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ABSTRACT OF DISSERTATION

Scott David Tomchek

The Graduate School  
University of Kentucky  
2005

CHARACTERIZING SENSORY PROCESSING IN  
AUTISM SPECTRUM DISORDERS

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ABSTRACT OF DISSERTATION

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A dissertation submitted in partial fulfillment of the  
requirements for the degree of Doctor of Philosophy in the  
College of Health Sciences  
at the University of Kentucky

By  
Scott David Tomchek

Lexington, Kentucky

Co-Directors: Dr. Ruth Huebner, Professor of Occupational Therapy  
and Dr. Lori Gonzalez, Professor of Communication Disorders

Lexington, Kentucky

2005

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## ABSTRACT OF DISSERTATION

### CHARACTERIZING SENSORY PROCESSING IN AUTISM SPECTRUM DISORDERS

*Rationale:* Autism is a neurodevelopmental disorder with onset prior to the age of three years characterized by qualitative impairments in social interaction and communication skill, along with a restricted repetitive and stereotyped pattern of behavior, interests, and activities. In addition to these core diagnostic features, aberrant sensory responding has also been widely reported in the literature describing children and adolescents with autism spectrum disorders (ASD). Aberrant sensory processing has, however, been infrequently studied compared to communication and cognition in autism and existing studies have had multiple methodological deficiencies, especially with sampling procedures.

*Purpose.* The purpose of this study is to describe patterns of sensory processing found in children with an ASD to test the relationship(s) of these patterns to diagnostic and developmental variables.

*Method.* Retrospective data collection was used to collect developmental and sensory processing variables of 400 children with an ASD. Sensory processing abilities were measured by the *SSP*.

*Results.* The majority of the sample (80.5%) had a diagnosis of autism. The average age of the sample was 49.58 months. The adaptive, social, language, and motor developmental variables were consistent with diagnostic patterns in that the children with Asperger Disorder demonstrated higher developmental levels than the children with autism and PDD-NOS. Eighty-nine percent of the sample demonstrated some degree of sensory processing dysfunction on the SSP Total Score with the greatest difficulties reported on the Underresponsive/Seeks Sensation, Auditory Filtering, and Tactile Sensitivity sections. Exploratory factor analysis identified 6 parsimonious factors: Low Energy/Weak, Tactile and Movement Sensitivity, Taste/Smell Sensitivity, Auditory and Visual Sensitivity, Sensory Seeking/Distractibility, and Hypo-responsivity. These factor variables contributed to explaining the differences in five of six developmental variables of the sample that are associated with the diagnosis of autism. Receptive language, adaptive and expressive language performance were significantly correlated with sensory processing factor scores.

*Conclusions.* Together, the sensory processing findings noted in this study describe a pattern of dysfunctional sensory modulation. These findings have significant implications for intervention programs involving individuals with an ASD, given the potential impact of these findings on a child's ability to maintain active engagement.

**KEYWORDS:** Autism Spectrum Disorders, Sensory Processing/Integration, Adaptive Functioning, Motor Performance, Development

Scott D. Tomchek

May 3, 2005

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CHARACTERIZING SENSORY PROCESSING IN  
AUTISM SPECTRUM DISORDERS

By

Scott David Tomchek

Ruth A. Huebner, Ph.D., OTR/L, FAOTA  
Co-Director of Dissertation

Lori Stewart Gonzalez, Ph.D., CCC-SLP  
Co-Director of Dissertation

Susan K. Effgen, Ph.D., PT  
Director of Graduate Studies

May 3, 2005

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DISSERTATION

Scott David Tomchek

The Graduate School  
University of Kentucky

2005



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DISSERTATION

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## DEDICATION

I have worked with many families who have struggled on a daily basis to cope with the behavioral challenges of their son or daughter with autism because of disordered sensory processing. I dedicate this research to each and every one of them. With a better understanding of the sensory symptoms it is my hope we can develop more effective intervention strategies to ease daily life.

## ACKNOWLEDGEMENTS

The following dissertation, while an individual work, benefited greatly from the insight and direction of many people. First, my Dissertation Committee Co-Chair Dr. Ruth Huebner, who exemplifies the drive and dedication of a scholar to which I aspire. Her constructive feedback and questioning have always challenged me to think more critically. In addition, Dr. Lori Gonzalez, my other Dissertation Committee Co-chair, provided instructive comments and positive encouragement which helped to sustain my motivation. Next, I wish to thank the rest of my Dissertation Committee, Dr. Susan Effgen, Dr. Hazel Forsythe, Dr. Colleen Schneck, and outside examiner, Dr. Belva Collins. Each individual committee member provided encouragement and insight that substantially improved the finished product.

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## CHAPTER 1

### BACKGROUND AND INTRODUCTION

This chapter includes the rationale, problem statement, research questions, as well as the strengths, limitations, and potential benefits of this study. These aspects provide direction for outlining the research study. The literature supporting the rationale is briefly reviewed here and then extensively reviewed in Chapter 2.

#### Rationale

Autism is a neurodevelopmental disorder with onset prior to the age of three years characterized by qualitative impairments in social interaction and communication skill, along with a restricted repetitive and stereotyped pattern of behavior, interests and activities (American Psychiatric Association, 2001; World Health Organization, 1993). Taking into account variations in diagnostic criteria and methodology, the prevalence of autism has been estimated to be 1 per 1,000 individuals (Fombonne, 1999; Gillberg & Wing, 1999) to as high as 1 per 500 (Kadesjo, Gillberg, & Hagberg, 1999; Rapin, 1997). National incidence studies report autism to be on the increase, with much debate in the field as to potential reasons (e.g., over diagnosis, changing diagnostic criteria, genetic factors) (Prior, 2003; Wing & Potter, 2002). For instance, the United States Department of Education (1999) reported a 172.86 percent increase in the number of children aged 6 to 21 years served under the Individuals with Disabilities Education Act (IDEA) from 1988-89 through 1997-98. Additionally, it is estimated that 500,000 to 1,500,000 people in the U.S. today have autism of some form (Autism Society of America, 2002). These figures likely represent a growing population of individuals who will be in need of comprehensive services including rehabilitation services.

In addition to the core diagnostic social-communication and repetitive behavior features of autism, aberrant sensory responding has also been widely reported in the literature describing children and adolescents with autism spectrum disorders (ASD). These sensory disturbances have been well documented in the basic science literature (Lincoln, Courchesne, Harms, & Allen, 1993; Ornitz, 1989; Ornitz, Lane, Sugiyama, & de Traversay, 1993; Yeung-Courchesne & Courchesne, 1997), clinical literature (Bauman, 1999; Dawson & Watling, 2000; Ermer & Dunn, 1998; Haas et al., 1996; Jones & Prior, 1985; Kientz & Dunn, 1997; Watling, Deitz, & White, 2001) and first-person accounts of living with autism (Cesaroni & Garber, 1991; Grandin, 1992; Williams, 1995). In fact, the initial appearance of these sensory processing findings often

predates diagnosis (Adrien et al., 1993; Baranek, 1999; Dahlgren & Gillberg, 1989; Lord, 1995). Given the prevalence of these findings and their early onset, several authors have suggested these sensorimotor findings represent another core diagnostic criterion for diagnosis of autism (Coleman, 1976; Coleman & Gillberg, 1985; Gillberg & Coleman, 2000; Ornitz, 1989; Zero to Three/National Center for Clinical Infant Programs, 1994).

*Sensorimotor* is a term that emphasizes the role of active, experienced-based learning (Murray & Anzalone, 1991), and defines the process of sensory integration (SI). It refers to the full gamut of processes, explanations and interventions arising from sensory integration theory and neurodevelopmental theories. Sensory processing and sensory integration are terms that therapists often use synonymously. Sensory processing is a broad term that refers to the way in which the central and peripheral nervous systems manage incoming sensory information from the senses (Lane, Miller & Hanft, 2000). It encompasses the reception, modulation, integration, and organization of sensory stimuli, including the behavioral responses to sensory input. Sensory integration, however, is only one component of sensory processing, and refers to the process of combining sensory information from one's body and the environment in a manner that leads to adaptive responding (Lane, 2000; Lane et al., 2000). It is important to highlight several components of this definition. Sensory integration is the dynamic processing and organizing of information from multiple sensory systems. It requires sensory information to be initially detected and registered as meaningful, modulated as it is processed centrally, and then responded to with a response that matches the stimuli (Anzalone & Williamson, 2000).

Sensory processing impairments in autism are theorized to reflect poor sensory integration and/or arousal modulation in the central nervous system (CNS) (Bauman & Kemper, 1994; Gillberg & Coleman, 2000; Haas et al., 1996), although the underlying mechanism remains speculative. Coincidentally, there has also been a recent effort to extensively investigate CNS features to identify a source for these sensorimotor impairments as well as to establish potential etiologies of ASDs. Based on these efforts, there is almost universal agreement that ASDs have neurobiological underpinnings (Bailey, Phillips, & Rutter, 1996; Bauman & Kemper, 1994; Cody, Pelphrey, & Pivan, 2002; Dawson et al., 2002a; Dawson et al., 2002b; Gillberg & Coleman, 2000; Huebner & Lane, 2001; Minshew, Sweeney, & Bauman, 1997; Waterhouse, Fein, & Modahl, 1996). When available research on these neurobiological underpinnings is considered with other developmental and behavioral data, behavioral phenotypes in ASDs are

beginning to emerge (Bauman & Kemper, 1994; Dawson, et al., 2002b; Eaves, Ho, & Eaves, 1994; Gillberg & Coleman, 1996; Rapin, 1997; Stevens et al., 2000). Nonetheless, current behavioral phenotyping findings often exclude relevant sensory and motor features of the disorder. These features are the focus of the proposed investigation in this proposal.

As a whole, however, sensory processing has received less attention in the literature than other developmental variables in autism (Baranek, 2002; National Research Council [Council], 2001). To some degree, the lack of consistency in findings likely also reflects the significant variability in research questions and methods used in this line of study. Further, studies have been limited by multiple deficiencies in sampling procedures, a lack of consistency in method(s) of measurement, sample sizes and ages of their samples, and generally lacked replication. As a result, any multivariate relationships among sensory processing and aberrant behaviors, core diagnostic features, or other developmental variables (e.g., cognition, language, socioeconomic, etc.) have not been established.

Research is needed to expand our understanding of sensorimotor aspects of autism and to determine the relevance of these findings on the variable developmental presentation of individuals with autism. To identify these patterns the research must investigate sensory processing, and consider it with other developmental and diagnostic indicators. Given the impact of these findings on other developmental areas, core diagnostic features in autism and the development of other aberrant behavior, these findings will serve as a mechanism to understand the complex behavior of individuals with an ASD and identify implications for early diagnosis and intervention.

This study is designed to investigate sensory processing and relate the findings to developmental and diagnostic indicators of autism. To compensate for the wide range of symptom variability in autism, a sample of data from 400 individuals with an ASD was gathered to improve statistical power. This large sample permitted analysis of patterns of sensory processing, factor analysis, and tests of multivariate relationships between sensory processing and developmental and diagnostic variables. Retrospective collection was used to gather data on individuals diagnosed with an ASD during a comprehensive team evaluation at a diagnostic center specializing in autism. Each participant received a comprehensive medical, psychological, speech and language, and occupational therapy evaluation. The resultant developmental (i.e.,

adaptive, social, communication, and motor) and sensory processing (i.e., Short Sensory Profile [SSP]) variables yielded from this evaluation process were analyzed.

Several analyses were conducted on the data set. Item analysis initially identified items yielding the highest reported dysfunction in this sample. Multivariate analyses of variance (MANOVA) was conducted to compare differences in several developmental measures based on the gender, diagnosis, and/or the functioning level of the subjects. Exploratory principal components factor analysis by varimax rotation was conducted on the 38 items of the SSP (Dunn, 1999) to identify latent variables and subtypes of autism. Correlation analysis between sensory processing factor loadings and adaptive, social, language, and motor skill developmental measures were conducted to determine the strengths of relationships. These analyses provided direction for further regression analysis.

### Problem Statement

Aberrant sensory processing has been studied infrequently compared to communication and cognition in individuals with autism and existing studies have had multiple methodological deficiencies, especially with sampling procedures. This literature begins to describe the prevalence and types of sensory processing symptoms demonstrated; however, it fails to establish multivariate relationships among these symptoms and aberrant behaviors, core diagnostic features, or other developmental variables in autism. The purpose of this study is to describe patterns of sensorimotor processing found in children with autism and to test the relationship(s) of these patterns to diagnostic and developmental variables.

### Research Questions

This study will be conducted using a retrospective chart review of 400 children diagnosed with an ASD. The research questions are:

1. What domains of sensory processing (e.g., tactile, auditory, oral-sensory, sensory seeking) on the SSP (Dunn, 1999) are identified as disordered in this sample of children with ASDs?
2. How does the sensory processing behavior identified in this group of children with an ASD differ from that identified in the standardization sample of typically developing children?
3. What is the latent factor structure found in the scores on the SSP?
4. Does the sensory processing in this sample differ for subgroups stratified by age, gender, autism diagnosis, or level of adaptive functioning?

5. Is there a relationship between item, factor, or total scores of the *SSP* and developmental and diagnostic variables of the sample?

#### Strengths and Limitations of the Study

The research design for this study sought to address the limitations of previous studies and incorporate the lessons learned during a pilot study of these methods. As demonstrated in the pilot study and other studies, individuals with autism have paradoxical responding to sensory input that differs qualitatively from individuals who are typically developing. This finding, coupled with the variability demonstrated in other developmental areas of individuals on the autism spectrum, indicates a need for investigations to employ larger samples. Larger samples will allow for more sophisticated research questions using valid statistical procedures to identify sensory processing clusters, explore relationships among these clusters and developmental variables and determine the impact of developmental differences on the presentation of these clusters. Together, these aspects promote improved statistical power (Cohen, 1992). Therefore, this study gathered data on an unprecedented 400 subjects with an ASD. In this study, sensory processing behavior and the developmental variables were measured at the time of initial diagnostic evaluation so that developmental measures reflect baseline performance at diagnosis rather than being confounded by progress after intervention. Consistent measures for all variables across subjects or cross-validation of measures are employed. These strategies, coupled with the fact that the data was collected at a diagnostic center where specialized training and clinical expertise in personnel related to ASDs is found in all disciplines promotes validity of the data set and findings.

The limitations of the design are directly related to the unique diagnostic aspects of ASDs. Developmental testing in general is a social communication process and therefore demands the skills that are the weakest for individuals on the autism spectrum. Therefore, obtaining valid developmental measures is difficult with this population. Given the inherent problems with utilizing standardized instruments with this group of children, criterion referenced instruments yielding developmental ages are often used. As such, utilizing developmental quotients as a means of comparing across instruments was employed in this study. Further, many of these instruments rely heavily on parent report. Although these are common practices in the autism literature (see Bibby, Eikeseth, Martin, Mudford, & Reeves, 2001; Lord &

Schopler, 1989; Rogers et al., 2003; Stone et al., 1997), both bring into question the validity of the resultant data.

### Potential Benefits of this Study

This study is designed to make a substantial contribution to understanding the variable behavioral presentations in ASDs. Because it is hypothesized that sensory processing is related to the core diagnostic features in autism and the development of other aberrant behavior, findings from this study may explain the complex behavior of individuals with an ASD and identify implications for early diagnosis and intervention. The findings may also differentiate groups of people with autism by sensorimotor pattern to investigate differential responding to various interventions (Huebner & Dunn, 2001). The findings then, will not only expand our understanding of autism, but also have the potential for contributing to the best practices for intervention with individuals with autism.

## CHAPTER 2

### LITERATURE REVIEW

This chapter includes a thorough review of the literature on sensory and motor findings in ASDs, an overview of the theory of sensory integration, and other relevant findings in autism. Initially, a thorough review of the current state of motor performance and sensory processing research in ASDs will be presented. Although it is beyond the scope of this proposal to thoroughly discuss the neuropsychology of ASDs (see Huebner & Lane, 2001 for a comprehensive review), theorized CNS functions and potential sites of dysfunction in ASDs will be integrated. Conclusions and limitations in the literature will be outlined to assist in the design of this study.

#### Sensorimotor Terminology and Theory

Historically, with the exception of specifically analyzing stereotypies as part of the “restricted behavioral repertoire” (APA, 2001), motor performance and sensory processing issues have been deemphasized in the assessment or treatment of ASDs (Filipek et al., 1999). With a recently expanded understanding of the neuropsychology of autism, greater emphasis has been placed on defining motor performance and sensory processing in empirical research. These findings, however, provide only a preliminary understanding of the behavioral manifestations seen in ASDs, and do not describe specific patterns of sensorimotor performance, nor relate these patterns to other features of autism.

*Sensorimotor* is a term emphasize the role of active, experienced-based learning (Murray & Anzalone, 1991) and defines the process of sensory integration (SI). It refers to the full gamut of processes, explanations, and interventions arising from sensory integration theory and neurodevelopmental theories.

Sensory processing and sensory integration are terms that therapists often use synonymously. Sensory processing is a broad term that refers to the way in which the central and peripheral nervous systems manage incoming sensory information from the senses (Lane, Miller, & Hanft, 2000). It encompasses the reception, modulation, integration, and organization of sensory stimuli, including the behavioral responses to sensory input. Sensory integration, however, is only one component of sensory processing, and refers to the process of combining sensory information from one’s body and the environment in a manner that leads to adaptive responding (Lane, 2000; Lane et al., 2000). It is important to highlight several components of

this definition. Sensory integration is the dynamic processing and organizing of information from multiple sensory systems. It requires sensory information to be initially detected and registered as meaningful, modulated as it is processed centrally, and then responded to with a response that matches the stimuli (Anzalone & Williamson, 2000). This process of continual regulation and organization of reactions to sensory input in a graded and adaptive manner is known as sensory modulation (Miller & McIntosh, 1998). Under normal conditions, following modulation, there is an adaptive response to the input. When sensory input is properly modulated, optimal levels of arousal will be maintained. From this optimal arousal base, an individual is more capable of motor performance and engagement in preferred occupations. Conversely, when sensory modulation is inadequate, the individual has difficulty regulating and organizing the sensory information to allow for adaptive responding. With inadequate sensory modulation an individual can demonstrate over-responsivity, under-responsivity, or inconsistent responsivity to environmental inputs. In turn, such responding further compromises arousal. The literature in autism has documented many such findings.

Lester and colleagues (Lester, Freier, & LaGasse, 1995) described human behavior in the context of the “4 A’s”: arousal, attention, affect, and action. The 4 A’s serve as a key to understanding how children understand and interact with their environment. Each of these processes is reciprocal; influenced by and influencing of the others. As an example, the ability to accomplish an action depends on sustained attention that depends on the ability to maintain an alert state. Successfully achieving a task then influences the alert state, attention, and affect. Therefore, all learning and development are predicated on adequate functioning of the 4 A’s

This framework is a useful way of describing the outcomes of the sensory processing (Anzalone & Williamson, 2000; Williamson & Anzalone, 1997). The 4 A’s provide a mechanism of summarizing and grouping sensory processing deficits found in individuals with autism. The model also provides a mechanism of highlighting deficits in sensory processing as a potential component in many of the behavioral manifestations of individuals with autism and thus highlights the importance of expanding this line of research (See Table 1).

What should be clear from analyzing the brief descriptions of the 4 A’s is the dependency of one process on the others and the significant contributions of sensory processing to each. As a result of this interdependence, children with sensory processing disorders may have difficulty detecting and registering sensory input, filtering stimuli, habituating to familiar stimuli and/or



Table 1

## 4 A's of Behavior, Sensory Processing Contributions and Findings in Autism

Process*	Defined*	Sensory Processing Contributions*	Theorized Expression in Autism
Arousal	The ability to maintain alertness and transition between different sleep and wake states	The current state of arousal influences sensory detection, registration and interpretation and conversely is influenced by sensory input (Anzalone & Williamson, 2000). Variability in responding to sensory input is linked to the child's state of arousal and previous sensory experiences (e.g., touch may be acceptable when drowsy, but not acceptable when fully alert).	-Variability in sensory responding across most sensory modalities
Attention	The ability to focus selectively on a desired stimulus or task; includes both selection and allocation	Poor sensory detection and registration limits the child's ability to attend. Children easily over-stimulated may be hypervigilant in a fight or flight protective mechanism.	-Hyper-focused attention on some aspect of an object or task -Inconsistent responding to sensory modalities (e.g., under-responding to language, yet fearful of loud noises)
Affect	The emotional component of behavior	Modulation of sensory input influences the intensity and amplitude of a child's emotional reactivity, which is governed by individual neurological thresholds (Dunn, 1997). High neurological thresholds require more sensory input for registration, leading to a low level of arousal that may manifest as dampened affect. Whereas low neurological thresholds may lead to high arousal and present as emotional lability or shutdown.	-Social aversion -Fear/anxiety -Emotional lability -Flat affect

Action	The ability to engage in adaptive goal-directed behavior.	Involves integration and coordination of perceptual, cognitive and motor abilities (Anzalone, 1993; Losche, 1990).	-Motor clumsiness -Impairments in gross and fine-motor skill -Praxis deficits
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*Note.* \*Summarized from Anzalone & Williamson, 2000, Lester et al., 1995, and Williamson & Anzalone, 1997 and used as a framework to summarize findings in autism.

formulating an adaptive response. With inaccurate sensory processing, output impairments may manifest in an inability to consistently respond adaptively to sensory input, inconsistent attending, poor ability to modulate arousal, delayed gross and fine motor development, and/or praxis (motor planning) deficits. These deficits may in turn, lead to communication and social impairments.

What will be clear from the review of literature that follows is that the sensory processing impairments noted in individuals with autism permeate each of the 4 A's. As such, the review of the current state of sensorimotor research includes descriptive studies of motor performance and sensory processing. Potentially related CNS functions and theorized sites of dysfunction in ASDs will be integrated throughout. Doing so will allow for discussion of integrated models of investigation to further elucidate the existence of these findings and their relationships to neuropsychological and diagnostic features.

#### Motor Performance.

*Postural Control/Gross Motor.* Historically, motor functioning has been studied in the context of developmental milestones (DeMyer, Hingtgen, & Jackson, 1981; Losche, 1990; Wing, 1972) and/or gait (Hallett et al., 1993; Kohen-Raz et al., 1992; Maurer & Damasio, 1982; Vilensky, Damasio, & Maurer 1981). In comparison to language and social skill, individuals with autism have been described as having better basic motor skill (Klin, Volkmar, & Sparrow, 1992; Wing, 1972). The timing and sequence of motor developmental markers have, however, been described as both delayed and qualitatively different in individuals with ASDs than that of typically developing children (Losche, 1990). Hypotonia has also been frequently reported in individuals with autism (Bauman, 1999; Haas et al., 1996; Rapin, 1996), though in at least one study no differences were noted when tone was compared to mental-age-matched typical children (Jones & Prior, 1985). Postural and movement abnormalities, along with general clumsiness has also been a frequent finding (DeMeyer, 1976; Ghaziuddin, Tsai, & Ghaziuddin, 1992; Jones & Prior, 1985; Kiln, Volkmar, Sparrow, Cicchetti & Rourke, 1995; Leary & Hill, 1996; Nass & Gutman, 1997). Gait disturbances, including toe walking and arching of the trunk (Eisenmajer et al., 1996; Haas et al., 1996; Hallett et al., 1993; Kohen-Raz et al., 1992; Vilensky et al., 1981), have been noted, though some studies have reported no group differences in gait beyond that accounted for by cognitive level (Jones & Prior, 1985; Rapin, 1996). Balance and vestibular responding deficits were also often reported. In some studies these deficits have been

linked to impairments in visually perceiving environmental motion (Gepner & Mestre, 2002; Gepner et al., 1995). Ball play deficits have also been reported in children with ASDs (Manjiviona & Prior, 1995; Miyahara et al., 1997).

*Fine and Visual-Motor Skill.* Handedness has been an initial area of study relating to fine motor skill. A high prevalence (approximately 40%) of ambiguous or inconsistent handedness has been reported in individuals with autism (Fein, Humes, Kaplan, Lucci & Waterhouse, 1984; Hauck & Dewey, 2001; McManus, Murray, Doyle, & Baron-Cohen, 1982; Satz, Green, & Lyon, 1989; Satz, Soper, Orsini, Henry, & Zvi, 1985; Soper, Satz, Orsini, Henry, Zvi, & Schulman, 1986) in contrast to rates of the typically developing population (approximately 4%) (Gudmundson, 1993). An increased prevalence of left handedness in individuals with autism (approximately 15-20%) when compared to normally developing children (approximately 9%) has also been reported in the literature (Fein et al., 1984; Hauck & Dewey, 2001; McManus et al., 1982; Satz, Green & Lyon, 1989; Soper et al., 1986).

When engaged in fine-motor task performance, individuals with ASDs have demonstrated manual dexterity deficits on standardized measures (Hughes, 1996; Manjiviona & Prior, 1995; Miyahara et al., 1997). Further, while several investigations have reported slower speeds for timed pegboard completion (Cornish & McManus, 1996; Minshew, Goldstein, & Siegel, 1997; Rumsey & Hamburger, 1990; Szatmari, Tuff, Finlayson, & Bartolucci, 1990), others have reported no group differences (Ghaziuddin et al., 1992; McEvoy, Rogers, & Pennington, 1993). Motor learning has also been implicated, as increased difficulty with learning self-care and graphomotor tasks has also been described in the literature (Szatmari, Bartolucci, & Bremner, 1989; Szatmari et al., 1990). Better performance by children with autism on goal-directed motor performance has been noted in purposeful contexts than in non-purposeful conditions (e.g., reach, grasp, and placing activities) (Hughes & Russell, 1993; Rogers, Bennetto, McEvoy, & Pennington 1996).

Most of the above studies utilized methodologies employing control groups of individuals who were typically developing and/or developmentally disabled and cognitively matched. Though not universal, these findings generally describe patterns of postural and movement abnormality that are qualitatively different from those in individuals who are typically developing or with other developmental disorders. Further, the convergence of the evidence can

not be attributed solely to co-morbid cognitive impairments in autism (Haas et al., 1996; Minschew et al., 1997).

*Praxis.* In an effort to determine if motor deficits exist in autism and if so, the expression of these deficits, studies have employed methods primarily at the descriptive level. Given the extent and frequency of findings from a motor performance standpoint, it is necessary to begin to elucidate the potential causes for these deficits. Specifically, current motor findings beg the question: Do the deficits in autism reflect poorly planned movement and therefore deficits in motor planning (praxis), do the findings reflect deficits in motor execution, or do they reflect a combination? In an attempt to address these questions, a fair amount of investigation has examined motor planning/praxis. Praxis refers to the planning and performance of a motor movement/task or series of motor movements/tasks. The ability to plan, sequence, and execute a movement depends on adequate sensory integration of visual, proprioceptive, vestibular and tactile senses, and adequate ability to produce motor output (Lane et al., 2000).

In autism, praxis has most often been investigated within the framework of motor imitation studies and been found to be impaired in the majority of children with autism. In one large longitudinal study, imitation impairments were noted in more than 60 percent of the cohort (Rapin, 1996). Many investigative studies of praxis in children with autism have focused on motor imitation of body movements, facial expressions, gestures, and/or motor tasks (Dawson, Meltzoff, Osterling, & Rinaldi, 1998; Jones & Prior, 1985; Ohta, 1987; Rogers et al., 1996; Stone et al., 1990; Stone & Lemanek, 1990). When investigating motor imitation of hand and arm movements, individuals with autism performed poorer than cognitively matched controls and often only partially responded to modeled motor actions (Charman, Swettenham, & Baron-Cohen, 1997; Jones & Prior, 1985; Ohta, 1987). Oral-motor praxis deficits, including poor range of movement, isolation of movement, and impaired execution of movement were noted in children with autism following verbal and imitative prompts (Adams, 1998; Rapin, 1996). Similarly, Rogers et al. (1996) noted that individuals with autism demonstrated deficits in motor imitation on pantomime tasks using hand and facial movements. Stone and colleagues (1990) also analyzed imitation abilities for 12 motor tasks. Performance of 22 children with autism was compared to performance of groups of children with mental retardation ( $n=15$ ), hearing-impairments ( $n=15$ ), and language-impairments ( $n=19$ ), and children who had no disability ( $n=20$ ). Imitation skills of the children with autism were significantly lower than those of the

children in all the other groups and was the most important characteristic differentiating the children with autism from the others.

In another study investigating neuropsychological correlates of six early diagnostic symptoms in autism (Dawson, et al.,1998), imitation abilities of young children with autism were compared to those of developmentally matched groups of children with Down Syndrome or typical development. Here, analysis of both immediate and delayed imitation abilities involved a range of tasks including gestures that the subjects could see themselves perform (e.g., hand opening/closing), those that they could not see themselves perform (e.g., eye blinking, mouth postures), novel acts (e.g., touching elbow to a panel), and familiar acts (e.g., banging blocks). Imitation from a gestural model was accomplished in the immediate imitation condition, whereas tasks with objects were modeled and followed by a 10-minute interval to evaluate the delayed condition. Performance of children with autism was significantly poorer than that of the other two groups for both immediate and delayed imitation tasks. Of the six autism symptoms evaluated (social orienting, immediate imitation, delayed imitation, shared attention, response to distress, and symbolic play), only the immediate imitation domain was significantly related to the severity of autism symptoms in this sample.

Several authors have also theorized about and investigated factors impacting praxis. When evaluating task context, individuals with autism have had better performance and praxis for tasks with a purposeful context over non-purposeful contexts (Hughes & Russel, 1993; Rogers et al., 1996; Stone, Oulsey, Yoder, Hogan, & Hepburn 1997). Several studies have also investigated the impact of task complexity on motor planning. In at least one study (Minshew et al., 1997), individuals with autism were reported to have intact motor planning for simple motor tasks, but impaired praxis for complex motor tasks. Several other authors have described similar patterns and theorized that the difficulties with performance on complex motor tasks may instead reflect diminished ability to use external visual feedback that affects postural control, quality of movement, and motor sequencing (Bennetto, Pennington, & Rogers, 1999; Kohen-Raz et al., 1992; Smith & Bryson, 1998; Stone et al., 1990). Similarly, Dawson and Lew (1989) in an early theory formulation of autism etiology, proposed that the complex information processing demands inherent in social situations exceeded the capabilities of young child with autism, leading to impaired capacity to engage in social exchanges (including imitation).

Only one study could be found that attempted to differentiate between the praxis (movement preparation) and movement quality (movement execution) components of a motor task (Rinehart, Bradshaw, Brereton, & Tonge, 2001). In this study, movement preparation and execution were measured during a simple motor reprogramming task utilizing an odd-ball paradigm. Results indicated that high functioning children with autism (aged 5 to 19) had intact movement execution, but atypical movement preparation when compared with typically developing, cognitively matched controls. More specifically, the children with autism demonstrated a lack of anticipation during movement preparation phases and therefore required more time to respond. The authors questioned if both motivation and attention factors (i.e., sustained attention, shifting attention/executive function) may have confounded the results mimicking decreased task preparation.

*Potentially Related CNS Sites.* These motor performance deficits may relate to some of the neuropsychological findings of the cerebellum in ASDs (Huebner & Lane, 2001). In ASDs, differences in cerebellar structure have consisted of decreased numbers of Purkinje cells (transmission and integration cells), decreased size of cerebellar lobes, and differences in the size and number of neurons in the cerebellar nuclei (Bauman & Kemper, 1994; Haas et al., 1996). Although many authors agree that individuals with ASDs experience cerebellar dysfunction (Bauman & Kemper, 1994; Courchesne, Townsend & Saitoh, 1994; Haas et al., 1996; Waterhouse, Fein & Modahl, 1996), further research is needed to define patterns of cerebellar dysfunction in relationship to functional motor performance in ASDs. Further, in addition to cerebellar theories, several different brain regions that have been found to be dysfunctional in autism are thought to play a role in motor imitation. These brain regions include the medial-temporal lobe (amygdala, hippocampus), ventromedial prefrontal cortex, and the inferior parietal cortex (Dawson et al., 2002b).

*Summary.* There are fewer empirical studies about motor development in autism than other developmental areas (Baranek, 2002; Council, 2001). Though there is variability symptom expression and no clear patterns of motor dysfunction, the evidence does converge to confirm the existence of motor impairments for many individuals with an ASD (Baranek, 2002; Dawson & Watling, 2000). Further, these motor impairments can not be attributed solely to co-existing cognitive impairments in autism (Haas et al., 1996; Minshew et al., 1997). Impairments in neurodevelopmental components (i.e., tone, balance) and postural control that are essential for

the development of skilled movement are found. Motor control deficits are also cited in literature describe both gross and fine-motor functions. Further, limitations in functional performance have also been related to these findings. A growing body of literature describing the impairments in praxis in autism may provide insight into the foundation for these motor symptoms.

Deficits identified in these areas will diminish performance of gross motor and fine/visual-motor skill, but are also likely to influence other core features of autism. For example, praxis/imitation deficits could account for a number of symptoms in autism including lack of interpersonal relatedness, limited peer play and imitation, difficulties in developing expressive language, symbolic play deficits, and difficulties generating new behaviors (Rogers et al., 1996; Rogers, 1998).

These motoric symptoms often contribute to the understanding of the neurological theories of autism (e.g., Dawson et al., 2002b; Minshew et al., 1997; Vilensky et al., 1981; Waterhouse et al., 1996). For example, Vilensky and colleagues (1981) noted that a group of children with autism exhibited gait abnormalities (i.e., shortened stride) resembling those seen in Parkinson's disease, implicating dysfunction in the basal ganglia. In another example, executive function (e.g., goal-directed behavior, cognitive flexibility and shifting, working memory) deficits and attention control deficits that have been described in autism (Minshew et al., 1997) leading some to implicate the frontal cortical functioning. Executive function deficits attributed to functioning of the frontal lobe have also been hypothesized to be components of the neuropsychological profile for individuals with autism. Specifically, the ventromedial prefrontal cortex is hypothesized to be the potential foundation for many of the core social deficits (i.e., joint attention, shared enjoyment) seen in young children with autism (Dawson et al., 2002a; Rogers, 1998), while the dorsolateral prefrontal cortex is thought to contribute to impairments in imitation ability also impacting social skill development (Dawson, 2002b; Dawson, et al., 1998; Rogers, 1998). These studies are only a few of the many of investigations attempting to define brain-behavior relationships in autism. Together, continued collaborative research at both the clinical and basic science levels may provide a better understanding of the neural basis and brain phenotype of this disorder (Bailey et al., 1996; Cody et al., 2002) and allow for better management of symptoms of the autistic disorder.



## Sensory Processing

Although sensory processing and sensory integration are terms often used synonymously in the occupational therapy literature, sensory integration is only one component of sensory processing. Sensory processing is a broad term that refers to the way in which the central and peripheral nervous systems manage incoming information from the senses (Lane et al., 2000). Additionally, occupational therapy practitioners also have a tradition of adopting terms from the neuroscience literature and loosely adapting them in ways that we believe reflect behavior (Miller & Lane, 2000). The neuroscience literature generally presents material at the level of processes and neural mechanisms, whereas the occupational therapy literature generally conveys information at the level of experience or behavior. Given this overlap in terminology, both fields describe and provide evidence of impaired sensory processing in autism (Adrien, Ornitz, Barthelemy, Sauvage, & Lelord, 1987; Baranek, 1999; Courchesne, Lincoln, Kilman, & Galambos, 1985; Courchesne, Lincoln, Yeung-Courchesne, Elmasian, & Grillon, 1989; Dahlgren & Gillberg, 1989; Kientz & Dunn, 1997; Ornitz, 1989; Ornitz et al., 1993; Osterling & Dawson, 1994; Rapin, 1991). Consequently, the review here will relate to both reported behavioral and neuropsychological findings of sensory processing in autism.

### Descriptive Behavioral Studies

The majority of evidence describing behavioral sensory responding stems from parental reports, retrospective video tape analysis, and firsthand accounts of living with autism. Findings will be organized and presented by studies reporting general abnormal responding and modulation of sensory input (including firsthand accounts and descriptive studies of sensory processing) and studies using sensory processing as a discriminative function between children with autism and those with other developmental disorders.

*Abnormal Sensory Responding.* Global impairments with modulating and responding to incoming sensory input have been widely reported in the literature describing the behavioral patterns and characteristics of autism (Adrien et al., 1987, 1992, 1993; Baranek, 1999; Dahlgren & Gillberg, 1989; Kientz & Dunn, 1997; Ornitz, 1989; Ornitz et al., 1993; Osterling & Dawson, 1994; Rapin, 1991). Additionally, these difficulties have been reported by individuals with autism themselves (Cesaroni & Garber, 1991; Grandin, 1992; Williams, 1995). Rates of unusual sensory responding (e.g., hypo or hyper-responding to incoming sensory input, paradoxical responding to sensory stimuli, unusual sensory interests, motor stereotypies) reported in the

autism literature range from 42% to 88% by some authors (Baranek, 2002; Kientz & Dunn, 1997; LeCouteur et al., 1989; Volkmar, Cohen, & Paul, 1986; Watling et al., 2001) to 30 to 100% by others (Dawson & Watling, 2000). Behaviors noted in these investigations involve multiple sensory systems.

Differences in *auditory processing* are one of the more commonly reported sensory processing impairments with the full range of atypical responding noted. Some investigations have noted auditory processing differences, with hyper-responding (Bettison, 1994), hypo-responding (Baranek, 1999; Osterling & Dawson, 1994) and fluctuating responding (Rapin, 1991) exhibited by individuals. In one retrospective chart review of developmental patterns in 200 cases with autism, Greenspan and Weider (1997) reported that 100% of the subjects demonstrated difficulties with auditory responding. Several authors have reported auditory hypersensitivity (Bettison, 1994; Dahlgren & Gillberg, 1989; Gillberg & Coleman, 1996; Grandin & Scariano, 1986; Rimland & Edelson, 1995; Vicker, 1993). In another survey of 233 parents of children with autism (Vicker, 1993), 134 (57.5%) of the parents reported that their children were sensitive to sound, with many of these sensitivities to everyday environmental noises. Similarly, of over 17,000 children with autism seen at the Autism Research Institute (Rimland & Edelson, 1995), approximately 40% were reported to have symptoms of sound sensitivity on its Diagnostic Questionnaire Form E-2. Further, Dahlgren and Gillberg (1989) found that sensitivity to auditory stimuli in infancy was a powerful discriminator between children with and without autism. In her book, *Emergence, Labeled Autistic* (Grandin & Scariano, 1986), Grandin, a well known professor and individual with autism, speaks openly about her sound sensitivity and its impact on her behavior. She describes a pattern of social withdrawal in response to loud noises as an attempt to shut out the noise.

Auditory hypo-reactivity has also been reported in the literature (Baranek, 1999; Osterling & Dawson, 1994; Wing, 1966). While some investigations have reported diminished response to name (Baranek, 1999; Osterling & Dawson, 1994), others have reported decreased responding to not only verbal but general noise as well (Wing, 1966). This hyporeactivity has been an early diagnostic consideration in that many children who have appeared to be deaf early in life have subsequently been diagnosed with autism (Wing, 1966).

Paradoxical *visual* responding is also reported in the literature. Avoidance of eye contact and inefficient use of eye gaze have been described as early features of autism (Baranek, 1999;

Gillberg & Coleman, 2000; Gillberg et al., 1990; Kientz & Dunn, 1997). These difficulties are often classified in the category of social abnormalities, however several authors (Dawson & Lew, 1989; Gillberg & Coleman, 2000; Gillberg et al., 1990; Miller, 1996; Wing, 1980) have explained diminished eye contact as a self-regulatory mechanism that compensates for difficulties with modulating visual input and consequently are best categorized in the context of abnormal sensory responding. Other studies have reported children with autism to have unusual visual inspection of objects (i.e., fingers, moving objects) (LeCouteur et al., 1989; Lord, Rutter, & LeCouteur, 1994).

Hyper-responsivity to *tactile* input has also been reported in the literature (Baranek, Foster, & Berkson, 1997; Cesaroni & Garber, 1991; Grandin, 1995). In firsthand accounts, touch has been described as not necessarily painful, but rather as an intense feeling that can be overwhelming and confusing (Cesaroni & Garber, 1991). Similarly, Grandin (1995) described the impact of touch on her overall emotional state. For example, certain clothing textures would make her extremely anxious, distracted and fidgety. Tactile hypersensitivity has also been investigated in relation to stereotypic behavior (Baranek et al., 1997). Children with autism in this study that had higher levels of tactile hypersensitivity were also more likely to display rigid or inflexible behaviors, repetitive verbalizations, visual stereotypies, and abnormal focused affection. These same behaviors are often associated with early diagnostic symptoms of autism.

Attention and arousal impairments have also been reported (Dawson & Lew, 1989; Ornitz, Guthrie, & Farley, 1977, 1978; Rapin, 1991; Volkmar et al., 1986) and could be explained as relating to impairments in modulating sensory input. Early studies by Ornitz and colleagues (1977, 1978) described a pattern of “disturbances in sensory modulation and motility” following parental report on a developmental inventory. These disturbances were noted to impact all sensory systems in over 70% of the children with autism in their samples under the age of 6 years. These findings were replicated in another sample using children with the same developmental profile (Volkmar et al., 1986). Clusters of unusual sensory and motor behaviors in this study included no response to sound (81%), increased sensitivity to loud noises (53%), visual inspection of hands or fingers (62%), and arm flapping (52%)

Sensory processing behaviors of children aged 3 to 6 years with (n=40) and without (n=40) autism gathered via parent report on the Sensory Profile (SP) (Dunn, 1999), were compared in another study (Watling, Deitz, & White, 2001). The performance of children with

autism was significantly different from that of children without autism on 8 of 10 factors. Factor differences were found for Sensory Seeking (i.e., movement, touch), Emotionally Reactive (i.e., poor coping and variability in emotional responding), Low Endurance/Tone (i.e., muscle weakness), Oral Sensitivity (i.e., picky eater, texture preferences for food), Inattention/Distractibility (i.e., auditory distractibility, hyperactivity, short attention), Poor Registration (i.e., hypo- or hyper-responsivity to sensory stimuli), Fine-Motor/Perceptual (i.e., writing and coloring concerns), and Other. Similarly, children with autism (n=143) in another study were reported to present with a variety of sensory processing difficulties on the Somatosensory Disturbance Subscale of the *Checklist for Autism in Young Children* (Mayes & Calhoun, 1999). One hundred percent of the children in this sample had one or more of the 10 symptoms in this category, with an average of 6.2 symptoms. Almost all (91%) had a love of movement and rough house play, tickling, and climbing. Atypical feeding patterns were noted in 75% of the sample. Many (71%) were unresponsive to verbal input and displayed unusual sensory inspection of objects (68%). The remaining characteristics were found in about half of the sample: covers ears to certain stimuli (59%), sleep disturbance (54%), tactile defensiveness (47%), fascination with visual stimuli (47%), high tolerance for pain (44%), and distress in crowds (43%).

*Discriminative Function of Sensory Processing.* Empirical data from clinical evaluations (Adrien et al., 1987; Gillberg et al., 1990), parent report measures (Dahlgren & Gillberg, 1989; Ermer & Dunn, 1998; Gillberg et al., 1990; Hoshino, Kumashiro, Yashima, Tachibana, Watanabe, & Furukawa, 1982; Kientz & Dunn, 1997; Watling, Deitz & White, 2001), and retrospective video analysis (Baranek, 1999; Adrien et al., 1992, 1993) are emerging to suggest that behavioral features of children with autism attributed to sensory processing differ qualitatively from children with other developmental disorders and in typically developing children. These qualitative differences in sensory processing behavior have frequently been key features discriminating between children with autism and children with other disabilities and/or typically developing. Rather than solely establishing group differences, studies reviewed here have included discriminative analysis as a component of the study methods.

Adrien and colleagues (1987) utilized observations and frequency counts of behaviors during a structured play session to differentiate between normal children, children with mental retardation, and children with autism and very low developmental ages. Although many

behaviors overlapped between the groups, nine behaviors (rubbing surface, finger flicking, body rocking, repetitive jumping, decreased eye contact, limited or inappropriate social smile and laugh, using object ritualistically, ignoring objects, and absent response to stimuli) discriminated children with autism from both normal children and children with mental retardation. These behavioral patterns might be interpreted as demonstrating hypo-responsiveness to input with sensory seeking or hyper-responsiveness to input with sensory avoidance. These findings were replicated by Rapin (1996) who found a pattern of atypical sensory modulation and motor stereotypies discriminated children with autism from children with other developmental disorders including mental retardation.

*Parent Report.* Some data suggest that early sensory processing abnormalities noted on parent report measures and/or interview may be among the first signs of autism (Dahlgren & Gillberg, 1989; Gillberg et al., 1990; Hoshino et al., 1982). In an early study (Hoshino et al., 1982), infants with autism did not respond to certain sounds, displayed hypersensitivity to food taste, and were insensitive to pain more frequently than typical infants or infants with other developmental disorders. More recently, sensory processing differences (i.e., overexcited when tickled, difficulties imitating movements, does not listen when spoken to, exceptionally interested in looking at things that move, unusual eye gaze to objects, plays with only hard objects) reported retrospectively by parents discriminated between children with ASDs and typical children under three years of age (Dahlgren & Gillberg, 1989; Gillberg et al., 1990). When considered together, the “abnormal responses to sensory stimuli” class of symptoms most clearly distinguished autism from mental retardation. Still further, hand and finger mannerisms, whole body mannerisms (other than rocking), and unusual sensory interests (especially visual inspection of objects), as recorded on the Autism Diagnostic Interview, discriminated children with autism from those with other developmental delays (LeCouteur et al., 1989; Lord et al., 1994).

Some studies (Ermer & Dunn, 1998; Kientz & Dunn, 1997) have investigated sensory processing using the *Sensory Profile (SP)* (Dunn, 1999; Dunn, 1994; Dunn & Westman, 1997;). Kientz and Dunn (1997) used scores on the *SP* in its test development phase to determine if these scores discriminated between children with autism (n=32) and without autism (n=64) and which items best discriminated between the groups. Although no significant between-group differences were noted on items when comparing the sub-groups of children with varying degrees of autism,

multivariate analysis showed that children with autism performed differently than children without autism on all categories of the *SP*. Furthermore, 84 of the 99 items (85%) in all categories differentiated the sensory processing skills of subjects with autism from those without autism. Items with the greatest frequencies in the group of children with autism included: is distracted or has trouble functioning if there is a lot of noise around, enjoys strange noise/looks for noise for noise's sake, has trouble staying between lines when coloring, avoids eye contact, shows preferences for certain tastes, continually seeks out movement activities, expresses discomfort during grooming, picky eater, has difficulty standing in line or close to other people, always on the go, difficulty paying attention, needs more protection from life than other children, has trouble "growing up", has difficulty tolerating changes in plans and expectations, is stubborn and uncooperative, poor frustration tolerance, and has difficulty making friends. As can be seen by analyzing these items, they reflect both sensory modulation and praxis deficits in autism, and the social and behavior characteristics often utilized in differential diagnosis.

In a follow-up study, Ermer and Dunn (1998) sought to determine which of the nine factors on the *SP* best discriminated between children with autism or pervasive developmental disorder (PDD) ( $n=38$ ), children with attention deficit hyperactivity disorder (ADHD) ( $n=61$ ), and children without disabilities ( $n=1,075$ ). The results yielded two discriminant functions: one that differentiated children with disabilities from children without disabilities and another that differentiated the two groups with disabilities from each other. Nearly 90% of the cases were classified correctly using these two functions. Specific to children with autism/PDD, 4 of the 9 factors were the best discriminators. The factors were: Sensory Seeking, Oral Sensitivity, Inattention/Distractibility, and Fine Motor/Perceptual, with a low incidence of behaviors reported within the Sensory Seeking factor and a high incidence of behaviors noted within the other factors.

A recent study (Rogers, Hepburn, & Wehner, 2003) assessed parent report of sensory reactivity of 102 young children across four groups: autism ( $n=26$ ), fragile X syndrome ( $n=20$ ), developmental disabilities of mixed etiology ( $n=32$ ), and typically developing children ( $n=24$ ). All groups were comparable in socioeconomic status, ethnic status, and overall mental age, and clinical groups were comparable in mean chronologic ages. Each subject participated in a diagnostic assessment battery to establish a definitive diagnosis and obtain levels of cognitive

functioning and sensory processing. Parent report on the *SSP* (Dunn, 1999) was used as the standard measure of sensory processing. Findings indicated that both children with fragile X syndrome and children with autism had significantly more sensory symptoms overall than the two comparison groups, though the children with autism did not differ significantly from children with fragile X syndrome. Both groups were more impaired than the developmentally delayed and typical developing children in auditory filtering and tactile sensitivity. Correlation analysis did not establish a relationship between developmental level or intelligence quotient (IQ) and sensory reactivity in children with autism or general developmental disorders. However, abnormal sensory reactivity had a significant relationship with overall adaptive behavior. No meaningful relationships were noted between sensory processing and social-communication scores on the *Autism Diagnostic Interview* (Lord et al., 1994) or *Autism Diagnostic Observation Schedule* (Lord, Rutter, DiLavore, & Risi, 1999).

*Video Analysis.* Other investigations have utilized retrospective video analysis to explore early sensory and motor features of children later diagnosed with autism (Adrien et al., 1992, 1993; Baranek, 1999; Osterling & Dawson, 1994; Werner, Dawson, Osterling & Dinno, 2000). Stereotypic behaviors, under and over responsiveness to auditory input, unusual postures, and unstable visual attention were found to be characteristic of infants later diagnosed with autism when compared to those of with other developmental disorders or with typical children (Adrien et al., 1992, 1993). These autistic behavioral features were observed during the first year of life and were noted to persist into the second year of life.

Baranek (1999) utilized retrospective videotape analysis to explore the predictive capability of sensorimotor observations of the sensory and social behavior of children 9 to 12 months of age who were later diagnosed with autism. She found that sensorimotor findings of social touch aversion, excessive mouthing of objects, as well as delayed response to name and decreased affect rating were found to be subtle yet salient predictors at 9-12 months of a subsequent autism diagnosis. These items also discriminated between children with autism ( $n=11$ ), children with developmental disabilities ( $n=10$ ), and typically developing children ( $n=11$ ). Although the above studies noted sensorimotor findings that distinguished children later diagnosed with autism, other researchers also using retrospective videotape analysis have not found early sensorimotor abnormalities in children with ASDs (Osterling & Dawson, 1994; Werner, et al., 2000).

*Potentially Related CNS Sites.* Many CNS structures are involved in this process of sensory processing. For example, the brainstem is involved in the maintenance of arousal and attention that directly influence sensory detection, processing and sensory modulation. In autism, differences in brainstem functioning have been implicated in delayed startle modulation (Ornitz, Lane, Sugiyama, & de Traversay, 1993) and differences in visual and/or auditory event related potentials (Ciesielski, Courchesne, & Elmasian, 1990; Lincoln, et al., 1993; Wong & Wong, 1991). Reduced cell size, fewer cell numbers, and increased cell density in the medial-temporal lobe (including the amygdala and hippocampus) have been described in autopsy studies of individuals with autism (Bauman & Kemper, 1994). These areas are thought to play a key role in representational memory; these authors then theorized that dysfunctional representational memory results in an insistence on sameness as seen in autism. In the context of sensory processing, representational memory impairments, previously experienced sensations in a different context/setting may be perceived as novel and result in hyper-responsiveness. Similarly, in an integrated review of neuropsychological findings in autism, Waterhouse and colleagues (1996) outlined four primary deficits in autism. One of these dysfunctions (calanesthesia) related to fragmented cross-modal information processing. Here, sensory experiences are inconsistently experienced and integrated, resulting in splintered sensory awareness and responding. Other authors have noted additional neuropsychological influences on sensory processing, notably the contributing roles of the cerebellum in sensory modulation (Bauman, 1999) and executive functions (Happe & Frith, 1996) in working memory and shifting attention. Given the impact of multiple contributions from various CNS centers, several authors have described a general pattern of dysfunctional information processing in autism rather than specific sensory processing deficits (Bauman, 1999; Ornitz, 1989).

*Summary.* The above research begins to describe the prevalence and manifestations of sensorimotor impairments in autism. Together, these findings indicate that most children with autism demonstrate sensory processing difficulties at some point in early development, though the pattern or cluster(s) of symptoms are inconsistently described. To some degree, the integrity of the findings is restricted because of methodological limitations present in the research such as the lack of consistency in the age of the samples, sampling methods, sensory processing measures, and the very limited attempts at replication. Most studies have employed relatively small sample sizes, compromising the validity of their findings, and most investigations failed to utilize



cognitively-matched controls. Several authors feel that the behavioral manifestations of dysfunctional sensory processing in autism are merely a product of the comorbid mental retardation and are not a unique feature of autism (Siegel, 1996; Volmar, Klin, Marans, & Cohen, 1997). Consequently, until well controlled longitudinal studies with appropriate sampling procedures are conducted, this discourse will continue.

### Neurophysiologic Measures of Sensory Processing

Studies investigating sensory processing at a neurophysiologic level are both less abundant and less current than studies of behavioral sensory processing. Some of the above described sensorimotor behaviors seen in autism have been thought to stem from problems with arousal modulation or habituation (Baranek, 2001; Dawson et al., 2002b; Ornitz, 1974) that result in withdrawal, rejection, or lack of response to sensory stimuli. Investigations have utilized blood pressure, heart rate, peripheral blood flow, and peripheral vascular resistance (PVR) as physiologic measures of arousal and responsivity to sensory input. Children with autism have been shown to demonstrate physiological overarousal to new events as indicated by increased heart rate (James & Barry, 1984; Kinsbourne, 1987; Kootz, Marinelli, & Cohen, 1982). Given this, individuals with autism may be more sensitive to environmental changes. These investigations also found individuals with autism to have slower rates of habituation. Further, individuals with autism were described as having difficulty filtering and modulating responses to novelty and demonstrated a pattern of sensory rejection of external stimuli that was associated with higher levels of arousal on measures of blood pressure, heart rate, and PVR (Kootz et al., 1982). These difficulties were the greatest in the children who were lower functioning. Other studies, in contrast, have not found evidence of overarousal, but instead have found underarousal to social contact (James & Barry, 1980; Corona, Dissanayake, Arbelle, Wellington, & Sigman, 1998).

Neurophysiologic measurement of sensory processing has centered on the auditory system. A few studies have utilized measurements of electrodermal reactivity (EDR) as a physiologic marker of sensory responsivity to auditory input (Bernal & Miller, 1970; Stevens & Gruzelier, 1984; van Engeland, 1984). Although hyperreactive sensory responding on EDR has been reported (Bernal & Miller, 1970; Stevens & Gruzelier, 1984), another study reported non-responding (van Engeland, 1984).

One focus of these investigations has centered on N1 components of auditory evoked response potentials (ERPs). The N1 is the first component of a long latency auditory response that occurs between 80 and 200 ms after stimulus onset. Actually, two negative waves are recorded and they differ in both peak latency and scalp region (Bruneau, Roux, Adrien, & Barthelemy, 1999). The first peak (N1b) culminates at fronto-central sites at around 100 ms post stimulus onset and the second culminates approximately 30 ms later at bitemporal sites. These N1 waves are thought to reflect basic auditory sensory processing and have the advantage of not being dependent on an overt response (Seri, Cerquiglioni, Pisani, & Curatolo, 1999). Therefore, they are suitable measures for use in studies of persons with minimal compliance.

Investigation of N1 in autism has centered primarily on the N1b peak; conflicting findings have been noted. In several studies, individuals with autism demonstrated a significantly prolonged latency and decreased amplitude of this N1 component (Courchesne et al., 1985; Courchesne et al., 1989; Oades, Walker, & Geffen, 1988; Seri et al., 1999). In other investigations, although differences did not reach statistical significance between individuals with autism and controls, the N1b component was found to be smaller than normal in the autism groups (Courchesne, Kilman, Galambos, & Lincoln, 1984; Kemner, Verbaten, Cuperus, Camfferman, & van Engeland, 1995; Lincoln, et al., 1995).

In one other study, Bruneau and colleagues (1999) compared both N1b and N1c amplitudes to auditory stimuli of differing intensity between children with autism, age-matched children with mental retardation, and normal children. While differences were not noted between the groups on N1b, significant differences were noted with respect to N1c. The autism group demonstrated abnormalities in this wave with markedly small amplitudes and pronounced peak latency delay.

Measurement of the P300 component of auditory ERPs has also been a focus of investigation. This P300 component is most often elicited using an odd-ball paradigm and is felt to be responsible for memory updating of novel stimuli and therefore also plays a role in directing attention. Similar to the N1 findings, lower P300 amplitudes have also been consistently reported in individuals with autism (Courchesne, et al., 1984; Courchesne, et al., 1985; Courchesne, et al., 1989; Niwa, Ohta, & Yamazaki, 1983).

*Summary.* As can be seen by the above review, neurophysiologic evidence of sensory processing is limited and outdated. This is not shocking given the difficulties that many persons

with autism encounter in tolerating the study methods. Findings that are available relate primarily to processing and responding to auditory input with significant variability in responding noted. Inconsistent patterns without a definitive neurophysiologic marker has been identified. Further, one investigation has concluded that noted differences in responding from their sample could be accounted for solely by cognitive limitations (Kootz & Cohen, 1981).

### Linking Behavioral and Neurophysiologic Measures of Sensory Processing

To date, only one study could be located that attempted to link behavioral and neurophysiologic measures of sensory processing (Miller, Reisman, McIntosh, & Simon, 2001). This study investigated the presence of sensory modulation dysfunction in small cohorts of children with autism (n=8), fragile X syndrome (n=23), attention deficit disorder (n=40) and typical children (n=46). Specific to the children with in the autism sample, the purpose of the study was to investigate differences in children among the different disorders, as well as investigate the relationships between measures of sensory modulation dysfunction and measures of potentially co-existing attention and emotional problems and compared the findings of the children with autism to the typically developing sample. Neurophysiologic measurement of sensation was gathered using a laboratory procedure that gauges responses to repeated sensory stimulation by measuring EDR. Parent report measures were utilized to gather behavioral sensory processing (*SSP*) and social-emotional dimensions (*Child Behavior Checklist [CBCL]* and *Leiter-Revised*). Findings indicated that the children with autism are physiologically under-reactive to sensation in that they demonstrated a depressed magnitude of EDR when compared to the typical and all of the other clinical groups. This finding is consistent with that previously reported by van Engeland (1984), though is not consistent with others reporting hyper-responsivity (Bernal & Miller, 1970; Stevens & Gruzelier, 1984). In contrast to these findings, behavioral measures of sensory processing on the *SSP* (Dunn, 1999), indicated severe sensory over-responsivity in the Tactile Sensitivity and Taste/Smell categories and moderate hypersensitivities in Movement and Visual/Auditory subtests. Significant emotional over-responsivity was also reported on the *CBCL* and *Leiter-Revised*, with particular problems noted with thought processes, adaptation, socialization, and withdrawn/depressed behaviors. Attention was moderately impaired, but less than sensory and emotional responding. The authors (Miller et al., 2001) conclude that the deficient sensory responsivity noted both neurophysiologically and behaviorally in autism likely impact emotional responding and the ability of individuals to

sustain attention. If so, previously described sensory processing difficulties found early in development may play a key role in the development of social-emotional responding in autism. However, given the small sample size and failure to cognitively match, caution should be exercised to avoid over interpreting these findings.

### Summary

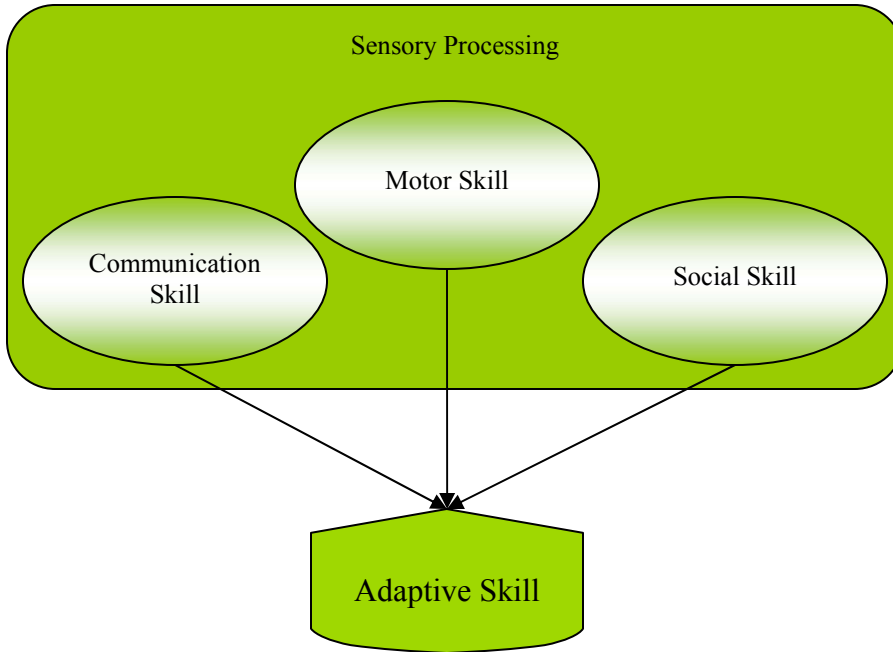
The above review of motor performance and sensory processing findings in ASDs from basic science, clinical, and laboratory investigations, as well as firsthand accounts of living with autism converge to confirm the presence of motor performance and sensory processing difficulties for most individuals with autism at some point in development. Although these findings provide some clarification as to the prevalence of motor and sensory processing impairments in autism, they fail to describe definitive patterns of sensorimotor performance given the significant variability in symptoms. To some degree the lack of consistency in findings likely also reflects the significant variability in research questions and methods used in this line of study. What should also be evident is the lack of consistency among these studies in the size and ages of their samples, method(s) of measurement, and lack of replication. No study investigating sensory processing in individuals with an ASD has included more than 40 subjects in the autism group, with the majority including less than 20. Previous research has also been limited by multiple deficiencies in sampling procedures (e.g., non-cognitively matched samples, samples of convenience).

So while the current state of sensorimotor research fails to identify specific patterns of motor performance and sensory processing in autism, it does begin to describe the prevalence and types of symptoms demonstrated. Additionally, these findings provide direction for future investigation. Because this is a newer area of study in comparison to other developmental areas in autism (Baranek, 2002; Filipek et al., 1999), the above reviewed evidence likely represent global findings at the ground level in a line of research. Similar to other developmental areas in autism, initial theories and findings are often more global and later shown to be inaccurate or to only partially appropriate in explaining the disorder. As the research design improves, the findings and nomenclature tend to be more specific and amenable to replication. Consider, for example, echolalia in autism. Kanner (1943, 1946), in his initial writings defining infantile autism, meticulously described examples of immediate and delayed echolalia in language functions and speculated on its probable functions. This work was not pursued for much of the following four

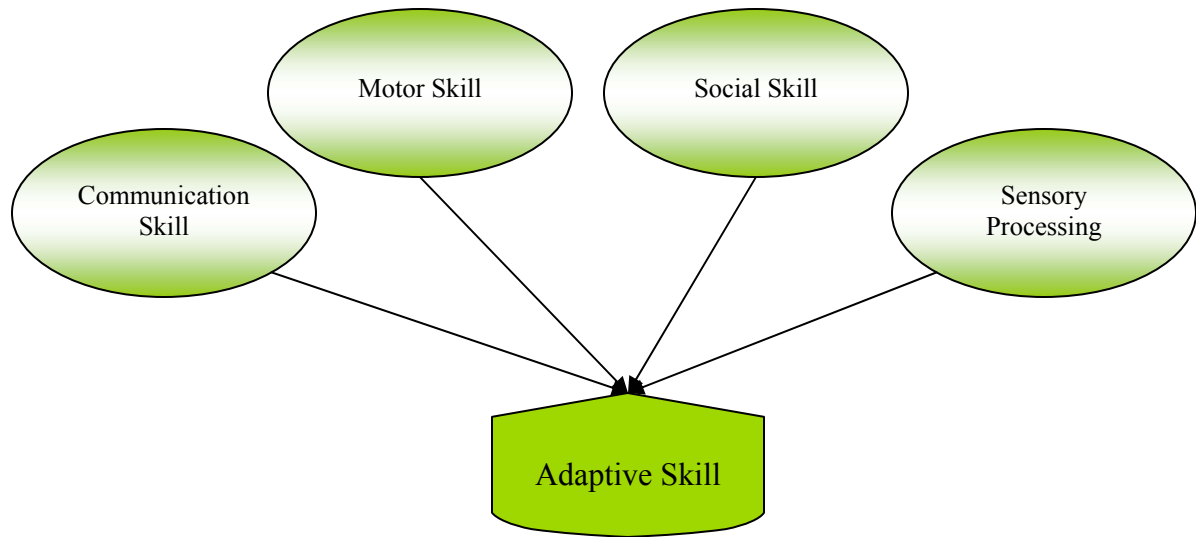
decades and instead, echolalia was seen as self-stimulatory behavior that lacked a language function and therefore was to be eliminated to allow more appropriate forms of language to be acquired (Lovaas, 1977; Lovaas, Koegel, Simmons, & Long, 1973; Lovaas, Litrownik, Mann, 1971; Schopler & Mesibov, 1985). Subsequent investigation by Prizant and colleagues (Prizant, 1983; Prizant & Rydell, 1984; Shuler & Prizant, 1985) has dramatically altered the view of echolalia. These works have identified seven functional categories of immediate echolalia and 20 of delayed echolalia. Of these, 13 (four immediate, nine delayed) are interactive in nature and serve definite communicative functions. This line of research identified the need to understand echolalia along a three-way continuum of intentionality, conventionality, and communicativeness (Prizant & Wetherby, 1989). These insights continue to have a significant impact on both assessment and intervention practices (Prizant, Wetherby, & Rydell, 2000).

With this caveat then, research is needed to expand our understanding of sensorimotor aspects of autism and determine the relevance of these findings on the variable developmental presentation of individuals with autism. This research must investigate motor performance and sensory processing in tandem, and must also scaffold these areas with other developmental and diagnostic indicators. Doing so will allow for the development of potential models that investigate the relationship of sensory processing to these developmental variables and the pooled impact on adaptive functioning. For instance, the investigation proposed in this project may provide insight into two such potential models (See Figures 1 and 2). In Figure 1, developmental communication, motor, and social variables are considered with in the context of adequate sensory processing. In this model, developmental functioning is dependent on adequate sensory processing functioning. In turn, the relationship between these variables contribute to the relative adaptive functioning of individuals. In Figure 2, however, sensory processing is considered a component developmental variable contributing with the other developmental variables to relative adaptive functioning.

Interpretation of the findings from this study will serve as a mechanism to understand the complex behavior of individuals with an ASD and have implications for early diagnosis and intervention. The findings may also differentiate groups of people with autism by sensorimotor pattern to investigate differential responding to various interventions (Huebner & Dunn, 2001). The findings then, will not only expand our understanding of autism, but also have the potential for contributing to the best practices for intervention with individuals with autism.



*Figure 1.* Developmental variables in the context of sensory processing.



*Figure 2.* Sensory processing as a developmental variable.

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## CHAPTER 3

### METHODOLOGY

This study utilized a retrospective chart review data collection for 400 children between the ages of 3 and 6 years diagnosed with an ASD. The chapter fully outlines the methodology used in this study.

#### Pilot Study Design

To initiate study of the research questions, pilot the methodology, and assist with the design of this study, data were collected from a retrospective chart review on 50 children diagnosed with an ASD at the Weisskopf Child Evaluation Center (WCEC) at the University of Louisville from January through October of 2001 (Tomchek & Huebner, 2002). Individuals referred for evaluation because of suspected autism receive comprehensive medical, psychological, speech and language and occupational therapy evaluations. The resultant data from the diagnostic and developmental measures were collected for analysis. An objective of this pilot was to explore all the available data to determine which variables were most complete and informative.

Charts were reviewed to extract specific social, neurodevelopmental, and medical/neurological variables relating to the diagnostic evaluation process. Social variables included information on the family structure, current living situation, and parent concerns. Neurodevelopmental variables (see Table 2) included measures of adaptive performance, intelligence (cognition), communication (receptive and expressive) ability, and motor performance (fine and visual-motor). In addition, the *SSP* (Dunn, 1999) was used to gather information on the sensory processing status of the individual. From a medical/neurological standpoint, growth measurements (height, weight, head circumference, and respective percentile ranks), handedness, dysmorphias, and neurological findings (muscle tone, strength, balance) were included.

Scheduling registries of children participating in autism diagnostic team evaluations were reviewed to identify potential subjects for the pilot study. Subjects between the ages of 3 and 8 years were included in the data set if the evaluation process yielded an autism spectrum diagnosis and complete diagnostic and developmental measures outlined in Table 2. Enrollment started with evaluations conducted in October 2001 and preceded back until complete data was collected on 50 subjects. Of the 50 subjects in the sample, 44 were male and 6 were female.



Table 2

## Neurodevelopmental Variables and Measures

Variable	Measure(s)	Procedure	Data Point
Cognition (IQ Estimate)	<i>Differential Abilities Scale</i>	Standardized administration and scoring	Standard score
	<i>Stanford Binet (Fourth Edition)</i>	Standardized administration and scoring	Standard score
	<i>Self-help/Adaptive Measure (Developmental Profile II or Vineland)</i>	Structured interview administration and scoring per manual to obtain developmental age. Converted to a standard score with a mean of 100 after determining percent of delay.	Extrapolated standard score
Expressive Language	<i>Rosetti Infant-Toddler Scale</i>	Structured interview and observation per manual	Developmental age in months
Receptive Language	<i>Rosetti Infant-Toddler Scale</i>	Structured interview and observation per manual	Developmental age in months
Motor Skill (Fine)	<i>Peabody Developmental Motor Scales – Visual-Motor Control Scale</i>	Standardized administration and scoring	Developmental age in months
Sensory Processing	<i>Short Sensory Profile</i>	Standardized administration and scoring	Profile total raw score

This ratio is close to the reported 4:1 boy to girl ratio in ASDs (Fombonne, 2003, 1999). Subjects ranged in age from 3 years, 3 months to 6 years, 8 months, with a mean age of 4 years, 5 months. The mean intelligence general estimate from cognitive measures was 60.43. Thirty-six of the individuals (72%) had a diagnosis of autism, with the remaining 14 (28%) diagnosed with Pervasive Developmental Disorder – Not Otherwise Specified.

Findings indicated that 70% (n=35) of the subjects were reported to have definite differences in sensory processing for the *SSP* total score in comparison to individuals in the standardization sample without disabilities. Sensory processing sections of the *SSP* that yielded the highest reported definite differences included: Under-responsive/seeking sensation (70%, n=38), auditory filtering (68%, n=34), taste and smell sensitivity (52%, n=26), touch sensitivity (50%, n=25), and visual and auditory sensitivity (38%, n=19). In analyzing items in the under-responsive/seeking sensation (i.e., seeks all kinds of movement and this interferes with daily routine, overly excitable during movement, touches people and objects, jumps from one activity to another) and auditory filtering (i.e., distracted or has trouble functioning if there is background noise, appear to not hear what you say, doesn't respond to name, difficulty paying attention) sections, difficulties largely reflect impairments with sustained attention. Given the importance of attention for meaningful active engagement in tasks and with others, these preliminary findings demonstrate the potential relationship between sensory processing findings and the development of active engagement for children with autism.

Correlation analysis revealed statistically significant relationships ( $p < .05$ ) between the under-responsive/seeking sensation difficulties and developmental measures of IQ, adaptive functioning, language expression and comprehension, and motor functioning. Similarly, statistically significant relationships ( $p < .05$ ) were noted between auditory filtering findings and developmental measures of IQ and adaptive functioning.

Descriptive statistics for the receptive language, expressive language, fine and visual-motor skill, sensory processing total score on the *SSP* dependent variables by functioning level can be seen in Table 3.

The 49 subjects were classified based on cognitive ability as high (IQ general estimate  $\geq 80$ ; n=6), moderate (IQ general estimate 60-79; n=17) or low functioning (IQ general estimate  $< 60$ ; n=26). A multivariate analysis of variance (MANOVA) with functioning level as the independent variables and receptive language, expressive language, fine and visual-motor skill,

Table 3

## Descriptive Statistics of Developmental Measures by Level of Functioning

Variable	Functioning	Mean	SD	N
SSP Total Score	Low	166.04	21.19	26
	Moderate	139.24	21.04	17
	High	128.50	30.55	6
	Total	152.14	154.51	49
Language Comprehension Developmental Age in Months	Low	14.96	9.57	26
	Moderate	25.06	13.38	17
	High	32.00	4.43	6
	Total	20.55	12.25	49
Language Expression Developmental Age in Months	Low	15.65	9.75	26
	Moderate	22.59	9.92	17
	High	32.83	11.96	6
	Total	20.16	11.42	49
Fine-Motor Developmental Age in Months	Low	26.65	10.84	26
	Moderate	33.71	11.32	17
	High	45.00	15.70	6
	Total	31.35	12.92	49

*Note.* One subject was excluded from analysis because of a missing data point on the fine-motor variable.

and SSP Total Score as the dependent variables. It was hypothesized that there would be a significant multivariate and between groups differences on the dependent variables depending on the functional level category.

Initially, the assumptions of MANOVA (i.e., independence, normality, equal covariance matrices for the dependent variables) were assessed. All scores for subjects were obtained independently. With respect to normality, scores tended to be slightly negatively skewed. Finally, Box's Test of Equality of Covariance Matrices yielded a value of 120.282,  $F(20, 813) = 4.66, p=0.00$ . Given this result, the null hypothesis of no differences is not supported and findings indicate that the covariance matrices are not equal. Given that the data from the pilot violated the normality and equality of variances assumption, coupled with the small group sizes in the pilot, a significance level of  $p < .01$  was selected to avoid a type one error when testing these hypotheses.

A significant multivariate effect was noted for functioning level with a Hotelling's Trace value of .521,  $F(8, 84) = 2.736, p = .010$ . This result with an effect size (using Eta Squared) of .207 indicates a large effect (Cohen, 1977) with good power (.915). Post hoc significant univariate effects were noted for the language comprehension dependent variable  $F(2, 46) = 8.511, p = .001$ , the language expression dependent variable  $F(2, 46) = 7.845, p = .001$ , and fine and visual-motor dependent variable  $F(2, 46) = 6.602, p = .003$ . These large effect sizes (Cohen, 1977) ranged from .223 to .270, with good power (range .893 to .956). Conversely, a significant univariate effect was not found for the Total SPP Score to differentiate functional level  $F(2, 46) = .227, p = .798$ .

Discriminant analysis was utilized to further investigate the presence of group differences on these variables. Pairwise group comparisons indicate that significant multipairwise differences exist between the low functioning and high functioning groups,  $F(4,43) = 3.850, p = .009$ . Further Post-hoc analysis of the low and high functioning groups in relation to the four dependent variables was explored using pairwise comparisons of estimated marginal means. Significant group differences were noted for the language comprehension dependent variable ( $p = .001$ ), the language expression dependent variable ( $p = .000$ ), and fine and visual-motor dependent variable ( $p = .001$ ). Significant group differences between the low and high functioning groups was also noted on these three dependent variables using Tukey HSD Multiple

Comparisons statistics, analyzing observed means. Significant group differences were not noted for the Total Score on the *SSP* ( $p = .600$ ).

To summarize, the findings of this pilot indicate that subjects in this sample process sensory input differently than typically developing peers as measured by the *SSP* (Dunn, 1999). Under-responsivity to sensory input and frequent seeking of sensory input correlated with developmental measures of receptive and expressive language, adaptive skill and fine motor performance. Significant group differences were noted between the low and high functioning subjects on receptive language, expressive language, and fine and visual-motor skill. Between functional level group differences were not significant for the Total Raw Score of the *SSP*.

#### Design Considerations for this Study

The research design for this present study sought to address the limitations of previous studies from the literature and incorporate the lessons learned during the pilot. In the pilot study, cognition was measured using multiple instruments that introduced bias and potential for error. In this study, consistent pre-determined measures are employed across subjects or cross-validation of measures have been implemented.

Given the variability in symptoms in autism, the present study used a sample of 400 individuals with an ASD to identify patterns of sensory processing and test multivariate relationships between these findings and developmental (i.e., adaptive performance, social skill, language) and diagnostic variables. As demonstrated in this pilot and other studies, individuals with autism have paradoxical responding to sensory input that differs qualitatively than individuals who are typically developing. This finding coupled with the variability demonstrated in other developmental areas of individuals on the autism spectrum, indicates a need for investigations to employ larger samples than the 50 included in the pilot. Larger samples will allow for more sophisticated research questions using valid statistical procedures to identify sensory processing clusters, explore relationships between these clusters and developmental variables and determine the impact of developmental differences on the presentation of these clusters. The research questions posed in this study require these statistical procedures.

Statistical power is a function of the interaction between the significance criterion (i.e.,  $\alpha$ ), the sample size, and the population effect size. Statistical power is improved with larger samples (Cohen 1992) such as the selection of 400 subjects. Statistical power of the findings could also be improved by increasing  $\alpha$ , but this choice is limited by an inherent

problem of significant variability in the functioning levels of the ASD population that challenges conducting any research. This variability and resultant lack of homogeneity of the sample may compromise the assumptions of statistical procedures (e.g., MANOVA) and the validity of the findings. Consequently, to lower the probability of a Type I error, a more stringent  $\alpha$  (e.g.,  $p \leq .01$ ), rather than a less stringent alpha is prudent. The variability in functioning also impacts the ability to estimate effect size. Although the effect sizes for the pilot data for most of the developmental variables were large, I have conservatively estimated a medium effect size by Cohen's scaling (Cohen, 1977). Therefore, to obtain statistical power at .80 for at an  $\alpha = .01$  when conducting a 3-group MANOVA as proposed in this study, the sample must include at least 218 subjects (Cohen, 1992). Avoiding Type I error is an important design consideration in this study.

Moreover, the use of factor analysis requires an even larger sample size. Various rules have been suggested in terms of the sample size required for reliable and valid factors. Stevens (2002) suggests at least 5 subjects per variable as the minimum needed. Using this criterion, the minimum sample required to conduct a factor analysis on the 38 items (variables) of the *SSP* (Dunn, 1999) would be 190 subjects. Guadagnoli & Velicer (1988), however, indicate that the most important consideration is the number of items within a factor and the absolute sample size. They recommend a sample size of at least 300 subjects if factors with only a few loadings are to be interpreted. Therefore, proceeding conservatively and taking these recommendations into account, the final sample of 400 subjects was selected. To date, no similar studies in autism have used a sample size as large as 400.

### Research Questions

This following research questions were explored:

1. What domains of sensory processing (e.g., tactile, auditory, oral-sensory, sensory seeking) on the *SSP* (Dunn, 1999) are identified as disordered in this sample of children with ASDs?
2. How does the sensory processing behavior identified in this group of children with an ASD differ from that identified in the standardization sample of typically developing children?
3. What is the latent factor structure found in the scores on the *SSP*?
4. Does the sensory processing in this sample differ for subgroups stratified by age, gender, autism diagnosis or level of adaptive functioning?

5. Is there a relationship between item, factor, or total scores of the *SSP* and developmental and diagnostic variables of the sample?

### Participants

A retrospective chart review was used to compile data on 400 individuals diagnosed with an ASD at the Weisskopf Child Evaluation Center (WCEC) at the University of Louisville. Data utilized in this study represents existing clinical data; no new data was collected. Four hundred participants were utilized to allow for valid statistical analysis proposed in this study.

Selection criteria for participants were the following: A query was formulated and implemented to identify children between the ages of 3 and 6 years who participated in an interdisciplinary diagnostic evaluation at the WCEC. The query output was sorted by date of service and represented a registry of the potential sample for inclusion in this study. To qualify for this study, children must have had an evaluation by developmental medicine, psychology, speech-language pathology, and occupational therapy that resulted in a diagnosis of autism, pervasive developmental disorder not otherwise specified, or Asperger's disorder. Although it is possible for children to have several comprehensive evaluations in this period of 4 years, only the initial diagnostic evaluation was utilized in this study so that developmental measures reflect baseline performance at diagnosis rather than a measure of progress after intervention. To be included in the data set, further inclusion criteria mandated that subjects must have completed adaptive, social, communication, motor and sensory processing measures during the evaluation process (see variables and measures descriptions below).

The scheduling and billing software of the WCEC was utilized to locate potential subjects via the query and identify children who meet the selection criteria. Chart review began with children evaluated most recently and worked back until 400 subjects with complete variables were enrolled.

### Center for Data Collection

The data collected and analyzed in this study represents existing clinical data resulting from autism diagnostic evaluations at the WCEC at the University of Louisville. The WCEC is a unique program in both the Commonwealth of Kentucky and the country in that it is one of the few programs that provides diagnostic, treatment, research, and training programs for individuals with an ASD. It is the only tertiary-level diagnostic and treatment center for individuals with an ASD in Kentucky. All disciplines receive specialized training and possess clinical expertise in

autism diagnosis and treatment. Approximately 2000 children are seen annually for diagnostic evaluations at the WCEC, with approximately 40% of that population involving evaluation/assessment services to individuals with an ASD. Individuals referred for evaluation because of suspected autism receive comprehensive medical, psychological, speech and language, and occupational therapy team evaluations, a process consistent with best practice guidelines from both the American Academy of Neurology (Filipek et al., 1999) and American Academy of Child and Adolescent Psychiatry (AACAP, 1999). Clinical specialists in each discipline used test administration procedures, methods, and measurements appropriate to individuals on the autism spectrum; data from the assessment were included in this study.

### Measures and Variables

Variables selected for analysis in this research then, are the resultant findings of the diagnostic evaluation process and are summarized in Table 4.

#### Independent variables include:

Sensory Processing. The primary variable in this study was reported behavioral sensory processing as measured by the *SSP* (McIntosh, Miller & Shyu, 1999). The *SSP* is a 38-item caregiver-report measure comprised of the items that demonstrated the highest discriminative power of atypical sensory processing among all the items from the long version: The *Sensory Profile* (Dunn, 1999). The full *Sensory Profile* from which the norms were established was standardized on 1,200 children and consists of 125 items in three domains: Sensory Processing (responses to basic sensory stimuli systems), Modulation (regulation of various combinations of input for use), and Behavioral and Emotional Responses. The *SSP* was formed using a three phase developmental process in which the item pool was narrowed based on discriminating properties of the items and cross-validating items with other items in the section or factor of the *Sensory Profile*. Therefore, the *SSP* is hypothesized to represent the key sections and factors from the long version of the Sensory Profile. Items are scored on a one to five one to five point scale, with lower scores indicating more impairment. The seven sections of the *SSP* with good internal and external validity (Dunn, 1999) found in a normative sample are: Tactile Sensitivity, Taste/Smell Sensitivity, Movement Sensitivity, Underresponsive/Seeks Sensation, Auditory Filtering, Low Energy/Weak, and Visual/Auditory Sensitivity. Internal consistency of the sections within the scale ranged from .70 to .90 (Dunn, 1999). Internal validity correlations for the sections ranged from .25 to .76 and were all significant at  $p < .01$ . Both section scores and a



Table 4

## Variables, Measures and Data Points

Variables	Measures	Data Point	Scale
Age	Age Calculator	Months	Ratio
Gender	Identified	0 or 1	Categorical
Diagnosis	Primary diagnosis	1, 2, or 3	Categorical
Adaptive	<i>SIB-R, DPII or VABS</i>	DQ*	Continuous
Expressive Communication	<i>PLS-3/4 or Rosetti</i>	Standard Score or DQ	Continuous
Receptive Communication	<i>PLS-3/4 or Rosetti</i>	Standard Score or DQ	Continuous
Gross Motor Quotient	<i>PDMS or PDMS-2</i>	Standard Score	Continuous
Fine Motor Quotient	<i>PDMS or PDMS-2</i>	Standard Score	Continuous
Social	<i>SIB-R or DPII</i>	DQ	Continuous
Sensory Processing Items	<i>Short Sensory Profile</i>	Item Scores	Continuous
Sensory Processing Sections	<i>Short Sensory Profile</i>	Subtotals Scores	Continuous
Sensory Processing Section Ratings	<i>Short Sensory Profile</i>	1,2, or 3	Categorical

*Notes:* Standard Score and DQ are on the same scale with a mean of 100. \*DQ = Developmental Quotient calculated using the following formula: developmental age/chronological age x 100

*SIB-R = Scales of Independent Behavior – Revised*

*DPII = Developmental Profile Second Edition*

*VABS = Vineland Adaptive Behavior Scales*

*PLS-3/4 = Preschool Language Scales (3<sup>rd</sup> or 4<sup>th</sup> edition)*

*Rosetti = Rosetti Infant Toddler Language Scales*

*PDMS = Peabody Developmental Motor Scales*

total score are interpreted on the *SSP* and will be treated as the independent variables. The Total Score is the most sensitive indicator of sensory dysfunction.

Given its short administration time (10 minutes) and value in screening for atypical sensory processing, the *SSP* is recommended for research protocols (Dunn, 1999; McIntosh et al., 1999). In this study, the *SSP* is most appropriate because in the early phase of its development the social-communication and motor items in the *Sensory Profile* were eliminated. Thus, the *SSP* isolates sensory processing that is less confounded by items overlapping with the diagnostic criteria of autism or components of the other developmental variables (e.g., social-communication and motor performance features). Another recent investigation used the *SSP* (Rogers et al., 2003) because of its relative freedom from inter-correlated measures of sensory processing and autism diagnosis. Initial studies of the validity of the *SSP* have demonstrated discriminate validity of >95% in identifying children with and without sensory modulation difficulties (McIntosh et al., 1999). Miller and colleagues (Miller, et al., 1999) designed a study to address some of the questions about the external validity and psychometric properties of parent questionnaires of sensory functioning in autism. They found that abnormal scores on the *SSP* were consistent with independent, clinical assessments of sensory modulation dysfunction by skilled occupational therapists. Most importantly, Miller and colleagues (1999) found that dysfunctional sensory processing scores correlated with abnormal psychophysiological responses to a series of sensory challenges. These findings corroborating physiological sensory processing with the *SSP* parent report of sensory processing difficulties held for children with typical development and for those with sensory processing disorders, further supporting the *SSP* as a valid measure of sensory processing. Although the work needs replication, this study provides support for use of the *SSP* as a valid measure of sensory responsivity in children (Rogers, et al., 2003)

Grouping variables include:

Child demographics. To examine potential differences in sensory processing the gender and age of the child at the time of evaluation will be recorded. Parent report of gender on an intake application was recorded, whereas age was calculated by Age Calculator shareware (AGS, 1997).

Autism spectrum diagnosis. To investigate differences in the dependent variables by diagnosis, the resultant ASD (i.e., autism, PDD-NOS, Asperger) assigned during the diagnostic

evaluation process was used to group subjects. The clinical ASD diagnosis was supported by at least one of the following: scores above the autism cut-off on the *ADI-R* (Lord et al., 1994); scores above the cutoff on the *Autism Diagnostic Observation Schedule (ADOS)*; (Lord, Rutter, DiLavore, & Risi, 1999); or endorsements on the DSM-IV TR checklist (APA, 2001). Clinical diagnoses were assigned by psychologists with extensive experience with autism and related disorders and specialized training in administration of the autism diagnostic instruments (i.e., *ADI-R* and *ADOS*) that included reliability studies.

Descriptive dependent variables included the neurodevelopmental status findings:

Adaptive Functioning. Measures of adaptive performance were utilized to investigate differences in the subjects for both the independent (i.e., *SSP*) and dependent measures (i.e., receptive and expressive language, motor performance, and social skill) by level of adaptive functioning. Indicators and measurement of functioning in autism have included primarily two different constructs: intelligence (IQ) and adaptive skill. While intelligence, as measured by intelligence tests, typically refers to the child's capacity to solve very specific problems in a structured situation, adaptive functioning refers to the child's ability to meet the demands of everyday life (Volkmar, 2003). Testing in general is a social communication process and therefore demands the skills that are the weakest for individuals on the autism spectrum. Therefore, obtaining a valid measure of intelligence is difficult with this population and this measure alone is not a clear indication of functioning. Further, studies investigating these constructs in autism have not found a definitive relationship between levels of intelligence and adaptive performance, especially in subjects with higher IQs (Bolte & Poustka, 2002; Carpentieri & Morgan, 1996; Kopp-Smily, 2003; Liss et al., 2001; Lord & Schopler, 1989; Platt, Kamphaus, Cole, & Smith, 1991; Schatz & Hamdan-Allen, 1995). That is, adaptive functioning may be low despite normal or high IQ. Platt and colleagues suggested these constructs represent two distinct psychological entities. Others have reported that in persons with autism, higher scores on intelligence were associated with only minor increases in adaptive skill (Bolte & Poustka, 2002; Kopp-Smily, 2003; Schatz & Hamdan-Allen, 1995). Other studies have shown that subjects with autism had more significantly impaired adaptive skill when compared to cognitively-matched controls with other developmental disorders (Carpentieri & Morgan, 1996; Liss et al., 2001). These inconsistencies, coupled with the consideration that communication, motor, and sensory processing difficulties directly impact adaptive performance have

underpinned the decision to select adaptive performance as the measure of functioning in this proposed investigation rather than IQ.

Three measures of adaptive performance are used in diagnostic evaluations: The *Developmental Profile II (DPII)*; Alpren, Boll, & Shearer, 1986), the *Scales of Independent Behavior – Revised (SIB-R)*; Bruininks, Woodcock, Weatherman, & Hill, 1997) and the *Vineland Adaptive Behavior Scales (VABS)*; Sparrow, Balla, & Cicchetti, 1984). The *DPII* is a 186-item inventory designed to assess a child's development in five areas of functioning: Physical (gross and fine motor), Self-Help, Social, Academic and Communication (receptive and expressive). It is designed for use with children from birth through 9 years, 6 months; however, though functional utility is limited to 7 years of age. As such, it is used at the WCEC in the diagnostic evaluation process for children under the age of 6. The *DPII* is administered by parent interview and yields raw scores that are converted to age scores. The normative sample for the *DPII* consisted of 3,008 children from birth to 12 years, 6 months. One potential limitation should be noted however, that the sample likely has a Midwest bias since the majority of the sample came from Indiana (91%), with the rest of the sample from the state of Washington (9%). Inter-scorer reliability data indicate satisfactory consistency among scorers. Internal consistency of the five subtests using a large sample of over 1,000 indicates reasonable alpha coefficients ranging from .78 to .87.

The *Scales of Independent Behavior – Revised (SIB-R)*; Bruininks, et al., 1997) is a comprehensive measure of functional independence and adaptive functioning in school, home, employment, and community settings. The scale provides norms for individuals from 3 months to 80+ years and can be used for individuals with and without disabilities. The *SIB-R* is organized into three forms and a Problem Behavior Scale, which will not be analyzed. The *SIB-R Full Scale* is composed of 14 subscales (259 items) divided into four adaptive behavior clusters each composed of two or more subscales. The adaptive behavior clusters are: Motor Skills, Social Interaction and Communication Skills, Personal Living Skills, and Community Living Skills. The Early Development Form is composed of 40 items sampled from the *SIB-R Full Scale*. The Early Development Form is designed to assess children from early infancy through 8 years of age or older individuals with severe developmental disabilities. The Short Form is composed of 40 items from the *SIB-R Full Scale*. It is designed as a screening measure for individuals of all ages. Each form yields 11 types of scores including standard scores, percentile

ranks, and adaptive skill age levels. At the WCEC, the *SIB-R* Full scale and Early Development Form are used primarily during the diagnostic evaluation process.

The *SIB-R* is based on the early development and standardization of the *Scales of Independent Behavior (SIB)*; Bruininks, Woodcock, Weatherman, & Hill, 1984). The instrument was standardized on a sample of 2,182 individuals in 15 states and more than 60 communities throughout the United States. The authors added 418 new individuals to the *SIB* stratified norming sample. The addition of these individuals to improve the representative sample updated the sample to match the demographics of the 1990 U.S. census figures. Several analyses and special studies are reported in the manual to verify that excessive bias does not exist due to gender, race, and other common demographics (Bruininks, et al., 1997). The group ranged in age from 3 months to 90 years and the authors used several stratification variables to achieve a sample representative of the United States population. Overall 13 items from the original *SIB* were deleted and 46 new items were added. With respect to internal reliability, median split-half reliabilities ranged from .88 to .98 for the four cluster and full scale scores. For the individual subscales, median split-half reliability coefficients (for all age levels) ranged from .70 to .88. For children with mental retardation, the split-half reliabilities were in the .90s for the clusters and subscales. Test-retest (4-week interval) reliabilities for children without disabilities ranged from .83 to .97 for the 14 subscales. For the clusters, the test-retest reliability (4-week interval) coefficients ranged from .96 to .97. The authors (Bruininks et al., 1997) report several studies as evidence of the construct validity of the *SIB-R* subtests and correlations of these subtests to tests and criteria traditionally used in the field of psychology, as well as comparisons between the performance of diverse groups of people.

The *Vineland Adaptive Behavior Scales (VABS)*; Sparrow et al., 1984) survey form is also used as a measure of adaptive behavior. The *VABS* is a 297-item standard parent interview that yields adaptive behavior standard scores (mean = 100, standard deviation = 15) and developmental ages across four domains (i.e., social, communication, daily living, and motor skills) and an adaptive behavior composite. The daily living domain will be used in this investigation.

The standardization sample for the *VABS* closely matched the population as described by 1980 U.S. census data. The ages of the 3,000 individuals in the sample ranged from newborn to 18 years, 11 months. Stratification variables included sex, race or ethnic group, geographical

region, community size, and parents' educational level. Norms are provided from birth to 18 years, 11 months. Separate norms also are provided for mentally retarded, emotionally disturbed, and physically handicapped children and adults. Three measures of reliability were reported in the manual--split-half, test-retest, and interrater reliability (Sparrow et al., 1984). Split-half reliability coefficients ranged from .84 to .98. Test-retest (2- to 4-week retest interval) reliability coefficients ranged from .80 and .90. Interrater reliability coefficients ranged from .62 to .75. Concurrent validity was established by correlating the *VABS* with various tests. With normal samples, correlations between the *Vineland* Adaptive Behavior Composite and several intelligence and ability tests ranged from .28 and .37. Higher correlations were noted (.47 to .82) in samples of persons with disabilities.

As a means of comparing *DP-II*, *SIB-R*, and *VABS* scores for subjects, adaptive ages on all measures were converted to developmental quotients using the following equation: adaptive age/chronological age x 100. Given the inherent difficulties with utilizing standardized instruments with this group of children, criterion referenced instruments yielding developmental ages are often used. As such, utilizing developmental quotients as a means of comparing across instruments is a common practice in the autism literature (see Bibby, Eikeseth, Martin, Mudford, & Reeves, 2001; Lord & Schopler, 1989; Rogers et al., 2003; Stone et al., 1997).

*Social Skill.* Given the potential impact of abnormal sensory processing on social relatedness and social development, relationships between sensory processing and social skill development was also be investigated. Like the adaptive variable, social skill development during the diagnostic evaluation process has been measured using *DP-II*, *SIB-R*, or *VABS*. For this study, the social variable will be a developmental quotient. The social age obtained on the *DP-II*, *SIB-R*, or *VABS* was converted to a developmental quotient using the following equation: social age/chronological age x 100.

*Communication (receptive and expressive) Ability.* Relationships between sensory processing and communication skill development were also be investigated. Variables were established for both receptive and expressive communication skill using one of three instruments: the *Rossetti Infant and Toddler Language Scale* (Rosetti, 1990) or the *Preschool Language Scale, Third (PLS-3; Zimmerman, Steiner, & Pond, 1992)* or *Fourth Edition (PLS-4; Zimmerman, Steiner, & Pond, 2002)*. Therefore, discussion here will include all three instruments.

The *Rossetti Infant and Toddler Language Scale* (Rossetti, 1990) is a criterion referenced assessment instrument used to assess the language skills of children from birth to 36 months. The scale assesses preverbal and verbal communication and interaction including: Interaction-Attachment, Pragmatics, Gesture, Play, Language Comprehension and Language Expression. For the purposes of this proposed investigation, areas relating to Language Comprehension (the child's understanding of verbal language with and without linguistic cues) and Language Expression (the child's use of preverbal and verbal behaviors to communicate with others) were only included. The scale was administered and scored by noting communicative behaviors through direct observation (spontaneously or elicited) and/or caregiver interview. The sample population on which the criterion referencing of items was based is not reported, but the author notes that the scale is "a compilation of author observation, descriptions of developmental hierarchies, and behaviors recognized by leading authorities in the field of infant and toddler assessment" (Rossetti, 1990, p. 10). Reliability and validity data were not reported.

Children able to participate in standardized language testing will be given either the *PLS-3* (Zimmerman et al., 1992) or *PLS-4* (Zimmerman et al., 2002). Given the retrospective nature of this proposed investigation, children receiving an evaluation before 2002 likely were evaluated using the *PLS-3*, whereas children evaluated more recently were evaluated using the more recently standardized *PLS-4*. Both instruments were designed to identify children from birth through 6 years, 11 months who have a language disorder or delay and were comprised of two scales: Auditory Comprehension and Expressive Communication. Whereas the Auditory Comprehension subscale was used to evaluate how much language a child understands, the Expressive Communication scale was used to determine how well a child communicates with others. Both instruments yield norm-referenced scores (standard scores, percentile ranks, and age equivalents) for each scale, as well as for a Total Language Score.

The *PLS-3* norms were based on the performances of 1,200 children, between the ages of 2 weeks and 6 years, 11 months. Although not randomly selected, the sample (stratified using the 1986 update of 1980 U.S. Census data) approximates the U.S. population for parent education level, geographic region, and race, but not for other variables. However, the sample population was not representative of a normal range of language abilities. Children were ineligible for participation in the standardization testing if they were previously identified as language disordered, were receiving any language remediation services, were at-risk because of

prematurity, had any condition such as Down syndrome known to cause a language disorder, or who had difficulties at birth that placed them at-risk for normal language development. The population that was tested, therefore, did not represent the normal range of language abilities, but rather only a distribution of typically developing children. Because these were distributed along the normal curve, those children falling 2 standard deviations or more below the mean actually were average in language ability. The resulting norms, therefore, may not accurately reflect the performance of children with language disorders compared to normally developing peers.

The reliability of the *PLS-3* (Zimmerman et al., 1992) Auditory Comprehension and Expressive Communication subscales evidenced adequate internal consistency with coefficient alphas  $>.80$ . Test-retest reliability coefficients ranged from .81 to .94 for Auditory Comprehension, Expressive Communication, and Total Language scores in a study of about 30 subjects each at age intervals 3-0 to 3-5, 4-0 to 4-5, and 5-0 to 5-11. Inter-rater reliability is reported as 89% agreement between two raters rating the open-ended Expressive Communication subscale items from a random sample of 80 norm-group protocols (20 each from 3-, 4-, 5-, and 6-year-old subjects). The authors note the scope and sequence of *PLS-3* tasks as support for content validity. The concurrent validity of the *PLS-3* was assessed by comparing scores on the *PLS-3* with the scores of three other tests of language. Correlations between performance on the *PLS-3* compared to the two other standardized instruments ranged from .66 to .88.

The *PLS-4* (Zimmerman et al., 2002) standardization included 1,564 children from ages 2 days to 6 years, 11 months. Within each age level, approximately half of the sample was male and half was female. A representative sampling based on the 2000 US Census was stratified by parent education level, geographic region, and race. Unlike the *PLS-3*, the sample includes a group of children ( $n=211$ ) with identified conditions/diagnoses. With respect to reliability, internal consistency was adequate with coefficient alpha ranging from .83 to .98 for the subscale scores and .90 to .97 for the Total Language Score. Test-retest (interval mean of 5.9 days) reliability coefficients ranged from .82 to .95 for the subscale scores and .90 to .97 for the Total Language Score in a sample of 218 randomly selected from the standardization sample. High inter-rater reliability was noted for the Expressive Communication scale (percent agreement of 99%). The authors report several studies as evidence of the construct validity.



For this study, the Auditory Comprehension and Expressive Communication standard scores were used as dependent variables. During both standardizations, these scores have had the best psychometric properties and predictive value in identifying language difficulties in children. Therefore, their use here is appropriate. Additionally, a criterion-prediction validity study by the instrument's authors indicate non-statistically significant differences in these scores, however, correlations between the two were questionable for Auditory Comprehension at .65 and approaching acceptable for Expressive Communication at .79.

To summarize the communication dependent variables, at the WCEC, children participating in the autism diagnostic evaluation process may be evaluated with one of the *PLS* instruments and/or a *Rossetti*. The *Rossetti* is used to assess and obtain age level of communication skills in children who have communication skills below the 36 month level and are unable to participate in structured *PLS-3/4* testing. In other cases, children are able to participate in structured testing and the *PLS-3/4* is used in isolation. However, if the validity of *PLS-3/4* findings is questioned by the evaluating speech-language pathologist for some reason (e.g., child effort, cooperation, etc.), the *Rossetti* will also likely be administered as a means of comparing obtained language levels on both instruments. For the purposes of this study, if available, *PLS-3/4* standard scores for Receptive and Expressive Communication subtests were used as the dependent variables. If only *Rossetti* scales are available, age scores for the Language Comprehension and Language Expression were converted to developmental quotients as previously discussed (i.e., language age/chronological age x 100) as a means of comparing scores with those on the *PLS-3/4*.

*Motor Skill.* To explore relationships between sensory processing and motor skill development, findings from the *Peabody Developmental Motor Scales (PDMS; Folio & Fewell, 1983)* or the *Peabody Developmental Motor Scales, Second Edition (PDMS-2; Folio & Fewell, 2000)*. Given the retrospective nature of this proposed investigation, earlier subjects likely will have been evaluated using the *PDMS*, whereas later subjects will have been evaluated using the more recently standardized *PDMS-2*. As such, discussion here will include both measures and evidence of construct validity between the measures.

When first published, the *PDMS* was the only test battery standardized on a population of children from birth to 84 months. The Gross Motor Scale had 170 items grouped into five skills clusters: Reflexes, Balance, Receipt and Propulsion, Nonlocomotor, and Locomotor. The Fine

Motor Scale had 112 items grouped into four skill areas: Grasping, Hand Use, Eye-hand Coordination, and Manual Dexterity. Standard scores (Developmental Motor Quotients) derived from raw scores are interpreted for the Gross and Fine Motor Scales, Total Score and each skill area within the scale. The *PDMS* was standardized on a sample of 617 children from 20 states across the United States. Test-retest and interrater reliabilities were high with coefficients in the .90s for the Gross and Fine Motor Scales and Total Score (Folio & Fewell, 1983; Gebhard, Ottenbacher, & Lane, 1994; Schmidt, Westcott, & Crowe, 1993). Construct validity has been demonstrated by showing children with motor problems scored significantly lower than children in the normative sample (Folio & Fewell, 1983; Palisano, Kolobe, Haley, Lowes, & Jones, 1995).

The *PDMS-2* (Folio & Fewell, 2000) is a motor assessment instrument for children birth to 72 months resulting from an item revision and re-standardization of the *PDMS*. The *PDMS-2* is comprised of six subtests organized into three scales that measure interrelated motor abilities developing early in life. The Gross Motor Quotient is a composite of the results from the four subtests consisting of a total of 151 items: Reflexes, Stationary, Locomotion, and Object Manipulation. The Fine Motor Quotient is a composite of the results of two of the subtests comprised of a total of 98 items: Grasping, Visual-motor integration. The Total Motor Quotient is a composite of the Gross and Fine Motor Scores to measure overall motor ability. The *PDMS-2* was normed on a sample of 2,003 children from 46 states in the United States and British Columbia, Canada. Studies of reliability of the *PDMS-2* has focused on three sources of error variance (content, time, and scorer) and have shown acceptable reliability coefficients (.89 - .98). Regarding validity of the *PDMS-2*, the authors demonstrated content validity in a number of ways. The content of the items on the *PDMS-2* were drawn from the Taxonomy of the Psychomotor Domain by Harrow (1972). Qualitative content validity, therefore, was demonstrated with the selection of subtests and items that demonstrate a developmental sequence, with functional skills progressing towards more integrated skills. Quantitatively, confirmatory factor analysis demonstrated acceptable discriminative indexes and provides additional evidence of content validity. Further, item bias was investigated using logistic regression to detect differential item functioning. Here, the full model (i.e., ability, group membership, and interaction between the ability and group membership) was compared to the

restricted model of ability alone. Based on analysis, no items were eliminated indicating that items differentiating ability were not influenced by group membership.

For this study, the Gross and Fine Motor Quotients of subjects on the *PDMS* or *PDMS-2* were utilized as dependent variables to reflect motor development status. During both standardizations, these quotient scores have had the best psychometric properties and predictive value in identifying motor difficulties in children. Therefore, their use here is appropriate. Additionally, criterion-prediction validity have supported the equivalency of the two *PDMS* versions with correlation coefficients exceeding .80 for the Gross Motor ( $r = .84$ ) and Fine Motor ( $r = .91$ ) Quotients.

### Data Collection

Retrospective chart reviews and data entry were completed by the doctoral student investigator. Data were entered directly into SPSS version 12.0 for Windows (SPSS, 2003). When completing the chart review, there is potential for error and a need to make judgments. For example, when determining the adaptive quotient, multiple adaptive measures may be available (e.g., *DP II*, *VABS*). In these cases, decisions needed to be made to formulate the adaptive quotient and perform related calculations. To examine the extent of rating bias or error, a subset of 25 charts were coded by a psychology doctoral student to establish inter-rater reliability. Alpha coefficients met the pre-established criteria of .98 or higher. Coefficients ranged from .99 for adaptive and social variables, to 1.0 for both motor and language variables. These findings indicate acceptable inter-rater reliability, reflecting adequate variable definitions. The database and files of data entry forms were maintained for HIPPA compliance and all procedures were approved through both the University of Louisville and the University of Kentucky Institutional Review Boards.

### Data Analysis

*Descriptive Statistics:* Several analyses were conducted on the data set to characterize sensory processing and potential relationships to developmental and diagnostic variables in this sample of children with an ASD. First, descriptive statistics were employed to describe the sample. Gender and diagnostic frequencies of the sample were determined. Means and standard deviations were calculated for subject age, as well as adaptive, social, language (receptive and expressive) and motor (gross and fine) variables for both the total sample and by diagnosis. Item analysis identified items yielding the highest reported sensory processing dysfunction in this

sample on the *SSP* (Dunn, 1999). Percentages of performance on *SSP* sections for the total ASD sample with in typical performance, probable difference, and definite difference classifications on the *SSP* summary scoring were calculated to reflect sensory processing performance in comparison to typical peers in the standardization sample.

*Factor Analysis:* An exploratory factor analysis was conducted to identify latent sensory processing variables in this sample of children with an ASD. Initially alpha coefficients for *SSP* items were calculated to establish the reliability of the data set. Given the exploratory nature of the analysis, a principal components factor analysis with varimax rotation was conducted on the 38 items of the *SSP* (Dunn, 1999) to obtain the initial factor solution. Here, uncorrelated linear combinations of the *SSP* items that account for the most variance were partitioned off by the principal components to form the factors (Stevens, 2002). Therefore, the first factor accounted for the maximum variance and successive factors accounted for progressively smaller portions of the variance. The factors were interpreted by using the factor loadings which is the component to variable (*SSP* item) correlation. Varimax rotation was selected to minimize the number of items that have high loadings on each factor and therefore simplify the interpretation of the factors. Additionally, the goal of this analysis was to identify clear patterns of sensory processing in this sample and therefore the uncorrelated nature of the factors support use of an orthogonal rotation. All factors with an eigenvalue (sum of the absolute values of the factor loadings) of greater than one were retained for initial interpretation. Items were retained with a loading of greater than .258 based on critical values for a correlation coefficient at  $\alpha = .01$  for a 400 subject sample (Stevens, 2002) and be loaded on only one factor. Initial conceptual interpretation of the factors and percentage of variance they account for allowed for visual analysis and further exploration to determine the most parsimonious factor structure.

*MANOVA:* Multivariate analyses of variance (MANOVA) was conducted to determine if differences in sensory processing factor variables on the *SSP* (Dunn, 1999) measures were dependent on: 1) the diagnosis of the subjects and/or 2) the adaptive functioning level of the subjects. To investigate differences by functioning level, the subjects were classified based on adaptive functioning as high (adaptive quotient > 80), moderate (adaptive quotient 60-79), or low functioning (adaptive quotient < 60) to conduct these analyses. MANOVA partitions the total variance in scores of the dependent variables into a ratio (i.e., *F* ratio) of variation within groups to variations between groups (Shavelson, 1996; Stevens, 2002). Initially the assumptions of

MANOVA (i.e., independence, normality, equal covariance matrices for the dependent variables) were assessed. All scores for subjects were obtained independently. With respect to normality, histograms of the factors were evaluated in relation to a normal distribution. Finally, Box's Test of Equality of Covariance Matrices was analyzed. However, given the inherent differences in the groups (diagnostic and functioning), the covariance matrices will not be equal we will likely fail to retain the null hypothesis. Given the group difference and the potential for not meeting all of the MAOVA assumptions, a significance level of  $p < .01$  was selected to avoid a type one error when testing these hypotheses.

Correlation analysis. Correlation analysis was conducted between sensory processing factor variables and adaptive, social, receptive language, expressive language, gross motor and fine motor skill developmental measures to determine if relationships exist. These analyses provided direction for further regression analysis.

## CHAPTER 4

### RESULTS

This chapter explores the results of this study. The data collection process and subject demographics will initially be described, followed by the results organized by the research questions and related analysis.

#### Data Collection

The query of the WCEC scheduling and billing software that identified potential subjects based on the inclusion criteria was implemented on January 20, 2005. Evaluation service dates were pulled from December of 2004 dating back to January of 1999. This query yielded a potential sample of 554 children between the ages of 36 months and 71 months with an ASD. Data collection began January 21, 2005 for children receiving initial diagnostic evaluations in December of 2004. Cases were included in the study only if all inclusion criteria (e.g., age, diagnosis, developmental, and diagnostic variables) were met. Data on potential children were excluded from the data set when variables were missing or not measured as outlined in the study design. For example, some children identified as potential subjects received a language measure other than one of the *Preschool Language Scales* (Zimmerman, Steiner, & Pond, 1992, 2002) or *Rosetti Infant-Toddler Language Scale* (Rosetti, 1990) or a motor measure other than one of the *Peabody Developmental Motor Scales* (Folio & Fewell, 1983, 2000). Data collection continued back until 400 children with complete data from a potential subject pool of 471 were included in the study. The last child was initially evaluated on January 3, 2000.

#### Subject Demographics

The sample demographics are summarized in Table 5 by diagnosis and for the total sample of 400 subjects. The majority of the children (n=322, 80.5%) met full criteria for autism, with a smaller group representation for PDD-NOS (n=67, 16.8%) and Asperger Disorder (n=11, 2.8%). Of the 400 subjects, 348 were male and 52 were female, a male to female gender distribution of 6.7:1. This represents a higher male to female ratio in this study compared with prevalence data for autism at a 4:1 male to female ratio (Fombonne, 2003, 1999). The average age of the sample was 49.58 months (5 years, 1 month). There were no differences in average age based on gender or diagnostic groups.

Table 5

## Sample Demographics by Diagnosis

Diagnosis	N	Gender		Mean Age	SD
		Male	Female		
Autism	322	277	45	49.35 months	10.60 months
PDD-NOS	67	61	6	49.61 months	10.14 months
Asperger	11	10	11	56.09 months	10.27 months
Total	400	348	52	49.58 months	10.54 months

## Developmental Performance

Descriptive statistics for the adaptive, social, receptive language, expressive language, gross motor, and fine motor developmental variables by diagnosis are displayed in Table 6. Developmental performance varied for each variable consistent with diagnostic criteria. That is, the Asperger Disorder group achieved at a higher level than either the PDD-NOS or autism groups.

## Sensory Processing Performance on the SSP

Reported performance classifications on the SSP for the total sample are summarized in Table 7. Findings indicated that 74.3% (n=297) of the subjects were reported to have definite differences in sensory processing for the SSP Total Score in comparison to individuals in the standardization sample without disabilities (Dunn, 1999). A *definite difference* indicates scores greater than two standard deviation from the mean for typically developing children in the standardization sample. Sensory processing sections of the SSP that yielded the highest reported definite differences included: Under-responsive/seeking sensation (81.0%, n=324), auditory filtering (70.8%, n=283), touch sensitivity (52.5%, n=210), taste and smell sensitivity (48%, n=192), and visual and auditory sensitivity (37.8%, n=151). Movement sensitivity (21%, n=84) and Low energy/weak (22.5%, n=90) sections had lower reported sensory processing differences.

When *probable* and *definite* differences classifications were summed as an indicator of children with some degree of sensory processing dysfunction, 89.3% (n=357) of the sample were rated as having some degree of dysfunction on the SSP Total Score, that is falling more than one standard deviation from the mean. Similarly, significant percentages of difference scores were found in separate sensory processing sections. For example, of the 400 children in the sample 90.3% (n=365) would fall into this classification in the underresponsive/seeking sensation, 87.6% (n=350) for auditory filtering, 74% (n=296) for tactile sensitivity, 63.1% (n=252) for visual/auditory sensitivity, and 61.3% (n=245) for taste/smell sensitivity. Ten children (2.5%), on the other hand, were reported to have typical performance in all sensory processing sections of the SSP.

The above analysis of sensory processing sections provides some insight into sensory processing items that yielded the highest reported dysfunction. Because the SSP is rated on a five-point scale, the highest reported differences discriminates items most affected by dysfunctional sensory processing behavior in autism. Table 8 presents percentages of children



Table 6

Mean (Standard Deviation) Developmental Performance by Diagnosis

Diagnosis	N	Adaptive	Social	Receptive Language	Expressive Language	Gross Motor	Fine Motor
Autism	322	53.63 (15.85)	44.93 (16.24)	35.98 (19.87)	35.07 (18.18)	68.51 (9.47)	67.76 (9.11)
PDD-NOS	67	68.48 (18.52)	62.18 (13.67)	57.17 (18.58)	57.16 (19.06)	71.82 (7.53)	70.25 (8.07)
Asperger	11	80.46 (24.00)	73.42 (12.25)	96.36 (8.94)	96.55 (10.52)	78.64 (7.15)	81.00 (10.55)
Total	400	56.85 (17.88)	48.60 (17.48)	41.19 (22.93)	40.46 (22.04)	69.34 (9.31)	68.54 (9.25)

*Note.* Values reflect standard score or developmental quotient with the mean of 100.

Table 7

Performance Classification on the *SSP* (Dunn, 1999) By Section

Section	Typical Performance		Probable Difference		Definite Difference	
	n	Percent	n	Percent	n	Percent
Tactile Sensitivity	104	26.0%	86	21.5%	210	52.5%
Taste/Smell Sensitivity	155	38.8%	53	13.3%	192	48.0%
Movement Sensitivity	237	59.3%	79	19.8%	84	21.0%
Underresponsive/Seeks Sensation	35	8.8%	41	10.3%	324	81.0%
Auditory Filtering	50	12.5%	67	16.8%	283	70.8%
Low Energy/Weak	242	60.5%	68	17.0%	90	22.5%
Visual/Auditory Sensitivity	148	37.0%	101	25.3%	151	37.8%
Total <i>SSP</i>	43	10.8%	60	15.0%	297	74.3%

*Note.* Data above reflects finding from all 400 subjects (100%).

Table 8

Percentages of Children Who Always or Frequently Displayed the Behaviors on the SSP.

Item	%
<b>Tactile Sensitivity</b>	
1. <b>Expresses distress during grooming</b>	<b>58.8</b>
2. Prefers long-sleeved clothing even when it is warm or short sleeves when it is cold	9.5
3. Avoids going barefoot, especially in grass or sand	13.5
4. Reacts emotionally or aggressively to touch	20.5
5. Withdraws from splashing water	13.5
6. Has difficulty standing in line or close to other people	20.5
7. Rubs or scratches out a spot that has been touched	11.5
<b>Taste/Smell Sensitivity</b>	
8. Avoids certain tastes or food smells that are typically part of children's diets	35.0
9. Will only eat certain tastes	12.5
10. Limits self to particular food textures/temperatures	39.0
11. Picky eater, especially regarding food textures	46.8
<b>Movement Sensitivity</b>	
12. Becomes anxious or distressed when feet leave the ground	7.0
13. Fears falling or heights	13.3
14. Dislikes activities where head is upside down	9.5
<b>Underresponsive/Seeks Sensation</b>	
15. Enjoys strange noises/seeks to make noise for noise's sake	48.5
16. <b>Seeks all kinds of movement and this interferes with daily routines</b>	<b>68.0</b>
17. <b>Becomes overly excitable during a movement activity</b>	<b>63.8</b>
18. <b>Touches people and objects</b>	<b>59.3</b>
19. Doesn't seem to notice when face and hands are messy	27.8
20. <b>Jumps from one activity to another so that it interferes with play</b>	<b>57.8</b>
21. Leaves clothing twisted on body	26.0
<b>Auditory Filtering</b>	
22. <b>Is distracted or has trouble functioning if there is a lot of noise around</b>	<b>56.5</b>
23. <b>Appears to not hear what you say</b>	<b>68.5</b>

24. Can't work in background noise	11.5
25. Has trouble completing tasks when the radio is on	16.0
26. Doesn't respond when name is called but you know the child's hearing is OK	47.3
<b>27. Has difficulty paying attention</b>	<b>74.8</b>
Low Energy/Weak	
28. Seems to have weak muscles	12.0
29. Tires easily, especially when standing or holding particular body positions	6.5
30. Has a weak grasp	11.8
31. Can't lift heavy objects	7.3
32. Props to support self	8.8
33. Poor endurance/tires easily	7.0
Visual/Auditory Sensitivity	
34. Responds negatively to unexpected loud noises	45.5
35. Holds hands over ears to protect ears from sound	40.8
36. Is bothered by bright lights after others have adapted to the light	12.8
37. Watches everyone when they move around the room	37.8
38. Covers eyes or squints to protect eyes from light	21.3

*Note.* Bold items are those with always or frequently reported behaviors by 50% or more of the parents.

reported as *always* or *frequently* demonstrating the behaviors on the *SSP*, with items yielding a 50% or higher threshold in bold. In the Under-Responsive/Seeks Sensation section, high frequency behaviors included: seeks all kinds of movement and this interferes with daily routine, overly excitable during movement, touches people and objects, and jumps from one activity to another so that it interferes with play. The Auditory Filtering subscale identified high frequency difficulties with these items: distracted or has trouble functioning if there is background noise, appear to not hear what you say, and difficulty paying attention items. The only other item meeting the 50% threshold was expresses distress during grooming within the Tactile Sensitivity subscale.

### Psychometric Properties of the *SSP*

Initially, Cronbach's alpha of internal consistency was generated to assess the reliability of the *SSP* in this study. Acceptable alpha coefficients were noted for the Total Scale (0.89). An analysis of the contributions of each item to internal consistency was also assessed; there were no items on the *SSP* that significantly diminished the alpha coefficients, suggesting the *SSP* items and whole measure were reliable.

An intent of this research was to examine the underlying factor structure of the *SSP* to determine if the factor structure for children with autism would differ from the factor structure reported for typically developing children. A principal component factor analysis with varimax rotation was conducted to identify the latent factor structure on the *SSP* in this sample of 400 children on the autism spectrum. Tests of the fit of the data set with the assumptions of factor analysis were conducted. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy was good at .825. Bartlett's Test of Sphericity was significant (approximate Chi-square = 6966.66,  $df = 703$ ,  $p = .000$ ), indicating that some of the variables in the data set are correlated with each other. Both these tests confirmed that the assumptions for factor analysis were met.

Initially 11 factors were identified with eigenvalues greater than 1.00 accounting for 67.73% of the variance in the *SSP* data. Items were assigned to one factor in the 11 factor structure based on the previously determined factor loading of .258 based on critical values for a correlation coefficient at  $\alpha = .01$  for a 400 subject sample (Stevens, 2002). In doing so, Factors 8 – 11 of this model each contained 2 items that loaded on the component. Additionally, some of the loadings in Factors 1 – 7 were difficult to interpret conceptually.

A smaller number of factors were desired to achieve the goal of parsimony using factor analysis. The plot of eigenvalues for components (see Figure 3), showed a point of scree between 6 and 8 factors. Consequently, a 6 and 8 factor solution were generated and analyzed to identify the most parsimonious model, conceptually sound solution, and maximum explanation of cumulative variance. An 8-factor model was explored and accounted for 59.17% of the variance, but like the 11-factor model had factors with only two items loading and as a whole was challenging to interpret.

The 6-factor solution best fit the data, was consistent with concepts of sensory processing, and accounted for 52.27% of the variance. The 6-factor solution identified the following factors that were labeled: Low Energy/Weak, Tactile and Movement Sensitivity, Taste/Smell Sensitivity, Auditory and Visual Sensitivity, Sensory Seeking/Distractibility, and Hypo-responsivity (see Table 9).

Factors scores from the 6-factor solution were saved to the data set for each child in the study. The factor scores were tested for normality using tests of kurtosis and skewness that should be within the +2 to -2 range when the data are normally distributed (Hutcheson & Sofroniou, 1999). All six factor scores met this criterion with kurtosis ranging from -1.137 to 1.461 and skewness ranging from -1.317 to .414. Thus the factor scores for sensory processing met the assumptions needed for analysis of variance.

#### Tests of Group Differences

An intent of this study was to identify group differences among children with autism based on diagnostic and demographic variables. Multivariate analyses of variance (MANOVA) was conducted to determine if differences in sensory processing varied by the diagnosis, adaptive functioning level, gender, or age of the subjects.

Sensory processing differences by diagnosis were analyzed first. Box's Test of Equality of Covariance Matrices tests on the diagnostic groups yielded a value of 90.76,  $F(42, 2307) = 1.86, p=0.01$ . Given this result, the homogeneity of variance assumption was violated and the covariance matrices were not equal. To compensate for the violation of this MANOVA assumption, a significance level of  $p < .01$  was selected for this analysis to avoid a type one error and the results of the analysis should be interpreted conservatively. With diagnosis entered as the grouping variable and the six factors scores entered as the dependent variables, a significant multivariate effect was noted for diagnosis with a Hotelling's Trace value of 0.08,

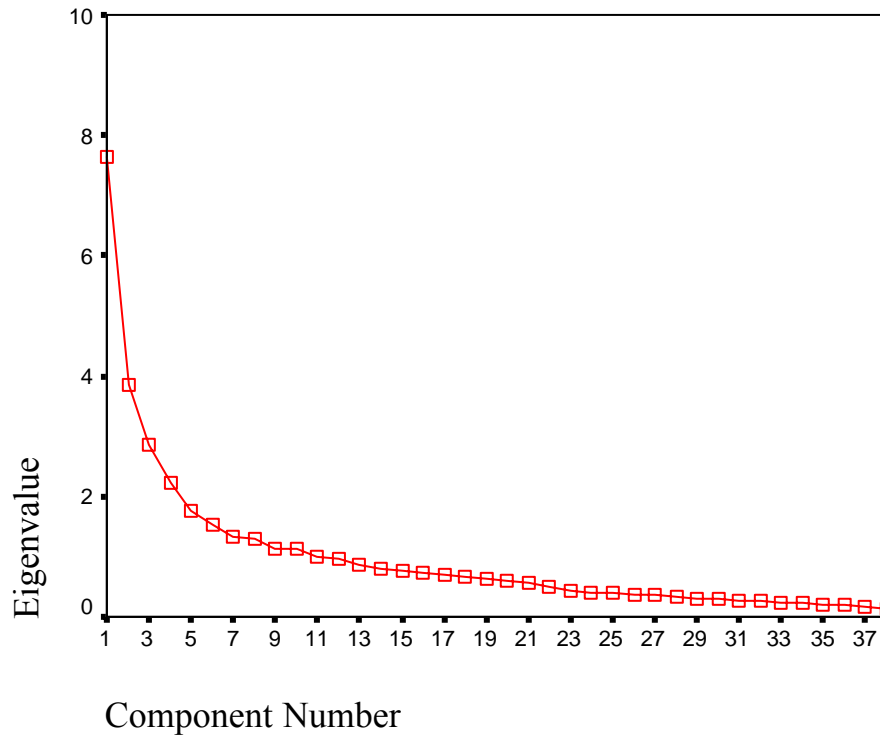


Figure 3. Scree Plot of SSP factor components.

Table 9

Derived Factor Structure on *SSP* Items of Individuals with an ASD.

	Factor with Loadings					
	1	2	3	4	5	6
<b>Factor 1: Low Energy/Weak</b>						
Seems to have weak muscles	.822					
Poor endurance/tires easily	.793					
Can't lift heavy objects	.779					
Has a weak grasp	.750					
Tires easily, especially when standing or holding particular positions	.745					
Props to support self	.702					
<b>Factor 2: Tactile and Movement Sensitivity</b>						
Reacts emotionally or aggressively to touch		.637				
Withdraws from splashing water		.631				
Rubs or scratches out a spot that has been touched		.586				
Becomes anxious or distressed when feet leave the ground		.584				
Fears falling or heights		.574				
Has difficulty standing in line or close to other people		.551				
Dislikes activities where head is upside down		.486				
Expresses distress during grooming		.460				
Avoids going barefoot, especially in grass or sand		.402				
Prefers long-sleeves even when it is warm or short when it is cold		.355				
<b>Factor 3: Taste/Smell Sensitivity</b>						
Will only eat certain tastes			.905			
Picky eater, especially regarding food textures			.901			
Avoids certain tastes or food smells typically part of child's diet			.853			
Limits self to particular food textures/temperatures			.852			
<b>Factor 4: Auditory and Visual Sensitivity</b>						
Can't work in background noise				.718		
Has trouble completing tasks when the radio is on				.699		
Holds hands over ears to protect ears from sound				.635		
Is distracted or has trouble functioning if there is a lot of noise				.631		



Responds negatively to unexpected loud noises	.620
Is bothered by bright lights after others have adapted to the light	.596
Covers eyes or squints to protect eyes from light	.493
Watches everyone when they move around the room	.457

**Factor 5: Sensory Seeking/Distractibility**

Becomes overly excitable during a movement activity	.773
Seeks all kinds of movement and this interferes with daily routines	.761
Jumps from one activity to another so that it interferes with play	.663
Has difficulty paying attention	.650
Enjoys strange noises/seeks to make noise for noise's sake	.556
Touches people and objects	.359

**Factor 6: Hypo-responsivity**

Doesn't seem to notice when face and hands are messy	.563
Doesn't respond when name is called but hearing is OK	.532
Appears to not hear what you say	.439
Leaves clothing twisted on body	.359

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Percent of variance explained	20.103	10.117	7.524	5.845	4.666	4.016
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$F(6, 784) = 2.619, p = .002$ . This result with an effect size (using Eta Squared) of .04 indicates a small to moderate effect (Cohen, 1977) with good power (.98). Post hoc significant univariate effects at a significance level of .01 were noted only for the Sensory Seeking/Distractibility factor,  $F(2, 7.72) = 7.987, p = .000$ . This univariate effect size was small to moderate (.04), with good power (.96). Tukey post-hoc analysis was utilized to further investigate the presence of group differences on this variable. Significant group differences were noted for the Sensory Seeking/Distractibility factor variable between the autism and Asperger Disorder groups ( $p = .000$ ) and indicated that children with autism tended to seek more sensory input than individuals with Asperger Disorder.

To investigate differences in the sensory processing factor variables by functioning level, the 400 subjects were classified into three groups based on adaptive functioning levels typically identified in the literature. High functioning was defined as an adaptive quotient  $> 80$ ;  $n = 47$ , moderate (adaptive quotient 60-79;  $n = 115$ ) or low functioning (adaptive quotient  $< 60$ ;  $n = 238$ ) to conduct these analyses. The homogeneity of variance assumption was met based on a Box's Test of Equality of Covariance Matrices that yielded a value of 50.28,  $F(42, 62393) = 1.16, p=0.226$ . A significant multivariate effect was noted for functioning level with a Hotelling's Trace value of .125,  $F(12, 782) = 4.09, p = .000$ . This result with an effect size (using Eta Squared) of .06 indicates a moderate effect (Cohen, 1977) with good power (1.0). Post hoc significant univariate effects were noted for the Taste/Smell Sensitivity factor score,  $F(2, 10.54) = 11.08, p = .000$  and the Sensory Seeking/Distractibility factor score,  $F(2, 5.42) = 5.54, p = .004$ . These univariate effect sizes were moderate (.06), with good power in both the Taste/Smell Sensitivity and Sensory Seeking/Distractibility factors (.992 and .852, respectively). All other analyses were non-significant. Tukey post hoc analysis was utilized to identify significant group differences for the Taste/Smell Sensitivity between the low and moderate functioning groups ( $p = .006$ ) and the low and high functioning groups ( $p = .000$ ). Significant group differences were also noted for the Sensory Seeking/Distractibility factor variable between the low and high functioning groups ( $p = .003$ ) and the moderate and high functioning groups ( $p = .015$ ). The low functioning group tended to have more pronounced food and oral preferences when compared to higher functioning group. The low and moderate functioning group also tended to seek more sensory input than the higher functioning group.

To investigate differences in the sensory processing factor variables by age of the subjects, the 400 subjects will be classified based on their whole year age (i.e., 3, 4, or 5 years) to conduct these analyses. With respect to the assumptions of MANOVA, the homogeneity of variance assumption was met with a Box's Test of Equality of Covariance Matrices yielded a value of 44.58,  $F(42, 224823) = 1.04, p=0.408$ . A significant multivariate effect was noted for age with a Hotelling's Trace value of .90,  $F(12, 782) = 2.92, p = .001$ . This result had a small to moderate effect size (.04) and good power (.991). Post hoc significant univariate effects were noted for the Auditory And Visual Sensitivity factor variable  $F(2, 397) = 13.17, p = .000$ . The univariate effect size was moderate (.06), with good power (.997). Significant univariate effects were not found for the other sensory processing factor variables. Tukey post hoc analysis identified significant differences between the 3-year-old and 4- year-old subject groups ( $p = .000$ ) and the 3 year old and 5 year old groups ( $p = .000$ ). The 3-year-old group was reported to experience less difficulties with auditory and visual sensitivity than either of the other age groups.

#### Prediction of Diagnostic Variables to Sensory Processing

An intent of this study was to assess the relative contributions of sensory processing to the developmental presentation of individuals on the autism spectrum. To test the predictive ability of sensory processing to the developmental variables, a series of multiple regression analyses were performed. Multiple linear regression was conducted with each developmental measure entered as the dependent variable and the six factors scores entered as the predictors. Five of the six regression models were significant. As can be seen in Table 10, the sensory factor variables contributed to 11% of the variance in the receptive language scores and nearly 10% of the variance for adaptive and expressive language performance.

#### Relationship of Diagnostic to Sensory Processing Variables

The contributions of each sensory processing factor score to the diagnostic variables are displayed in Table 11. Significant correlations ( $p = .01$ ) were noted between the Taste/Smell Sensitivity and the adaptive and social developmental variables. The Auditory And Visual Sensitivity factor variable was correlated ( $p = .01$ ) with both receptive and expressive development. The Sensory Seeking/Distractibility factor variable significantly correlated with all of the developmental variables. Lastly, the Hypo-Responsivity factor correlated with adaptive performance and both language variables.

Table 10

Percent of Variance in Developmental Variable Accounted for by Sensory Factors

Variable	R Square
Receptive Language	.113 ( $p = .000$ )
Expressive Language	.098 ( $p = .000$ )
Adaptive	.096 ( $p = .000$ )
Social	.060 ( $p = .009$ )
Gross Motor	.040 ( $p = .013$ )
Fine Motor	.025 ( $p = .128$ )

*Note.* Percentage of variance as measured by R Square

Table 11

Correlations between Sensory Processing Factors and Developmental Variables (n = 400)

	Low Energy/ Weak	Tactile & Movement Sensitivity	Taste/Smell Sensitivity	Auditory & Visual Sensitivity	Sensory Seeking/ Distractibility	Hypo-responsivity
Adaptive	.055	.058	.224**	-.062	.162**	.098*
Social	.025	.078	.129**	-.054	.157**	.096
Receptive Language	-.125*	.057	.096	-.198**	.161**	.139**
Expressive Language	-.120	.043	.074	-.181**	.150**	.144**
Gross Motor	.071	.011	.057	-.013	.132**	.120
Fine Motor	-.003	.037	.058	.038	.124*	.056

\* $p < .05$ . \*\* $p < .01$ .

## Summary

This study analyzed sensory processing abilities of 400 children on the autism spectrum as measured by the *SSP* (Dunn, 1999). The majority of the sample (80.5%) had a diagnosis of autism. The average age of the sample was 49.58 months. The adaptive, social, language, and motor developmental variables were consistent with diagnostic patterns in that the children with Asperger Disorder demonstrated higher developmental levels than the children with autism and PDD-NOS. Eighty-nine percent of the sample demonstrated some degree of sensory processing dysfunction on the *SSP* Total Score with 74.5% in them in the definite difference classification of greater than 2 standard deviations from the mean. The greatest difficulties were reported on the Underresponsive/Seeks Sensation, Auditory Filtering and Tactile Sensitivity sections of the *SSP*.

Exploratory factor analysis identified six parsimonious factors: Low Energy/Weak, Tactile and Movement Sensitivity, Taste/Smell Sensitivity, Auditory and Visual Sensitivity, Sensory Seeking/Distractibility, and Hypo-responsivity. These factor variables contributed to explaining the differences in five of six developmental variables of the sample that are associated with the diagnosis of autism. Most notably receptive language, adaptive and expressive language performance were significantly correlated with sensory processing factor scores.

Differences in the sensory processing factors were also noted when the sample was grouped by diagnosis, functioning level, and age. On the Sensory Seeking/Distractibility factor, children with autism or who were lower functioning demonstrated more sensory seeking than those who had Asperger Disorder or were higher functioning. The lower functioning group also had more pronounced food and oral preferences. Older children in the sample also tended to demonstrate more auditory and visual sensitivity. Together, these findings begin to delineate patterns of sensory processing and their relationships to developmental functioning and the diagnostic indicators of autism.

## CHAPTER 5

### DISCUSSION AND CONCLUSIONS

This study was undertaken to more clearly describe sensory processing behaviors in a large sample of 400 children on the autism spectrum and relate these findings to the developmental and diagnostic variables of the subjects. This chapter will explore the study results, relate these findings to the literature, and explore the strengths and limitations of the study. Conclusions drawn from the study findings will have implications intervention in autism and provide direction for future research.

#### Sensory Processing Performance on the SSP

The first and second research questions targeted describing sensory processing in this sample of children with an ASD. Using the *SSP* (Dunn, 1999) Total Score as an overall indicator of sensory processing dysfunction, the vast majority of the sample ( $n = 357$ ) demonstrated elevated levels of sensory processing difficulty. Seventy-four percent of the sample ( $n = 297$ ) demonstrated performance on the *SSP* two standard deviations below the mean for children in the standardization sample and another 15% ( $n = 60$ ) scored more than one standard deviations below this mean score. These initial study findings replicate previous investigations (Kientz & Dunn, 1997; Watling et al., 2001) that found increased sensory processing difficulties among children with autism.

While the question of differentiation between children with and without autism is an important one, findings in previous studies fail to define patterns of sensory processing for children with autism compared to typically developing children. In this study, deficits in a variety of sensory processing abilities were found. Over 90% of the sample was reported to be underresponsive to sensory input, but to seek sensation. The most prevalent sensory symptoms in this Underresponsive/Seeks Sensation section included: seeks all kinds of movement and this interferes with daily routine, overly excitable during movement, touches people and objects, and jumps from one activity to another so that it interferes with play. Notably, these items were among the highest reported sensory symptoms of this sample on the *SSP*. These items are consistently elevated in studies involving children with an ASD (Kientz & Dunn, 1997; Rogers et al., 2003; Watling et al., 2001).

Significant sensory processing differences were also noted within the Auditory Filtering section among 87.6% ( $n = 350$ ) of the sample and included these high frequency items:

distracted or has trouble functioning if there is background noise, appear to not hear what you say, doesn't respond when name is called and difficulty paying attention . In general, children with autism in this sample appear to tune out language, while being somewhat distracted by environmental noises. These findings support previous research reports that have similar auditory sensory responsivity patterns (Adrien et al., 1987; Baranek, 1999; Gillberg et al., 1990; Osterling & Dawson, 1994).

Tactile sensitivity difficulties, also well documented in the autism literature discussing sensory processing, especially in first-hand accounts of living with autism (Baranek et al., 1997; Cesaroni & Garber, 1991; Grandin, 1995). Tactile sensitivity symptoms were also demonstrated in this study among 61.3% of the sample (n = 296) in a difference classification with the most reported difficulty tolerating grooming and hygiene tasks.

The sensory processing findings on the *SSP* in this study are consistently elevated item in studies involving children with an ASD (Kientz & Dunn, 1997; Rogers et al., 2003; Watling et al., 2001). Direct comparison between the current sensory processing findings and those of Kientz and Dunn (1997) are summarized in Table 12. It should be clear that the items yielding the highest frequency of dysfunctional sensory processing are the same in both studies. Although direct comparison of items in other investigations is not possible given reporting methods, it should be noted that the *SSP* sections (Rogers et al., 2003) and *Sensory Profile* factors (Watling et al., 2001) that best discriminated autism from those studies contained these same high frequency items. Together, these findings begin to elucidate clear patterns of sensory processing dysfunction in ASD and provide a background for considering and analyzing factor analysis findings.

### Sensory Processing Factors

The third and fourth research questions of this study examined the underlying factor structure of the *SSP* to determine if the factor structure for children with ASD would differ from the factor structure reported for typically developing children or if it would differentiate with in subgroups of children with autism be age, gender or functioning. The exploratory factor analysis for the sample of children with an ASD yielded a six factor structure that was conceptually consistent with sensory processing. The six factors were: Low Energy/Weak, Tactile and Movement Sensitivity, Taste/Smell Sensitivity, Auditory and Visual Sensitivity, Sensory Seeking, and Hypo-responsivity. Factor 1, Low Energy/Weak consisted of the same item



Table 12

Comparison of Percentages of Children Who Always or Frequently Displayed the Sensory Processing Behaviors Found in Current and Kientz and Dunn (1999)

Item	Current	Kientz & Dunn, 1997	
	Autism n=400	Autism N=32	No Autism n=64
<b>Tactile Sensitivity</b>			
1. <b>Expresses distress during grooming</b>	<b>58.8</b>	<b>68.8</b>	<b>4.7</b>
2. Prefers long/short sleeved clothing even when it is warm/cold	9.5	28.1	0.0
3. Avoids going barefoot, especially in grass or sand	13.5	21.9	3.1
4. Reacts emotionally or aggressively to touch	20.5	25.0	0.0
5. Withdraws from splashing water	13.5	25.1	0.0
6. Has difficulty standing in line or close to other people	20.5	56.3	1.6
7. Rubs or scratches out a spot that has been touched	11.5	6.3	0.0
<b>Taste/Smell Sensitivity</b>			
8. Avoids certain tastes/food smells typically part of a child's diet	35.0		
9. Will only eat certain tastes	12.5		
10. Limits self to particular food textures/temperatures	39.0		
<b>11. Picky eater, especially regarding food textures</b>	<b>46.8</b>	<b>50.0</b>	<b>12.5</b>
<b>Movement Sensitivity</b>			
12. Becomes anxious or distressed when feet leave the ground	7.0	18.8	0.0
13. Fears falling or heights	13.3	31.3	4.7
14. Dislikes activities where head is upside down	9.5	21.9	1.6
<b>Underresponsive/Seeks Sensation</b>			
<b>15. Enjoys strange noises/seeks to make noise for noise's sake</b>	<b>48.5</b>	<b>50.0</b>	<b>21.9</b>
<b>16. Seeks all kinds of movement which interferes with routines</b>	<b>68.0</b>	<b>56.3</b>	<b>17.0</b>
<b>17. Becomes overly excitable during a movement activity</b>	<b>63.8</b>	<b>37.5</b>	<b>1.6</b>
<b>18. Touches people and objects</b>	<b>59.3</b>	<b>40.6</b>	<b>10.9</b>
19. Doesn't seem to notice when face and hands are messy	27.8	43.8	4.7
<b>20. Jumps form one activity to another and it interferes with play</b>	<b>57.8</b>		
21. Leaves clothing twisted on body	26.0	37.6	4.7

Auditory Filtering			
22. <b>Is distracted or has trouble functioning if there is a lot of noise</b>	<b>56.5</b>	<b>68.8</b>	<b>4.7</b>
23. <b>Appears to not hear what you say</b>	<b>68.5</b>	<b>46.9</b>	<b>7.8</b>
24. Can't work in background noise	11.5	9.4	1.6
25. Has trouble completing tasks when the radio is on	16.0		
26. Doesn't respond when name is called but child's hearing is OK	47.3	21.9	9.4
27. <b>Has difficulty paying attention</b>	<b>74.8</b>	<b>75.0</b>	<b>3.1</b>
Low Energy/Weak			
28. Seems to have weak muscles	12.0	31.3	1.6
29. Tires easily	6.5	25.1	0.0
30. Has a weak grasp	11.8	34.4	0.0
31. Can't lift heavy objects	7.3	25.0	0.0
32. Props to support self	8.8	9.4	0.0
33. Poor endurance/tires easily	7.0		
Visual/Auditory Sensitivity			
34. Responds negatively to unexpected loud noises	45.5	25.0	3.1
35. Holds hands over ears to protect ears from sound	40.8	21.9	3.1
36. Is bothered by bright lights after others have adapted to the light	12.8	15.7	10.9
37. Watches everyone when they move around the room	37.8	28.2	10.9
38. Covers eyes or squints to protect eyes from light	21.3	18.8	15.6

*Notes.* Missing percentages reflect differences in item construction and therefore no comparison is available. Bold items are those with always or frequently reported behaviors by 50% or more of the parents.

composition of the Low Energy/Weak section of the *SSP*. Although this factor accounted for the most variance (20.10% of the 52.27%), items comprising this factor were among the lowest reported problematic sensory behaviors. This finding may suggest that the children with autism in this sample that did experience difficulties in these areas may demonstrate unique patterns.

Factor 2, Tactile and Movement Sensitivity, represents a merging of items from both the Tactile Sensitivity and Movement Sensitivity sections of the *SSP*. With the exception of the expression of distress during grooming item in the Tactile Sensitivity section, the rest of the Tactile Sensitivity and Movement Sensitivity items in this factor were not reported to be frequently displayed sensory behaviors in this sample. Interestingly, when comparing the items in this factor in relation to the sensory processing factor structure for typically developing children developed on the *Sensory Profile*, only one Tactile Sensitivity item (i.e., avoids going barefoot, especially in grass or sand) loaded on a factor whereas all of the Movement Sensitivity items loaded on a Sensory Sensitivity factor. In this study, 74% of the sample were reported to have difficulties with tactile processing on the *SSP*. Further, children with autism in another study (Rogers et al., 2003) were reported to have more frequent behaviors on the Tactile Sensitivity section of the *SSP* than developmentally delayed and typical children. Tactile processing difficulties are also well documented in the autism literature (Baranek et al., 1997, Cesaroni & Garber, 1991; Grandin, 1995; Kientz & Dunn, 1997). Given the high prevalence of tactile processing findings that are not well represented in a factor structure describing behavior of typically developing children, the Tactile and Movement Sensitivity factor identified in this study likely represents a clustering of behavior qualitatively different and unique to children autism that are not found in typically developing children.

The Tactile and Movement Sensitivity factor may also highlight the important neurological connections upon which sensory processing is predicated. The coordination and timing of movement has long been a function attributed to the cerebellum. The cerebellum has been theorized by some as an associated area of neurological dysfunction in autism (Waterhouse, Fein, & Modahl, 1996). In post-mortem autopsy studies of individuals with ASDs, differences in cerebellar structure have consisted of decreased numbers of Purkinje cells, decreased size of cerebellar lobes, and differences in the size and number of neurons in the cerebellar nuclei (Bauman & Kemper, 1994; Fatemi et al., 2002; Lee et al., 2002; Haas et al., 1996). The Purkinje cells in the cerebellar cortex are large association neurons that receive information from multiple

sensory systems including the tactile system. Given their multiple inputs from a number of sensory systems, a primary function of the Purkinje cells is to integrate and transmit sensory information, with many of their connections being with inhibitory interneurons (Palmen, van England, Hof, & Schmitz, 2004). The cerebellum then plays a key role in not only the coordination of movement, but also has a key role in integrating sensory information from a number of sensory systems (including the tactile system) and modulating it. Because of the consistence of cerebellar findings in autism and the fact that the Tactile and Movement Sensitivity factor loaded with both tactile and movement items, it suggests a common origin of such behaviors and provides the impetus for theorizing the foundation for these relationships as possibly residing in the cerebellum.

The Taste/Smell Sensitivity factor (Factor 3) is comprised of the same items in the Taste/Smell Sensitivity section of the *SSP*. The factor items describe sensitivity to particular tastes, textures, and temperatures of food. Foods that are typically part of a child's diet might be aversive to children who have a strong preference for or a strong aversion to smells (Ermer & Dunn, 1998). In this study, sensory preference items in this factor relating to food texture and temperature were reported to be present in 39% to 47%, whereas items relating more directly to taste and smell were reported less frequently (12%). Differences were also noted in this study between higher and lower adaptive functioning groups on this factor, with the low functioning group tending to have more pronounced food and oral preferences when compared to higher functioning group. Children with autism in another study (Rogers et al., 2003) were also noted to have more difficulties on these same items of the *SSP* than comparison groups of children who were typically developing, had Fragile X Syndrome or developmental delay. A similar factor structure on the *SP* (Dunn, 1999) has been used to establish its discriminative properties. In addition to the four items on the Taste/Smell Sensitivity (Factor 3) of *SSP*, the Oral Sensory Sensitivity factor on the *SP* includes four additional items measuring preferences for tastes and smells. This Oral Sensory Sensitivity factor has been shown to discriminate between children with autism and those who are typically developing (Ermer & Dunn, 1998; Watling et al., 2001), as well as between children with autism and those with Attention Deficit Hyperactivity Disorder (ADHD) (Ermer & Dunn, 1998). In both cases, the autism groups demonstrated a higher incidence of behaviors in this factor than comparison groups. Together, findings from previous studies and this investigation clearly document a pattern of oral sensory preferences in children

with autism. Further item analysis across studies would be beneficial in delineating more precise deficits based on taste, texture or smell and the relative contributions of each of these preferences.

The Auditory and Visual Sensitivity Factor (Factor 4) includes all items from the Visual/Auditory Sensitivity section of the *SSP*, as well as three additional items from the Auditory Filtering section relating to difficulty with filtering out environmental noises during task performance (i.e., can't work in background noise, trouble completing tasks if the radio is on, distracted or has trouble functioning if there is background noise). There was significant variability in this sample in the incidence of reported behaviors in this factor, yet it accounted for 5.85% of the variance in the *SSP* data. Visual distractibility and sensitivity to light items were reported less frequently in this sample. Sensitivity to loud noises was however, reported in 45.5% of the sample. There was more variability in reported auditory filtering functions with significant difficulty reported for distracted or has trouble functioning if there is background noise (56.5%), whereas less difficulty was reported for other auditory filtering items (11.5% - 16%). As a whole however, like in this study, the Auditory Filtering section of the *SSP* does appear to represent an area of weakness for children with an ASD (Rogers et. at., 2003) and is consistent with communicative disorders. The presence of auditory hypersensitivity in ASDs is well documented in the literature (Bettison, 1994; Dahlgren & Gillberg, 1989; Gillberg & Coleman, 1996; Grandin & Scariano, 1986; Rimland & Edelson, 1995; Vicker, 1993). Interventions directly targeted at decreasing auditory sensitivity have been developed (e.g., auditory integration training) and are being investigated for their efficacy; the results of have been mixed with equal numbers of studies supporting its use as there are studies demonstrating no benefit (Bettison, 1994; Rimland & Edelson, 1995; Vicker, 1993).

The Sensory Seeking/Distractibility factor (Factor 5) includes most of the items from the Underresponsive/Seeks Sensation section of the *SSP*, along with one item from the Auditory Filtering section (i.e., has difficulty paying attention). These Underresponsive/Seeks Sensation items in this factor, coupled with the difficulty paying attention item from the Auditory Filtering section were the highest reported sensory symptoms in this sample. Group differences were also noted on this factor, with children with autism or were lower functioning demonstrating more sensory seeking than those who had Asperger Disorder or were higher functioning. On the sensory processing factor structure for typically developing children developed on the *SP*, there

are two separate factors reflecting Sensory Seeking and Inattention/Distractibility abilities. With the exception of the difficulty paying attention item, all other items in the Sensory Seeking/Distractibility factor in this study are contained in the Sensory Seeking factor on the *SP*. Studies analyzing the discriminate properties this Sensory Seeking factor have yielded mixed results. Similar to findings in this investigation, children with autism in another study reported a high incidence of sensory seeking behavior when compared to age and gender-matched controls without disabilities (Watling et al., 2001). Ermer and Dunn (1998), on the other hand, reported a low incidence of sensory seeking behavior in their sample of children with autism when compared to both children with ADHD and children without disabilities. Further, the lack of sensory seeking behavior in the children with autism discriminated them from both children with out disabilities and those with ADHD. The Inattention/Distractibility factor of the *SP* contains all of the Auditory Filtering items from the *SSP*, along with the visual distractibility item contained in the Auditory and Visual Sensitivity Factor. Like in this study, items in this factor also tend to be highly reported findings (Ermer & Dunn, 1998; Watling et al., 2001).

Factor 6, Hypo-responsivity, contains items from several *SSP* sections. Two Auditory Filtering items reflecting diminished response to language are included, along with one item each from Tactile Sensitivity (doesn't seem to notice when face and hands are messy) and Underresponsive/Seeks Sensation (leaves clothing twisted on body) sections are contained in this factor. While the *appears not to hear what you say* (68.5%) and *doesn't respond when name is called* (47.3%) Auditory Filtering items in this factor were reported as highly displayed behaviors, the other two items were not as highly reported (2.60% - 27.8%). Diminished response to name in children with autism has been previously reported (Baranek, 1999; Osterling & Dawson, 1994), whereas others have reported decreased responding to not only verbal but general noise as well (Wing, 1966). Notably, a higher incidence of under-responsivity to having face or hands messy (43.8%) and clothing (37.6%) were reported by Kientz and Dunn (1997) in their study of children with autism. Without analyzing standard error, differences however likely can be attributed to differences in sample size in that the Kientz and Dunn study included only 32 children with autism. Interestingly, in this study the only age differences were noted on this factor with older children in the sample demonstrating more auditory and visual sensitivity.

The six factor solution identified in this study represents a factor structure for children with autism. Although there are similarities to the factor structure and some of the specific

factors of typically developing children on the *SSP*, differences are evident. Tactile and Movement Sensitivity items of the *SSP* merged to form a single factor. Auditory Filtering items from the *SSP* were spread across three factors describing auditory and visual sensitivity, distractibility, and sensory hypo-responsivity. Underresponsive/Seeks Sensation items from the *SSP* loaded on two separate factors (i.e., Sensory Seeking/Distractibility and Hypo-responsivity). These findings either suggest qualitative differences in sensory processing in autism that are not found in typically developing children in the *SP* standardization or suggest that the factor structure of the *SSP* needs refinement to support a taxonomy of sensory processing. The noted differences between autism and non-autism subjects in multiple studies, provides support for the belief that qualitative differences in sensory processing in autism exist when compared to typically developing children.

#### Relationships Between Sensory Factors and Development

Another important line of inquiry and the fifth research question in this study was to establish relationships between the sensory factor variables and scores on the developmental variables associated with autism. When analyzing the predictive value of the six factors to each of the six developmental variables (i.e., adaptive, social, receptive and expressive language, gross and fine-motor), five of the six regression models were significant. The sensory factor variables contributed to 11% of the variance in the receptive language scores and nearly 10% of the variance for adaptive and expressive language performance. This line of investigation has seldom been explored in studies of sensory processing in ASDs, rather factor structures of typically developing children on the *SP* have been applied to autism samples to determine their ability to discriminate between samples by disability or diagnosis. This former line of research is useful in documenting the validity of the *SP*, but less useful in documenting unique patterns of sensory processing specific to autism. Only Rogers and colleagues (Rogers et al., 2003) analyzed the predictive value of sensory responsivity and they focused their analysis on one developmental variable - adaptive skill. In their study, the developmental level of the subjects accounted for the most variability in adaptive behavior, with the sensory responsivity accounting for only 4% of the variance in adaptive functioning. Given the greater predictive values of the sensory factor variables observed in this study on key language, adaptive and social variables in ASD diagnosis, it would appear that these sensory aspects play a role in the variable developmental presentation of individuals on the autism spectrum.

A potential model for summarizing the variable developmental presentation of individuals with an ASD as a function of the relationship between sensory processing and the developmental variables is depicted in Figure 4. In this model, the functioning of the communication, adaptive, social, and motor developmental variables are related to the relative functioning of each of the other variables. Further, the functioning of these variables is influenced by, and considered in the context of, the individuals ability to process sensory input. Reflecting the correlation and regression analysis findings in this study, sensory processing in the model is shown to have greater influence on communication, adaptive and social variables. Together, the interaction between all these variables is theorized to describe the variable developmental presentation of individuals with an ASD.

Current efforts to define and develop a phenotype in autism often target theorized neurobiological underpinnings in conjunction with developmental and behavioral data to propose behavioral phenotypes in ASDs (Bauman & Kemper, 1994; Dawson, et al., 2002b; Eaves, Ho, & Eaves, 1994; Gillberg & Coleman, 1996; Rapin, 1997; Stevens et al., 2000). Nonetheless, current behavioral phenotyping investigations often exclude sensory symptoms, demonstrated in this study to be conceptually related and predictively relevant to autism. Given these findings, future studies investigating behavioral phenotypes in autism, will be strengthened by the inclusion of sensory symptoms that may account for more variance in diagnosis or contribute to differentiating subtype patterns.



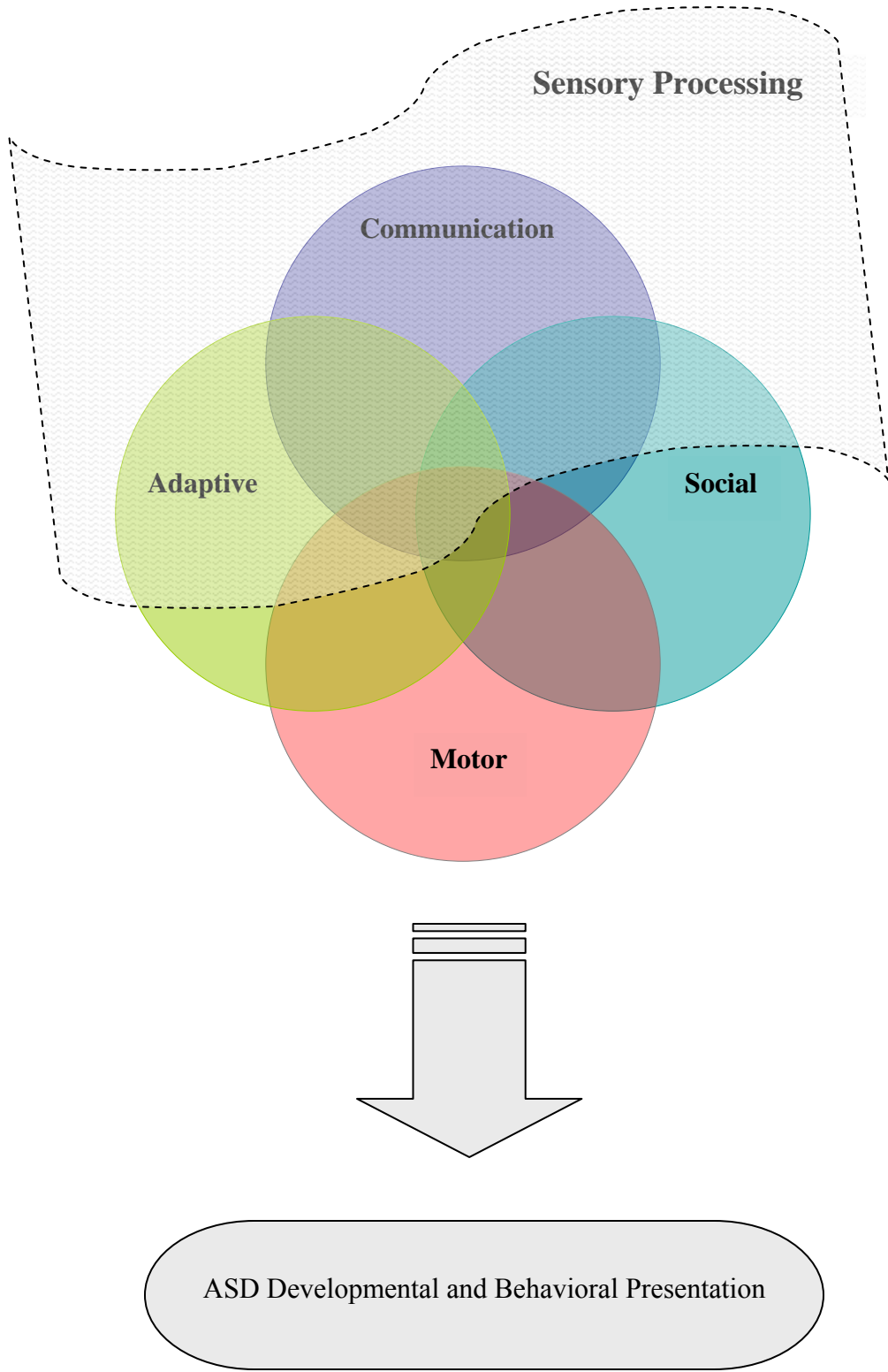


Figure 4, Developmental presentation in ASDs as a function of the interaction between the developmental variables in the context of sensory processing.

### Study Limitations and Strengths

The results of this study should be interpreted cautiously. In part, the limitations of this study are directly related to the unique diagnostic aspects of ASDs. Developmental testing is a social communication process and optimal performance is in part dependent on the weakest skills for individuals on the autism spectrum, probably compromising the validity of developmental measures. As a result, criterion referenced instruments yielding developmental ages are often used in lieu of utilizing standardized instruments with this group of children and were employed in this study. Many of these instruments rely heavily on parent report. Although using parent report measures and developmental quotients are common practices in the autism literature (see Bibby, Eikeseth, Martin, Mudford, & Reeves, 2001; Lord & Schopler, 1989; Rogers et al., 2003; Stone et al., 1997), they introduce an unknown amount of bias that could either inflate or diminish true performance.

Sensory symptoms were also considered only in the context of behavioral observations via a parent report measure. The source of behavioral observations as arising from discrepancies in sensory processing is assumed, rather than demonstrated. Another profession might interpret similar findings as representing behavioral disorders, social skill deficits, or limitations in cognition. To validate the *SSP*, validation of models linking behaviorally observed sensory symptoms with neurophysiologic evidence are needed. Replication of the findings like those of Miller and colleagues (2001) correlating dysfunctional sensory processing scores on the *SSP* with abnormal psychophysiological responses are vital. Doing so will likely require integrated research questions involving expertise from a number of disciplines (e.g., neuropsychology, occupational therapy, neurology). However, the findings from Miller et al. (2001) begin to document that scores on the *SSP* are related to measurable changes in neurophysiologic responding.

This study employed a sample of convenience from one region of the country and therefore may not represent the entire population of children with autism. No normative data was collected or available except from the test developers. Therefore, interpreting the study findings was also somewhat limited by the lack of a comparison group of children with developmental difficulties other than autism. Use of a comparison group would allow for testing the effects of co-existing developmental deficits (e.g., language delay, adaptive functioning deficits) on patterns of sensory processing.

In spite of the above limitations, this study had many strengths. Previous studies with similar research questions have employed 40 children with autism at most; this study with an unprecedented sample size of 400 children with autism has greater statistical power to elucidate the research questions. Despite, the difficulties with obtaining valid developmental measures on the population with autism, the use of data from one diagnostic center specializing in autism may have improved the reliability of the scores because of the professional expertise, skill in evaluating autism, and small number of professionals. Additionally, consistent measures for all variables across subjects or cross-validation of measures were employed with complete data collected for all 400 subjects. These factors directly address potential concerns related to retrospective collection. Further, because there are normative samples for the *SSP*, the results of this study could be compared to findings with typically developing children.

### Implications for Practice

Together, the sensory processing findings noted in this study describe a pattern of dysfunctional sensory modulation. That is, children appear to be having difficulty with filtering and modifying sensory stimuli to develop an appropriate response. Sensory modulation has been defined as the capacity to regulate and organize the degree, intensity, and nature of responses to sensory input in a graded and adaptive manner (Miller & Lane, 2000). This allows the individual to achieve and maintain an optimal range of performance and to adapt to challenges in daily life. When an individual is properly modulating sensory input, s/he will respond adaptively by maintaining optimal levels of arousal. From this optimal arousal base, maximal performance in skilled occupations can be built. When sensory modulation is inadequate, the individual has difficulty regulating and organizing the sensory information to allow for adaptive responding. For example, attention may be directed to all sensory events in the environment, instead of filtering out some of the input and allowing the individual to focus on the relevant sensory events (Lane, 2000).

Children with sensory modulation problems demonstrate hyper-responsivity, hypo-responsivity, or lability in response to sensory stimuli (Dunn, 1997, 2000; Hanft, Miller, & Lane, 2000; Royeen & Lane, 1991). Emotional sequella also accompany these behaviors. Observable behavior manifestations of these difficulties are noted in Table 13. In *hyper-responsivity*, the child responds to incoming sensations to a greater extent than would be expected given the external contextual demands. Hyper-responsiveness may result in the individual responding

Table 13

Classification of Behavioral Manifestations of Sensory Modulation Difficulties from the *SSP* (Dunn, 1999)

Sensory System	Hyper-Responsivity	Hypo-Responsivity
Tactile	<ul style="list-style-type: none"> <li>-Expresses distress during grooming</li> <li>-Avoids going barefoot, especially in grass or sand</li> <li>-Reacts emotionally or aggressively to touch</li> <li>-Withdraws from splashing water</li> <li>-Has difficulty standing in line or close to other people</li> <li>-Rubs or scratches out a spot that has been touched</li> </ul>	<ul style="list-style-type: none"> <li>-Touches people and objects</li> <li>-Doesn't seem to notice when face and hands are messy</li> <li>-Leaves clothing twisted on body</li> </ul>
Oral	<ul style="list-style-type: none"> <li>-Avoids tastes/food smells typically part of a child's diet</li> <li>-Picky eater, especially regarding food textures</li> </ul>	<ul style="list-style-type: none"> <li>-Will only eat certain tastes</li> </ul>
Movement	<ul style="list-style-type: none"> <li>-Becomes anxious or distressed when feet leave the ground</li> <li>-Fears falling or heights</li> <li>-Dislikes activities where head is upside down</li> </ul>	<ul style="list-style-type: none"> <li>-Seeks all kinds of movement which interferes with routines</li> <li>-Becomes overly excitable during a movement activity</li> </ul>
Auditory	<ul style="list-style-type: none"> <li>-Distracted or has trouble functioning if there is a lot of noise</li> <li>-Can't work in background noise</li> <li>-Has trouble completing tasks when the radio is on</li> <li>-Responds negatively to unexpected loud noises</li> <li>-Holds hands over ears to protect ears from sound</li> </ul>	<ul style="list-style-type: none"> <li>-Enjoys strange noises/makes noise for noise's sake</li> <li>-Appears to not hear what you say</li> <li>-Doesn't respond when name is called but hearing is OK</li> </ul>

Visual

- Bothered by bright lights after others have adapted
  - Watches everyone when they move around the room
  - Covers eyes or squints to protect eyes from light
-

defensively (autonomic nervous system “fight or flight” response) to a stimulus that is generally considered harmless or non-threatening. Because of this defensive avoidance, hyper-responsivity has also been described as sensory defensiveness. Emotional responses associated with hyper-responsive behaviors include explosiveness, aggressiveness, and hostile behaviors; when over-stimulated, a child may become anxious and/or clingy. Attention may fluctuate from distractibility to input and to an over-focused, vigilant approach to tasks in an effort to screen out noxious stimuli (Hanft, Miller, & Lane, 2000; Williamson & Anzalone, 1997). In *hypo-responsivity*, the individual responds to incoming sensations to a lesser extent than individuals with typical modulation and may result in diminished or delayed responding to sensory input from the environment. These difficulties have also been referred to as sensory registration impairments. Emotional responses associated with hypo-responsivity include a lack of emotional range in social relationships and a diminished attention sometimes interpreted as a lack of interest. Behaviorally then, children with sensory modulation difficulties can exhibit over-responsivity as they actively seek to avoid sensory input in the environment and/or hypo-responsivity and passivity as they fail to orient and respond to typical levels of sensory input in the environment (Dunn, 1997; Miller & Lane, 2000; Miller & Summers, 2001). Such responses can seem contradictory, and this pattern is seen in the results of this study.

Sensory modulation impairments then, limit a child’s ability to sustain attention, regulate arousal, and ultimately achieve and maintain an optimal range of performance for adaptation and learning. Deficits in sensory modulation among persons with autism have been well documented in the basic science literature (Lincoln et al., 1993; Ornitz, 1989; Ornitz et al., 1993; Yeung-Courchesne & Courchesne, 1997), in clinical literature (Bauman, 1999; Dawson & Watling, 2000; Ermer & Dunn, 1998; Haas et al., 1996; Jones & Prior, 1985; Kientz & Dunn, 1997; Rogers et al., 2003; Watling et al., 2001) and in first-person accounts of living with autism (Cesaroni & Garber, 1991; Grandin, 1992; Williams, 1995). In fact, the initial appearance of these sensory processing findings often predates diagnosis (Adrien et al., 1993, Baranek, 1999; Dahlgren & Gillberg, 1989; Lord, 1995). Consistent with these findings, children in this study were noted to have sensory modulation difficulties. The sensory symptoms identified as most frequently dysfunctional in this study have been directly related in item construction to functional limitations in the child’s ability to engage in daily routines and play.

The findings of this study then have major implications for intervention programs involving individuals with an ASD. Recently, the U. S. Department of Education, Office of Special Education Programs, National Research Council formed the Committee on Educational Interventions for Children with Autism (Council, 2001) and charged the committee to integrate the scientific, theoretical and policy literature and create a framework for evaluating scientific evidence concerning the effects and features of educational programming for young children with autism. The primary focus of the charge was to define effective educational programs for children with autism under the age of 8 years with the conclusion that educational programming for young children with autism need to promote *active engagement* (Council, 2001). This view is also supported by several other reviews and analyses of effective programs for individuals with autism (Dawson & Osterling; 1997; Dunlap, 1999; Hurth et al, 1999; Strain et al, 1998). Active engagement is a component of various treatment approaches like discrete trial training (Lovaas, 1987), incidental teaching (McGee, Morrier, & Daly, 1999) and structured teaching (Lovaas, 1987; McGee, Morrier, & Daly, 1999; Schopler, Mesibov & Daly, 1995) that have shown effectiveness.

The key component to the active engagement construct is the ability to sustain attention to an activity or person (de Kruif & McWilliam, 1999; McWilliam & Bailey, 1992). Active engagement is a qualitative construct that includes the focus and level of engagement (e.g., pretend play, attention, persistence, participation, and undifferentiated behavior). Engagement goes beyond measurement of the amount of time a child spends in an activity to capture important behaviors for learning (de Kruif & McWilliam, 1999) such as the child's motivation for mastery and the extent of goal-directed behavior. Active engagement is a stable construct that appears to be related to internal child factors (temperament or diagnosis), observable child behaviors (level of play skill), and environmental factors (type of classroom activity) (de Kruif & McWilliam, 1999; McWilliam & Bailey, 1995; McWilliam, Trivette, & Dunst, 1985).

Given the magnitude of core social, communication, and play impairments in autism, extensive study has provided a taxonomy and sufficient descriptions of the patterns of social, play, and communicative skills that are now being applied to study and improve active engagement. On the other hand, the nature of sensory processing in children with autism, the impact on learning, and the potential contributions to engagement are sparsely delineated. This study and its findings are a first step in more clearly defining patterns of sensory responding in

autism. Eighty-nine percent of the sample demonstrated some degree of sensory processing dysfunction on the *SSP* Total Score with 74.5% in them in the definite difference classification of greater than 2 standard deviations from the mean. The greatest difficulties were reported on the Underresponsive/Seeks Sensation, Auditory Filtering and Tactile Sensitivity sections of the *SSP*. Exploratory factor analysis identified 6 parsimonious factors: Low Energy/Weak, Tactile and Movement Sensitivity, Taste/Smell Sensitivity, Auditory and Visual Sensitivity, Sensory Seeking/Distractibility, and Hypo-responsivity that could be utilized as a descriptive taxonomy in autism. These identified behavioral patterns directly impact the child's ability to sustain engagement in activities. Children who are auditorily, visually, tactilely, taste/smell and/or movement sensitive may seek sensory input or appear distractible as they seek to avoid sensory input in the environment and/or hypo-responsive and passive as they fail to orient and respond to typical levels of sensory input in the environment (Dunn, 1997; Miller & Lane, 2000; Miller & Summers, 2001). These sensory modulation deficits represent a mismatch between the external contextual demands of the child's environment and his/her internal characteristics (e.g., attention, emotion, sensory processing) (Miller et al., 2001) and impairs the child with autism's ability to sustain active engagement with people or activity at hand. Recognizing these sensory processing contributions as a vital component of the environment reduces the degree to which skill development rests solely on internal child factors and guides parents, teachers, and practitioners on effective environmental strategies that can improve child engagement to yield optimal outcomes (Reinhartsen, Garfinkle, & Wolery, 2002; Ruble & Dalrymple, 1996, 2002; Wolery, 2000; Wolery & Garfinkle, 2002)

### Research Directions

The findings of this study provide directions for potential future sensory processing research involving individuals with an autism spectrum disorder. Initially, further analysis utilizing this data set appears warranted. Comparison of *SSP* item performance between this sample of children with an ASD in this study and the initial standardization sample of typically developing children from the *SSP* will identify further differences between these groups. Additionally, cluster analysis utilizing the developmental and sensory processing variables will further discriminate autism features and explore ASD behavioral phenotypes. Replication of the findings of this study in groups of children with an ASD will establish the generalizability of findings. Further, the study methods employed in this study need replication with groups of



children with other disabilities to establish if the patterns identified in this study are specific to children with an ASD or whether they are consistent with developmental disability. Together, these studies may allow for the development of measures of sensory processing specific to children with an ASD. This line of investigation will ultimately allow for a clearer understanding of the contributions of sensory processing to the variable presentation of individuals with an ASD and will have implications for early diagnosis and intervention.

### **CONCLUSIONS**

Children with an ASD in this sample demonstrated were reported to have difficulties with processing and responding to sensory input. Eighty-nine percent of the sample demonstrated some degree of sensory processing dysfunction on the *SSP* Total Score. Children were reported to be underresponsive, seek sensory input, have difficulty filtering auditory input, and sensitive to tactile input. Exploratory factor analysis identified six sensory processing factors: Low Energy/Weak, Tactile and Movement Sensitivity, Taste/Smell Sensitivity, Auditory and Visual Sensitivity, Sensory Seeking/Distractibility, and Hypo-responsivity. Together, these sensory processing findings noted in this study describe a pattern of dysfunctional sensory modulation. Sensory modulation deficits limit a child's ability to sustain attention, regulate arousal, and ultimately achieve and maintain an optimal range of performance for adaptation and learning. These skills are fundamental to functional performance and therefore likely play a role in developmental performance. As such, sensory processing patterns identified in this study contributed to explaining the differences in communication, adaptive, social, and motor abilities of the sample that are associated with the diagnosis of autism.

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## Appendix A

# Short Sensory Profile



## SENSORY PROFILE

Winnie Dunn,  
Ph.D., OTR, FAOTA

Child's Name: \_\_\_\_\_ Birth Date: \_\_\_\_\_ Date: \_\_\_\_\_

Completed by: \_\_\_\_\_ Relationship to Child: \_\_\_\_\_

Service Provider's Name: \_\_\_\_\_ Discipline: \_\_\_\_\_

### INSTRUCTIONS

Please check the box that **best** describes the frequency with which your child does the following behaviors. Please answer all of the statements. If you are unable to comment because you have not observed the behavior or believe that it does not apply to your child, please draw an X through the number for that item. Please do not write in the Section Raw Score Total row.

#### Use the following key to mark your responses:

**ALWAYS**

When presented with the opportunity, your child always responds in this manner, 100% of the time.

**FREQUENTLY**

When presented with the opportunity, your child frequently responds in this manner, about 75% of the time.

**OCCASIONALLY**

When presented with the opportunity, your child occasionally responds in this manner, about 50% of the time.

**SELDOM**

When presented with the opportunity, your child seldom responds in this manner, about 25% of the time.

**NEVER**

When presented with the opportunity, your child never responds in this manner, 0% of the time.

Item		ALWAYS	FREQUENTLY	OCCASIONALLY	SELDOM	NEVER
<b>Tactile Sensitivity</b>						
1	Expresses distress during grooming (for example, fights or cries during haircutting, face washing, fingernail cutting)					
2	Prefers long-sleeved clothing when it is warm or short sleeves when it is cold					
3	Avoids going barefoot, especially in sand or grass					
4	Reacts emotionally or aggressively to touch					
5	Withdraws from splashing water					
6	Has difficulty standing in line or close to other people					
7	Rubs or scratches out a spot that has been touched					
<b>Section Raw Score Total</b>						
<b>Taste/Smell Sensitivity</b>						
8	Avoids certain tastes or food smells that are typically part of children's diets					
9	Will only eat certain tastes (list: _____)					
10	Limits self to particular food textures/temperatures (list: _____)					
11	Picky eater, especially regarding food textures					
<b>Section Raw Score Total</b>						
<b>Movement Sensitivity</b>						
12	Becomes anxious or distressed when feet leave the ground					
13	Fears falling or heights					
14	Dislikes activities where head is upside down (for example, somersaults, roughhousing)					
<b>Section Raw Score Total</b>						
<b>Underresponsive/Seeks Sensation</b>						
15	Enjoys strange noises/seeks to make noise for noise's sake					
16	Seeks all kinds of movement and this interferes with daily routines (for example, can't sit still, fidgets)					
17	Becomes overly excitable during movement activity					
18	Touches people and objects					
19	Doesn't seem to notice when face or hands are messy					
20	Jumps from one activity to another so that it interferes with play					
21	Leaves clothing twisted on body					
<b>Section Raw Score Total</b>						

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Item		ALWAYS	FREQUENTLY	OCCASIONALLY	SELDOM	NEVER
<b>Auditory Filtering</b>						
22	Is distracted or has trouble functioning if there is a lot of noise around					
23	Appears to not hear what you say (for example, does not "tune-in" to what you say, appears to ignore you)					
24	Can't work with background noise (for example, fan, refrigerator)					
25	Has trouble completing tasks when the radio is on					
26	Doesn't respond when name is called but you know the child's hearing is OK					
27	Has difficulty paying attention					
<b>Section Raw Score Total</b>						
<b>Low Energy/Weak</b>						
28	Seems to have weak muscles					
29	Tires easily, especially when standing or holding particular body position					
30	Has a weak grasp					
31	Can't lift heavy objects (for example, weak in comparison to same age children)					
32	Props to support self (even during activity)					
33	Poor endurance/tires easily					
<b>Section Raw Score Total</b>						
<b>Visual/Auditory Sensitivity</b>						
34	Responds negatively to unexpected or loud noises (for example, cries or hides at noise from vacuum cleaner, dog barking, hair dryer)					
35	Holds hands over ears to protect ears from sound					
36	Is bothered by bright lights after others have adapted to the light					
37	Watches everyone when they move around the room					
38	Covers eyes or squints to protect eyes from light					
<b>Section Raw Score Total</b>						

**FOR OFFICE USE ONLY**

**Summary**

**Instructions:** Transfer the score for each section to the Section Raw Score Total column. Plot these totals by marking an X in the appropriate classification column (Typical Performance, Probable Difference, Definite Difference):

**SCORE KEY**

1 = Always	4 = Seldom
2 = Frequently	5 = Never
3 = Occasionally	

Section	Section Raw Score Total	Typical Performance	Probable Difference	Definite Difference
Tactile Sensitivity	/35	35 ----- 30	29 ----- 27	26 ----- 7
Taste/Smell Sensitivity	/20	20 ----- 15	14 ----- 12	11 ----- 4
Movement Sensitivity	/15	15 ----- 13	12 ----- 11	10 ----- 3
Underresponsive/Seeks Sensation	/35	35 ----- 27	26 ----- 24	23 ----- 7
Auditory Filtering	/30	30 ----- 23	22 ----- 20	19 ----- 6
Low Energy/Weak	/30	30 ----- 26	25 ----- 24	23 ----- 6
Visual/Auditory Sensitivity	/25	25 ----- 19	18 ----- 16	15 ----- 5
<b>Total</b>	<b>/190</b>	<b>190 ----- 155</b>	<b>154 ----- 142</b>	<b>141 ----- 38</b>

\*Classifications are based on the performance of children without disabilities (n = 1,037).

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## Vita

Scott D. Tomchek, M.S., OTR/L

Date of Birth: 03/18/1969

Place of Birth: Two Rivers, WI

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### ***Education:***

State University of New York at Buffalo: Buffalo, NY  
Master of Science in Occupational Therapy - June, 1993  
Specialization: Developmental Pediatrics and Early Intervention  
GPA: 3.938

University of Wisconsin- Milwaukee: Milwaukee, WI  
Bachelor of Science in Occupational Therapy - June, 1991  
Summa Cum Laude, GPA: 3.802

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### ***Positions and Appointments:***

7/95 - Present **Manager, Developmental Services and Chief Occupational Therapist:**

University of Louisville, Weisskopf Child Evaluation of Center: Louisville, KY

10/93 - 7/95 **Staff Occupational Therapist:**

Audubon Regional Medical Center: Louisville, KY

6/93 - 10/93 **Staff/Traveling Occupational Therapist:**

Kadlec Medical Center: Richland, WA

5/92 - 5/93 **Research Assistant:**

Children's Hospital of Buffalo PACT Program: Buffalo, NY

5/92 - 5/93 **Graduate Assistant:**

SUNY at Buffalo Pediatric Training Grant: Buffalo, NY

8/91 - 5/92 **Research/Teaching Assistant:**

SUNY at Buffalo Department of Occupational Therapy: Buffalo, NY

6/91 - 8/91 **Staff Occupational Therapist:**

Holy Family Medical Center: Manitowoc, WI

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**Scholarly Activities:**

**Grant Funding:**

*Student Investigator:* U.S. Department of Education (DOE), Student-initiated Research Projects: *The Nature of Sensorimotor Processing in Autism: Implications for Active Engagement.* Approved, not funded, 11/03

*Co-Investigator:* Database on Autism: Sensory, Motor, Medical, Psychological, Language, and Neuropsychological Variables. (P.I.: Ruth Huebner, PhD, OTR/L) Funded by an Eastern Kentucky University, University Research Committee - Faculty Research Grant

**Publications:**

**Journal Articles:**

**Tomchek, S.D.,** Lane, S.J. & Ottenbacher, K.J.(1997). Preacademic skill development in children who were full-term low birth weight infants.

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**Book Chapters:**

**Tomchek, S.D.** (2001). Sensorimotor assessment of individuals with autism spectrum disorders. In, R. A. Huebner, *Autism: A Sensorimotor Approach to Management*, Aspen: Gaithersburg, MD.

Geis, R.M. & **Tomchek, S.D.**(2001). Applications of sensorimotor approaches. In, R. A. Huebner, *Autism: A Sensorimotor Approach to Management*. Aspen: Gaithersburg, MD.

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**Tomchek, S.D.** (1999). The nervous system. In S. Porr and E.B. Rainville, *Pediatric Therapy: A Systems Approach*. F. A. Davis: Philadelphia.

Ottenbacher, K.J. & **Tomchek, S.D.** (1993). Measurement in rehabilitation research: Consistency vs. Consensus. In C. Granger and G. Gresham (eds), *New Developments in Functional Assessment in Rehabilitation Medicine*. W. B. Saunders: New, York.

**Manuscripts In Press:**

**Tomchek, S. D.** & Schneck, C. (2005). Evaluation of Handwriting. In, C. Pehoski and A. Henderson (Eds), *Development of Hand Skills in the Child (Second Edition)*. Philadelphia: Elsevier

Watling, R. A., **Tomchek, S. D.**, & LaVesser, P. D. (2005). Official Statement of the American Occupational Therapy Association: The Scope of OT Services for Individuals with Autism Spectrum Disorders Across the Lifespan. In Press, *American Journal of Occupational Therapy*.