2007). The rationale for this taxonomy is to provide a framework for scholarly debate, differentiate diagnostic subtypes of SPD, target subtypes with specific treatment interventions and improve homogeneity of samples used in research. Each subtype or pattern of response describes "individual differences in detecting, regulating, interpreting and responding to sensory input." (Miller et al., 2007, p. 136). Subtypes are categorized into three main groups consisting of the Sensory Discrimination Disorder (SDD), which refers to deficient interpretation of qualities of sensory stimuli needed to detect similarities or differences among stimuli; the Sensory-Based Motor Disorder (SBMD) which refers to deficient postural control and movement resulting from inaccurate sensory information and the Sensory Modulation Disorder (SMD) which refers to deficient regulation, via inhibition or facilitation of neural messages by the CNS that result in over or under response to sensation (Miller et al., 2007). It is the SMD subtype that often confounds samples of participant subjects due to combining over and under responsive subjects within this group. Therefore, in this taxonomy the SMD group are further broken down into

sensory overresponsive or sensory underresponsive categories. The parsing of each subtype within this taxonomy is an important strategy to achieve precise data on which to base a framework for scholarly debate.

In addition to a more specific diagnostic taxonomy, quantified physiologic measurement of response to sensation has generated an increased recognition of SPD among the scientific community as operationally defined in the field of occupational therapy. This is an important distinction because within field of occupational therapy the construct SPD refers to atypical behavioral response to sensation based on poor sensory integration (SI) in the central nervous system (Miller et al., 2007; Pfeiffer, Koenig, Kinnealey, Sheppard & Henderson, 2011) whereas outside of occupational therapy, SI is viewed as a neurophysiologic cellular process (Miller et al).

Regardless of the view taken, sensory processing disorders are prevalent among children with and without disabilities (Interdisciplinary Council on Developmental and Learning Disorders [ICDL], 2005). Interestingly, in children with disabilities SPD is considered a comorbid factor. In the literature these disabilities include extreme behaviors attributed to psychiatric diagnoses which is found in the *DSM-IV-TR* (Brown, 2009) such as ASD, ADHD, Fragile X syndrome and learning disabilities. Prevalence estimates range from 5% - 13% among children without disabilities (Ahn, Miller, Milberger & McIntosh, 2004; Ben-Sasson et al., 2009), 40% - 88% for children with disabilities (Ahn, Miller, Milberger & McIntosh, 2004; ICDL, 2005;

Miller-Kuhaneck, Henry, Glennon, & Mu, 2007; Tomcheck & Dunn, 2007) and approaching 90-100% in children with ASD (Leekam, Nieto, Libby, Wing & Gould, 2007; Silva & Schalock; Tomcheck & Dunn, 2007). Currently, SPD is recognized as a disorder in three classification references: the Diagnostic Manual for Infancy and Early Childhood (ICDL, 2005), Diagnostic Classification of Mental Health and Developmental Disorders of Infancy and Early Childhood, Revised (DC: 0-3R, 2005), and the Psychodynamic Diagnostic Manual (PDM Task Force, 2006) [Miller et al., 2007]. However, SPD is not recognized as a valid diagnostic category in the primary classification reference used by the health care industry, the Diagnostic and Statistical Manual of Mental Disorders (*DSM-IV-TR,* 2000) because at the time of its last revision in 2000, evidence that SPD exists in people who have no other psychopathology was lacking and therefore did not meet the criteria for inclusion in the DSM (Brown, 2009). Based on the criteria of the *DSM-IV-TR*, health insurance companies do not pay for sensory integration therapy to treat SPD because it is viewed as an experimental treatment and as such have no evidence to support for it (Aetna, 2009; United Healthcare, Inc, 2009).

The credibility or evidence in support of SI therapy hinges upon reliable physiologic measures that support the existence of SPD and clinical effectiveness of sensory integration treatment. During the last ten years, research studies have utilized various tools which indirectly measure

physiologic sensory processing (Mangeot, et al., 2001; McIntosh, Miller, Shyu & Hagerman, 1999; Miller, Anzalone, Lane, Cermack & Osten, 2007; Miller, et al., 1999) in an attempt to provide evidence in support of SI therapy. Although through this increased utilization of physiologic sensory processing measures awareness and acceptance of the existence of SI therapy is growing (Miller et al., 2007), reliability of the measurement tools used is still lacking and thus further critical analysis of the reliability of these measurement tools is needed.

It has been purported that the response to sensations is linked with behavioral performance and is the level of behavioral and physiologic arousal mediated by the autonomic nervous system as it responds to environmental stimuli (Ayres, 1979; Bundy, Lane & Murray, 2002; Davis & Gavin, 2007; Schaaf & Miller, 2005). According to Ayres, response to environmental stimuli is dependent upon several factors: the level of brain maturation, the ability to organize and mediate impulses from the sense receptors, form perceptions and plan a response that meets the demands of the environment. Over or under-response to sensation in this model is indicative of brain immaturity and poor organization of information received from the sense receptors. The result of poor organization or impaired sensory processing can result in behavioral and or learning problems (Ayres; Bundy, Lane, & Murray; Davies & Gavin; Schaaf & Miller).

Researchers have assessed behavioral response to sensation and results are mixed (Hoehn & Baumeister, 1994; Leong & Carter, 2008). The assessment of physiologic response to sensation in the field of occupational therapy was first initiated in 1999 using a laboratory paradigm called the Sensory Challenge Protocol (SCP) [Mangeot, et al., 2001; McIntosh, et al., 1999; Miller, et al., 1999]. This protocol measures electrodermal activity (EDA), which is a change in the electrical conductance of the skin in response to an environmental stimulus. Based on the sweat gland circuit-loop, EDA measures strength of change in skin conductance to electrical charge as reflecting sympathetic nervous system arousal in response to sensation (Fowles, 1986; Vertrugno, Liguori, Cortelli & Montragna, 2003). During the SCP, EDA is measured as skin conductance level (SCL) at rest and as skin conductance (SCR) response to a specific sensory stimulus. The resting phase is known as tonic level skin conductance comprised of slow changes in conductance in the absence of specific stimuli. The response phase is known as phasic level skin conductance comprised of fast changes in skin conductance in response to specific stimuli. The SCP assesses EDA based on changes in skin conductance. Greater change in SCR infers greater sympathetic nervous system arousal during the processing of sensation (Chritchley, 2002; Fowles, 1986; Vertrugno, 2003).

In the field of psychophysiology, EDA as a measure of autonomic response to stimulation has been used since the 1950's to distinguish

patterns of response between groups (Lacey, Bateman, Van Lehn, 1953; Lacey & Lacey, 1958; Mundy-Castle & McKiever, 1953). These patterns of response were fairly reproducible upon immediate retest (Lacey, Van Lehn, 1952). Noxious stimulation such as a cold pressor test was often used as a stimulus (Lacey, Bateman, Van Lehn, 1953; Lacey & Lacey, 1958; Mundy-Castle & McKiever, 1953). Two distinct patterns of response, stabile and labile, were observed that connected SCL patterns with phasic SCR. Individuals demonstrating high frequency response to stimulation were identified as electrodermal labiles. Conversely, individuals demonstrating few responses were identified as electrodermal stabiles (Lacey & Lacey, 1958). Various methodologies were developed to measure EDA which made comparison of studies difficult. In 1981, standards for EDA measurement were established (Fowles, et al., 1981). Studies comparing response patterns between groups continued. In 1984, one such study compared SCL and SCR in adult euthymic patients with affective disorders and normal controls (Iacono, Lykken, Haroian, Peloquin, Valentine, Tuason, 1984). Results revealed affective patients responded significantly less to balloon burst and tones than controls. Several measures of EDA demonstrated moderate to high one-year retest reliability (Spearman correlation .45 to .69) in both groups. Another study investigated stability of SCL and SCR among adult schizophrenic and normal subjects. The subjects were exposed to auditory stimuli in a test retest design over a one-year period. Reliability of

SCL over time was significant ($p < .005$) for normal subjects $r = .61$ and symptom free schizophrenic subjects $r = .43$ (Schell, Dawson, Nuechterlein,Subotnik, Ventura, 2002). Measures of individual response characteristics, amplitude, latency, rise time, and half recovery time were generally lower and not as stable. This study implemented non-noxious tones as well as noxious tones. The noxious tones were specifically included to gauge SCR response (Schell et al).

The SCP is comprised of non-noxious sensory (Ayres, 1979) stimuli that has been well described in the literature as linked with over or under response in children with SPD (Ayres, 1979; Mangeot, et al., 2001; McIntosh, et al., 1999; Miller, Coll, Schoen, 2007; Miller, et al., 1999; Miller, Schoen, James, Schaaf, 2007; Reynolds, Lane, 2008; Roberts, Mazzocco, Murphy, Hoehn-Saric, 2008; Su, Wu, Yang, Chen-Sea, Hwang, 2010). Behaviorally, children with SPD typically over or under respond to one or more of the following sensory domains, movement, touch, sound, bright lights and taste/smell (Ayres, 1979; McIntosh, 1999; Miller et al., 1999). Based on these behavioral descriptions, the SCP presents non-noxious stimuli in the same 5 sensory domains in a controlled manner (McIntosh, 1999). The domains presented are:

1. Auditory (sound)- a professionally recorded tone and fire-engine siren playing at 90 decibels (Psylab computer software).

2. Visual (bright lights) – 20-watt strobe light set at 10 flashes per second (5” x 3.5” x 2” Product code: MS-1, Noveltylights.com).
3. Olfactory (taste/smell) – wintergreen oil (methyl salicylate, Anandaapothecary.com) kept approximately 1.25 cm deep in a 30ml vial with a cotton ball.
4. Tactile (touch) – 5 cm turkey craft feather (B706M Turkey Marabou short mixed loose 1-4”, www.featherplace.com).
5. Vestibular (movement) – Chair (12”h, 13”d, 14”w) tipped slowly and smoothly backward to a 30° angle.

Each of the sensory domains consist of 8 stimuli presentations, lasting 3 seconds each, in a pseudo random time order of 15-19 seconds apart and 20 seconds between each domain.

While the SCP is currently being used extensively for the purposes of measuring physiologic reactions to sensory stimuli and their association with functional performance, the reliability of this measurement has been sparse. In fact, since 1999 when the SCP was first used to investigate SPD, three studies have analyzed reliability. McIntosh and colleagues (1999) used the SCP to investigate physiological responses to environmental stimuli among and between typically developing children (n = 13) and children with sensory modulation disruption (n=13), part of the family of SPD’s (McIntosh et al). Implementing a test retest design on measures of magnitude of response, number of responses and proportion (probability of response), results

indicated a strong positive correlation across time ($r = 0.79 – 0.82$). Limitations include no means or standard deviations reported, nor number of raters. This correlation only addresses an association and is not as meaningful as an ICC which addresses agreement of multiple factors that may contribute to error variance in a measurement.

The second study (Miller et al., 1999) that used the SCP and derived reliability scores, compared children with Fragile X syndrome (n=25) and typically developing children (n=25) using the same variables as the McIntosh study, magnitude of response, number of responses and proportion of responses. Significant differences between groups were found. Reliability was estimated using a subset of 6 participants (4 Fragile X and 2 controls). Test retest reliability on all dependent measures demonstrated significant positive correlations: magnitude of response (r (5) = 0.94, p <0.01): number of peaks (r (5) = 0.96, p <0.001): proportion of stimuli responded to (r (5) = 0.88, $p < 0.01$). Similar to the McIntosh study, limitations include very small sample size, no means or standard deviations reported, nor number of raters. Therefore, the utility of the data obtained with this tool is still unknown.

The third study conducted in 2008 by Schoen and colleagues, used the SCP to study arousal and sensory reactions among children with high functioning autism and Asperger's Syndrome. Between group t – tests on all variables revealed no significant differences therefore participants were treated as one group. Fourteen participants completed a retest of the SCP.

ICC reliability results indicate moderate reliability of skin conductance level (ICC = .45 - .51) and phasic variables (75% had ICC = .33 or greater with a median of .45). The authors suggest electrodermal measures in this study are relatively stabile. Limitations of this study include small sample size for the retest participants and lack of a control group.

So in order to support the use of skin conductance measures to analyze sensory processing the reliability of the tool must first be addressed. Although investigatory studies have already used the SCP to confirm behavioral assessments (Su, Wu, Yang, Chen-Sea, & Hwang, 2010) and report outcomes that link abnormal SCR with typically developing children and children clinically diagnosed with ADHD, Fragile X syndrome or SPD (Mangeot, et al., 2001; McIntosh, et al., 1999; Miller, et al., 1999), as evidence based clinicians we recognize that limitations associated with the methodology limit the power of those results. These studies have reported outcomes that quantify a link between sensory processing and EDA without first establishing reliability of the tool. The purpose of this study is to establish the reliability of EDA to measure sensory processing in typically developing children and children with ASD. Determining reliability of EDA as a measure reflecting sensory processing in children with ASD and typically developing children is necessary to differentiate ASD from other groups and contribute significantly to the strength of the outcomes measured by EDA (Schoen et al., 2008). Four questions were posed and directed this research investigation:

1. Is the test-retest measure of electrodermal activity (EDA) a reliable measure of physiologic sensory processing in children with and without Autism Spectrum Disorder (ASD)?

H_1: Variance among repeated measures are due to real variance and not random error implementing ICC, EDA is a reliable measure of physiologic sensory processing in children.

2. Is there a relationship between tonic and phasic patterns of arousal among typically developing children and children with ASD?

H_2: A significant relationship exists between tonic and phasic patterns of arousal among typically developing children and among children with ASD.

H_{2a}: Phasic patterns of response among typically developing children and children with ASD consisting of high amplitude/magnitude, increased frequency and decreased habituation will show a significant relationship with higher SCL and frequency NSR's.

H_{2b}: Phasic patterns of response among typically developing children and children with ASD consisting of low amplitude/magnitude, decreased frequency and increased habituation will show a significant relationship with lower SCL and frequency NSR's.

H_{2c}: Based on patterns of response, children with ASD and typically developing children can be divided into hi and low responder groups to improve homogeneity of sample.

3. Is there a relationship between EDA and behavioral response to sensation as determined by the Short Sensory Profile?

H_3: A significant negative relationship exists between EDA amplitude/magnitude of response and SSP total score.

H_{3a}: Low score on the SSP is significantly associated with hyperresponsive and hyporesponsive EDA amplitude/magnitude of response.

4. Is there a difference in EDA response to sensation between typically developing children and children with ASD?

H_4: A significant difference in EDA response to sensation exists between typically developing children and children with ASD.

H_{4a}: Mean amplitude/magnitude of response to sensation among children with ASD will be significantly different than typically developing children.

Chapter II

REVIEW OF THE LITERATURE

Sensory Integration Theory

Developed as a model of brain function that connects learning and behavior disorders with neural processing, Sensory Integration (SI) theory was proposed by Dr. A. Jean Ayres in the late 1960's. Ayres, an occupational therapist and educational psychologist, with postdoctoral training in neuroscience developed this theory to explain how deficits in interpreting sensations from the body and environment were associated with learning difficulties, both academic and motor (Bundy & Murray, 2002; Mauer, 1999). Ayres based her theory on principles of neuroscience, psychology and education of the time as well as her personal observations of children with learning, developmental and emotional disorders. Ayres observed that many children with these disorders also had deficits in interpreting sensation from the body and environment. Therefore, she reasoned that perhaps sensory interpretation difficulties were the result of a malfunction in neural processing that interfered with putting the information together in an organized manner and was therefore connected to learning and behavior disorders. Ayres (1972) defined SI 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" (Bundy & Murray, 2002). The theory of SI states that behavior and learning problems are the result of impaired integration of sensory information.

SI Assumptions

Ayres developed her theory of SI based on assumptions that are closely aligned with principles of developmental psychology, neuroscience, education and occupational therapy (Schaaf & Miller 2005): (1) sensorimotor development is an important substrate for learning; (2) brain development is shaped through interaction between the individual and the environment; (3) the nervous system is plastic and capable of change; (4) meaningful sensorimotor activity is a powerful agent of plasticity (Mauer, 1999; Miller et al., 2007; Schaaf & Miller, 2005). Ayres described the basis for her SI principles in her book Sensory Integration and the Child (1979) by detailing the neurobiological roots of learning in children. In her analysis, she used Piaget's theory of learning (1952) and neurobiologic studies during the early 1960's regarding enriched environments and sensory deprivation (Rosenzweig & Bennett, 1996) to provide the foundations for her theory of SI.

The role of the environment in development is central to SI theory (Ayres, 1979), Piaget's theory of learning (1952) and plasticity (Rosenzweig & Bennett, 1996). Up until the 1950's, most scientists and

educators believed that interacting with the environment had little or no effect on a child's capacity to learn (Ayres, 1979; Hall, 2000). This belief was challenged by Piaget's Theory of Cognitive Development that described four stages of learning that occurred in a specific sequence, one stage building upon another until reaching brain maturity. Similarly to SI theory, Piaget asserted that a child's interaction with the environment was a critical factor in development and learning (Ayres, 1979; Hall, 2000). Interaction in Piaget's theory was operationally defined as a combination of experience and internal processing (Hall, 2000). Again, like Ayres, Piaget emphasized the ability of the child to put together or process sensory and motor information in order to make sense of the information and respond to it. Piaget described information processing as assimilation or accommodation. Assimilation in his model is taking in new information (sensory and motor) and fitting it in to existing beliefs and accommodation is a change in beliefs based on new information. A change in beliefs generated an adaptive response required to function in the environment (Ayres, 1979; Hall, 2000; Piaget 1953).

Change, assimilation, accommodation and adaptive response to the environment are possible due to the plasticity of the brain, especially the young brain (Ayres, 1979, Piaget, 1953, Rosenzweig and Bennett, 1996). Ayres viewed brain functions in newborns and individuals with sensory integration dysfunction as immature. Subsequently, interactions with the environment both internally, brain body experience and externally,

environmental experience, were assumed to facilitate brain development and maturity (Iarocci & McDonald, 2006; Mauer, 1999; McIntosh, Miller, Shyu, & Hagerman, 1999; Miller et al., 2007; Schaaf & Miller, 2005; Will et al., in press). In SI theory brain maturity is viewed as the ability to organize or put together electrical impulses received from the sense receptors of the body in such a way that a meaning or perception is formed. As these perceptions are formed the brain mediates a movement response to that perception. According to SI theory, if that response effectively meets the demands of the environment, the child experiences satisfaction or purpose to movement. This experience adds to the complexity of the response moving forward. Thus given that plasticity of the brain occurs with experience/rich environments (Rosenzweig & Bennett, 1996), the brain moves along a continuum of development eventually leading to brain maturity.

Ayres (1979) analysis of the ability of the brain to change in structure and function was based upon neuroscientific research performed on animals in enriched environments. Researchers such as Mark Rosenzweig of the University of California, Berkeley, were interested in analyzing use-induced plasticity of the nervous system, a postulate first proposed by Donald Hebb in 1949 (Rosenzweig & Bennett, 1996). In this model, rats that were exposed to training were compared to a control group. Behaviorally, the trained rats demonstrated greater problem solving abilities. Neuroanatomically the trained rats had neurochemical changes in the cerebral cortex as well as

increased cortical thickness, synaptic contacts, dendritic spines and branching (Rosenzweig & Bennett, 1996). Rosenzweig and colleagues performed a series of experiments during the 1960's that showed the same neuroplastic changes occurred among rats in enriched environments (Ayres, 1979; Rosenzweig & Bennett, 1996). In her analysis, Ayres stated:

> In the experiments done by Rosenzweig and his associates, one group of rats spent time in an enriched environment, while another group was in an impoverished environment. The enriched environment was a cage in which there were lots of things to do, such as climbing up ladders, running in treadmills, walking over the bristles of a brush, and exploring mazes; the rats in this cage were also picked up and handled by humans. The impoverished environment was a bare cage without any of these opportunities for vestibular, tactile and proprioceptive stimulation. After a time the rats were killed and their brains dissected and analyzed.
>
> Rosenzweig and associates, as well as many other scientists, have done a number of variations on this experiment. In almost every case, they found that rats from the enriched environment had heavier cerebral cortex's, more of the chemicals that keep the brain healthy, more of the interconnections between neurons. Each of these indicates that these rats had a greater capacity for processing sensations and using sensory information (Ayres, 1979, p.137).

Ayres approach in developing her SI Theory was similar to that of Piaget's sensorimotor stage, the first stage of his Theory of Cognitive development (learning), which occurs between birth and 2 years old. Piaget stated in this stage the child learns about his body first and then his environment in response to motor actions. Perceptions (thoughts) are generated through sensation and movement (Ayres, 1979; Hall, 2000; Piaget 1953). Ayres SI theory was based on assumptions closely aligned with Piaget's Theory of Learning: (a) sensorimotor development provides the underlying support for learning to occur. Learning occurs as spatial and temporal aspects of multiple sources of sensation are combined to form a representation (perception) of an object or action. Perception then allows planning and coordination of a motor response (Ayres; Hall; Mauer, 1999; Miller et al., 2007; Schaaf & Miller, 2005) (b) Brain development is shaped through interaction between the individual and the environment. Motor responses further develop perception of objects and actions and lead to more complex plastic changes and (c) meaningful sensorimotor activity is a powerful agent of plasticity (Mauer, 1999; Miller et al., 2007; Schaaf & Miller, 2005). Ayres viewed meaningful sensorimotor activity as motivated engagement in a task by an individual that successfully achieves a desired motor response or result. Planned responses that permit an individual to experience success in the environment are meaningful, exposure to meaningful responses produce plasticity.

Ayres assumptions of how plasticity changes one's behavior (Ayres, 1979; Rosenzweig & Bennett, 1996) also contributed to the framework for SI theory. Creating an environment that would motivate and engage a child would elicit a goal directed motor response (behavior) and in Ayres view produce change in brain structure and function (Ayres; Mauer, 1999; Miller et al., 2007; Schaaf & Miller, 2005). Accordingly, these plastic changes would improve one's sensory perception and ultimately the ability to learn in an academic environment (Ayres; Mauer; Miller et al.; Schaaf & Miller).

The tenets of Ayres SI Theory stem from the integrated notion of Piaget's Cognitive Development Theory, neurobiologic research of the 1960's regarding brain plasticity and enriched environments and Ayres personal observations of learning disabled children. Since that time, new research has strengthened scientific understanding of structural, molecular, and cellular changes in neural functions that support the notion that meaningful sensory motor activities can be mediators of plasticity (Greenough, Black & Wallace, 1987; McKenzie, Nagarajan & Merzenich, 2003; Pinaud, Tremere, Penner, Hess, Robertson, & Currie, 2002; Rema, Armstrong-James, Jenkinson & Ebner, 2006; Schaaf & Miller, 2005). Clearly, the central principles of neural plasticity, learning theory and SI theory all connect changes in brain structure and function to brain development. Therefore, an analysis of what is known and not known about SI theory is a logical next step necessary to determining its scientific validity as a theory.

Behavioral SI Studies

Most of what is known about the effectiveness of treatment based on SI theory has been attained through observation of behavior and use of rating scales to measure change. Prior to 2003, more than 80 articles related to the effectiveness of the SI approach were published, yet not one met the criteria of a randomized controlled outcome study (Miller, Coll & Schoen, 2007). In an effort to merge results from these studies, four research syntheses (Arendt, MacLean, & Baumeister, 1988; Hoehn & Baumeister, 1994; Ploatajko, Kaplan, & Wilson, 1992; Schaffer, 1984) and two meta-analyses (Ottenbacher, 1982; Vargas & Camilli, 1999) of studies were conducted between 1972 and 1994 and published. Results from these reviews have continued the controversy regarding the measurement of behavioral change due to changes in sensory processing. In their critique of SI therapy, Hoehn and Baumeister (1994) analyzed 1 meta analysis (Ottenbacher 1982) and 6 studies from 1982 to 1992 and argued that SI is “a hypothetical neurological process” (p.338) and concluded that the studies reviewed are open to numerous criticisms in terms of methodology and operational definitions of dependent and independent variables. Hoehn and Baumeister (1994) were definitive in their criticism of SI studies because they believed all the studies were flawed due to the fact that SI had not been established as a neurological process and therefore identifying dependent and independent variables was untenable.

Schaaf and Miller (2005) analyzed the 2 Meta analytic reviews measuring SI treatment effectiveness and noted methodological flaws as well. Data regarding task engagement, daily life skills and regulation of arousal level were typically used as the dependent variable in many of these studies to assess SI treatment based behavioral change. Many of these studies used rating scales to measure this behavior pre and post treatment. Schaaf and Miller (2005) note approximately half of these studies demonstrated SI treatment as having some effectiveness while the other half had the same effectiveness as other forms of treatment. In general, interpreting these results were challenging due to broad definitions of the independent variable (SI treatment), and methods used to measure the dependent variable (observable behavior). In fact, Schaaf and Miller (2005) noted that the broad definitions of variables and heterogeneity of study samples increased within-group variability and decreased the probability of finding group differences. Most importantly, none of the studies in the Meta analytic reviews were randomized controlled trials, the gold standard for outcome studies (Portney and Watkins, 2008). Therefore, conclusions from these reviews supporting or refuting the SI approach are not based on rigorous cause and effect evidence.

A recent analysis (2008) on the effectiveness of SI therapy by Leong and Carter (2008) concurs that identifying and measuring the dependent variable is still the main problem in most SI studies (Leong & Carter, 2008).

Leong and Carter (2008) summarized again research on the efficacy of SI treatment segregating research articles into two parts, part one starting with the Ottenbacher (1982) meta analyses and ending with Vargas and Camilli (1999) meta analyses, and part two using studies not included in part one from 1994 until 2006. Once again, poor methodology was cited in studies that used rating scales to measure areas of deficient sensory processing but were not specifically linked to functional outcomes and therefore, interpretation of results was not clear. Leong and Carter suggested any changes in sensory processing could therefore be attributed to other phenomena and not necessarily sensory integration therapy (SIT). The more recent studies examined by Leong and Carter focused on immediate or short term effects on behaviors such as task engagement, self-stimulation or injurious behaviors. Specifically Leong and Carter, concluded that calming, deep pressure; gentle swinging and vibration techniques could affect behavior in the short term, but lacked proof of long-term neurological change. They further contend that long-term behavior change is desired as it is more indicative of neurological change than short-term behavioral changes. Accordingly, Leong & Carter state the theoretical framework of SIT is fundamentally flawed because accurate identification of why the intervention works has not been described. Clearly, the available qualitative studies, observations or case studies are not strong enough to determine the value of

SI theory. Therefore, alternate methods to determine SI theory validity must be considered.

Physiology and Sensory Processing

In addition to the issues noted in the literature regarding SI, Ayres' theoretical principles have been expounded upon using advancements in technology, science and clinical practice. Of note is the development of methods used to quantitatively measure physiological sensory processing as an indicator of how sensations are integrated or working together, in a neurological process of organizing sensation from the environment and one's own body, to produce an effective motor, behavior, emotion or attention response (Miller et. al, 2007).

Although, the taxonomy (Miller et.al, 2007) describing Ayres view of SI has been updated and expanded upon, the view of the process that filters and organizes sensation to facilitate interaction and an adaptive brain response is still held in high regard (Davies & Gavin, 2007; McIntosh et al., 1999; Miller et al., 2007; Schaaf & Miller, 2005). Following Ayres' definition of SI as a process, it is prudent to review what this process is. Sensory receptors in human beings are structures that convert sensations into electrical impulses (Iarocci & McDonald, 2006). So, if an individual sees something, feels something, or hears something, those sensations are converted into an electrical signal that travels to the brain and a response to the stimulation is

generated. One way to ascertain the amount an individual responds to stimuli is to measure their electrodermal activity after stimulation (Fowles, 1986; McIntosh, Miller, Shyu, & Hagerman, 1999). Electrodermal activity refers to changes in electrical conductance of the skin associated with eccrine sweat-gland activity innervated by the sympathetic branch of the autonomic nervous system (Fowles, 1986; Malmivuo & Plonsey, 1995; McIntosh, Miller, Shyu, & Hagerman, 1999; Roberts, Mazzocco, Murphy, & Hoehn-Saric, 2008; Schell, Dawson, & Filion, 1988). There are two levels of electrical skin conductance that can be measured, skin conductance at rest (SCL), which is a slowly changing wavelength representing electrical activity of the skin in the absence of a discrete stimulus and skin conductance response (SCR) which is a rapid change in electrical activity of the skin in response to a discrete stimulus (Fowles, 1986; Malmivuo & Plonsey, 1995; Schell, Dawson, & Filion, 1988). A method to measure electrodermal activity in response to repeated sensory stimulation called the Sensory Challenge Protocol (SCP) was used in a 1999 study by McIntosh and colleagues to determine differences in response to sensation between two groups of children (McIntosh et al., 1999; Schaaf & Miller, 2005). Since that time, the SCP, has been implemented in numerous studies (Hagerman et. al, 2002; Mangeot et. al, 2001; Miller, Coll, & Schoen, 2007; Miller et. al, 1999; Schaaf & Miller, Seawell, & O'Keefe, 2003; Schoen, Miller, Brett-Green, & Hepburn, 2008; Su, Wu, Yang, Chen-Sea, & Hwang, 2010) assessing response to sensation in children, however, the reliability of

the SCP measures have not been established. The relevance of these studies requires a review of electrodermal activity and EDR as a measurement tool.

Electrodermal Activity

Electrodermal activity (EDA) is the electrical activity of the skin. There are two ways to measure electrodermal activity, from the outside, exosomatic or from the inside, endosomatic. Fere observed the first recorded observation of decreased exosomatic skin electrodermal resistance as a response to emotional or sensory stimulation in 1888 (Fowles, 1986; Venables & Christie, 1980).

Charles Fere was a neurologist and student of Jean Martin Charcot, the father of the science of neurology (Guillain, 1959 as cited by Neumann & Blanton, 1970). Charcot and colleagues at the Salpetriere hospital in France used electrotherapy to treat patients. Charcot also used hypnotism in the treatment of hysterical patients and theorized that hypnotism affected the electrical activity of the body and thus wanted to investigate the physical basis of this affect (Bloch, 1993; Neumann & Blanton, 1970). Charcot enlisted Fere to investigate his electrical theory of hypnosis. During this time, Fere also became interested in automatic movements. It was in this context that Fere began his research in electrodermal activity. Fere used a hand dynamometer to ascertain the effect on muscle tension due to sensory and emotional

stimulation. His sample consisted of hysterical patients and normal subjects under hypnosis and when awake. Subjects held the hand dynamometer and were exposed to a range of sensory stimuli including sound, color, pain, tactile, gustatory and olfactory (Neuman & Blanton, 1970). Results indicated an increase in hand pressure exerted when stimuli were presented. To investigate the influence of electrical activity among hysterical patients, Fere repeated the experiment and used a galvanometer instead of the dynamometer. He placed electrodes on the anterior surface of the forearm of subjects as they were exposed to external stimuli (Bloch, 1993; Neumann & Blanton, 1970). Results indicated decreased skin resistance or increased current flow with each separate stimulus among the hysterical subjects (Bloch, 1993; Neumann & Blanton, 1970). Results among normal subjects were not as distinct. Ultimately, Fere's experiment did not support Charcot's electrical theory of hypnosis (Neumann & Blanton, 1970).

Later, in 1889, Tarchanoff measured endosomatic skin resistance [skin potential](Fowles; Venables & Christie). According to Neumann & Blanton, (1970), Tarchanoff based his work on the work of Swiss neurologist Hermann 1878 (Bloch, 1993; Neumann & Blanton, 1970). Hermann theorized, "excitation current was secretory in nature" (Neumann & Blanton, 1970, p464). Hermann designed an experiment to try to separate excitation current from resting current. He applied current to frog specimens, subtracting out the resting current from the ingoing current to measure the

excitation current. He observed that the secretory process started after stimulation exceeded the resting current level. He repeated this experiment on cat footpads and eventually human's and found skin current was more easily detected in areas where sweating is produced and EDR activity was stronger as electrodes were moved closer to the palms (Neumann & Blanton, 1970). Integrating Hermann and Fere's findings Tarchanoff concluded that the phenomenon of skin potential was highly correlated with sweat gland distribution and therefore, related to the action of nerves involved with secretion (Neumann & Blanton, 1970). Tarchanoff reported that current flows from sweat gland rich areas to sweat gland poor areas and further hypothesized "the feeling of conscious effort or stimulus intensity" of the subject is more important than the actual intensity of the stimulus presented (Neumann & Blanton, 1970).

Although various methodologies have been developed to measure EDR, recent attempts have been made to standardize procedures for the measurement of electrodermal response (Fowles, et al., 1981). Six experts, Don C. Fowles, Margaret Christie, Robert Edelberg, William Grings, David Lykken and Peter Venables (1981), were charged by David Shapiro, PhD, editor of the Journal Psychophysiology, and clinical psychologist at UCLA to formulate standardized procedures and allow results to be shared and interpreted by researchers all over the world (Fowles, et al., 1981, University of California, Los Angeles, 2009). These experts cite a previous proposal for

standardization developed by Lykken and Venables (1971), as the foundation for the committee's final recommendations (Fowles, et al., 1981), which are listed in Table 1. Standardization procedures were not the only major change that occurred in EDA measurement at this time. Temporal aspects of response such as latency, rise time and recovery (habituation) were included to further analyze response measurement.

Table 1

Standards Skin Conductance Measurement

Component	Recommendation
Measurement Choice	Skin Conductance
Electrodes	Silver-Silver Chloride Sodium Chloride Paste
Area of Skin Contact	Double sided adhesive collars ensure contact area equal to diameter of hole in collar
Electrode Placement	Thenar or hypothenar eminences one hand or Medial and distal phalanges one hand
Signal Conditioning	Apply constant 0.5 volt across 2 electrodes
Tonic Level Control	Subtract out portion of tonic SCL to increase sensitivity to smaller phasic responses

Note. Standards adapted from the work of Fowles, Chrisite, Edelberg, Grings, Lykken & Venables, 1981.

Sweat Gland Circuit

Measurement of the temporal aspects of electrodermal response has been widely recognized as an effective measurement tool of sympathetic nervous system (SNS) activity based on the notion that control of the sweat glands is mediated exclusively by the SNS (Carmona, Holland, Stratton & Harrison, 2008; Demaree, Pu, Robinson, Schmeichel, & Everhart, 2006; Fowles, 1986; Kylliainen & Hietanen, 2006; Miller et al., 1999; Naveteur, Buisine & Gruzelier, 2005; Schwerdtfeger, 2006; Van Lang et al., 2007; Venables & Christie, 1980; Wijnen, Heutink, Boxtel, Eilander & Gelder, 2006). Results from experiments that eliminate sweat gland activity by pharmacological or surgical means have shown an absence of EDR (Fowles, 1986; Gladman & Chiswick, 1990; Martin & Venebles, 1966; Venebles & Martin, 1967). Based on these experiments, the authors suggest that this "evidence conclusively points to a contribution by the sweat glands" in the generation of electrodermal response (Fowles, 1986; Miller et al., 1999; Venables & Christie, 1980).

Sweat glands are part of a complex organ, the skin. Skin has three basic functions, protect the body from injury, regulate body temperature and communicate with the brain about the environment (Fowles, 1986; Venables & Christie, 1980). The skin is composed of three layers, epidermis, dermis and hypodermis. The epidermis is comprised of 5 sublayers that contain healthy living cells at its base and dead cells at the surface (Malmivuo &

Plonsey, 1995). The dermis contains blood vessels and the hypodermis contains the sweat glands. The base of the sweat gland is a coiled tube that travels in a winding manner up through the dermis to an opening in the surface of the skin.

There are two types of sweat glands, apocrine and eccrine. Apocrine glands are located in the axillae and pubic area at a density of 200 – 300 cm^2 (Venables & Christie, 1980). Apocrine glands are not controlled by the nervous system, rather they are stimulated by adrenaline. Eccrine sweat glands are located all over the body with a density of 100 – 200 cm^2 in the trunk and increased density of 2000 cm^2 in the palm and plantar areas (Venables & Christie, 1980). Eccrine glands are solely controlled by the SNS. Higher subcortical (hypothalamus and amygdala) and cortical areas (prefrontal cortex) of the brain mediate sympathetic stimulation (Critchley, 2002; Nolte, 2008) as a physiological survival mechanism. Cortical control of EDA appears to be dependent upon the context of the situation (Critchley). The level of arousal required to meet the demands of the environment may need to be increased in response to a frightening or attention getting stimulus. Increased arousal triggers a sequence of events that occur to adjust body arousal to meet the demands of behavior in the environment. Regions within the hypothalamus, amygdala and pre-frontal cortex initiate this sequence (Critchley, Nolte). The hypothalamus turns the SNS response on. The amygdala contributes to the intensity of SNS response through vast

connections with the hypothalamus and prefrontal cortex as it conveys drive related behavior patterns and subjective feelings of emergency or danger (Nolte). The amygdala can be considered a higher order modulating influence on the hypothalamus (Nolte). The prefrontal cortex mediates the amount of anticipatory attention towards environmental stimuli (Critchley, Nolte). This modulation of body arousal to environmental stimulation is observable in EDA patterns and is the basis of application of EDA to psychophysiological research (Critchley). Support for cortical control of SNS response and measurement of EDA to indicate intensity of response has been demonstrated using lesion and stimulation studies.

Lesion and stimulation studies in humans have identified areas of the brain that control sympathetic activity. Critchley (2002) cites a study regarding stimulation of limbic areas such as amygdala and hippocampus as "producing strong ipsilateral EDA responses" which is "consistent with lateralization of sympathetic control" (Critchley, p.135). Lesions to pre-frontal cortex and right parietal lobe and anterior cingulate reduce the magnitude of EDA. Critchley also cites neuroimaging studies that examined the relationship between brain activity and EDA. Pre-frontal regions and hippocampus are associated with attention, motivation, decision-making and episodic memory (Critchley, Nolte 2008). Connections of these brain regions with the amygdala provide both the attention and emotional arousal components, which together contribute to EDA responses. Critchley posits

these findings link arousal and attention via a “common neural substrate” (Critchley, p.137). Descending pathways from the brain (premotor cortex, hypothalamus and limbic system and reticular formation) travel via the ipsilateral ventrolateral horn of the spinal cord to the post-ganglionic synapse, which secretes acetylcholine instead of the usual sympathetic neurotransmitter nor-adrenaline (Critchley; Fowles, 1986; Venables & Christie, 1980). Acetylcholine stimulates the base of the sweat gland and plasma like fluid is secreted. Discharge of sweat to the skin in part results from contraction of the myoepithelial chain that surrounds the sweat duct. Goodall (1970) [as cited by Venables and Christie, 1980] suggests an adrenergic neurotransmitter innervates this myoepithelial chain contraction.

Sweat is a good conductor of electrodermal activity due to the fact that it contains the equivalent of a 0.3% NaCl salt solution. Electrodes are usually placed at the palmar or plantar areas secondary to the significant density of eccrine glands in those regions. As the eccrine glands fill and sweat flows onto the skin, conductance increases and so does the EDR response. When conductance between skin electrodes increases, sympathetic stimulation is deduced.

Measurement

Electrodermal response can be categorized by where the voltage measured occurs (exosomatic or endosomatic) and whether the measure is concerned with tonic (background) or phasic (time varying) response. EDR measures phasic external voltage. A constant voltage source (for example 0.5 volts) is applied via an amplifier that is connected to the skin through electrodes filled with 0.3% NaCl electrode paste and the resistance of the skin completes the circuit. The subject does not feel this small amount of voltage. The current that flows through the skin as the voltage is applied, can be detected and displayed. Because the constant voltage applied to the skin is known and the current flow can be measured, the skin's conductance can be determined by the amplifier. The output of the amplifier is the skin's conductance expressed in units called micro Siemens (µS) [iworx/CB Sciences, 2009].

Various terms are used when measuring EDA. If a study is measuring exosomatic skin resistance, skin resistance level (SRL) measures tonic activity and skin resistance response (SRR) measures phasic activity. Likewise, skin conductance level (SCL) refers to tonic measures and skin conductance response (SCR) refers to phasic activity and is used throughout this dissertation when referring to EDA. The committee lead by Don C. Fowles (1981) recommends using skin conductance based on the following advantages. As electrical activity declines, data expressed in resistance

terms fluctuate randomly but when expressed in conductance measures the decline is orderly. According to Venables and Christie (1980) it is easy to separate tonic measures from phasic by "backing off" or subtracting the SCL and thereby measuring SCR amplitude at a greater gain. Less resetting of the back off control is required with SCL/SCR due to its orderly decline as compared with the random fluctuations using SRR/SRL.

The variable that is measured is either skin resistance or its reciprocal, skin conductance. According to Ohm's law (R=V/I), skin resistance is equal to voltage applied between 2 electrodes on the skin divided by the current passed through the skin (iworx/CB Sciences, 2009). Conductance is equal to current passed through the skin divided by voltage applied between 2 electrodes, C=I/V. Edelman proposed a model of skin conductance in 1972 (cited in Malmivuo & Plonsey, 1995). Edelman proposed that sweat glands act as variable resistors, as the ducts fill with sweat, conductance increases (resistance decreases). The amplitude of the change in conductance is dependent upon the amount of sweat in the ducts as well as the number of sweat glands involved. According to Edelman, phasic changes in skin conductance occurs when sweat ducts in the epidermis fill, and recovery of skin conductance back to tonic level occurs when moisture is deposited on the skin or reabsorbed by the sweat glands. Convincing evidence from experiments demonstrate a direct correlation between sweat gland activity and SCR. When sweat gland activity is stimulated, SCR frequency increases,

when sweat gland activity is eliminated pharmacologically or surgically, there are no SCR signals (Malmivuo & Plonsey, 1995).

Normal patterns of electrodermal activity consist of baseline slow tonic changes and fast phasic changes (SCR). Baseline skin conductance is different for every individual. Typical tonic (baseline) levels range from 10-50µS (iworx/CB Sciences, 2009). Baseline levels vary over time secondary to psychological state and autonomic regulation. Phasic skin conductance levels change in response to environmental stimuli. Startling sights, sounds, smells, or movement will elicit time related changes in skin conductance known as SCR (iworx/CB Sciences, 2009). SCR occurs upon the background of tonic baseline levels. The aforementioned phasic skin conductance change results in response patterns that deviate from the regular rhythmic patterns of SCR.

Response Patterns

A connection between tonic baseline non specific response (NS-SCR) and phasic response (SCR) was observed in a 1953 study conducted by Mundy-Castle & Mckiever. In this study the authors found that SCR response patterns were a consistent representation of an individual's personality trait. In their study auditory stimuli was presented to subjects and two different patterns of electrodermal responses were noted, responses occurring to specific auditory stimuli and responses occurring non-specifically (NS-SCR)

or spontaneously. These authors compared SCR response measures during exposure to specific auditory stimuli. They found subjects who had few or no NS-SCR (tonic level) also had few specific responses to stimuli (phasic level). They labeled these individuals personality trait as stable (Mundy-Castle & McKiever). Conversely, subjects with many NS-SCR's (tonic level) before and during stimuli presentation also had many strong responses to specific stimuli (phasic level). They labeled these individuals personality trait as labile (Mundy-Castle & McKiever). Study results revealed a significant association between SCR and age (labile group predominantly younger than stable group). Incidence of habituation was significantly greater in stable group compared to labile group (Mundy-Castle & McKiever).

Mundy-Castle & McKiever (1953) found differences between stables and labiles were based on two factors. Stables habituation rate reflected strength of excitatory/inhibitory processes. Labiles were not assessed similarly because habituation was interrupted by increased response to next stimulus. Authors posit this lack of habituation among labiles was due to decrease cortical control, possibly due to brain immaturity over lower autonomic centers. The association between SCR and age of labiles as predominately younger, along with decreased habituation to stimuli occurring because of decreased cortical control over lower centers is indicative of brain immaturity. This notion is similar to previously presented findings (Critchley, 2002; Nolte 2008) that prefrontal cortex modulates lower centers that control

autonomic reactivity and the idea of brain immaturity as a factor in over-response to sensation is linked with Ayres theory of SI.

During the same time period, researchers at the Fels Research Institute in Ohio conducted a series of experiments studying autonomic reactivity. One study of typically developing children ages 6-18 years (57 boys, 53 girls) used four autonomic measures (blood pressure [BP], heart rate [HR], heart rate variability [HRV] and EDR) to construct a reaction profile (Lacey & Van Lehn, 1952). Baseline measures of children in relaxed state were compared to exposure to a stress, a cold pressor test (immersion of bare foot into 4℃ pan of water). The measure of reaction was a percentage change from baseline to stress level. T-scores were used to represent percentage change with an average of 50 and SD of 10. A T-score of 60 represented one SD above the mean (Lacey & Van Lehn, 1952).

Results indicated typical children respond to stress with a specific autonomic pattern. Frequency distribution of responses ranged from 0.75 – 5.75 SD units between maximum and minimum response. Half of the group had 2.0 or greater response, indicating different reactivity (Lacey & Van Lehn, 1952). The test-retest reliability coefficients of these pattern scores ranged from 0.43-0.78 $p < .0001$ (Lacey & Van Lehn, 1952). Based upon these values it is highly unlikely these patterns occurred by chance.

Lacey, Bateman and Van Lehn (1953) hypothesized individuals would respond with a similar pattern of autonomic activation regardless of the

stress. They exposed 85 male college students ages 19-21 years to four stressors, mental math, hyperventilation, letter association and the cold pressor test. T-scores were used to transform EDR, heart rate (HR) and heart rate variability (HRV) measures that comprised six patterns of response. Using probability theory, chance frequencies of response patterns were calculated. Expected and obtained frequencies were compared. Expected frequency for maximum and high patterns of response were 28, obtained 62 with a difference of +34. Low and minimal pattern response expected frequency was 57, obtained 23 with a difference of –34, Chi Square 61.566 (Lacey, Bateman & Van Lehn, 1953). These obtained difference scores are not likely to have occurred by chance thus supporting their hypothesis that the pattern of autonomic activation within the same physiologic domain will be the same regardless of the type of stressor.

Response patterns were further described by Lacey and Lacey in 1958, although they hypothesized that a decrease in magnitude of response would occur with adaptation, they were surprised to discover the “systematic importance of frequency of response as a reliable characteristic of an individual” (Lacey & Lacey, 1958, p. 149). This characteristic or personality trait is operationally defined as a human behavioral response to stimulation mediated by the “level of sympathetic tonus” (Lacey & Lacey, 1958, p. 149). Sympathetic tone is represented by the frequency of autonomic responses to stimulation that underlies the personality trait of an individuals response

patterns to stimulation. These response patterns exist at rest or under stress. Response patterns under stress and at rest were demonstrated using a test retest design. The authors measured skin resistance response of twenty-eight women during rest and stressful activities. Kymograph tracings revealed two distinct patterns of skin resistance recording. Individuals with flat, monotonous tracings were called stabiles. Individuals with chaotic tracings were called labile (s) (Lacey & Lacey, 1958). The same two patterns were observed during recordings under stress. Further analysis showed frequency of distribution shape, range and medians under the two conditions were significantly correlated with each other. The Wilcoxon signed-rank test was used to determine differences in skin resistance within each pair of measures at rest and under stress (Lacey & Lacey, 1958). Results were significantly correlated with a rank order correlation coefficient of 0.76, $p <$ 0.001 at rest and $p < 0.01$ during stress (Lacey & Lacey, 1958). Skin resistance increased for women under stress at a significant level $p < 0.01$ and resting rate was found to be predictive of non-resting rate at $p < 0.01$ (Lacey & Lacey, 1958). Meaning that women with flat even tracings during rest had “tidy records” (Lacey & Lacey, 1958, p.159) during stress, responses occurred just before, during and right after stimulus presentation. Women with chaotic tracings at rest showed increased chaotic response rates throughout stress testing (Lacey & Lacey, 1958).

Currently, these response patterns are accepted as reliable representations of an individual's personality trait (iworx/CB Sciences, 2009). Individuals demonstrating high frequency spontaneous skin reaction and slow habituation to repeated exposure to stimulation are identified as electrodermal labile (s). Conversely, individuals demonstrating few spontaneous skin reactions and quick habituation are identified as electrodermal stabiles (iworx/CB Sciences, 2009). Schell, Dawson & Filion, 1988 studied the effect of tasks that require attention among a sample of college students (n=75). The study consisted of three one-hour laboratory sessions over a three-month period. Each laboratory session was divided into phases of rest and attention tasks. Attention tasks were further divided into orienting tasks, attract initial attention, reaction time task, speed of attention reaction and signal detection task, attention over time. Group differences between labile and stabile subjects were analyzed using *t* – tests of skin conductance means over trials (n = 45 due to attrition factors), α .05. Results indicated labile (s) had higher SCL than stabiles with larger orienting responses $t = 5.69$, $p < .001$ and faster speed of reaction time, $t = 2.86$, $p < .01$ (shorter latency, rise time and half recovery time) [Schell, Dawson & Filion, 1988]. Attention over time was significantly greater than stabiles, $t = 5.49$, $p < .001$ (Schell, Dawson & Filion, 1988). Their results determined that labile (s) are generally better at vigilance tasks than stabiles. Accordingly, some researchers believe these traits

represent a basic difference in information processing among individuals (iworx/CB Sciences, 2009).

Skin Conductance

Skin conductance responses or increases in the conductance of skin may last 10-20 seconds. Similar to tonic level individual differences, phasic level differences are demonstrated as well. Spontaneous SCR's, that are not event related, may occur to varying degrees. The typical frequency of spontaneous SCR's is between 1-3 per minute (iworx/CB Sciences, 2009).

The parameters of event related SCR's that can be quantified, as shown in Figure 1, are amplitude in micro Siemens; latency, rise time and half-recovery time. The difference between tonic skin conductance levels, at the time the response is evoked, and the skin conductance at the peak of the response is measured in terms of amplitude and rise time (iworx/CB Sciences, 2009). Typical values for rise time are 1-3 seconds (iworx/CB Sciences, 2009). Latency is the time between the stimulus and the onset of the event, usually 3 seconds or less. Half-recovery time is the time between the peak of the response and the point after the peak when conductance returns to an amplitude that is half the amplitude of the peak. Typical values for this parameter are 2-10 seconds (iworx/CB Sciences, 2009).

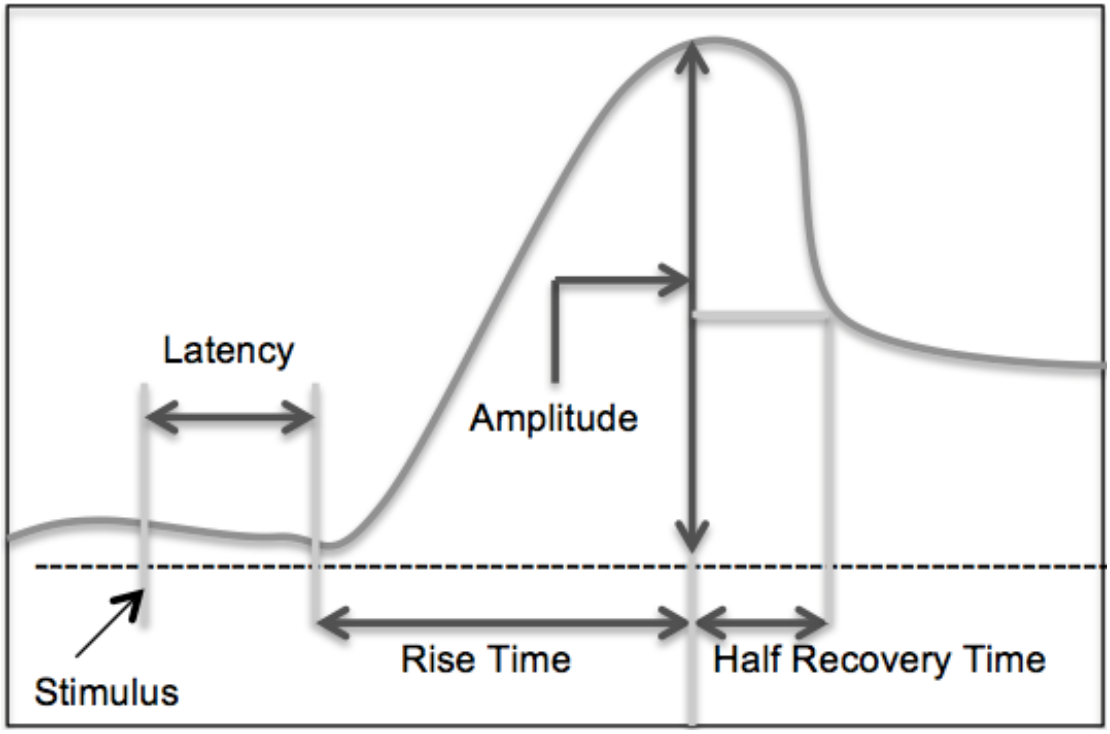

Figure 1. Graphical representation of principal EDA components (modified). Adapted from Dawson, Schell & Fillon (1990). The Electrodermal System (p. 207). In J.T. Cacioppo & L.G. Tassinary (Eds.), Principles of Psychophysiology: New York: Cambridge University press.

Skin conductance as a psychophysiological measure of ANS function is frequently used in research examining neurodevelopment, anxiety, post-traumatic stress disorder (PTSD), schizophrenia, autism, and more recently sensory processing disorders (Aubert-Khalfa, Roques & Blin, 2008; Gladman & Chiswick, 1990; Green, Nuechterlein, & Satz, 1989; Hernes et al., 1994; Kyllianinen & Hietanen, 2006; McIntosh et al., 1999; Miller, et al, 1999; Naveteur, Buisine & Gruzelier, 2005; Ohman & Hultman, 1998; Schell,

Dawson, Nuechterlein, Subotnik, & Ventura, 2002; Schell et al., 2005; Schoen et al., 2008; Schwerdtfeger, 2006). All these conditions share a common linkage to emotional and physiological reactions to sensations. A substantial proportion of these reactions are categorized as significantly hyper-responsive or hypo-responsive.

Decreased amplitude of SCR to stimuli is indicative of hypo-responsiveness, whereas increased amplitude indicates hyper-responsiveness. A mixture of hyper-arousal and hypo-arousal is common among children with autism. In fact, except for autism, the dominant pattern among clinical groups is low SCR (Miller et al., 1999). Since tonic skin conductance level (SCL) is influenced by changes in skin hydration (moisture) it is not the best indicator of SNS activity (Venables & Christie, 1980). SCR on the other hand is less influenced by hydration changes and allows evaluation of specific responses to each stimulus (Miller, et al., 1999).

Skin hydration is not the only influence on measures of electrodermal responses. Anxiety has been repeatedly observed to be associated with reduced electrodermal activity. This phenomenon is interesting because anxiety is associated with activation of the SNS. A detailed review of this phenomenon is addressed in the skin conductance and anxiety section of this paper.

Skin Conductance and Neurodevelopment

Investigation of SCL in infants has revealed a developmental sequence indicating a maturational process of the sympathetic nervous system in response to the environment and to specific stimuli (Gladman & Chiswick, 1990). These studies implement the term emotional sweating to define the rise in SCL or SCR in response to stimuli that distinguishes this response from sweating due to increased temperature (thermoregulation).

There are two types of sweat response, emotional and thermoregulatory. An emotional sweat response occurs in the palmar and plantar areas and is "in part functionally independent from thermoregulatory sweating" (Vetrugno, Liguori, Cortelli, & Montagna, 2003, p. 258). Vetrugno and colleagues used Positron Emission Tomography (PET) scans to provide criterion support for the use of SCL and SCR. PET scans showed metabolic activity in the cingulate gyrus with arousal and deficits in selective attention with anterior cingulotomy. They found that the anterior cingulate cortex (ACC) controls emotional sweating. The dorsal ACC receives and processes visual sensory (somatic) input, and the ventral ACC processes visceral sensory input. The ACC integrates somatic and visceral information and sends it to the thalamus, which switches the resting SCL to response firing spikes to alert or arouse the orienting response. The orienting response consists of "rapid eye-head movements directed toward a novel stimulus associated with electroencephalogram (EEG) signs of arousal and autonomic

variations. Emotional sweating and the sympathetic skin response constitute important components of the orienting response, occurring anytime attention is directed to a novel and significant stimulus" (Vetrugno et al., 2003, p. 258). In addition, imaging studies reveal a positive correlation with neural activity in the motor and cingulate cortex with sympathetic skin response in subjects experiencing emotional stimuli (Vetrugno et al.). This process inextricably links emotion, arousal and attention.

To analyze how SCL was related, if at all, to level of arousal, Gladman and Chiswick (1990) studied development in prenatal resting babies. The study used heel pinprick (obtaining blood sample) as the stimulus. All babies in the study were aroused one minute after pinprick using SCL measures and clinical observation of state of arousal on a four-point scale.

Results indicate no difference in SCL level before and after pinprick in babies less than 36 weeks gestational age. As the gestational age of babies increased the percentage of SCL response increased with 30% (7 of 23) of babies between 36-39 weeks and 91% (20 out of 22) of babies between 40-43 weeks demonstrating an increase in SCL one minute after pinprick (Gladman & Chiswick, 1990). The authors suggest their results support SCL as a phenomenon that occurs in babies old enough to have developed emotional sweating.

Results also indicated a link between level of arousal and SCL. The authors found babies less than 40 weeks gestational age demonstrated a constant SCL regardless of their state of arousal. However, an association between state of arousal and SCL before and after stimulation was found in babies older than 40 weeks ($p = 0.03$) [Gladman & Cheswick, 1990]. Higher SCL levels were measured in babies older than 40 weeks when awake compared to those that were asleep. The author's state babies older than 40 weeks gestational age can modulate SCL with their state of arousal. They further state modulation of SCL is a function of nervous system maturity.

Gladman and Cheswick's (1990) results were supported by a 2002 study (Hernes et al.) investigating SCL and SCR during the first year of life. Hernes and colleagues defined skin conductance as reflecting "the level of readiness of the nervous system or cortical vigilance, and may be altered by the infants state of arousal" (Hernes et al., p. 837). SCL was measured using the number of waves per second and wave amplitude while subjects were in prone and supine 3 minutes each. SCR was measured using percentage of infants that responded, waves per second, wave amplitude, latency, and recovery time and habituation patterns in response to an auditory stimulus. Measurements were carried out using Edelberg guidelines at six different points in the first year of life. ANOVA for mean SCL was positively correlated to arousal ($p < 0.001$). Arousal was measured using a clinical observation rating the (four point scale alert to asleep) amplitude of the waves and

number of the waves per second. Results reveal a significant increase in SCL waves per second and amplitude ($p < 0.001$) during first 10 weeks of life (Hernes et al., 2002). The authors posit that their results demonstrate SNS association with arousal after birth with SCL modulation continuing to mature with the most significant gains made during the first 10 weeks of life.

Skin Conductance and Anxiety

Studies implementing SCR among anxious individuals have determined that anxiety and attention share the same neuroanatomical pathway (Siepman et al., 2007, Navetuer et al., 2005) and impact the SCR that is generated. Autonomic responses to negative or emotional stimuli are often used to show anxiety drug effectiveness in healthy individuals. Previous studies have determined that sympathetic activity is closely linked to emotions and SCR can be generated by frightening stimuli, loud noise, angry face or an emotional distracter (Siepman et al.; McIntosh et al., 1999; Venables & Christie, 1980). The use of SCR is important because subjective reports of anxiety often lead to a very large placebo effect when testing anxiety-reducing drugs (Siepman et al.). It is interesting to note both tonic and phasic EDA are reduced in highly anxious individuals.

To investigate why anxious individuals have reduced SCR and SCL, Naveteur and colleagues (2005) compared two groups of women, anxious and non-anxious, exposed to negative stimuli during two conditions, task

performance and no task. Results indicate an overall higher SCR response during task performance compared to the control group. The authors posit an attentional model that proposes a greater amount of resources are allocated to the task and therefore fewer resources are available to inhibit the impact of distracters. Reduction of SCR during the control condition was viewed as a normal inhibitory process. These authors manipulated the conditions to analyze the ability of the subjects to separate out the distractions while performing a task.

To separate out the difference between physiological responses and subjective mood Siepman and colleagues, 2007, used a low dose of lorazepam, an anxiety-reducing drug (benzodiazepine) to test arousal to frightening stimuli using SCR as an index. Low doses of lorazepam do not have a sedative effect and therefore, level of alertness and subjective reports of mood are not affected (Siepmann et al.). This strategy is important because it helps control the placebo effect when testing anti-anxiety drugs. Autonomic responses are not affected by low doses of lorazepam and can therefore be used to gauge the effectiveness of reducing sympathetic response to frightening stimuli.

To quantify SCR before administration of drug, Siepmann and colleagues (2007) calculated differences between mean amplitude of tonic and phasic SCL/SCR during exposure to neutral and aversive stimuli among healthy male subjects (n=12, ages 23-32). To determine effectiveness of the

drug, SCR's were recorded after administration. Results indicate SCR's were significantly decreased, $p < .05$ (Siepmann et al., 2007) in response to negative stimuli 1-3 hours after ingestion of lorazepam, and no decrease in SCR among the placebo group. A concurrent measure of alertness, Pupillary Unrest Index (PUI) was implemented as a comparison measure. A high value PUI indicates sleepiness and a low value indicates alertness. PUI measures reveal no change in alertness level before and after ingestion of drug or placebo. Clearly, a state of readiness requires one to be alert and attentive in order to respond to stimuli.

Skin Conductance and Post Traumatic Stress Disorder

Skin conductance measures are often used as part of a study design to determine the physiological effects of a treatment. To ascertain how eye movement desensitization and reprocessing therapy (EMDR) works, Sondergaard and Elofsson measured various physiological changes in the body that occur during EMDR. Eye movement desensitization and reprocessing therapy has successfully treated post-traumatic stress disorder (PTSD) [Sondergaard & Elofsson, 2008]. The authors hypothesize that eye movements produce physiological effects that change how the body reacts to PTSD symptoms.

To determine how the body reacts to EMDR, Sondergaard and Elofsson (2008) measured five physiological parameters; pulse rate, finger

temperature, SCR, breathing frequency, and parasympathetic tone via heart rate variability. During EMDR therapy pulse rate went down, finger temperature went up, SCR decreased, breathing frequency initially increased and then gradually decreased and parasympathetic tone increased. When the therapy session ended, all these measures returned to baseline levels. Sondergaard and Elofsson assert the trend during therapy was psychophysiological dearousal, which is a decrease in pulse rate, skin conductance, breathing frequency and heart rate. They cited a 2003 study by Barrowcliff, Gray, MacCulloch, Freeman, and MacCulloch that used SCR to study physiological reactions to white noise during eye movement. Again initial increased frequency of breathing shifted to decreased frequency of breathing, increased finger temperature along with decreased heart rate and skin conductance were also measured. The authors state these physiologic responses are specific to eye movement therapy and therefore validates their hypothesis that EMDR produces specific physiologic effects. These effects occur as a result of “the alternative state – specifically relaxation” (Sondergaard & Elofsson, 2008, p.285) produced by eye movement therapy. “Decreased SCR to external stimuli indicate psychophysiological de-arousal and habituation” (Barrowcliff et al., 2003, Elofsson et al., 2008, Wilson et al., 1996, as cited by Sondergaard & Elofsson, 2008).

Skin Conductance and Schizophrenia

Skin conductance as a predictor of symptom onset and outcome in schizophrenic subjects has been studied extensively (Green, Nuechterlein, & Satz, 1989; Ohman & Hultman, 1998; Schell, Dawson, Nuechterlein, Subotnik, & Ventura, 2002; Schell et al., 2005). Skin conductance measures are often the basis for dividing subjects into groups of responders and non-responders. A 1989 study by Green and colleagues assessed the relationship between schizophrenic symptoms and level of anticholinergic medications using tonic and phasic skin conductance measures as the dependent variable. Non-responders were those subjects that did not have a phasic skin conductance orienting response to neutral auditory stimuli. The percentage of non-responders among schizophrenic subjects is around 40-50% whereas among the normal population the percentage of non-responders is around 5-10% (Green, Nuechterlein, & Satz; Ohman & Hultman, 1998; Schell et al., 2005). This finding has been replicated consistently in the literature and has led to the notion that separation of schizophrenic subjects into two subgroups of responders and non-responders based on presence or absence of skin conductance orienting response is reliable (Green, Nuechterlein, & Satz). These same authors hypothesized non-responders would have higher levels of negative symptoms (apathy, lack of emotion, poor social function), lower tonic skin conductance levels and

lower frequency of non-specific responses. No significant differences in symptomatology were found between these two groups.

A 1998 study by Ohman and Hultman separated subjects into groups according to responsivity. Non-responders were defined as subjects who did not show a SCR of at least .05 microSiemens on any of the first two stimulus presentations. Each group was then assessed using regression analysis to determine if there was an association between responsivity and obstetric complications. A reliable association between low level of skin conductance response and obstetric complications among children of schizophrenic parents was observed, Chi Square (1, $N = 79$) = 4.06, $p < .05$.

Stability of electrodermal variables among schizophrenic subjects over a one-year period was investigated in a 2002 study (Schell, Dawson, Nuechterlein, Subotnik & Ventura). This study also separated subjects into groups according to response or non-response status and compared them with normal controls. Schell and colleagues point out two basic differences between schizophrenic subjects and controls in terms of response patterns. First, schizophrenic subjects show less orienting skin conductance response to stimuli and those subjects that do show orienting response tend to have abnormally high levels of tonic skin conductance level and greater frequency of non-specific skin conductance responses. Therefore, this study investigated the stability of both tonic and phasic measures over a one-year period.

Results indicate moderate test-retest stability of tonic (SCL & NSR) and phasic (number or orienting responses and magnitude of responses) measures after one year (Schell et al., 2002), however individual response measures (amplitude, rise time, rise rate and half recovery time) were lower and therefore not as stable. A significant group effect was found between normal and clinical subjects for tonic NSR, $F = 6.91$, $df = 1,104$, $p < .01$. Clinical subjects had higher NSR levels both initially and after one year follow up than the normal subjects. To further analyze this difference between groups, normal and clinical subjects were both divided into responder and non-responder groups based on orienting response (OR). An OR of 0 indicates non-responder status. Results indicate no difference in frequency of NSR's between non-responder groups. Among responder groups a significant difference in NSR's was found for initial 2.52 vs. 1.41 ($t = 2.24$, $df = 60$, $p < .03$) as well as one-year follow up measure, 3.19 vs.1.47 ($t = 2.46$, $df = 56$, $p < .02$) [Schell et al., 2002). The clinical group had significantly higher levels of NSR's than the normal control group. In their discussion of findings, these authors note EDA variables have both trait and state properties (Schell et al). State is viewed as arousal level (presence or absence of symptomatology) whereas trait is viewed as a characteristic of personality.

To investigate EDA as a predictor of functional outcome and negative symptoms in schizophrenia, researchers used the Brief Psychiatric Rating Scale to measure symptoms and skin conductance (SCL, NSR, OR) to

measure response to environmental stimuli in 78 adult schizophrenic subjects and compared them to a control group of 36 normal adults. The clinical group was divided into two subgroups at the end of the one-year period based on functional outcome. Good outcome was defined as those who showed both good social and work outcome, poor outcome were those who showed poor social and work outcome. Group comparison using skin conductance measures revealed SCL, NSR and OR were significantly positively intercorrelated, r (NSR & SCL) = .61, r (NSR & OR) = .72, r (SCL & OR) = .55, all dfs = 76, all ps < .01 (Schell et al., 2005). The good and poor outcome groups were compared to the control group using skin conductance measures to ascertain percentage of responders versus non-responders in each group. Chi square analysis revealed no difference in percentage of non-responders between good and poor outcome groups. The poor outcome group had significantly higher number of NSR's than controls, t = 3.12, df = 111, p < .01 (Schell et al.). There was no difference in NSR's between the good outcome group and controls.

Schell and colleagues (2005) suggest that good outcomes are associated with lower levels of tonic and phasic skin conductance in schizophrenic subjects. They further posit hyper arousal may interfere with cognitive processing and the ability to sustain attention and solve problems thereby negatively impacting the ability to discriminate relevant information. Higher levels of tonic and phasic skin conductance may indicate a

vulnerability to stressors and result in misinterpretation of stimuli that results in abnormal response to environmental stimuli.

These studies show there is still a lack of consensus regarding predictive ability of skin conductance as it relates to symptom onset in schizophrenia. Percentage of responders and non-responders in samples may affect outcome of studies. Dividing samples into subgroups appears to indicate both high and low skin conductance response negatively impacts ability to function among schizophrenic subjects.

Skin Conductance and Autism

Two studies implemented EDA measures to investigate group differences between children with autism and typically developing children. One study used SCR measures to examine the effect of eye contact on physiologic arousal. Known factors such as infant's preference to focus on face-like stimuli, especially with eyes open stirred interest in the possible physiologic mechanisms occurring.

Kyllianinen & Hietanen, (2006) noted poor eye contact as part of the autism spectrum as defined by the *DSM-IV* criteria and designed a study to compare response to eye contact between children with and without autism. According to these researchers review of the literature, eye contact has been shown to generate greater SCR than unreciprocated gaze. Conversely, there are also studies that demonstrate no difference between direct eye contact

and unreciprocated gaze (Kyllianinen & Hietanen, 2006). The authors attempted to address this discrepancy in the literature with their 2006 study.

In this study the researchers investigated the effects of direct gaze and indirect gaze on electrodermal responses. Kyllianinen & Hietanen (2006) expected straight gaze to generate stronger SCR responses than the averted gaze in children with autism as compared to typically developing children. Children looked at a monitor and were shown 12 face stimuli, 6 male and 6 female presented in random order, consisting of 6 straight gaze and 6 averted gaze. Between each stimulus, the child was asked if the face had a straight or averted gaze to ensure that the child had looked at the stimulus.

Data was analyzed implementing an experimental within subjects design looking at group assignment and stimulus response. SCR was defined as maximum amplitude change from baseline at the stimulus onset during a 5 second time window starting after 1 second from the stimulus onset till the end of the stimulus presentation (Kyllianinen & Hietanen, 2006). Magnitude of SCR was determined by combining the response size and response frequency.

Results indicate a lower mean response overall between the clinical group (mean=.29 µMho, SD=.17) and the control group (mean=.51µMho, SD=.37); however, the difference was not statistically significant. The effect of gaze however between the two groups was significant. Typically developing children showed no difference in SCR response between straight

gaze (mean=.49 µMho, SD=.41) and averted gaze (mean=.53 µMho, SD=.32). Responses among children with autism demonstrated a stronger response to straight gaze (mean=.35 µMho, SD=.22) than to averted gaze (mean=.24 µMho, SD=.14) [Kyllianinen & Hietanen, 2006].

The authors posit that these results indicate a stronger level of arousal among children with autism, which may be triggered by eye contact rather than averted gaze. These results support the long held notion that children with autism avoid eye contact to prevent or decrease overwhelming or uncomfortable physiological stimulation.

The second study conducted by Schoen, Miller, Brett-Green & Hepburn (2008) implemented EDA to study arousal and sensory reactions among children with high functioning autism (HFA) and Asperger's Syndrome (AS). Thirty eight children ages 5-15 diagnosed with HFA or AS participated in the Sensory Challenge Protocol, (McIntosh et al.,1999) during which SCL and SCR is collected during baseline and while subjects are exposed to six different sensory stimuli. Between group *t*-tests across all variables revealed no significant differences for baseline SCL or SCR measures of magnitude, latency and habituation and were therefore treated as a single group while conducting further analyses.

Visual analysis of SCL for each individual during baseline and ultimately throughout the experiment and during recovery was plotted and then divided into 2 groups according to arousal level. A cut-off point of 6µS

was used to categorize high and low arousal groups. Two tonic patterns were observed, low amplitude SCL and less variability and high amplitude SCL and higher variability. Throughout the experiment, strong correlations between baseline SCL and mean SCL were found, $r = .931 - .996$; $p < .001$ (Schoen et. al, 2008).

While, phasic SCR comparisons did not reach statistical significance, several trends were evident in the data. Interestingly, the high SCL group had higher magnitudes, faster latencies and slower habituation while the low SCL group had lower magnitudes, slower latencies and faster habituation.

Within six weeks of the first test, 25 of the 38 subjects were contacted (due to grant funding parameters) to participate in a second test to complete the study. Nine subjects refused and 2 didn't show up, leaving 14 subjects in the retest sample. Test-retest reliability was calculated on all tonic and phasic variables of the 14 subjects that completed the second testing (71% HFA and 29% AS). Results indicate moderate reliability of SCL (ICC = .45 - .51) and phasic variables (73% had ICC= .33 or greater with a median of .45). The authors suggest electrodermal measures in this study are "relatively stable" (Schoen et al., 2008, p.424) based on similar reliability correlations reported for typically developing samples (Iacono et al., 1984; Schell, Dawson, & Filion, 1988; Schell, Dawson, Nuechterlein, Subotnik, & Ventura, 2002; Vossel & Zimmer, 1990). Schoen and colleagues point out that clinical groups tend to have less stability (Schell er al., 2002) due to decreased

arousal regulation. According to Portney and Watkins (2009) ICC values above .75 are indicative of good reliability, below .75 poor to moderate. The ICC value .45 - .51 for SCL may be described as moderate or relatively stable. The ICC value of .33 for SCR is poor in terms of reliability and not relatively stable. These authors are not interpreting the data based on ICC values reported by Portney and Watkins, rather they are comparing the results of their study of a clinical group to previous findings in the literature of normal groups with the added caveat that clinical groups have less stability secondary to deficient arousal regualtion. In addition, the small retest sample size negatively affected the ability to determine stability of EDA measures and generalize study results. More studies are needed to ascertain stability of EDA measures over time and compare clinical group response to control group response.

Skin Conductance and Sensory Processing Disorder

Collection of physiologic data measuring SNS response to sensory stimuli for group comparison was initiated by Lucy Miller when she established a laboratory paradigm called the Sensory Challenge Protocol. Miller collaborated in two studies in 1999 using this laboratory procedure. In both studies Miller used electrodermal activity, measured as SCR to stimulation, as the dependent variable.

In the first study, she collaborated with McIntosh and colleagues (1999) to investigate whether children clinically diagnosed with “disrupted nervous-system processing of sensory stimuli” (McIntosh et al., 1999, p. 608) or sensory modulation disruption (SMD) would present with different physiological responses to environmental stimuli when compared to children without SMD. SMD is part of the family of SPDs that present as a pattern of over responsiveness (heightened awareness, distraction or avoidance) or under responsiveness (deficient notice or attention) to sensory stimulation from the environment or one’s own body.

McIntosh, Miller and colleagues (1999) presented evidence that children clinically identified as having behavioral sensory modulation disruptions (SMD) demonstrated abnormal physiological reactions to sensory stimuli compared to a control group of children (without SMD). Implementing the SCP, the aforementioned evidence was collected by measuring SCR to environmental sensory stimuli in a sample of 38 children, 19 with SMD and 19 controls. Three SCR variables were analyzed, magnitude, number and proportion. SCR tracings within the group with SMD demonstrated a hyper-responsive pattern of larger amplitudes and more responses after each stimulus when compared to the control children. The children with SMD had larger responses to stimuli (mean 0.063 log micromhos, SD 0.052) than control group (Mean 0.026, SD=0.20; F[1,28]=6.50, P=0.017) [McIntosh et al., 1999]. With repeated exposure, both groups showed decreases in the

magnitude of their responses such that habituation to the stimulus was emerging. Further, children with SMD demonstrated a greater number of responses to each stimuli (mean1.17, SD=0.66) than children in the control group (mean 0.64, SD 0.54; F[1,28]=5.11, P=0.032) [McIntosh et al.). The greater number of responses attributed to the SMD group profile is similar to individuals identified as electrodermal labiles, those with less cortical inhibition over SNS activity. In response to repeated stimulation, both groups habituated but at different rates, as evidenced by contrasts in linear and quadratic trends. Proportion of responses was not significant between the two groups, although the SMD group was slightly higher than the control group. Results demonstrated that the absence of SCR to sensory stimuli was more common among children with SMD than controls. Therefore, the authors excluded (McIntosh et al.) these children and their matched controls were excluded when evaluating habituation and magnitude of response to stimuli in order to avoid decreasing the average SCR levels in the SMD group.

In her analysis of the data collected, she observed that individuals with conditions causing unusual responses to stimuli often exhibited abnormal SCR. Results indicated significant differences in physiologic responses of children with and without SMD.

In the second study, Miller and colleagues (1999) compared individuals with Fragile X syndrome n = 25, with a control group n = 25.

Fragile X syndrome is a genetic mutation of the X chromosome that causes mental retardation, learning disabilities and behavioral problems. (Miller et al., 1999; National Institutes of Health, 2011). These researchers hypothesized that hyperarousal, hyperactivity, aggression and anxiety associated with Fragile X syndrome may be related to strong reactions to environmental stimuli. The same variables measured in the SMD study were measured again: mean magnitude of response to each stimulus, the number of responses to each stimulus and the subject's probability (proportion) of responding to stimuli at each trial. Test retest reliability on all dependent measures demonstrated significant positive correlations: magnitude of responses ($r(5) = 0.94$, $P<0.01$): number of peaks ($r(5) = 0.96$, $P<0.001$): proportion of stimuli to which the person responded ($r(5) = 0.88$, $P<0.01$) in an effort to establish probability of responding to stimuli at each trial (Miller et al., 1999). ANOVA's were used to analyze group differences. Statistically significant group differences were found between individuals with and without Fragile X syndrome. The Fragile X group demonstrated greater magnitude of response (M=0.09 log micromhos, SD=0.02)(M=0.02, SD=0.02) more responses per stimulation (M=1.7, SD=1.0) (M=0.58, SD=0.43) and a greater proportion of trials (M=0.75, SD=0.28) than did controls (M=0.38, SD= 0.26)[Miller et al.,1999] . Lower rates of habituation among the SMD group were demonstrated as well. Patterns of SCR responses to one sensory modality were predictive of the other four modalities. Miller (1999) posits that

since electrodermal activity indexes sympathetic nervous system activity, the data suggest that over-arousal to sensation in children with Fragile X syndrome implicates a dysfunction of cortical inhibition of the SNS.

Reliability SCR

Although efforts to show reliability of SCR as an indirect measure of sensory processing in this analysis is sparse, the larger issue is the utility of the data already obtained. This gap in the literature needs to be addressed to support or refute the strength of SCR as an indirect measure of sensory processing. If reliability of SCR is supported using ICC measures it would provide essential information necessary to develop norms which can be used to screen children for SPD, validate SI therapy as a treatment for SPD and support inclusion of SPD in the DSM as a distinct disorder based on reliability criteria established by the DSM-V workgroup which states:

> we consider new diagnoses (or subtypes) for addition to DSM-V – the demonstration of at least moderate to good reliability would also be an important criterion for their inclusion in DSM-V. In general, we would not expect to support the addition of new diagnostic entities in DSM-V without some evidence that they are reliable (Kendler, Kupfer, Narrow, Phillips, & Fawcett, 2009).

The next section of this paper will present reliability and validity information that is currently known on SCR.

Reliability is defined as the degree that repeated measurements agree and are error free (Rothstein & Echternach, 1993). There are 4 subcategories of reliability that comprise a total measure of reliability, they are internal consistency, intertester reliability, intratester reliability and test re-test reliability. As shown in table 2 and table 3, twelve studies were analyzed based on their use of SCL and SCR as an index of SNS function.

Table 2

Reliability Skin Conductance Measures

	Internal Consistency	Test Re-Test
Aubert-Khalfa 2008	X	
Gladman 1990	X	
Hernes 2002	X	
Kyllianen 2006	X	
McIntosh 1999	X	$r = 0.79 – 0.82$
Naveteur 2005	X	
Roberts 2008	X	
Schestatsky 2007	X	Chi-Square = 20.11 (P<0.001) $r = 0.61 – 0.65$
Schoen 2008	X	ICC > 0.33
Siepman 2007	X	
Sondergaard 2008	X	
Vetrugno 2003	X	

Note. Internal consistency based on skin conductance representing sympathetic nervous system arousal.

Table 3

Validity Skin Conductance Measures

	Construct	Content	Criterion	Concurrent	Predictive	Prescriptive
Aubert-Khalfa 2008	X*					
Gladman 1990	X*					
Hernes 2002	X*					
Kyllianen 2006	X**					
McIntosh 1999	X*	X			X	
Naveteur 2005	X*					
Roberts 2008	X*			X[ab]		
Schestatsky 2007						
Schoen 2008	X**					
Siepmann 2007				X[c]		
Sondergaard 2008				X[defg]		
Vetrugno 2003			X	X[h]		
Total	8	1	1	4	1	0

Note. *Construct validity based on the work of Fowles, Christie, Edelberg, Grings, Lykken & Venables, 1981.

**Construct validity based on the work of Dawson, Schell & Fillion, 1990.

a Vagal Tone
b Heart Rate
c Pupillary Unrest Index
d Heart Rate Variability
e Pulse Rate
f Finger Temperature
g Breathing Frequency
h Positron Emission Tomography

All twelve studies demonstrated internal consistency by using skin conductance as a measure that represents one basic phenomenon, arousal of the SNS. Stability was reported in three of the studies. One study performed the re-test measurement one week apart and results indicated a positive correlation between the two measurements, r = 0.79 – 0.82 (McIntosh et al., 1999). The other study performed the re-test measurement 2-6 weeks apart and found moderate test re-test reliability with ICC coefficients greater than .33 (Schoen et al, 2008). A third study showed reliable latency between stimuli and appearance of peak, *r* - .61 - .65. Also, an association between peak amplitude and type of stimuli, neutral stimuli was linked to low amplitude and painful stimuli was linked to high amplitude (Schestatsky et al., 2007). None of the twelve studies contained any information or results regarding intratester or intertester reliability.

Validity is assessed according to six components that represent total validity, concurrent, construct, content, criterion based, predictive and prescriptive validity (Rothstein & Echternach, 1993). Eight studies discussed construct validity, the theoretical basis for using skin conductance and the interpretation of the measure. Four studies compared skin conductance measures to another measure obtained approximately at the same time, achieving concurrent validity. These concurrent measures consisted of PET scans, pulse rate, heart rate, heart rate variability, finger temperature, breathing frequency, and pupillary unrest index (which are all measures).

One study demonstrated content validity by indicating exactly how and to what extent skin conductance measurement reflected SNS arousal (McIntosh et al., 1999). This same study also contained predictive validity by demonstrating significant differences in sensory profile scores among groups of high, low and midrange skin conductance responders. One study (Sonderson & Elofsson, 2008) linked skin conductance along with 4 other biologic markers to demonstrate physiological change occurring due to a treatment protocol used in the study. Overall, these results support the validity of skin conductance as a useful, meaningful measure of physiologic reactions to sensation. However, none of the studies addressed prescriptive validity, the ability to prescribe appropriate treatment, based on the interpretation of the skin conductance measure. The lack of prescriptive validity of SI treatment in the literature raises the primary concern again and supports the need to develop a tool that can reliably measure treatment effectiveness.

Summary

This review of the literature has described the standardized procedures to record SNS response using EDA as measured by skin conductance, the theoretical basis for using skin conductance to quantify response to sensation (Dawson et al., 1990; Gladman & Chiswick, 1990; Green, Nuechterlein, & Satz, 1989; Hernes et al., 2002; iworx/CB Sciences, 2009; McIntosh et al., 1999; Miller et al., 1999; Ohman & Hultman, 1998; Schaaf & Miller, 2005;

Schell, Dawson, Nuechterlein, Subotnik, & Ventura, 2002; Schell et al., 2005; Schoen et al., 2008; Sondergaard & Elofsson, 2008; Vetrugno et al, 2003) and EDA measurement studies that have established an observed and quantified link between sensory processing and skin conductance (Aubert-Khalfa et al., 2008; Gladman & Chiswick, 1990; Hernes et al., 2002; Kylliainen & Hietanen, 2006; McIntosh et al., 1999; Miller et al., 1999; Naveteur et al., 2005; Roberts et al., 2008; Schestatsky et al., 2007; Schoen et al., 2008; Siepman et al., 2007; Sondergaard & Elofsson, 2008; Van Lang et al., 2007; Vetrugno et al., 2003).

As this review has shown, reliability and validity of skin conductance measurement as an index of sensory processing has been sparse, resulting in a lack of consensus specifically in regard to how to interpret the data. Therefore, using skin conductance measures to analyze sensory processing would be much more powerful if the reliability and validity of the measurement were addressed. Based upon this limitation, future studies should focus on providing data to fill those gaps and increase the body of knowledge regarding sensory processing disorders.

Chapter III

METHODS

Design

This methodological research study is a prospective exploratory test-retest design assessing the use of skin conductance response (SCR) as an index of sensory processing.

Participants

A convenience sample of boys between the ages of 4 – 11 years with and without a diagnosis of ASD were recruited from private and public New Jersey Schools, Barpak Occupational Therapy clinic, Bergenfield, New Jersey and Seton Hall University (SHU) campus. Flyers were posted in the clinic, schools and common areas of SHU encouraging parents to contact the primary investigator to get more information regarding study participation.

Selection criteria

Parents interested in participating in the study were contacted by the primary investigator. The investigator screened the potential participant during a telephone interview by asking a series of questions regarding type of

school attended, medical history, medications, participation in any therapies, and sensitivity to sensations.

Inclusion criteria

1. Boys ages 4 – 11 years old.
2. Able to sit for 30 minutes and follow simple directions.
3. Children with confirmed ASD via school records or parent report.
4. Typically developing children free of medical or neurological conditions.

Exclusion criteria

Children with the following conditions were excluded from the study to avoid confounding variables that may affect response to sensation.

1. Medical or neurological conditions other than autism.
2. Hearing loss or visual impairments.
3. Children taking medications known to affect arousal.
4. Children who are not able to follow simple commands.

To ensure safety and appropriate ethical conduct working with subjects, the study was submitted to the institutional review board at Seton Hall University and was approved on 01/04/2013 Participants signed an assent form and parents signed a consent form before participating in the study. Subjects were assigned a numerical code to maintain anonymity.

Children and or their parents were able to discontinue participation at any time.

Instrumentation

Hardware

Using an integrated laboratory system, (Psylab System, Contact Precision Instruments, Cambridge, MA) measurement of skin conductance is collected following the procedures recommended by Martin & Venebles (1980) and the Fowles committee (1981). The Psylab Stand Alone Monitor (SAM) provides a connection between the subject and SAM as well as connection between SAM and the computer software. Data is collected from the subject via electrode placement, and converted to digital at the electrode source, then transmitted to the computer software. The skin conductance coupler (SC5) contains a 24-bit accuracy A-D converter which converts the signal from analogue to digital before sending it to the SAM unit. A self-calibration system adjusts itself each time the SC5 is turned on by connecting to known conductance values. The internal converter encompasses the entire range (0 – 100 micro Siemens) of skin conductance measures with enough sensitivity to detect small changes (Contact Precision Instruments, 2003) therefore control over amplifier gain is not necessary. No high pass filter is provided because of the direct coupling of the signal that avoids potential distortion by the filter (Contact Precision Instruments). A fixed low

pass filter of 10 Hz is adequate because skin conductance response takes a few seconds to complete (Contact Precision Instruments). Digital data is then sent to the computer software system.

To begin data collection, the subject is connected to the SAM unit via one pair of 8mm diameter silver/silverchloride (Ag/AgCl) skin conductance electrodes (Contact Precision Instruments EL 122) filled with Mansfield R & D electrode paste 0.05-M NaCl electrolyte paste (TD-246, discountdisposables.com). The electrodes are secured to the thenar and hypothenar eminence of the left hand using Mansfield R & D electrode collars (TD-22, discountdisposables.com). The electrodes are further secured to the subject's hand using 50.8 mm wide Coban self-adhesive wrap (Nexcare, 3M). The electrodes are directly attached to the SC5 which, applies a constant 0.5 volt potential across the electrode pair. The SC5 is connected to the SAM unit.

A 3-lead snap dot EKG set is attached to EKG conductive adhesive electrodes and then applied to the subject's chest at the base of rib cage in a triangular pattern (EL-126, Contact Precision Instruments). The electrode heart rate variability data is transmitted to a bioamplifier, filtered and sent to the SAM unit for conversion of the signal from analogue to digital.

Using the SAM software system, the researcher creates a new file with subject number, date and then the record button is turned on. The skin conductance and heart rate variability signals are collected. When the

subject is ready and the signals look visually conditioned, F9 button is clicked to initiate recording baseline data. After 3-minute baseline recording, presentation of the stimuli may begin. A pre-recorded message cues the researchers to press the F9 button to begin each sensory domain. An external connector, the BIN8 stimulator, synchronizes presentation of auditory and visual sensory stimuli via its connection to the SAM unit. Olfactory, tactile and movement stimuli are presented by the research helper upon verbal cue via headset. Finally, a 3-minute recovery period is recorded and the session is complete.

Software

There are two software programs in this laboratory procedure. The first program, SAM.EXE (Contact Precision Instruments, 2003) is the application which runs the SCP. This program records skin conductance, and directs the hardware as to what to do in order to control delivery of sensory stimuli.

Psylab 7 analysis system (Contact Precision Instruments, 2003) is a windows offline system used to reduce and modify data collected using SAM. Physiologic waveform data collected during the testing sessions are converted to numeric lists and may then be exported to excel for analysis. In addition, the waveforms can be further analyzed using review windows. Review windows show waveform data collected for all stimuli domains. Each

domain can be viewed separately in a review window. The review window is separated into eight 10-second blocks representing 8 stimulus presentations. Each 10-second block can be further analyzed using a zoom-in feature in a magnified form. Baseline and recovery domains can be analyzed in review windows as well. Each of these domains is presented in 18 10-second blocks.

Variables

Dependent Variables

The Sensory Challenge Protocol measures both tonic and phasic skin conductance. Tonic dependent variables in this study consisted of background skin conductance level (SCL) and non-specific skin conductance response (NSR) [Dawson, Schell, & Filion, 1990; 2000]. Tonic skin conductance is the absolute level of conductance in the absence of measurable phasic response. In this laboratory procedure, tonic measures were obtained during baseline and recovery and between 0.0 and 0.8 seconds and between 4 – 10 seconds after stimulus presentation. NSR is a rapid increase in SCL (at least .02 μS) in the absence of a specific stimuli. NSR frequency is the number of non-specific responses per minute.

SCL in this study was operationally defined as mean amplitude of absolute level of skin conductance of at least .02 μS during rest periods, averaged across 10-second blocks. NSR is a change in SCL during rest in

the absence of a stimulus or during post stimulus time period between 4 and 10 seconds as an average rate per minute (Dawson, Schell, & Filion, 1990; 2000; Schoen et al., 2008). Typical SCL values among normal adults are 2 – 20 μS, NSR per minute 1-3 (Dawson, Schell, & Filion).

Phasic dependent variables are rapid changes in skin conductance level in response to a specific stimulus within a specific time window. Phasic response to specific stimuli (SCR) is presented as a waveform with four components, latency, rise time, amplitude and half recovery time (Dawson, Schell, & Filion, 1990; 2000). The waveform component definitions are based on the work of Dawson, Schell and Filion.

a) Latency – Time between stimulus onset and SCR initiation.
b) Rise time – Time between SCR initiation and SCR peak.
c) Amplitude – Phasic increase in skin conductance following onset of stimulus.
d) Half recovery time – Time between skin conductance peak and point of 50% recovery of SCR amplitude.

SCR is a rapid increase in SCL in response to a specific stimuli. Mean value SCR response is computed using amplitude, which is all non-zero responses to specific stimuli or magnitude, the mean value of all stimulus presentations including zero response.

In this study, the following phasic components of skin conductance were analyzed based on definitions by Schoen et al, 2008:

1. Magnitude (MAG) – Mean magnitude of SCR (including zero response)
2. Amplitude (AMP) – Mean amplitude of SCR (all non-zero responses)
3. Orienting Response (OR) – Amplitude of SCR to first stimulus presentation.
4. Latency (LAT) – Average time from onset of SCR to peak within a sensory domain (when an SCR was present).
5. Habituation (HAB) – Number of stimulus presentations before 2 trials with no response. (Dawson, Schell, & Filion, 1990; 2000).

Behavioral dependent variables in this study consisted of section and total scores on the Short Sensory Profile (SSP). The SSP (Dunn, 1999) is a 38-item parent report measure of functional behaviors associated with abnormal responses to sensory stimuli (Mangeot et al., 2001). High scores indicate typical performance, low scores indicate abnormal response to sensation. Norms for the full Sensory Profie were developed and standardized on 1,200 children. The 7 sections of the SSP are Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Underresponsive/Seeks Sensation, Auditory Filtering, Low Energy/Weak, and Visual/Audiotry Sensitivity. The reliability and validity of the tool are excellent (Ahn et al., 2004; Dunn, 1999; Mangeot et al, 2001;McIntosh et al., 1999; Tomchek & Dunn, 2007). Internal reliability of the SSP total test is > .95

(Cronbach's alpha) for a sample of children (n=38) with and without disabilities. Subscale reliabilities of that same sample range from .70 to .90 (Ahn et al.; Dunn; Mangeot et al.; McIntosh et al.; Tomchek & Dunn). Inter-scale correlations ranging from .25 to .76 suggest the subscales measure unique dimensions (Ahn et al.). Discriminant validity was shown by McIntosh and colleagues (1999) in their comparison of children with SPD's and age and gender matched controls of typically developing children (n=38). The SPD group had significantly lower group scores compared to the controls. Moreover, the abnormal SSP scores were significantly associated with abnormal EDA in response to sensation, determining initial convergent validity (Ahn et al., McIntosh et al.; Tomchek & Dunn). In this current study, scores from SSP will also be correlated with skin conductance measures.

Independent Variables

The independent variables were the two groups, control and ASD, the two testing sessions, test 1 and test 2 during six conditions consisting of sensory stimuli presented to the subject, which included sound (tone and siren), visual (strobe light), olfactory (wintergreen oil), tactile (feather) and vestibular stimulation (tipping back chair).

Procedure

Prior to the testing, the researcher and research assistant (RA) sets up the testing materials, checked equipment status and dimmed the lights. Subjects and their parents came to the testing site (Barpak clinic or Seton Hall Human Performance Lab) two times during a six-week period. The researcher explained the procedures involved in the experiment using lay terminology. Children signed an assent form if they were seven years or older. Parents signed a consent form before beginning the laboratory session, and provide identifying information such as address, date of birth of child. During the first testing session, parents completed the Short Sensory Profile.

The RA took the child to the space lab (testing area) and introduced him to the laboratory setting which was designed to look like the inside of a spaceship. Ambient lighting in the room was set to a low level throughout the procedure. The child was invited to sit in a sturdy chair with a space ship control panel in front of him. A video clip of the movie Apollo 13 was displayed showing the astronauts as they are hooked up with electrode placement before launch into space. The researcher explained to the child that he too would be hooked up with stickers just like the astronauts before beginning the procedure. As the child watched the video, three electrodes are placed on the child's chest in a triangular pattern at the base and center of the rib cage. Two smaller electrodes were placed on the left thenar and hypothenar eminences of the left hand, 2-inch wide coban wrap was used to

further secure lead placement. When electrode placement was complete, the child was instructed to sit still like a robot, keep feet flat on floor with left hand palm up, resting on armrest. No talking during the space trip unless it was an emergency, we can talk when the space trip is over. The researcher told the child we are ready to start and data collection began.

The laboratory protocol took about 45 minutes to complete. Eight conditions (domains) were presented in the following order, baseline, tone, visual, siren, olfactory, tactile, movement and recovery. Baseline and recovery record tonic measures, periods of rest were there were no stimuli presented during these condiitons. The six sensory conditions presented are:

1. Auditory - a professionally recorded tone playing at 90 decibels (Psylab computer software).
2. Visual – 20-watt strobe light set at 10 flashes per second (5” x 3.5” x 2” Product code: MS-1, Noveltylights.com).
3. Auditory – a professionally recorded fire-engine siren playing at 90 decibels (Psylab computer software).
4. Olfactory – wintergreen oil (methyl salicylate, Anandaapothecary.com) kept approximately 1.25 cm deep in a 30ml vial with a cotton ball. The helper dons a sterile glove, removes the cotton ball and places thumb over top of vial. Synchronizing stimuli presentation with pre-recorded cue, the helper takes thumb off vial and places it about 2.5 cm from subjects

nose, centered between nose and lips. The helper moves the vial from left to right to left in a 2.5 cm path following the synchronized pre-recorded count of 3 seconds heard as 1, 2, 3).

5. Tactile – 5 cm turkey craft feather (B706M Turkey Marabou short mixed loose 1-4", www.featherplace.com). The helper places the feather on the subjects right ear canal and slides the feather down along the chin line, to the bottom of the chin and then up the chin line to the left ear, following a 3 second count.
6. Movement (vestibular) – Chair (12"h, 13"d, 14"w) tipped slowly and smoothly backward to a 30° angle.

Each of the six sensory conditions consist of 8 stimuli presentations, lasting 3 seconds each, in a pseudo random time order of 15-19 seconds apart and 20 seconds between each condition. Data collection began by starting the Psylab software data acquisition protocol. From this point the computer provides directions to guide the procedure. The researcher and RA communicated through headsets and the child's baseline level was set. The protocol could be stopped if adjustments need to be made or if there was a disruption or the child does not wish to proceed.

At the beginning of the protocol, the computer program announces via headsets begin baseline. SCL and NSR were recorded for three minutes. At the end of the baseline condition, the child was commended for following the rules and sitting quietly. Following the script, the child was prepared before

each sensory condition that he was going to hear something, or see something, smell something or feel something. The computer announced the beginning of each condition to the researchers and the stimuli were presented to the child. Skin conductance response to each stimuli were collected along with continued SCL and NSR frequency. As data collection occured, the researcher monitoring the computer also made note of any possible artifacts that may have confounded the data collected. Using an artifact log, the researcher noted what the artifact was and when it occurred. Artifacts included excessive movement of the child or environmental disruption (loud noise, equipment problems).

Analysis

Data Reduction

Data reduction began by creating a macro (math calculations) for the subjects file. The macro was completed on the same day of testing, usually right after the data collection was finished. The macro was created using Psylab 7 software and results were saved using the extension .xls (excel). This file was then opened and formatted to fit on one excel workbook sheet. Then a picture of the data (skin conductance waveform) was created using the paint program. The subject's file could be viewed for all conditions, specific conditions and specific 10-second blocks using a zoom in feature.

Data Grooming

This process consists of comparing the subjects excel spreadsheet, paint files and artifact log and tracking results of this process by creating a subject summary table. The researcher first checked the excel sheet for consistency of values, unusual values and missing values. Data from the excel sheet was then compared to the paint files and artifact log. If a condition was skipped or an artifact was identified, it was noted on the subject summary table and the excel sheet was then modified and saved as a revised subject file.

If a condition was skipped, the missing rows were inserted into the excel spreadsheet so a complete 84 rows were listed. The block number column was adjusted and the values of the affected condition were cleared out. If an artifact was identified, the value for that trial in the Excel spreadsheet was replaced with a 99. The number 99 was not used in any calculations of averages for that condition in any of the Excel spreadsheets.

Creating the Database

Individual subject Excel data were copied and pasted into an EDA data subject template. This template performs calculations on the variables such as averages, frequency counts, and natural log transformations. Calculation results were then copied and pasted into the EDA database in preparation for descriptive statistical analysis using SPSS version 21.

Statistical Analysis

Descriptive statistics will summarize EDA dependent variable data as measured using SCR magnitude, SCR amplitude, SCL, NSR and habituation. An intraclass correlation coefficient for each dependent variable was used to assess test-retest measures of EDA scores under each condition for each group separately. A Pearson *r* measure assessed the relationship between tonic and phasic EDA variables and also the relationship between phasic EDA response (amplitude and magnitude) with SSP scores. A 2 x 2 repeated measures ANOVA, mixed design with one between factor with 2 levels (TD vs ASD) and one within factor with two levels (Test 1 vs Test 2) was used to assess group differences.

Chapter IV

RESULTS

Subjects

Initial total subject pool (n=49) consisted of 23 TD and 26 ASD. Sixteen subjects were excluded from analysis due to excessive artifact (n=6), technical difficulty (n=4), inability to tolerate test (n=5), not showing for the second test (n=1), yielding 33 viable participants. One participant was removed during analysis due to technical difficulty leaving 32 viable participants, 18 TD and 14 ASD.

Reliability

Phasic Variables

Reliability of the total subject pool (n=32) for phasic amplitude measures were good to moderate, with ICC's ranging from .60 -.81. The TD group reliability was good to moderate as well, with ICC's ranging from .48 - .82. Reliability of the ASD group was good to moderate with ICC's ranging from .42 - .83. See table 4 for ICC values.

Table 4.

Test Re-Test Reliability Amplitude

	Total					TD					ASD				
SCP Cond	M 1	SD	M 2	SD	**ICC**	M 1	SD	M 2	SD	**ICC**	M 1	SD	M 2	SD	**ICC**
Tone	0.19	0.14	0.19	0.20	**0.81**	0.22	0.14	0.19	0.20	**0.80**	0.16	0.14	0.19	0.21	**0.83**
Vis	0.27	0.17	0.25	0.21	**0.67**	0.30	0.18	0.29	0.22	**0.56**	0.23	0.17	0.19	0.18	**0.79**
Siren	0.24	0.17	0.23	0.22	**0.63**	0.25	0.16	0.26	0.25	**0.48**	0.21	0.19	0.19	0.17	**0.81**
Olf	0.21	0.17	0.18	0.13	**0.60**	0.25	0.19	0.19	0.15	**0.57**	0.14	0.12	0.18	0.11	**0.71**
Tac	0.23	0.16	0.18	0.17	**0.75**	0.29	0.17	0.22	0.21	**0.76**	0.15	0.12	0.12	0.09	**0.46**
Vest	0.32	0.22	0.25	0.19	**0.73**	0.39	0.25	0.27	0.21	**0.82**	0.23	0.14	0.23	0.17	**0.42**
Avg	0.24	0.17	0.21	0.19	**0.70**	0.29	0.18	0.24	0.21	**0.67**	0.19	0.17	0.18	0.16	**0.67**

Note. Amplitude does not include zero response.
n = 32

Reliability of the total subject pool (n=32) for magnitude of response were good to moderate, with ICC's ranging from .50 - .75. The TD group reliability was good to moderate for 5 of 6 domains, ranging from .51 - .83. The reliability for the ASD group was high to moderate for 5 of 6 domains, ranging from .56 - .87. See Table 5 for ICC values.

Table 5.

Test Re-Test Reliability Magnitude

	Total					TD					ASD				
SCP Cond	M 1	SD	M 2	SD	**ICC**	M 1	SD	M 2	SD	**ICC**	M 1	SD	M 2	SD	ICC
Tone	0.12	0.12	0.11	0.15	**0.75**	0.13	0.11	0.10	0.13	**0.62**	0.11	0.13	0.12	0.17	**0.87**
Vis	0.16	0.13	0.10	0.11	**0.64**	0.18	0.13	0.09	0.08	**0.51**	0.15	0.13	0.12	0.15	**0.76**
Siren	0.15	0.14	0.14	0.14	**0.50**	0.14	0.12	0.14	0.15	**0.11**	0.16	0.17	0.13	0.14	**0.76**
Olf	0.11	0.11	0.10	0.11	**0.70**	0.13	0.13	0.10	0.12	**0.74**	0.09	0.08	0.11	0.10	**0.65**
Tac	0.15	0.12	0.12	0.16	**0.69**	0.19	0.12	0.15	0.20	**0.65**	0.09	0.10	0.07	0.07	**0.56**
Vest	0.22	0.15	0.18	0.16	**0.72**	0.26	0.18	0.18	0.18	**0.83**	0.17	0.11	0.17	0.14	**0.37**
Avg	0.15	0.13	0.13	0.14	**0.67**	0.17	0.13	0.13	0.14	**0.57**	0.13	0.12	0.12	0.13	**0.66**

Note. Magnitude includes zero response.
n = 32

Based on results described in Tables 4 and 5, EDA as measured using skin conductance is a reliable measure of physiologic sensory processing in children with ASD and TD children.

Tonic Variables

An analysis of tonic ICC reliability was determined prior to examining correlations between the tonic and phasic variables. Tonic Skin Conductance Level (SCL) during baseline and recovery reveal good to moderate ICC reliability for total (n=32) and individual groups, see Table 6 for ICC values. Tonic Non-Specific Response (NSR) during phasic and SCL recovery domains reveal high to good reliability for total and individual groups, see Table 7 for ICC values.

Table 6.

Test Re-Test Reliability Measures (SCL)

	Total					TD					ASD				
SCP	M 1	SD	M 2	SD	**ICC**	M 1	SD	M 2	SD	**ICC**	M 1	SD	M 2	SD	**ICC**
Base	1.11	0.81	0.86	1.04	**0.66**	1.25	0.69	0.99	1.00	**0.65**	0.93	0.94	0.69	1.11	**0.65**
Rec	1.52	0.78	1.34	0.93	**0.71**	1.60	0.69	1.42	0.88	**0.68**	1.42	0.90	1.24	1.01	**0.73**
Avg	1.31	0.78	1.04	1.03	**0.69**	1.42	0.69	1.20	0.94	**0.67**	1.16	0.89	0.84	1.14	**0.69**

Note. SCL = Skin Conductance Level
n = 32

Table 7.

Test Re-Test Reliability Measures (NSR)

	Total					TD					ASD				
SCP Cond	M 1	SD	M 2	SD	**ICC**	M 1	SD	M 2	SD	**ICC**	M 1	SD	M 2	SD	**ICC**
Tone	6.81	8.45	4.31	5.83	**0.85**	3.75	3.76	1.74	1.77	**0.62**	11.06	11.18	7.88	7.54	**0.82**
Vis	5.71	6.41	4.25	5.45	**0.71**	3.60	3.27	1.62	1.86	**0.51**	8.46	8.40	7.69	6.67	**0.62**
Siren	6.02	8.46	5.23	6.18	**0.80**	2.57	3.42	2.43	2.21	**0.75**	10.45	10.85	8.84	7.74	**0.72**
Olf	5.77	7.01	4.35	5.50	**0.93**	2.78	3.78	2.01	2.75	**0.84**	9.90	8.40	7.60	6.74	**0.92**
Tac	6.60	6.35	5.23	6.11	**0.76**	5.35	4.73	3.00	2.61	**0.57**	8.21	7.87	8.13	8.01	**0.78**
Vest	7.07	6.71	7.66	7.85	**0.82**	4.10	4.77	4.70	4.70	**0.84**	10.89	7.04	11.52	9.50	**0.68**
Rec	6.89	6.68	6.64	6.22	**0.82**	4.69	5.19	3.41	2.64	**0.69**	9.71	7.46	10.80	7.08	**0.80**
Avg	6.41	7.15	5.38	6.16	**0.82**	3.83	4.13	2.70	2.65	**0.69**	9.81	8.73	8.92	7.61	**0.76**

Note. NSR = Non Specific Response
n = 32

Patterns of Response

Correlations between Tonic and Phasic EDA variables

Correlations for Baseline SCL and Phasic EDA variables, as shown in Table 8, and correlations for Recovery SCL and Phasic EDA variables as shown in Table 9, were high to moderate for both groups (.415 - .960). Correlations were stronger during test 1 for the ASD group, but not the typically developing group.

Table 8.

Baseline SCL and Phasic EDA Correlations by Group

	ASD Amplitude		**TD** Amplitude	
Test	SCP Domain	r	SCP Domain	r
1 & 2	4 of 6 (Olf & Mvt)	.597 - .752	6 of 6	.478 - .706
1	5 of 6 (Mvt)	.558 - .920	6 of 6	.542 - .75
2	4 of 6 (Olf and Mvt)	.543 - .706	4 of 6 (Tone & Mvt)	.583 - .702
	ASD Magnitude		**TD** Magnitude	
1 & 2	4 of 6 (Olf and Mvt)	.588 - .740	4 of 6 (Tone and Mvt)	.527 - .793
1	5 of 6 (Mvt)	.596 - .960	4 of 6 (Tone and Mvt)	.550 - .775
2	4 of 6 (Olf and Mvt)	.557 - .641	4 of 6 (Tone and Mvt)	.526 - .823

Note. Mvt = Movement, Olf = Olfactory, and Tac = Tactile. Correlations two-tailed, $p < .05$. ASD group n = 14 and TD group n = 18

Table 9.

Recovery SCL and Phasic EDA Correlations by Group

	ASD Amplitude		**TD** Amplitude	
Test	SCP Domain	r	SCP Domain	r
1 & 2	6 of 6	.449 - .751	6 of 6	.512 - .677
1	4 of 6 (Tone and Mvt)	.568 - .854	5 of 6 (Olf)	.616 - .689
2	6 of 6	.547 - .698	5 of 6 (Mvt)	.567 - .718
	ASD Magnitude		**TD** Magnitude	
1 & 2	6 of 6	.415 - .748	5 of 6	.464 - .742
1	5 of 6 (Mvt)	.554 - .935	4 of 6	.495 - .742
2	6 of 6	.547 - .647	5 of 6 (Mvt)	.473 - .751

Note. Mvt = Movement, Olf = Olfactory, and Tac = Tactile. Correlations two-tailed, $p < .05$.
ASD group n = 14 and TD group n = 18.

Correlations between Tonic NSR and Phasic Variables

No relationships were found between NSR and amplitude and magnitude.

Correlations between Habituation and Phasic Variables

Table 10.

Habituation and Phasic EDA Correlations by Group

ASD Amplitude		**TD** Amplitude	
SCP Domain	r	SCP Domain	r
5 of 6 (Mvt)	.462 - .517	1 of 6 (only Mvt)	.45
ASD Magnitude		**TD** Magnitude	
5 of 6 (Mvt)	.473 - .558	4 of 6	.450 - .637

Note. Mvt = Movement. Correlations two-tailed, $p < .05$. ASD group n = 14 and TD group n = 18

Based on the results presented in Tables 8, 9 and 10, a relationship between tonic and phasic patterns of arousal among TD children and children with ASD is present.

Relationships among and between baseline SCL, mean NSR's and mean habituation were analyzed to determine patterns of response in each group. NSR frequency for both groups were positively correlated with baseline SCL and habituation. As shown in Table 11, Group 1 (ASD) revealed positive relationships among and between Baseline SCL, Habituation and NSR's. Higher SCL in the ASD group were related to patterns of response of higher NSR frequency and decreased habituation to stimuli. Group 2 (TD) revealed a positive relationship between NSR frequency and SCL, NSR frequency and habituation. No relationship

between habituation and SCL was found. Higher SCL indicated a pattern of response of increased frequency of NSR, but not habituation.

Table 11.

Correlation Response Patterns

Condition			MeanHab	MeanSCL	MeanNSR
1	MeanHab	Pearson Correlation	**1**	**.577****	**.804****
		Sig. (2-tailed)		**.002**	**.000**
		N	**28**	**27**	**28**
	MeanSCL	Pearson Correlation	**.577****	**1**	**.527****
		Sig. (2-tailed)	**.002**		**.005**
		N	**27**	**27**	**27**
	MeanNSR	Pearson Correlation	**.804****	**.527****	**1**
		Sig. (2-tailed)	**.000**	**.005**	
		N	**28**	**27**	**28**
2	MeanHab	Pearson Correlation	**1**	**.253**	**.597****
		Sig. (2-tailed)		**.137**	**.000**
		N	**36**	**36**	**36**
	MeanSCL	Pearson Correlation	**.253**	**1**	**.523****
		Sig. (2-tailed)	**.137**		**.001**
		N	**36**	**36**	**36**
	MeanNSR	Pearson Correlation	**.597****	**.523****	**1**
		Sig. (2-tailed)	**.000**	**.001**	
		N	**36**	**36**	**36**

**. Correlation is significant at the 0.01 level (2-tailed).

Responder Groups

An analysis was conducted to investigate homogeneity of groups using baseline data to investigate whether two responder subgroups (hyporesponder and hyperresponder) would emerge as suggested by (Schoen, et al, 2008). Mean baseline SCL for each subject was plotted and a cut point of 6 μS (Schoen, 2008) was used to separate high responders from low responders within each group. The ASD group Mean SCL was lower compared to the TD group. The ASD group had a greater percentage of hypo responders (86%) than the TD group (78%). See Figure 2 and 3 for details. In order to categorize participants as non-responders the authors used a definition of non-responding on the first trial in at least one sensory domain (Schoen, 2008; Van Engeland, 1984). Based upon this definition the results indicate that 29% of the ASD group were non-responders and 14% of the TD group were non-responders. Based on patterns of response, children with ASD and TD children can be divided into high and low responder groups to improve homogeneity of sample. Additionally, based on results of ICC reliability of baseline NSR (Total = .67, TD = .65, ASD = .57) an analysis was conducted to investigate association between Mean baseline NSR frequency and Mean NSR (6 sensory stimuli and recovery). Results indicate a strong association between Mean Baseline NSR and Mean NSR for total group $r = .83$, TD group $r = .89$ and ASD group $r = .82$, $p < .01$. Based on these results,

baseline NSR frequency may be another viable method to ensure homogeneity of sample.

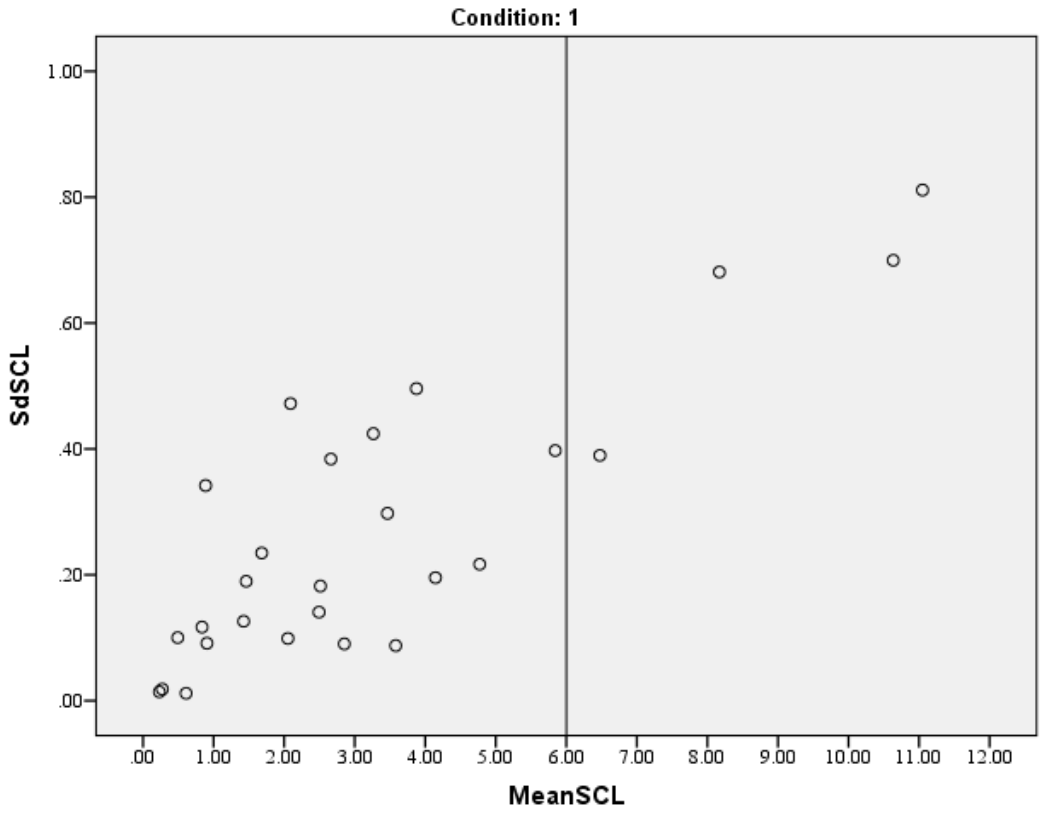

Figure 2. Cut-point based on mean and standard deviations in baseline SCL of ASD group.

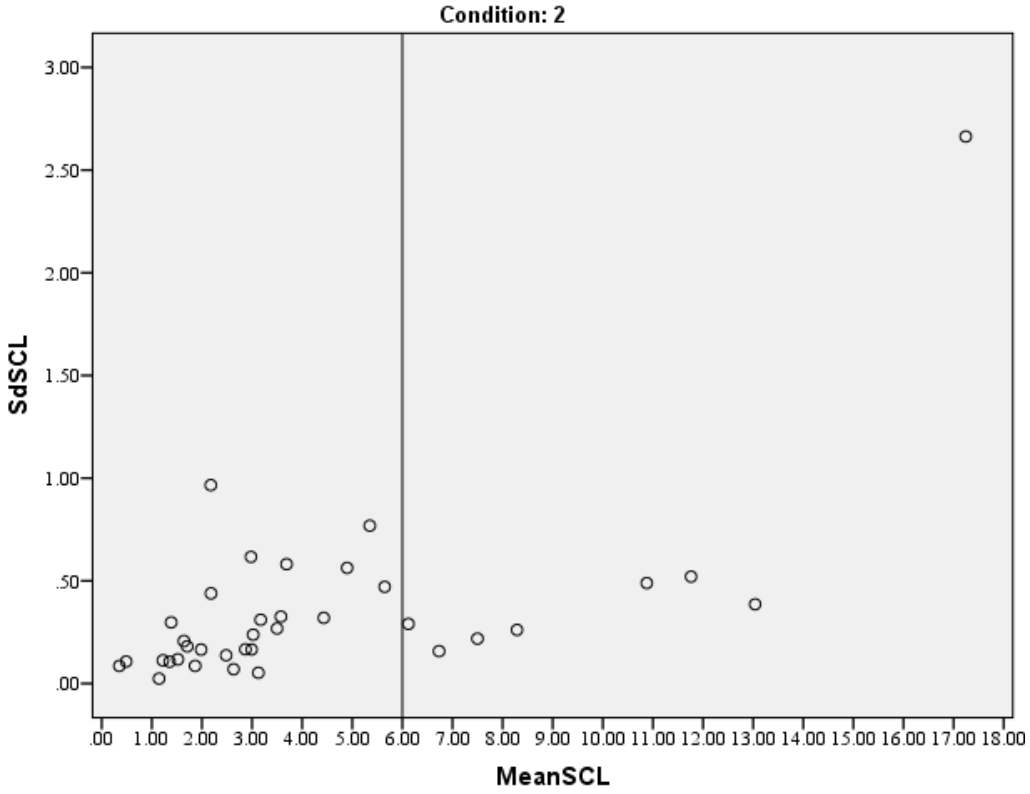

Figure 3. Cut-point based on mean and standard deviations in baseline SCL of TD group.

Correlations between EDA measures and SSP

Pearson's correlation coefficient was used to investigate relationships between EDA phasic measures (amplitude and magnitude) on the SCP and SSP. The analysis was conducted on total group scores and sessions combined as well as by group scores of both sessions combined as shown in

Table 6. Results for total group and sessions combined revealed no significant relationships at the r ≥ .5 level for amplitude or magnitude.

Amplitude

Results for total group and ASD group sessions combined revealed no significant relationships for amplitude. Results for the TD group, sessions combined revealed interesting relationships and trends between various SCP conditions and SSP subsections of movement sensitivity and low energy/weakness, see Table 12.

Magnitude

No relationships were found between the SCP measures and SSP scores for the total group, ASD group or TD group.

Table 12.

Correlations between EDR Measures and SSP

TD Amplitude		
SCP Domain	SSP Section	r
Tone	Mvt Sens	-.462*
Tone	Low Energy	-.484*
Visual	Mvt Sens	-.498*
Visual	Low Energy	-.554*
Siren	Mvt Sens	-.501*
Olfactory	Mvt Sens	-.524*
Olfactory	Low Energy	-.589**
Tactile	Mvt Sens	-.631**
Tactile	Low Energy	-.670**
Tactile	Vis/Aud	-.514*

Note. TD group (n = 18), ASD group (n = 14)
* $p \leq .05$, ** $p \leq .01$.

Based on the results in Table 12 there is a significant negative relationship between EDA amplitude response in 5 SCP conditions with the SSP subsection of movement sensitivity and low energy/weakness for the TD group. High score in SSP subsections of movement sensitivity and low energy/weakness were inversely related to low amplitude in 5 SCP conditions.

Within group between session differences

A General Linear Model: Series of Repeated Measures Analysis (RM-ANOVA) was used to detect differences between and within groups since the observations were not independent. The General Linear Model for RM-ANOVA is a special procedure that accounts for this dependence in observations and tests for differences across individuals for the set of dependent variables. A mixed design (2 X 2 RM-ANOVA) with one between factor with two levels (TD vs ASD) and one within factor with two levels (Test 1 vs Test 2) was used. Since there were no significant interactions, post hoc comparisons were not performed. There were no significant differences in between session comparisons for the ASD group. There was one significant difference in between session comparison for the TD group (magnitude visual domain), $F(1,28) = 6.447$, $p = .017$.

Between group differences phasic variables

The multivariate analysis revealed a significant difference between groups with pairwise comparisons at .05 level showing a significant difference between groups on the tactile domain for amplitude (p = .017) and for magnitude (p = .032), see Figure 4 and Figure 5.

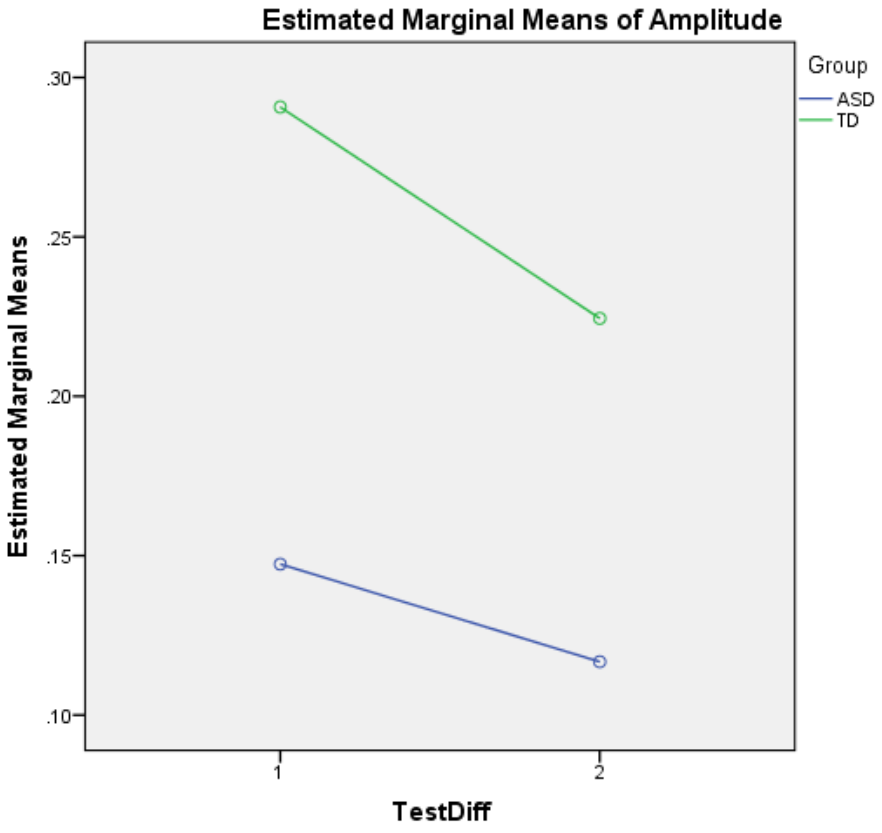

Figure 4. Between Group Difference Amplitude Tactile Domain, p = .05.

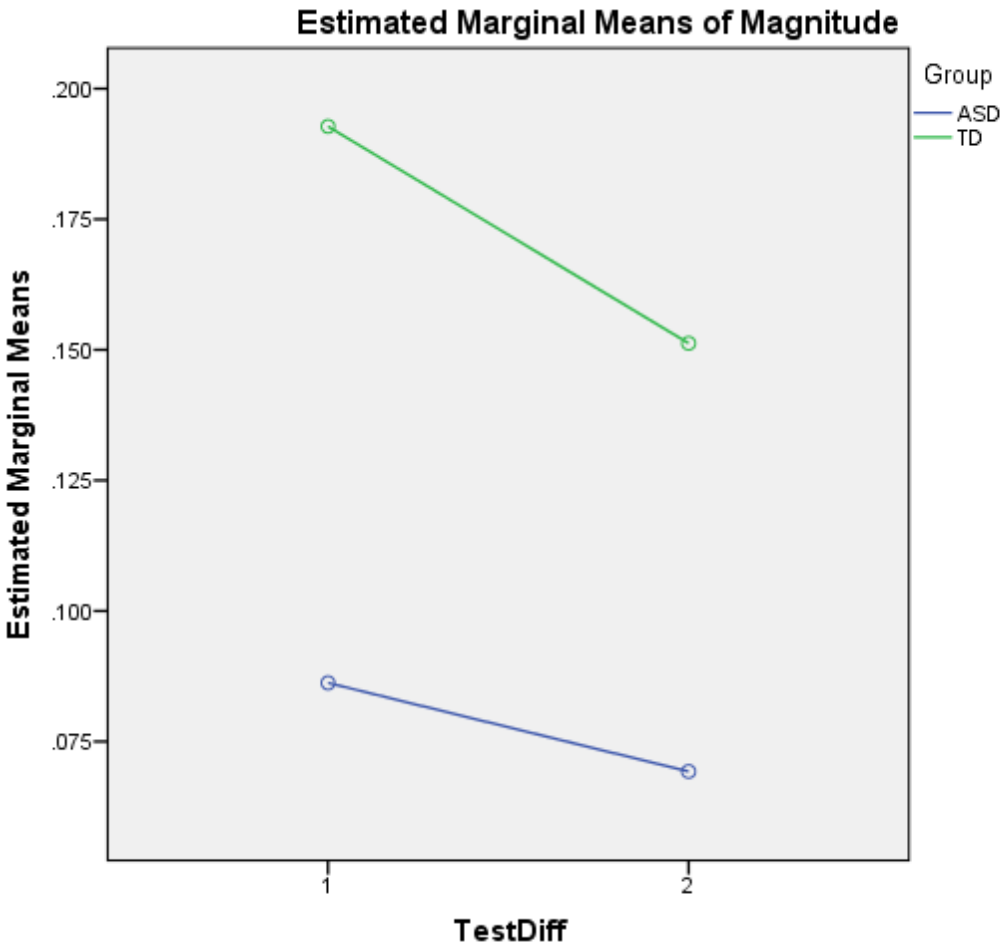

Figure 5. Between Group Difference Magnitude Tactile Domain, $p = .05$.

Between group differences tonic variables

A two sample independent t-test was used to detect the presence of differences between groups for mean NSR. The *t*-test revealed a significant difference between the groups, $t\,(62) = 4.62$, $p = .000$, see Figure 6.

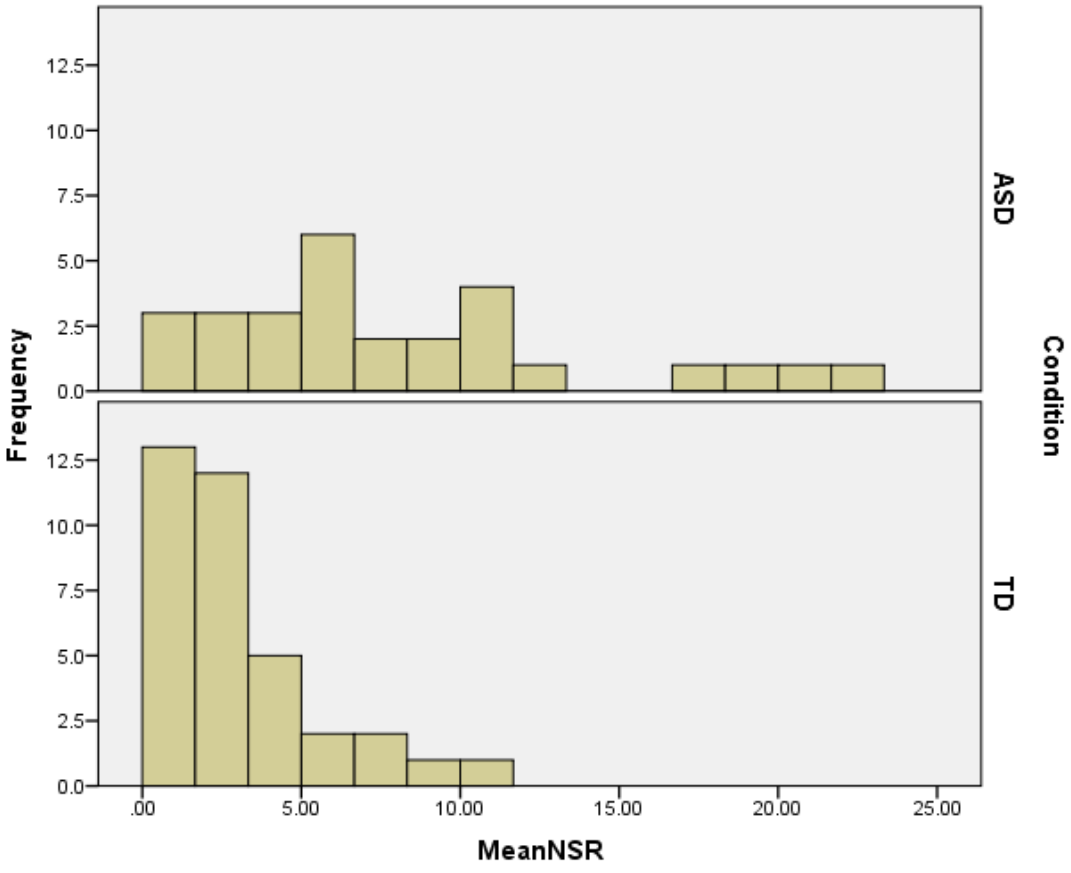

Figure 6. Between Group Differences Mean NSR, $p = .000$, two-tailed.

Based on the results described in Figures 4, 5, and 6, a significant difference in EDA response to sensation exists between TD children and children with ASD.

Chapter V

DISSCUSSION

Studies using the Sensory Challenge Protocol (SCP) to measure electrodermal activity (EDA) using skin conductance have reported outcomes that identify a link between sensory processing and EDA without first establishing the reliability of the tool. This study is one of the first repeated measures designs to determine the reliability of EDA using the SCP in children with ASD and typically developing children. Findings from this study will assist the scholarly community in determining the strength and utility of outcomes previously reported in the literature and to differentiate ASD from other groups.

Reliability EDA Measurement in Sensory Processing

The most important outcome of this study is that the ICC reliability measures obtained for phasic and tonic variables support the Sensory Challenge Protocol as a reliable tool to measure arousal level and sensory reactivity in TD children and children with ASD. The range of good to moderate ICC reliability scores in this sample suggest that EDA can be used as an index of sensory processing as it is a reasonably stable measure that

would effectively detect change. This finding is consistent with Schoen et al. (2008) who found good to moderate reliability for phasic magnitude of response for five of six SCP domains and moderate reliability for tonic SCL and NSR in children with ASD. However, these findings extend upon Schoen et al. work as it includes a comparison group of TD children and also investigates the phasic amplitude response. In the present study as a group, the TD children presented with higher mean amplitude of response and greater variability than ASD children, however average ICC reliability for each group was the same (.67). Results for magnitude of response reveal slightly higher mean magnitude of response and variability of TD children compared to ASD children, however ICC reliability was lower (.57) for TD than the ASD group (.66). This result is interesting because the average ICC reliability for the ASD group was virtually the same for amplitude and magnitude of response, whereas for the TD group magnitude of response was lower than the amplitude of response. Upon reflection, the inclusion of zero response in the calculation of magnitude of response had a greater effect on the higher mean scores in the TD group than in the lower mean scores of the ASD group. This finding is supported by the literature that shows TD children were more reactive to sensory stimuli than children with ASD (Schoen, Miller, Brett-Green & Nielsen, 2009) and children with ASD have lower mean response overall compared to a control group (Kyllianinen & Hietanen, 2006). Based on the higher mean and standard deviations in the TD group for both

amplitude and magnitude, as well as lower ICC average reliability for magnitude of response, it is reasonable to suggest that TD children have a greater range of variability of response than ASD children.

The larger range of variability among the TD group likely reflects greater flexibility in sensory response to changes in the environment. This flexibility allows adjustments in arousal level and response to sensation in order to organize a successful response to the environment.

Response flexibility is described in Sensory Integration Theory (SIT) as the autonomic nervous systems ability to regulate arousal level and attention to sensory stimuli in order to adapt and organize a successful response. This ability to adapt to change or demonstrate flexibility in response to change is indicative of brain maturity. Therefore it is reasonable to suggest based on these results that the greater physiologic flexibility of sympathetic nervous system response using EDA shows greater brain maturity in the TD group compared to the ASD group. The decreased brain maturity and flexibility of response in children with ASD may be the foundation for decreased behavioral flexibility and adaptation to change.

Response Patterns as Indicators of Personality Trait

The literature shows a developmental sequence of SCL in infants as a maturational process of the sympathetic nervous system (Gladman & Chiswick, 1990; Hernes et al., 2002). In addition, the literature also reveals a

connection between tonic baseline levels (SCL) and phasic skin conductance response (SCR) in studies analyzing patterns of response (Gladman & Chiswick; Hernes et al.; iworx/CB Sciences, 2009; Lacey, Bateman & Van Lehn, 1953; Lacey & Lacey, 1958; Lacey & Van Lehn, 1952; Mundy-Castle & McKiever, 1953; Schell, Dawson & Fillion, 1988; Schoen et al., 2008). These studies indicated patterns of response could be used to describe the level of sympathetic tone as an individual personality trait that could separate samples into personality traits of high responder and low responder groups. Operational definitions of high and low responder groups vary among each study. The basis of the difference between responder groups in each of these studies relies on the frequency of response to stimuli and the ability of the higher cortical prefrontal cortex to modulate lower autonomic reactivity, operationally defined as brain maturity (Critchley, 2002; Gladman & Chiswick; Hernes et al; Lacey & Lacey; Mundy-Castle & McKiever; Nolte, 2008).

In our study to analyze possible response patterns, we conducted a reliability analysis of tonic SCL and NSR prior to examining correlations between tonic and phasic variables. Results revealed good to moderate ICC reliability for SCL (Table 6) and high to good reliability for NSR (Table 7), therefore correlations between tonic and phasic EDA variables (amplitude and magnitude) were then analyzed. Interestingly, we found high to moderate correlations between tonic SCL and phasic EDA variables for both groups (Table 8 & 9). This finding is consistent with Schoen et al. (2008) who

found positive correlations between baseline SCL and phasic magnitude in children with ASD. In the Schoen study, as baseline SCL increased, magnitude of response increased (except for the movement condition) and ability to habituate to the stimuli was slower. In our study, as baseline SCL increased, both magnitude and amplitude increased for both groups, except for movement condition as measured by magnitude of response and ability to habituate was slower. Surprisingly, no relationships were found between tonic NSR and phasic amplitude and magnitude, and thus does not support the findings from the only other study found in the literature (Mundy-Castle & McKiever, 1953) which looked at this association. In their study, Mundy-Castle and McKiever found subjects who had few NSR's also had few SCR's but were able to habituate faster and subjects with many NSR's had many SCR's and habituated slower. Interestingly, the subjects with greater NSR's and SCR's were predominantly younger than the subjects with few NSR's and SCR's. The authors posit the younger group of subjects habituated slower due to brain immaturity over lower autonomic centers. It is important to note, that this earlier study was conducted with normal college age subjects and not children with and without ASD as in our study which might have influenced the results.

Continuing our analysis of response patterns in each group, relationships among and between mean baseline SCL, mean NSR and mean habituation (HAB) were conducted. In the TD group, we found positive

correlations between SCL & NSR (r = .52) and NSR & HAB (r = .60), p < .01. No relationship was found between SCL and HAB in the TD group. In the ASD group, we found SCL, NSR and HAB were positively intercorrelated, r (SCL & HAB) = .58, r (SCL & NSR) = .53, r (HAB & NSR) = .81, p < .01. Higher SCL levels were associated with greater NSR frequency and slower habituation to stimuli and lower SCL levels were associated with lower NSR frequency and faster habituation to stimuli. These two different patterns of response are consistent with Lacey & Lacey's 1958 study in which they described two distinct patterns of response at rest and under stress in adult women. Women with flat even tracings, indicating few NSR's and faster habituation were identified as stabiles and women with chaotic tracings, indicating high frequency NSR's and slower habituation were identified as labiles. Another study that is consistent with our findings (Schell et al., 2005) divided a group of schizophrenic adults into groups based on good or poor functional outcome after one year and compared them to a control group. In their group comparison they found SCL & NSR were positively correlated, r = .61, p < .01. In addition the poor outcome group had a significantly higher number of NSR's than controls, t = 3.12, df = 111, p < .01 (Schell et al). Schoen and colleagues (2008) utilized response patterns in their analysis of high and low SCL groups and found the high SCL group (mean > 6 μS) had greater variability (larger SD's) and slower habituation while the low SCL

group (mean < 6 μS) had less variability (smaller SD's) and faster habituation. Thus, the result from our study further support Schoen's findings.

The findings in our study when looking at subgroups is consistent with that of Schoen (2008) findings except for comparisons with the TD group. We found the ASD group had lower Mean SCL than the TD group. The ASD group had a greater percentage (86%) of low responders compared to the TD group (78%) and a greater percentage (29%) of non-responders compared to the TD group (14%). In fact, the percentage of non-responders in the Schoen study was exactly the same as our study, 29%. Although Schoen and colleagues did separate their ASD group into high and low responder groups in order to conduct further analysis on the variability of the data between groups, they did not do the same with the non-responders.

Correlation between EDR and SSP

The literature prior to 2009 shows an association between low scores on the SSP and abnormally high or low electrodermal response to sensation on the SCP in children with sensory modulation disorder and typically developing children, determining initial convergent validity (Ahn et al., 2004; McIntosh et al.,1999). McIntosh and colleagues (1999) divided participants into three groups reflecting abnormally low EDR magnitude response (absence of EDR response), midrange response (0.02 log micromos) and abnormally high response (minimum magnitude response (0.06 log

micromos). The high and low responder groups were associated with low scores on SSP. However, Schoen and colleagues recent (2009) study found no significant correlations between the SSP and reactivity variables (amplitude or magnitude) of the SCP. Results from our study revealed no significant relationships for amplitude or magnitude for total group and ASD group sessions combined. However, results for the TD, revealed interesting relationships and trends between five SCP conditions for amplitude and SSP subsections of movement sensitivity and low energy/weakness. Both of these SSP subdomains are linked with the vestibular system. Movement sensitivity is linked with over-response to vestibular input and low energy weakness is linked with under-response to vestibular and proprioceptive sensation (Schoen, et al., 2009). The TD group overall high total scores on the SSP and subdomains of movement sensitivity and low energy weakness indicated normal behavioral response and were inversely related to mid-range amplitude in 5 SCP domains. This result expands upon the McIntosh study that found high or low EDR magnitude response was positively correlated with low SSP scores. In addition, the multiple correlations may be due to the fact that TD children do not have multiple sensory abnormalities and therefore a high score in movement sensitivity on the SSP would logically correlate with mid-range scores in more than one sensory domain. The mid-range scores were low enough and consistent enough among the TD group to link them inversely.

Based on these results, using the SSP as an indicator or a valid convergent instrument of EDA response to sensation for the ASD group is not supported. Yet, for the TD group it is plausible. There is a significant negative relationship between EDA amplitude response in 5 SCP conditions with the SSP subsection of movement sensitivity and low energy/weakness in the TD group. High score in SSP subsections of movement sensitivity and low energy/weakness were inversely related to midrange amplitude in 5 SCP conditions.

Group Differences Phasic Reactivity

Differences in EDA using SCR were found between children with ASD compared with TD children in the tactile condition of the SCP for both amplitude and magnitude. The importance of the tactile system as a prime neural organizer was discussed by Ayres in her literature review in 1979. She pointed out that a human embryo was made up of three layers of cells in which the outer layer developed into the skin and nervous system. She suggested that since the skin and nervous system shared the same origin, that tactile input had a major role in neural organization. The lower reactivity to tactile stimuli in the ASD group is indicative of a less organized neural response, or brain immaturity. These findings extend and support previous studies implementing the Sensory Challenge Protocol that differentiate response to sensation of clinical groups of children (ADHD, Fragile X, SMD,

ASD) compared to TD children (Mangeot, et al., 2001; McIntosh et al., 1999; Miller et al., 1999; Schoen et al., 2009). In the present study, children with ASD were less reactive to sensory stimuli than TD children. This result differentiates children with ASD from prior studies using the SCP that found greater reactivity among children with Fragile X Syndrome (Miller et al), SMD (McIntosh et al) and ADHD (Mangeot et al), compared to TD children. Mangeot and colleagues (2001) found children with ADHD demonstrated greater variability of reactivity on the SCP when compared to TD children. Based on these results they suggested that part of the sample group may have normal reactivity and part may have greater reactivity indicating co-morbid SMD. The differences in response among each clinical group is an important step in applying appropriate Sensory Integration Therapy interventions. However reactivity is not the only aspect that may point to appropriate treatment interventions, arousal level may also hold great potential for treatment as well as improving homogeneity of sample groups for research.

Group Differences Tonic Arousal Level

Significant differences between groups were found for mean NSR. Children with ASD had significantly greater frequency of non-specific responses compared to TD children. Frequency of NSR in our study was positively correlated with tonic SCL and habituation rate. These findings are

similar to the two distinct patterns of response described earlier by Lacey and Lacey in 1958, stabiles, few NSR's and faster habituation and labile (s), high frequency NSR's and slow habituation rate and also Schell and colleagues (2005) study of schizophrenic adults that linked poor outcome with high frequency NSR's compared to controls. The significant difference between groups on tonic arousal level may also point to appropriate treatment interventions as well as improved homogeneity of samples in children with ASD. Methods to improve homogeneity of samples in children with ASD based on physiologic measures of sympathetic tone may facilitate greater convergent study results and ultimately greater consensus and understanding of the efficacy of SIT.

Chapter VI

CONCLUSION

In summary, there have been no studies published to date that have examined the reliability of electrodermal activity as an indicator of sensory processing in children with ASD and TD children. In the literature, researchers using the Sensory Challenge Protocol have reported outcomes that quantify a link between sensory processing and electrodermal activity without first establishing the reliability of the tool. The results of our study support the use of EDA using the SCP as a reliable tool. Furthermore, these findings improve the utility and power of outcomes already reported in the literature that link sensory processing with EDA and thus supports Ayres SI Theory assumption that response to sensation is a neural process linked to nervous system arousal level. In addition, our results support the existence of response patterns based on level of sympathetic tone (arousal level). Response patterns among children with ASD and TD children can be discriminated using EDA and thereby improve homogeneity of subject groups according to their level of sympathetic tone.

Limitations

Several limitations of our study must be noted. First, generalizability of our study results are limited because we used a convenience sample of children recruited from New Jersey schools and therapy clinics which do not represent the general population of the United States. The subjects in the clinical group were primarily high functioning children with ASD and therefore based on this factor, the ASD group is not generalizable to the full spectrum of ASD functioning. The majority of the lower functioning ASD subjects in our sample were not able to tolerate the testing procedure. In addition, since this was a sample of convenience, volunteers that met study criteria were accepted as they presented during our recruitment phase, therefore age-matched controls were not feasible. The design of the repeated measures also allows for the possibility of test anxiety during the first session or a learning effect between the two sessions. Although there was no within group differences for the ASD group, there was one within group difference for the TD group on magnitude of visual domain. Finally the size of our sample was small and thus the results need to be replicated with a larger sample size.

Despite the limitations of our study, our findings have expanded our knowledge base regarding reliability of SCP and EDA as an indicator of sensory processing in children with ASD and TD children. Based on this reliability, exploration of responder patterns also known as sympathetic tone or personality trait has increased our understanding of possible alternatives to

improve homogeneity of ASD samples. Improved homogeneity of ASD samples will have a positive impact on research methodology, operational definitions of responder groups and ability to effectively measure change as a result of Sensory Integration Treatment.

Future Directions

Recommendations for future research include replication of this study using a larger sample size. Implementation of responder group or responder pattern strategies to investigate alternatives to improve homogeneity of ASD sample groups. Investigate using baseline SCL and NSR to categorize subjects based on responder types. Investigate association between categories of responder types with specific SI treatment strategies. Measure change as a result of SI treatment.

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Appendix A
Pilot Study

Pilot Study

The primary purpose of the pilot study was to test the feasibility of the study design and assess the methodological soundness prior to proceeding on to a larger study. The secondary purpose of the study was to investigate if using skin conductance response (SCR) is a reliable measure over time within the context of response to sensation.

Design

A prospective exploratory test-retest design assessing the use of skin conductance response (SCR) as an index of sensory processing was used. Specifically, scores from test one and test two of each subject were correlated to determine reliability of the measure.

Research Questions

To ascertain reliability of EDA as a measure reflecting sensory processing, two research questions were investigated.

1. Is electrodermal response (EDR) a reliable measure of physiologic sensory processing in children with and without Autistic Spectrum Disorder (ASD)?

H_1: Variance among repeated measures are due to real variance and not random error implementing ICC, EDR is a reliable measure of physiologic sensory processing in children.

2. Is there a relationship between EDR and behavioral response to sensation as determined by the Short Sensory Profile?

H_2: A significant negative relationship exists between EDR magnitude of response and SSP total score.

H_{2a}: Low score on the SSP is significantly associated with hyper responsive and hypo responsive EDR magnitude of response.

Pilot Study Objectives

1. Is recruitment strategy effective?
2. Are forms clear and easy to fill out, how much time is required?
3. Can children tolerate procedure?
4. What are the temporal and spatial constraints of setting up the equipment?
5. How long does it take to run the procedure?
6. Can data appropriate for SPSS analysis be obtained in order to answer research questions?

Subjects

A convenience sample of 2 typically developing boys between the ages of 4 – 11 years were recruited from private and public New Jersey Schools and Barpak Occupational Therapy clinic, Bergenfield, New Jersey. Flyers (Appendix E) were posted in the clinic and schools and encouraging

parents to contact the primary investigator to get more information regarding study participation.

Selection criteria

Parents interested in participating in the study contacted the primary investigator. The investigator screened the potential participant during a telephone interview by asking a series of questions regarding type of school attended, medical history, medications, participation in any therapies, and sensitivity to sensations (Appendix B Initial Contact Form).

Exclusion criteria

Children with the following conditions were excluded from the study to avoid confounding variables that may affect response to sensation.

5. Medical or neurological conditions other than autism.
6. Hearing loss or visual impairments.
7. Children taking medications known to affect arousal.
8. Children who are not able to follow simple commands.

Inclusion criteria

5. Boys ages 4 – 11 years old.
6. Able to sit for 30 minutes and follow simple directions.
7. Children with confirmed ASD via school records or parent report.

8. Typically developing children free of medical or neurological conditions that may affect response to sensation.

To ensure safety and appropriate ethical conduct for working with subjects, this study was submitted and approved by the institutional review board at Seton Hall University. The investigator has completed the National Institutes of Health web-based course "Protecting Human Research Participants" and received certification to conduct this research (Appendix F). Participants signed an assent form (Appendix C) and parents signed a consent form (Appendix D) before participating in the study. Subjects were assigned a numerical code to maintain anonymity. Children and or their parents may discontinue participation at any time.

Procedure

Prior to the testing, the researcher and research assistant set up the testing materials, checked that the equipment was running properly and dimmed the lights. Subjects and their parents came to the testing site (Barpak clinic) two times during a six-week period. The researcher explained the procedures involved in the experiment using lay terminology. Children signed an assent form if they were seven years old or older. Parents signed a consent form before beginning the laboratory session, and provided identifying information such as address, date of birth of child (Appendix G

Identifying Information Form). During the first testing session, parents completed the Short Sensory Profile.

The child was then taken to the space lab (testing area) by the helper and introduced to the laboratory setting which was designed to look like the inside of a spaceship. Ambient lighting in the room was set to a low level throughout the procedure. The child was invited to sit in a sturdy chair with a space ship control panel in front of him. A video clip of the movie Apollo 13 was displayed showing the astronauts as they were hooked up with electrode placement before launch into space. The researcher explained to the child that he too will be hooked up with stickers just like the astronauts before beginning the procedure. As the child watched the video, three electrodes were placed on the child's chest in a triangular pattern at the base and center of the rib cage. Two smaller electrodes were placed on the left thenar and hypothenar eminences of the left hand, 2-inch wide coban wrap was used to further secure lead placement. When electrode placement was complete, the child was instructed to sit still like a robot, keep feet flat on floor with left hand palm up, resting on armrest. No talking during the space trip unless its an emergency, we can talk when the space trip is over. The researcher told the child we are ready to start and data collection began.

The laboratory protocol took about 45 minutes to complete. Eight domains were presented in the following order, baseline, tone, visual, siren, olfactory, tactile, movement and recovery. Baseline and recovery recorded

tonic measures as there were no stimuli presented during these domains. The six sensory domains presented were:

7. Auditory - a professionally recorded tone playing at 90 decibels (Psylab computer software).
8. Visual – 20-watt strobe light set at 10 flashes per second (5” x 3.5” x 2” Product code: MS-1, Noveltylights.com).
9. Auditory – a professionally recorded fire-engine siren playing at 90 decibels (Psylab computer software).
10. Olfactory – wintergreen oil (methyl salicylate, Anandaapothecary.com) kept approximately 1.25 cm deep in a 30ml vial with a cotton ball. The helper donned a sterile glove, removed the cotton ball and placed thumb over top of vial. Synchronizing stimuli presentation with pre-recorded cue, the helper took thumb off vial and placed it about 2.5 cm from subjects nose, centered between nose and lips. The helper moved the vial from left to right to left in a 2.5 cm path following the synchronized pre-recorded count of 3 seconds heard as 1, 2, 3).
11. Tactile – 5 cm turkey craft feather (B706M Turkey Marabou short mixed loose 1-4”, www.featherplace.com). The helper placed the feather on the subjects right ear canal and slid the feather down along the chin line, to the bottom of the chin and then up the chin line to the left ear, following a 3 second count.

12. Movement (vestibular) – Chair (12”h, 13”d, 14”w) tipped slowly and smoothly backward to a 30° angle.

Each of the six sensory domains consisted of 8 stimuli presentations, lasting 3 seconds each, in a pseudo random time order of 15-19 seconds apart and 20 seconds between each domain. Data collection began by starting the Psylab software data acquisition protocol. From this point the computer provided directions to guide the procedure. The researcher and helper communicated through headsets and the child’s baseline level was set. The protocol was stopped if adjustments needed to be made or if there was a disruption or the child did not wish to proceed.

At the beginning of the protocol, the computer program announced via headsets begin baseline. SCL and NSR were recorded for three minutes. At the end of the baseline domain, the child was commended for following the rules and sitting quietly. Following the script, the child was prepared before each sensory domain that he was going to hear something, or see something, smell something or feel something. The computer announced the beginning of each domain to the researchers and the stimuli were presented to the child. Skin conductance response to each stimuli were collected along with continued SCL and NSR frequency. As data collection occured, the researcher monitoring the computer also made note of any possible artifacts that may confound the data collected. Using an artifact log, the researcher noted what the artifact was and when it occurred. Artifacts include excessive

movement of the child or environmental disruption (loud noise, equipment problems).

Instrumentation

Hardware

Using an integrated laboratory system, (Psylab System, Contact Precision Instruments, Cambridge, MA) measurement of skin conductance was collected following the procedures recommended by Martin & Venebles (1980) and the Fowles committee (1981). The Psylab Stand Alone Monitor (SAM) provided a connection between the subject and SAM as well as connection between SAM and the computer software. Data was collected from the subject via electrode placement, and converted to digital at the electrode source, then transmitted to the computer software. The skin conductance coupler (SC5) contains a 24-bit accuracy A-D converter which converted the signal from analogue to digital before sending it to the SAM unit. A self-calibration system adjusted itself each time the SC5 was turned on by connecting to known conductance values. The internal converter encompasses the entire range (0 – 100 micro Siemens) of skin conductance measures with enough sensitivity to detect small changes (Contact Precision Instruments, 2003) therefore control over amplifier gain was not necessary. No high pass filter was provided because of the direct coupling of the signal that avoids potential distortion by the filter (Contact Precision Instruments). A

fixed low pass filter of 10 Hz was adequate because skin conductance response takes a few seconds to complete (Contact Precision Instruments). Digital data was then sent to the computer software system.

To begin data collection, the subject was connected to the SAM unit via one pair of 8mm diameter silver/silverchloride (Ag/AgCl) skin conductance electrodes (Contact Precision Instruments EL 122) filled with Mansfield R & D electrode paste 0.05-M NaCl electrolyte paste (TD-246, discountdisposables.com). The electrodes were secured to the thenar and hypothenar eminence of the left hand using Mansfield R & D electrode collars (TD-22, discountdisposables.com). The electrodes were further secured to the subject's hand using 50.8 mm wide Coban self-adhesive wrap (Nexcare, 3M). The electrodes were directly attached to the SC5 which, applied a constant 0.5 volt potential across the electrode pair. The SC5 was connected to the SAM unit.

A 3-lead snap dot EKG set was attached to EKG conductive adhesive electrodes and then applied to the subject's chest at the base of his rib cage in a triangular pattern (EL-126, Contact Precision Instruments). The electrode heart rate variability data was transmitted to a bioamplifier, filtered and sent to the SAM unit for conversion of the signal from analogue to digital.

Using the SAM software system, the researcher created a new file with subject number, date and then the record button was turned on. The skin conductance and heart rate variability signals were collected. When the

subject was ready and the signals looked visually conditioned, the F9 button was clicked to initiate recording baseline data. After 3-minute baseline recording, presentation of the stimuli began. A pre-recorded message cued the researchers to press the F9 button to begin each sensory domain. An external connector, the BIN8 stimulator, synchronized presentation of auditory and visual sensory stimuli via its connection to the SAM unit. Olfactory, tactile and movement stimuli were presented by the research helper upon verbal cue via headset. Finally, a 3-minute recovery period was recorded and the session was complete.

Software

There were two software programs in this laboratory procedure. The first program, SAM.EXE (Contact Precision Instruments, 2003) is the application which runs the SCP. This program recorded skin conductance, and directed the hardware as to what to do in order to control delivery of sensory stimuli.

Psylab 7 analysis system (Contact Precision Instruments, 2003) is a windows offline system used to reduce and modify data collected using SAM. Physiologic waveform data collected during the testing sessions were converted to numeric lists and then exported to excel for analysis. In addition, the waveforms were further analyzed using review windows. Review windows show waveform data collected for all stimuli domains. Each domain

was viewed separately in a review window. The review window was separated into eight 10-second blocks representing 8 stimulus presentations. Each 10-second block can be further analyzed using a zoom-in feature in a magnified form. Baseline and recovery domains were analyzed in review windows as well. Each of these domains were presented in 18 10-second blocks.

Variables

Dependent Variables

The Sensory Challenge Protocol measured both tonic and phasic skin conductance. Tonic dependent variables in this study consist of background skin conductance level (SCL) and non-specific skin conductance response (NSR) [Dawson, Schell, & Filion, 1990; 2000]. Tonic skin conductance was the absolute level of conductance in the absence of measurable phasic response. In this laboratory procedure, tonic measures were obtained during baseline and recovery and between 0.0 and 0.8 seconds and between 4 – 10 seconds after stimulus presentation. NSR was a rapid increase in SCL (at least .02 μS) in the absence of a specific stimulus. NSR frequency was the number of non-specific responses per minute.

SCL in this study was operationally defined as mean amplitude of absolute level of skin conductance of at least .02 μS during rest periods, averaged across 10-second blocks. NSR was a change in SCL during rest in

the absence of a stimulus or during post stimulus time period between 4 and 10 seconds as an average rate per minute (Dawson, Schell, & Filion, 1990; 2000; Schoen et al., 2008). Typical SCL values among normal adults are 2 – 20 μS, NSR per minute 1-3 (Dawson, Schell, & Filion).

Phasic dependent variables were rapid changes in skin conductance level in response to a specific stimulus within a specific time window. Phasic response to specific stimuli (SCR) was presented as a waveform with four components, latency, rise time, amplitude and half recovery time (Dawson, Schell, & Filion, 1990; 2000). The waveform component definitions were based on the work of Dawson, Schell and Filion.

e) Latency – Time between stimulus onset and SCR initiation.
f) Rise time – Time between SCR initiation and SCR peak.
g) Amplitude – Phasic increase in skin conductance following onset of stimulus.
h) Half recovery time – Time between skin conductance peak and point of 50% recovery of SCR amplitude.

SCR is a rapid increase in SCL in response to specific stimuli. Mean value SCR response is computed using amplitude, which is all non-zero responses to specific stimuli or magnitude, the mean value of all stimulus presentations including zero response.

In this study, the following phasic components of skin conductance were analyzed based on definitions by Schoen et al, 2008:

3. Magnitude (MAG) – Mean magnitude of SCR (including zero response)
4. Amplitude (AMP) – Mean amplitude of SCR (all non-zero responses)
5. Orienting Response (OR) – Amplitude of SCR to first stimulus presentation.
6. Latency (LAT) – Average time from onset of SCR to peak within a sensory domain (when an SCR was present).
7. Habituation (HAB) – Number of stimulus presentations before 2 trials with no response. (Dawson, Schell, & Filion, 1990; 2000).

Behavioral dependent variables in this study consisted of section and total scores on the Short Sensory Profile (SSP). The SSP (Dunn, 1999) is a 38-item parent report measure of functional behaviors associated with abnormal responses to sensory stimuli (Mangeot et al., 2001). High scores indicate typical performance, low scores indicate abnormal response to sensation. Norms for the full Sensory Profie were developed and standardized on 1,200 children. The 7 sections of the SSP are Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Underresponsive/Seeks Sensation, Auditory Filtering, Low Energy/Weak, and Visual/Audiotry Sensitivity. The reliability and validity of the tool are excellent (Ahn et al., 2004; Dunn, 1999; Mangeot et al, 2001;McIntosh et al., 1999;

Tomchek & Dunn, 2007). Internal reliability of the SSP total test is > .95 (Cronbach's alpha) for a sample of children (n=38) with and without disabilities. Subscale reliabilities of that same sample range from .70 to .90 (Ahn et al.; Dunn; Mangeot et al.; McIntosh et al.; Tomchek & Dunn). Inter-scale correlations ranging from .25 to .76 suggest the subscales measure unique dimensions (Ahn et al.). Discriminant validity was shown by McIntosh and colleagues (1999) in their comparison of children with SPD's and age and gender matched controls of typically developing children (n=38). The SPD group had significantly lower group scores compared to the controls. Moreover, the abnormal SSP scores were significantly associated with abnormal EDA in response to sensation, determining initial convergent validity (Ahn et al., McIntosh et al.; Tomchek & Dunn). In this current study, scores from SSP were also correlated with skin conductance measures.

Independent Variables

The independent variables were the two subjects, the two testing sessions, test 1 and test 2 and the sensory stimuli presented to the subject, which include sound (tone and siren), visual (strobe light), olfactory (wintergreen oil), tactile (feather) and vestibular stimulation (tipping back chair).

Analysis

Data Reduction

Data reduction began by creating a macro (math calculations) for the subjects file. The macro was completed on the same day of testing, usually right after the data collection was finished. The macro was created using Psylab 7 software and results were saved using the extension .xls (excel). This file was then opened and formatted to fit on one excel workbook sheet. Then a picture of the data (skin conductance waveform) was created using the paint program. The subject's file was viewed for all domains, specific domains and specific 10-second blocks using a zoom in feature.

Data Grooming

This process consisted of comparing the subjects excel spreadsheet, paint files and artifact log and tracking results of this process by creating a subject summary table. The researcher first checked the excel sheet for consistency of values, unusual values and missing values. Data from the excel sheet was then compared to the paint files and artifact log. If a domain was skipped or an artifact was identified, it was noted on the subject summary table and the excel sheet was then modified and saved as a revised subject file.

If a domain was skipped, the missing rows were inserted into the excel spreadsheet so a complete 84 rows were listed. The block number column was adjusted and the values of the affected domain were cleared out. If an artifact was identified, the value for that trial in the Excel spreadsheet was cleared out. Calculations of averages for that domain were completed without including the cleared out value in any of the Excel spreadsheets.

Creating the Database

Individual subject Excel data were copied and pasted into an EDA data subject template. This template performed calculations on the variables such as averages, frequency counts, and natural log transformations. Calculation results were then copied and pasted into the EDA database in preparation for descriptive statistical analysis using SPSS version 14.

Statistical Analysis

Summary of descriptive statistics such as means and standard deviations are provided in Table 4. To explore the relationship between test 1 and test 2 SCR, a scatterplot was generated and ICC calculations (Table 4) were conducted. To explore the relationship between SSP scores and SCR measures, a Pearson correlation coefficient was calculated.

Results

A scatterplot (Figure 2) indicates that the variables (test 1 and test 2) are related in a linear fashion and are therefore suitable for a correlation analysis (Pallant, 2010). A visual analysis of the scatterplot reveals the points form a line traveling in a positive direction (bottom left to top right). The clustering of points around the fit line suggest the relationship between the variables are moderately strong. There are no apparent outliers. An analysis using Pearson's correlation coefficient indicates a significant relationship between SSP raw scores and SCR $r(0) = 1.00$ or -1.00, $p < 0.01$. Due to the extremely small sample this result is of no practical importance, but does demonstrate the feasibility of performing this test with a larger sample of n = 30.

Table 4

Test Re-test SCR

Domain	Mean (SD)	ICC	*p* value
Tones	0.11(.06)	0.54	0.38
Visual	0.09(.02)	0.34	0.44
Siren	0.08(.02)	0.97	0.11
Olfactory	0.09(.02)	0.92	0.17
Tactile	0.03(.01)	0.99	0.03
Movement	-0.10(.01)	0.99	0.03
Total	0.05(.02)	0.8	

Note- Subject scores across two measurement sessions

Conclusion

Based upon the study findings in this pilot study the feasibility of the study design and methodology was sound thus enabling the investigator to move forward to investigate if using skin conductance response (SCR) is a reliable measure over time within the context of response to sensation in a larger study.

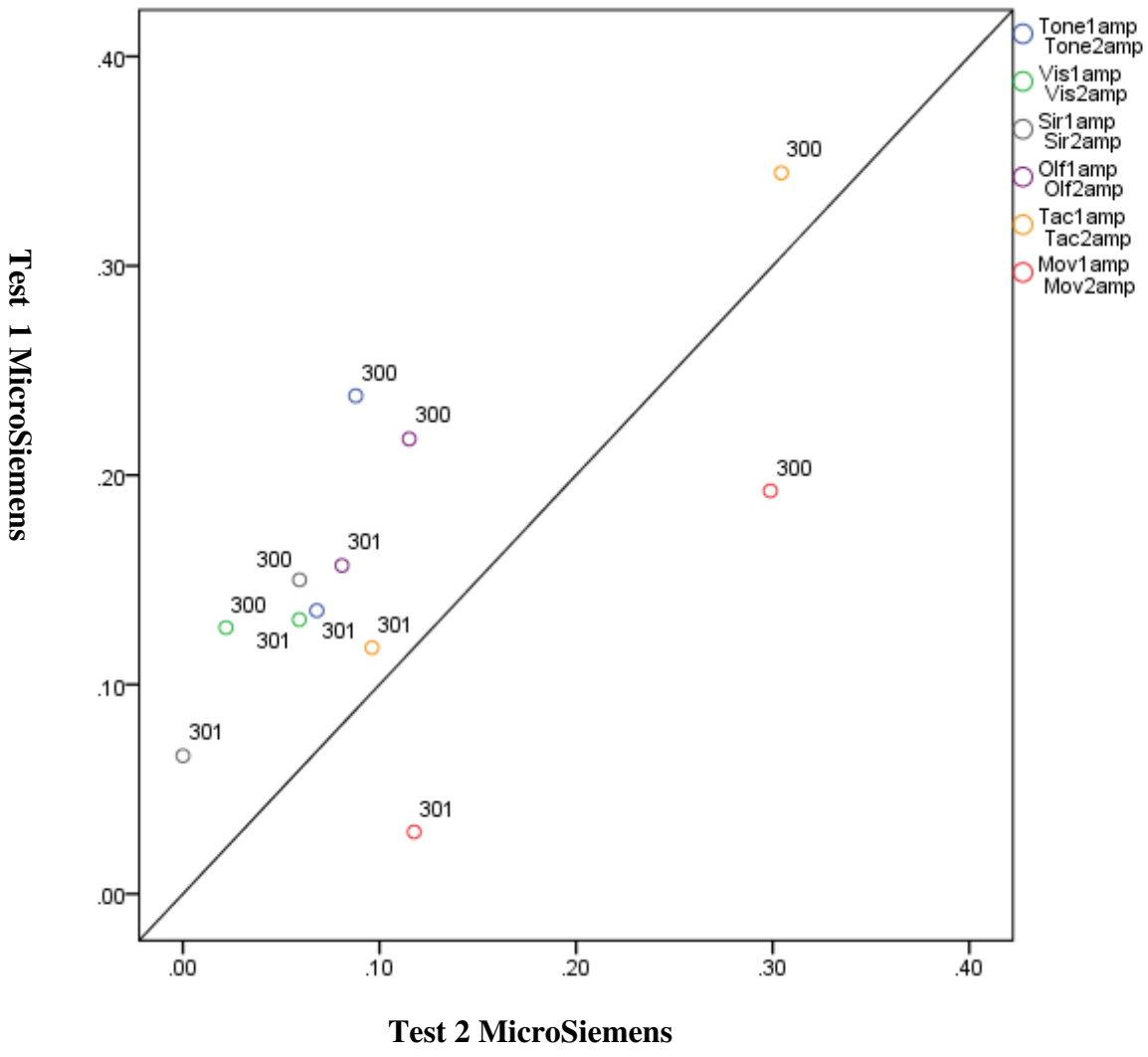

Figure 3. Mean amplitude skin conductance response by subject.

Appendix B
Initial Contact Form

Initial Contact Form

Study Title: Reliability of Electrodermal Activity as an Indicator of Sensory Processing.

Brief Study Description:

The purpose of this study is to evaluate children's responses to smell, sound, sight, touch and movement. We will measure sweat gland activity and heart rate while your child is exposed to various sensory experiences similar to those they experience daily. It is important to understand how children process sensation in order to develop a framework to assess treatment strategies designed to decrease abnormal responses to sensation. Abnormal response to sensation has been linked with learning and behavior problems in children. The procedure requires approximately one hour. You will be required to come for testing two times. You may remain in the room with your child if you prefer. If your child wants to stop for any reason or appears to be in distress, the testing will be terminated immediately. Does this sound like something you think your child would be interested in doing?

Medical History:

1. Name
   _____
2. Age _____
3. Gender _____
4. Does your child have any brothers between the ages of 4 and 11? ____ If so would you be interested in letting them participate in this study? _____
5. When did your child receive a diagnosis of autism (**If parent of child with ASD)**?
   _____
6. Does your child have any other medical diagnosis (**If parent of child with ASD**)?
   _____
7. Does your child have any medical or developmental disabilities (**If parent of a child without ASD**)?
   _____

8. Has your child had a hearing test? _____ What were the results of that test?
   _____

9. Has your child had a vision screening? _____ What were the results of the screen? _____

10. Is your child currently taking any medications?
    _____

11. Does your child understand simple commands such as “Bring me the cup”? _____

12. Does your child verbally or gesturally respond to your questions such as “ Would you like water or juice”?_____

13. Approximately how long is your child able to remain seated while engaged in an
    activity?_____

14. Does your child require frequent movement breaks during seated activities?
    _____

15. Does your child have any sensitivities to sensation? _____ If so, please describe _____

16. Does your child receive Occupational therapy or any related service ie:

    Physical therapy, speech therapy, ABA, etc… _____

    _____

Inclusion Criteria met:
Your child has met the criteria for our initial testing. The next step is to schedule your child’s first testing session.

Inclusion Criteria not met:
Your child has not met study criteria. We sincerely appreciate your interest in our study and look forward to sharing the results of our study with you and others when we are finished.

Appendix C
Assent

SETON HALL UNIVERSITY
1 8 5 6

Seton Hall University
Institutional Review Board
JAN 04 2013
Approval Date

Assent

Study Title: Reliability of Electrodermal Activity as an Indicator of Sensory Processing in Typically Developing Children and Children with Autism Spectrum Disorders.

Expiration Date JAN 04 2014

My name is Barbara Schupak. I am an Occupational Therapist. Just like you go to school, I also go to school at Seton Hall University. You came here today to help me with my school project. When you are ready we will look at your skin and heartbeat while we have you smell something, touch your chin with a feather, look at a blinking light, listen to a tape of siren sounds, and tip you slowly back in a chair, like a rocking chair. We will look at your heart beat by placing three stickers with wires on them on your chest and your skin by placing two tiny stickers on your hand (show child electrodes). The stickers do not hurt. (Possibly let child try one on). Your mom/dad/guardian can be in the room with you the whole time. If you want to stop the testing let us know and we will stop right away. The reason we are doing this is to see how children's bodies react to touching things, smelling things, seeing things, hearing things and moving. If it's ok with you, you may be videotaped, you or your mom/dad/guardian can ask to see the tape and may ask that the tape be thrown away at any time.

Nothing we do today will hurt you, although it is possible that you will not like some things that you see, hear, smell or feel. If this happens let us know right away and we will stop the testing.

By helping me with this project you may help us find ways to help children who have problems with the certain things they see, hear, feel or smell. But you do not have to help me with this project. No one will be mad at you if you choose not to.

Any information that you or your mom/dad/guardian gives us will be kept a secret. No one will see this information except for me and the people I work with. All information will be kept for three years and then we will throw it away.

You and your mom/dad/guardian will be given a copy of this paper stating that you want to help me with my project by looking at something, listening to some things, feeling something and smelling something.

If you have any questions about this project you or your mom/dad/guardian can call or write to me by email at schupaba@shu.edu or by phone at 201-244-0844 or 973-275-2076.

I agree to allow videotaping of testing sessions. Yes_____ No_____

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SETON HALL UNIVERSITY
1856

Child's name _____ Child's Signature _____

Parent/Legal Guardian's name _____ Parent/Legal Guardian's Signature _____

Date _____

Seton Hall University
Institutional Review Board

JAN 04 2013

Approval Date

Expiration Date JAN 04 2014

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Appendix D
Consent

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Consent Form

Study Title: Reliability of Electrodermal Activity as an indicator of Sensory Processing in Typically Developing Children and Children with Autism Spectrum Disorders.

The purpose of this consent form is for the parent/guardian to give, Barbara M. Schupak, MPH,OT the primary investigator for this research and doctoral student of the School of Health and Medical Sciences at Seton Hall University, permission to approach _____ (the child) to participate in this study.
Child's Name

Purpose and Duration of Study:
The purpose of this study is to evaluate children's responses to touch, smell, sight, sound and movement. Heart rate and sweating responses will be measured while the child is exposed to various sensory experiences similar to the sensory experiences that the child is exposed to everyday. It is important to study children's responses to sensation in order to better understand exactly how children process sensory information and to provide a foundation upon which treatment strategies can be developed that may help these children function better at home, school and in the community. The total testing time is approximately one hour. Forty children will participate in the study. Twenty of the children will have autism and twenty of the children will not have autism.

Procedures:
The parent/guardian and the child will come to the Human Performance Lab at Seton Hall University located in Duffy Hall or Barpak Occupational Therapy in Bergenfield, NJ. The parent/guardian and the child will be asked to come two times. The parent/guardian will be asked at the initial visit to fill out the Short Sensory Profile, a 46-item caregiver questionnaire about the child's behavioral responses to sensation such as the child's ability to pay attention or eat a variety of foods. This part should take approximately 20 minutes. While the parent/guardian fills out the Short Sensory Profile, the researcher (Barbara M. Schupak) will be acquainting the child to the laboratory setting, by reading the assent form to them. If the child agrees to participate and is comfortable in the lab setting, the researcher will measure the child's heart rate and sweating response while the child smells wintergreen oil, feels touch to his/her chin lightly with a feather, looks at a series of blinking lights, listens to an audio tape of siren sounds, and sits while tipped slowly back in a chair. The researcher will measure heart rate by placing three electrodes (small stickers that transfer signals to the computer) on the child's chest. The researcher will measure sweating response by placing two small

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electrodes (small stickers that transfer signals to the computer) on the child's hand. The parent/guardian may remain in the room with the child the entire time. If the child wants to stop or is in apparent distress the testing will be halted immediately. Each session will take approximately 30 minutes. The total time for the first session including introducing the child to the lab, completion of the Short Sensory Profile and the administration of the sensory stimulation should take approximately one hour. All subsequent sessions should take approximately 45 minutes. Each session will be videotaped in order to make sure the information collected on the computer matches the way the child responded to the sensation.

Confidentiality:
Care will be given to preserve the confidentiality of all information that the parent/guardian provided. All forms and videotapes with the child's name or designated code on it will be kept in a locked file cabinet at Seton Hall University. Electronic data will be stored on a USB memory key and stored in a locked file cabinet at Seton Hall University. Only the researchers will have access to these files and videotapes.

Anonymity:
Each child will receive a special code for data collection purposes to assure anonymity. All information will be kept for three years and then shredded.

Potential Risks:
None of the procedures are painful, although it is possible that some children may find some sensations uncomfortable. If this occurs testing will be halted immediately.

Potential Benefits:
The child will not benefit directly from participation in this study. However, the findings of this study may help define how children respond to sensation as well as lay a foundation for future studies in the treatment of sensory processing disorders.

Alternative treatments:
The alternative to the child participating in this study is to not participate in this study. This is not a treatment study and therefore does not affect any current treatment procedures that the child may be involved in.

Expiration Date JAN 04 2014

Seton Hall University
Institutional Review Board

JAN 04 2013

Approval Date

School of Health and Medical Sciences
Department of Graduate Programs in Health Sciences
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Videotape:
Each testing session will be videotaped if the parent/guardian agrees. The parent/guardian and the child have the right to request to view the tape and may request the tape be destroyed at any time. All videotapes will be coded to assure anonymity. All videotapes will be destroyed at the end of the three-year period.

The parent/guardian agrees to allow videotaping of testing sessions.

Yes_____ No_____

Voluntary nature of study:
Participation in this study is completely voluntary. The parent/guardian and the child may refuse participation or withdraw permission at any time. If the child does participate, the parent/guardian or the child may request that testing be stopped at any time.

The parent/guardian will be given a copy of this signed and dated informed consent form stating that permission was given for the child to participate in the study.

Contact Information:
If the parent/guardian has any questions or concerns about this study please contact the principal investigator, Barbara M. Schupak, MPH,OT, by email at schupaba@shu.edu or by phone at 201-244-0844 or 973-275-2076 or Ms. Schupak's mentor, Genevieve Pinto-Zipp, PT, EdD., Associate Professor, School of Health and Medical Sciences, Seton Hall University.

Dr. Genevieve Pinto-Zipp
(973) 275-2457
Fax (973) 275-2171
Genevieve.Zipp@shu.edu
Alfieri Hall Rm. 31

Institutional Review Board
(973) 313-6314
Fax (973) 275-2361
irb@shu.edu
Presidents Hall Rm. 325

Expiration Date JAN 04 2014

Seton Hall University
Institutional Review Board
JAN 04 2013
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The parent/guardian gives permission to ask _____ (the child) to be in this study.
Child's Name

_____
Parent/Legal Guardian's name

_____ _____
Parent/Legal Guardian's signature Date

_____ _____
Subject or Authorized Representative Date

Seton Hall University
Institutional Review Board

JAN 04 2013

Approval Date

Expiration Date JAN 04 2014

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Appendix E
Flyer

Children Needed for a Study on Sensory Processing

We are investigating how children with and without autism spectrum disorder respond to touch, smell, sight, sound and movement. We will measure heart rate and sweat gland activity while your child is exposed to everyday sensory experiences.

Eligibility Requirements:

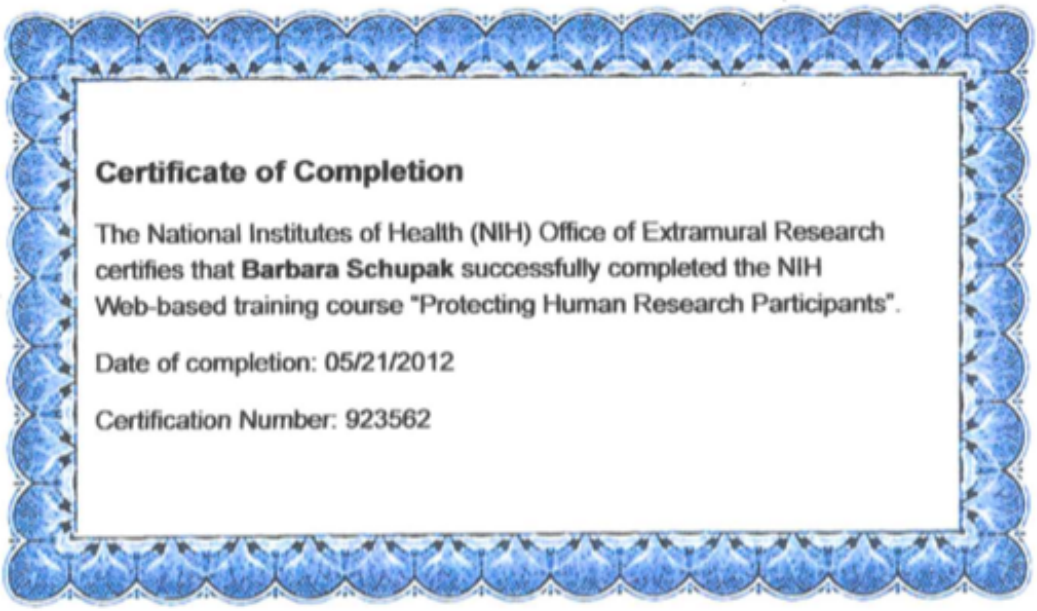
- Typically developing boys or boys with autistic spectrum disorder
- Ages 4-11 years
- Free of any medical or psychological disorders
- Not currently taking any medications known to affect arousal level
- Able to follow simple directions
- Able to remain seated for approximately 30 minutes with breaks as needed

The study will be conducted at Seton Hall University in South Orange, New Jersey and Barpak Occupational Therapy Bergenfield, New Jersey and will require two visits of approximately one hour each.

FOR MORE INFORMATION ON THIS STUDY OR TO SCHEDULE A TIME FOR TESTING PLEASE CONTACT:

Barbara M. Schupak, MPH,OT
School of Health and Medical Sciences
Seton Hall University
201-244-0844 or 973-275-2076
schupaba@shu.edu

Appendix F
Certificate of Completion



Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that **Barbara Schupak** successfully completed the NIH Web-based training course "Protecting Human Research Participants".

Date of completion: 05/21/2012

Certification Number: 923562

Appendix G
Identifying Information Form

Identifying Information

Study Title: Reliability of Electrodermal Activity as an Indicator of Sensory Processing

Child's name_____

Parent/s name/s_____

Address_____

Phone number_____

Child's age_____

If your child has autism, when did he receive the diagnosis?_____

Does your child have a seizure disorder or has your child ever experienced seizures? _____ Please explain_____

_____

Is your child currently taking any medications?_____ If so please

explain_____

Has your child had a hearing test in the recent past?_____
What was the result of that test?_____

School name/location _____

Is your child in a self-contained classroom (only special education students) or in an inclusive classroom (both regular education and special education students)?

_____

Does your child currently receive any therapies or has received any therapies in

the past (ie: OT, PT, Speech, ABA) ? _____ If so please specify_____

_____

Has your child ever received any alternative therapies such as Auditory Integration Training or Nutritional Therapy?_____ If so please specify_____

Does your child have any apparent sensitivities to sensation? _____If so please specify _____

Does your child understand simple commands such as "Bring me the book"?_____

Does your child verbally or gesturally respond to your questions such as " Would you like milk or juice"?_____

What are your child's favorite things to do/hobbies? Please be specific. For example: my child love to watch blues clues _____

_____

Child's Doctor's name/s and phone number

_____

Other pertinent information

_____

Appendix H
IRB Approval

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January 4, 2013

Barbara Schupak
838 Schaefer Ave.
Oradell, NJ 07649

Dear Ms. Schupak,

The Seton Hall University Institutional Review Board has reviewed the information you have submitted addressing the concerns for your proposal entitled "Electrodermal Activity as an Indicator of Sensory Processing in Typically Developing Children and Children with Autism Spectrum Disorder". Your research protocol is hereby approved as revised under full review.

Enclosed for your records are the signed Request for Approval form and the stamped original Consent Form, Assent Form, Assent Script, recruitment flyer. Make copies only of these stamped documents.

The Institutional Review Board approval of your research is valid for a one-year period from the date of this letter. During this time, any changes to the research protocol must be reviewed and approved by the IRB prior to their implementation.

According to federal regulations, continuing review of already approved research is mandated to take place at least 12 months after this initial approval. You will receive communication from the IRB Office for this several months before the anniversary date of your initial approval.

Thank you for your cooperation.

In harmony with federal regulations, none of the investigators or research staff involved in the study took part in the final discussion and the vote.

Sincerely,

Mary F. Ruzicka, Ph.D.

Mary F. Ruzicka, Ph.D.
Professor
Director, Institutional Review Board

cc: Dr. Genevieve Pinto Zipp

Office of Institutional Review Board
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