EFFECT OF AN ACUTE SENSORY INTEGRATION THERAPY ON THE POSTURAL STABILITY
AND GAZE PATTERNS OF CHILDREN WITH AUTISM SPECTRUM DISORDER

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EFFECT OF AN ACUTE SENSORY INTEGRATION THERAPY ON THE POSTURAL STABILITY AND GAZE PATTERNS OF CHILDREN WITH AUTISM SPECTRUM DISORDER

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ABSTRACT

EFFECT OF AN ACUTE SENSORY INTEGRATION THERAPY ON THE POSTURAL STABILITY AND GAZE PATTERNS OF CHILDREN WITH AUTISM SPECTRUM DISORDER

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Children with Autism Spectrum Disorder (ASD) struggle with sensory regulation, resulting in decreased motor control, unusual gaze patterns, and decreased postural stability. Sensory integration therapy is a common therapy used to help children with ASD with these issues, however, there is insufficient quantitative research concerning the actual results of sensory integration therapy with respect to human biomechanics. It was the objective of this study to quantify the acute effects of a vestibular treatment on postural stability and gaze patterns of children with ASD. Five children with ASD and five TD children participated in the posturography protocol, and four children with ASD and 4 TD children participated in the eye tracking protocol portion of the study. The study used a pre-test, post-test methodology to evaluate changes caused by a vestibular swing therapy. Postural control data was collected while subjects stood on a balance plate under a variety of sensory conditions Gaze fixation were recorded via eye tracking
equipment while subjects played fine and gross motor games. It was determined that
the subjects with ASD who underwent the posturography study demonstrated improved
postural stability and dynamic postural complexity, especially in the eyes open/flat plate
condition. This improvement included decreased sway range, mean sway velocity, sway
root mean square and increased M/L Sample Entropy. Although only 5 subjects were
tested, the results of a nonparametric Wilcoxon Ranks Test were approaching
significance (p = .08) for the MV parameter. There were no conclusive trends generated
from the eye tracking data. The results suggest that children with ASD experience a
beneficial effect from an SI therapy protocol and that posturography is a test method
that could be further employed to study this phenomenon. Currently, eye tracking does
not appear to be an ideal evaluative tool for a short-term therapy protocol.
My thesis is dedicated to my family—Mom, Dad, Baba, Anna, Julia, and Matthew, I love you all so much and deeply appreciate all the wisdom, encouragement, and strength you have given me throughout my life.

This is also dedicated to my fiancé, Jimmy, who encouraged me to get my graduate degree and has loved, supported, and helped me maintain a great sense of humor throughout the process.
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CHAPTER 1

INTRODUCTION

1.0 Background and Significance

1.1 Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) is a developmental disorder that first becomes evident in early childhood [1]. ASD is characterized by a lack of socialization abilities, language deficiencies, motor issues, and a wide range of unusual and repetitive behaviors [1-3]. Individuals with ASD exhibit symptoms such as toe walking, hand flapping, lack of eye contact, muteness or delayed speech, self-injury, non-imaginative play, and the inability to initiate or maintain social contact [1-3]. Additional symptoms include acute self-isolation, “obsessive insistence on the preservation of sameness,” an inability to establish joint attention, pronoun reversal, a tendency toward literalness, exceptional rote memory, and difficulty regulating sensory input [1-4]. These symptoms can cause a person to appear unsocial, rigidly adherent to certain schedules or routines, unable to converse normally, and prone to breakdowns when overwhelmed. ASD is a spectrum disorder that has a wide range of pervasiveness and severity of disability.
which includes the diagnoses of autism disorder, Asperger’s Disorder (AS), and Pervasive Developmental Disorder Not-Otherwise-Specified (PDD-NOS).

In most cases, autism becomes evident when a child is 18 to 36 months old and the diagnosis is reached based on a combination of the atypical behaviors listed above rather than a concrete biological or genetic indicator [3]. The gender of an individual is a factor related to severity: males are four times more likely to be diagnosed with autism than females, however when females are diagnosed their prognosis is often more severe [4]. The long term prognosis for individuals with ASD varies extensively. Some children, with early and extensive therapeutic intervention, can improve to the point where they can live fairly normal lives [1]. Without the aid of extensive early intervention, however, only 1-2% of individuals with ASD ‘catch up’ to their neurotypical peers [1]. Additionally, simply receiving the correct therapy does not guarantee success; in most cases, a child has to fall on the higher functioning half of the ASD spectrum to show the kind of improvements that result in leading an independent life as an adult [1].

1.2 Sensory Processing

One symptom that deeply impacts the life of individuals with ASD is the inability to properly process and organize sensory information [5, 6]. Sensory processing is the means by which the brain organizes and interprets sensory information from both the body and the surrounding environment [5, 6]. The brain receives sensory input from a range of sensory systems—visual, audial, tactile, proprioceptive, vestibular, visceral, taste, and olfactory—and organizes them so an individual can understand his or her
environment and his or her own response to it [5, 6]. This is an extremely complicated process that requires intricate coordination between multiple parts of the brain, and deficits of this processing impair a person’s quality of life [5-7]. When the brain struggles to organize sensory input, it can hinder a child’s ability to concentrate, socialize, remain seated, be comforted, appropriately respond to environmental changes, learn academic material, and ‘follow the rules’ [5, 6]. Children with ASD often are unable to concentrate on simple tasks or seem unreasonably upset when placed in a new environment—both traits that are attributed to sensory processing deficits [8]. They are often unable to learn in a typical classroom setting and struggle with forming or maintaining friendships [5, 7].

The neurology of autism offers an explanation of the disease-specific mechanisms behind the sensory integration exhibited by individuals with ASD [9]. Researchers have determined that ASD most likely impacts the central nervous system and brain, and neurological connectivity issues could potentially result in problems integrating information from multiple sensory and neural systems [9]. The intricate coordination involved in relaying signals between multiple regions of the brain is vital for the transmission and processing of sensory information and any disruption in these signals could account for some of the symptoms experienced by children with ASD [9]. Anatomic and pathologic abnormalities in the cerebellum and possibly the basal ganglia have been identified as potential contributors to the sensory processing impairments in children with ASD [10-18].
1.3 Sensory Integration Therapy

Sensory Integration (SI) therapy is a therapy designed to address the sensory processing issues experienced by individuals with ASD [19, 20]. A subset of occupational therapy, SI therapy is based on the theory that if a child experiences a multitude of novel sensory experiences while being physically and cognitively challenged, his central nervous system will develop enhanced neural plasticity, allowing him to better organize internal and external sensory input [5, 6, 21]. Neural plasticity is the process by which the brain alters neural pathways and synapses in response to changes in a person’s behavior, internal bodily processes, or the surrounding environment [22]. Neural plasticity includes promoting neurogenesis, or the promotion of neuron growth, and changing synaptic connections by reinforcing, reducing, or adding them [22]. This allows the brain to better respond and adapt to changes in a healthy way.

Children who undergo SI therapies have been reported to exhibit a range of benefits that can include decreased levels of anxiety, stress, repetitive behaviors, and hypersensitivity [5-7]. Many children also experience an increase in social behaviors, concentration abilities, and memory [6, 7]. It is theorized that these changes occur because a child who can better organize sensory information is likely to be less distracted by miscellaneous sensory input and better equipped to handle the correct feedback [5, 19].

Because SI therapy is designed to stimulate multiple senses and cognitively and physically challenge the child, SI therapies include a wide range of activities and equipment [20]. Occupational therapists (OTs) conducting a SI therapy use a range of
sensory stimulating equipment, toys, games, and activities [23]. The following examples are common practices and tools used within SI therapy: multisensory rooms, therapy swings, proprioceptive clothing, pressure-inducing activities such as applying deep pressure to a child with a pillow, manipulating toys with different weights and textures, experiencing different odors and sounds, navigating obstacle courses, and learning new games [19, 23]. The therapist leads the child through different forms of play while exposing the child to a wide range of sensory stimuli such as vestibular rocking in the form of a swing, full body pressure from devices such as a SteamRoller, or a combination of both in the form of a net swing (as seen in Figure 1.1). While engaging the children in play, therapists encourage imaginative play, provide motor challenges, and deliver a ‘just right’ level of challenging sensorimotor tasks [6].

Figure 1.1: Equipment commonly used by SI therapists. From left to right—Booster Swing, Steamroller, and Cuddle Swing [24].

Some therapists conduct SI therapy sessions in multisensory rooms, or rooms that are specially designed to provide ‘stimulating multimedia environment to encourage people to use and explore their senses - whatever their level of ability’ [25]. Figure 1.2 depicts some examples of a multi-sensory room.
Reynold et al. reviewed studies that placed lab rats in an ‘enriched environment’ designed to mimic sensory integration therapy environments [6]. The purpose of these studies was to determine the effect of a SI therapy for rats who had been manipulated in utero to mimic a variety of developmental disorders (including autism). The enriched environments that the rats were placed in were designed to providing cognitive, sensory, and physical stimulation [6]. This stimulation came in the form of increased exercise space, equipment such as wheels and climbing apparatuses, and interesting objects that were regularly rotated out [6]. A series of controls were kept in a standard cage [6]. When the brains of the rats were dissected, the rats exposed to the enriched environment expressed a much greater degree of neural plasticity, defined by Reynolds et al. as an increase in the nervous system’s ability to change in response to the environment [6]. This increase in neural plasticity was demonstrated in an increase in the brain’s dendritic branching, a higher rate of synaptogenesis in the cerebellum, hippocampus, and motor cortex, and an increase in the generation of neurons [6]. The rats also expressed behavioral differences that included a more typical pain response,
reduced hypersensitivity, decreased repetitive behaviors, decreased anxiety, and increased appropriate social behavior [6]. For humans, examining the effectiveness of the therapy is harder since the brain cannot be dissected and examined in this way. As such, SI therapy is generally evaluated by the qualitative analysis of a child’s progress [28]. This is done by determining ‘baseline’ measurements of areas of desired improvements such as specific wanted/unwanted behaviors, motor skills, verbal abilities, social skills, and sensory integration skills and then measuring improvements after exposure to the therapy [7, 29].

1.4 Need for Better Understanding of Sensory Integration

Despite the widespread use of sensory integration—roughly 90% of American occupational therapists employed in public schools utilize this method—there is little objective, quantitative research that actually analyzes physiological effects of the therapy [28, 30]. Current studies have examined changes in behavior, academic performance, and motor skills to determine the progress a child makes after a SI program [7, 19, 29, 31-35]. These evaluative methods have a subjective aspect to them that contributes to the wide range of both positive and negative SI therapy study findings [7, 28, 31, 36].

Physiological, quantifiable data could be potentially used to better understand SI therapy. Equipment such as therapy swings have been used to greatly augment the effectiveness of a sensory integration therapy program, however, there are few instances where physiological data is used to analyze the potential of these products [7,
The ability to quantify a child’s physical response to equipment such as therapy swings is vital for several reasons: to help OTs understand what results were obtainable and what equipment instigated the more significant improvement, thus increasing their ability to develop best evidence-based practice and prioritize specific therapy protocols; and to defend the development, expense, and use of therapy equipment [6, 28]. Furthermore, if the beneficial therapeutic results of sensory integration could be proven, it could serve as an argument basis in regards to insurance reimbursement practices and public school special education programs, thus greatly increasing the number of developmentally challenged children who could have access to this treatment.

1.5 Using Biomechanics to Quantify Human Performance

Clinical biomechanists utilize a variety of sensors to examine pathologies, disorders, and natural processes such as aging [37, 38]. Two physical systems commonly studied by biomechanists are postural stability (balance) and gaze, both of which are inherently tied to a person’s ability to properly process sensory information. Balance requires an individual to process sensory information from the visual, vestibular, and proprioception sensory systems to maintain upright standing. Similarly, gaze and eye movements require the brain to quickly and accurately organize sensory information to visually track objects [39]. Due to each system’s reliance on sensory processing, postural stability data and gaze data could be used to evaluate any physiological changes generated by a SI therapy protocol. The following sections review the concepts behind
the study of postural stability and gaze patterns, highlighting the rationale behind studying both physical systems. The sections also discuss ASD research conducted by researchers evaluating postural stability and gaze patterns. Due to the research focus of the author, the main emphasis will be placed on the posturography method.

1.6 Postural Stability and Posturography

Postural stability is the body’s ability to make small muscular adjustments to remain standing upright, contributing to the body’s inherent postural sway. Posturography is the quantitative assessment of an individual’s postural sway (and, indirectly, postural control) via a force measuring platform [40]. The postural sway of a person can be measured even when a person is ‘quietly standing’—e.g. standing still without moving, talking, or looking around—because humans are not statically immobile. Although a person might appear to be unmoving, they minutely sway in all directions as they stand. This is due to the fact that humans are inherently unstable and are constantly swaying in one direction until they unconsciously correct themselves and shift their sway in the opposite way [40]. The true definition of postural sway is the anterior/posterior (A/P) and medial/lateral (M/L) displacement of an individual’s center of mass (COM). As it is highly difficult to experimentally measure COM movements, researchers can use force plates to track the displacements of a person’s center of pressure (COP), which is the total sum of the vertical force a human body exerts on the ground [40-43]. The relationship between COM and COP can be thought of in terms of the body’s COP reacting in an attempt to account for the displacements of the COM
The high correlation between COM and COP make it appropriate to study COP as an indicator of COM sway. A force plate can track the trajectory of the COP, collecting data that provides insight about an individual’s postural control. The collected COP data can be used to investigate physical mechanisms of specific disorders or natural processes such as aging, aid in early diagnosis, and track patient progress during a therapy regime [44-46].

Researchers who utilize posturography to collect data have a wide range of options when it comes to selecting posturography parameters. Traditional stability parameters use linear analyses to quantify the amount of sway that occurs [47, 48]. The most common type of traditional stability parameters are time domain parameters, and include parameters such as COP Sway Range, COP sway velocity, RMS, and Sway Area. A second class of traditional sway parameters are frequency domain variables, such as Fast Fourier Transform (FFT) ratios and Power Spectral Densities. These parameters quantify aspects of the frequency-based behaviors of postural sway, like the frequency of the distribution of the COP displacement [40]. Another analysis method is nonlinear measures which are used to examine the sway patterns, rather than simply the sway magnitude, to obtain a more complicated look how the postural control system is working.

The study of human performance from a nonlinear perspective arose from the realization that healthy physiological systems are actually much more irregular and complex than previously thought [49, 50]. Originally, scientists believed that physiological processes operated in a state of homeostasis—that systems such as
human heartbeat or postural control would ideally have a very low degree of variability and would always strive to return to a highly regular, or periodic, state [50]. Researchers have since discovered that, even under basal resting conditions, healthy human processes exhibit highly complex patterns that are tied into regulatory processes throughout the body [49]. These complex patterns contain a degree of variability that exists on a spectrum, with periodicity on one end and random chaos on the other [49]. Current research suggests that there is an ideal degree of variability in human performance and that a healthy human would fall somewhere between perfectly periodic and completely chaotic [49, 51-53]. These dynamic patterns allow the body to have a higher range of adaptive responses to the environment—for example, dynamic sway patterns aid in maintaining balance in varying environments, while dynamic patterns at the cellular level allow for a better response to pH changes or foreign pathogens [49, 50, 52, 54]. As Lipsitz states, ‘Complexity begets functionality’ and the more complex responses a system can generate, the better it is able to handle various environmental shifts [49, 52]. Decreases and increases in complexity, are associated with decreases in health and increases in frailty [49, 50].

The postural stability of individuals with ASD has been studied from both a traditional linear perspective and a nonlinear standpoint. Researchers have found that children with ASD exhibit decreased postural control and decreased dynamic complexity when compared to TD individuals [11-18, 55-57]. Although there are several mechanisms that could all contribute to this reduced postural control, nearly all of the studies identified sensory processing deficit as one of the main probable causes [11-18,
In summary, postural stability is a complex, interactive system that is dependent on sensory inputs from the visual, vestibular, and proprioceptive systems and the brain’s ability to correctly receive and process these inputs [16, 58]. The body’s dependence on the ability to correctly process these sensory interactions can lead to balance issues in individuals who have sensory processing deficits. Therefore, the postural control system could be used as a benchmark to gauge any changes in an individual’s sensory processing.

1.7 Gaze Analysis

Gaze tracking is another way researchers can analyze physical behavior of human subjects. Gaze tracking has been used to study neurology, psychology, and the relationship between cognitive and mental conditions and oculomotor abnormalities [59]. Gaze analysis includes the study of rapid, or saccadic, eye movements, visual fixations, and scene explorations and provides data about how humans use visual fixations during social situations or cognitive challenges [60]. Common analyzed gaze parameters include quantifying visual fixation count and duration, eye velocity and acceleration, saccades, and gaze trajectories [39, 61, 62]. The face is a highly important social communication tool amongst humans, however, individuals with ASD display several unusual social and gaze behaviors [63]. Researchers have used gaze analysis to study the visual behavior of individuals with ASD in an effort to understand what mechanisms contribute to the socialization deficits exhibited by individuals with ASD [62-66].
Studies have found that children with ASD have abnormal gaze pattern when compared to TD controls [39, 62, 64, 67]. These abnormal gaze patterns include reduced eye contact time, a tendency to shift gaze away from a speaker, spending more time focused on a speaker’s mouth rather than the speaker’s eyes, the use of peripheral vision to examine objects in an unusual manner, and poorer visual performance when tracking targets into right visual fields [39, 62, 64, 67]. The initial theories that explained these abnormal gaze patterns revolved around the social deficits present in children with ASD. However, more recent evidence indicates abnormal gaze patterns could also be related to sensory integration issues. Dawson et al., Gillberg et al., and Miller have presented theories suggesting these abnormal gaze patterns are self-regulatory mechanisms to aid a child’s struggling with integration of visual input, and Takarae et al. also noted how sensory processing deficits could affect gaze patterns [39, 68-70]. Like posturography, the reliance of gaze patterns on sensory processing abilities could make gaze tracking a useful method to examine improvements in sensory processing.

1.8 Research Aims and Hypothesis

Currently, there has been no work done to evaluate physiological changes caused by an SI therapy—literature review was conducted from 1975 to 2013 and found no studies done in these areas. It was the objective of the author to conduct a pilot study that quantified the acute effects of a SI vestibular swing treatment on postural stability and gaze patterns. The goals of this study included: identifying any shifts in post-therapy postural or gaze patterns, exploring the usefulness of the balance
plate and gaze trackers in this application, and determining whether a full-scale study was appropriate. Due to the research focus of the principal investigator, the main emphasis was on the postural stability data. It was hypothesized that the subjects with ASD would display improved postural stability control, as measured by decreased sway range, velocity, and RMS and a shift in sample entropy values to ones that more closely resemble their TD peers, after an SI therapy session. It was also hypothesized that the children would display increased socially relevant gaze fixations, indicating a decrease in self-regulating gaze patterns post-therapy.
CHAPTER 2

METHODOLOGY

2.0 Research Protocol

The primary protocol for this study was a posturography protocol. In addition a secondary exploratory eye tracking study was conducted. Due to the exploratory nature of both studied, both were designed to be pilot studies. Both protocols studied separate groups of TD children and children with ASD.

2.1 Postural Stability Testing

2.1.0 Subject Demographics

Five children with ASD and five typically developing (TD) children participated in the posturography protocol. The average age of the subjects with ASD was 9.2 ± .45 years, the average height was 54.8 ± 2.36 inches, the average weight was 81.76 ± 21.0 lbs., and the average age of diagnosis was 4.8 ± 2.64 years. The TD children had an average age of 7.4 ± 2.06 years, an average height of 50.4 ± 5.89 inches, and an average weight of 61.72 ± 20.76 lbs. All of the subjects with ASD were male, which was expected due to the higher rate of diagnosis seen in this gender.
2.1.1 Subject Inclusion and Exclusion Criteria

Participants were vetted with the same inclusion/exclusion criteria. Participants with ASD required a parent self-report of a diagnosis by a physician or psychologist of “autistic disorder” or “Asperger’s disorder” as described by the American Psychiatric Association's Diagnostic and Statistical Manual-IV, Text Revision (DSM-IV-TR). Children with PDD-NOS were not included in this study. As balance is known to change with maturity, subject ages fell between 5 and 10 years to limit physical effects due to early childhood development and the onset of puberty [71]. Subjects were required to be verbal, placing them in upper half of the spectrum’s IQ range. This criterion was utilized to increase the likelihood of subject compliance and ensure subjects did not have intellectual development disorder, formally diagnosed as mental retardation (MR), which could have potentially produced confounding results [15]. The ability to verbalize aided the subjects’ understanding of directions and increased the likelihood of subjects successfully completing the protocol. Subjects were required to have no changes in medications in the six weeks prior to participation to reduce potentially confounding factors. Subjects who self-reported any health issues that could have affected balance and gaze patterns were excluded. These issues included gait or balance disorders, neurological diseases, cardiac problems, a history of seizures, and any significant surgeries within six months of testing. Refer to Appendix A for the full subject health checklist. All procedures were approved by the University of Dayton IRB Institutional Review Board and the parent or legal guardian of the subjects gave written informed consent. Subjects wore comfortable clothes and took their shoes off for the study.
2.1.2 Subject Recruitment
Subjects with ASD were recruited in a variety of ways. Flyers were posted on bulletin boards in Dayton Children’s Hospital, local therapy sites including ABC Therapy offices, Therapy Connections, Integration Station, numerous online support groups’ Facebook pages (including the Dayton chapter of the Autism Society), Autism Speaks’s research website, Dayton Public libraries, and on the University of Dayton’s campus announcement service. Flyers were distributed electronically to local church-based support groups, autism scholarship recipient schools within two hours, home school support forums, all Summit Academies within two hours, and to the families on SEAT’s (Students for Effective Autism Treatment) mailing list. Subjects were also recruited from Linden Grove school in Cincinnati, OH. The researchers also used word of mouth to gain recruits. TD subjects were recruited from university faculty, local families known to the researcher, and via word of mouth.

2.1.3 Test Structure
The setup of the study was a pretest/posttest. Before posturography testing began, the researcher used two different evaluations (The Functional Reach Test and the Bilateral Coordination Test) to assess the overall balance and coordination of each subject. For the posturography protocol, two tests were conducted before the SI therapy and two tests were conducted post-therapy. The first pre-therapy test was used to expose the children to the testing protocol and give them a ‘practice run.’ The second pre-therapy test was the test used to collect the data that would be used in the final
analysis. The two post-therapy tests were designed to examine the immediate effect of the therapy and whether that effect lasted beyond a waiting period of 3-5 minutes. Figure 2.1 demonstrates the flow of events for the test protocol.

![Test Protocol Flow Chart](image)

**Figure 2.1**: Test Protocol Flow Chart

Due to the unique challenges children with ASD face, the posturography protocol was designed to be as child friendly as possible. This was accomplished by keeping trial durations as short as possible, providing optional breaks between trials, demonstrating each step of the protocol to the child before asking him or her to perform it herself, and
paying close attention to the subject to ensure they were never distressed. The PI of the study worked for three years as a Discrete Trial Training (DTT) aide for an Applied Behavioral Analysis Therapy program, a peer reviewed therapy for children with ASD, and drew on her previous experience to ensure each child was comfortable and not upset during the study. As a final measure to keep the child as comfortable as possible, the adult or legal guardian of the child remained in the same room the entire time.

2.1.4 Pre-Testing Procedures

After the subject’s age, weight, and height were recorded, the subject underwent a functional reach test and a BOT2 bilateral coordination test. These tests were conducted to establish baseline demographic information for each subject group that would be used to identify potential covariates and support conclusions drawn from the main experimental protocols. The functional reach test measures the degree to which a subject can maintain balance while in an upright position [72]. Functional reach is defined as the maximum forward displacement a subject achieves when extending their dominant arm and leaning forward [72]. Known values have been published denoting the normal performance of individuals for this test [73]. When performing a functional reach test, the subject stood along a wall marked with a meter stick [72]. Subjects were instructed to make a fist and extend their dominant arm at a right angle to their body [72]. Subjects remained in this position for approximately 5 seconds, leaned forward as far as they can without losing their balance, then returned to their original stance [72]. The maximum displacement of the subject’s fist was recorded and
the functional reach test was repeated three times [72]. An average of all three trials was later calculated. Figure 2.2 depicts the motion of a functional reach test.

![Figure 2.2: The Functional Reach Test](image)

Subjects then underwent a BOT2 Bilateral Coordination Test. The BOT2 Bilateral Coordination test, one of the subtests of the Bruinicks-Oseretsky Test of Motor Proficiency, is a test designed to be used as a standardized measure of motor proficiency [74]. It can be used on children as young as 4 years old and evaluates body control with respect to sequential and simultaneous movement coordination of upper and lower limbs [74]. A child’s score on the BOT2 Bilateral Coordination Test can also be compared to charts of national averages, allowing a researcher to evaluate where a subjects falls, percentagewise, with respect to age and gender matched peers [74]. The following tasks comprise the BOT2 bilateral coordination test [74].
Table 2.1: BOT2 Bilateral Coordination Task Description

<table>
<thead>
<tr>
<th>BOT2 Bilateral Coordination Test Tasks</th>
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<tr>
<td><strong>Item 1</strong></td>
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<td><strong>Item 6</strong></td>
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<td><strong>Item 7</strong></td>
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</table>

Before requesting the child perform each task, the researcher would demonstrate it. Once the child indicated they understood the directions, the researcher instructed the child to perform the task until told otherwise. If a subject was unable to score the maximum score on the first trial they were given one more chance to try [74]. Once the Functional Reach Test and BOT2 Bilateral Coordination tests were complete, the subject moved on to the main experimental protocol.

2.1.5 Swing Procedures

The SI integration therapy protocol chosen for this study was a vestibular therapy swing. Therapy swings are a commonly used tool in SI therapies and are designed to help a child learn to better regulate vestibular and proprioceptive input, build muscle tone, and improve coordination [8, 29, 68, 75]. There are various styles of therapy swings, from meshed nets to platform swings to cylindrical bolster swings. These swings, as described in Chapter 1, provide stimulating vestibular input that helps a child learn to better regulate his or her sensory response while physically challenging the child [29, 68]. Therapist working with a child on a vestibular swing often uses the
swing to promote socialization, communication, engagement, and teamwork [7]. A properly trained parent can supervise their child on a vestibular swing at home, increasing the benefits the child receives. The sensory integration therapy for this study was provided by a platform swing as seen in Figure 2.3.

![Figure 2.3: Platform Swing](image)

Engaging and educational posters were placed around the swing to provide a stimulating, child-friendly environment.

The platform swing and portable frame was loaned from Southpaw Enterprises for the duration of this study. The platform swing consists of a low platform with ropes anchored at each corner. The swing is comprised of a wooden, circular platform covered with a carpet. The edges of the swing were padded and plastic piping covered the ropes of the swing to prevent rope burn. The swing also had two wooden grab bars located
above a child sitting in it. The swing frame was a collapsible itinerant frame rated to support up to 300 lbs. Therapy Connections loaned the exercise mat.

A child can sit, stand, or lie prone on the swing while an occupational therapist or trained adult supervises. The swing routine was designed to last approximately ten minutes, as previous studies have shown that even a short exposure to vestibular stimulation has a measurable effect on children [29, 76]. The PI of this study designed the swing therapy with input from physical therapists (PTs) and OTs from a local therapy clinic. The PI also shadowed both therapists while they worked with children who had a range of developmental disabilities on several different swings. Based on what was observed and on suggestions offered by both therapists, the PI developed a swing protocol to use with the children in this study. Although several other researchers assisted in data collection for this study, only the PI administered the swing therapy to the children who participated in this study to increase the consistency of the therapy experience across subjects. A range of activities took place during the ten minute swing routine and each child received a similar protocol. Throughout the entire routine, the PI socially engaged the child to provide the same level of social interaction provided by an OT during a typical SI therapy regime. This included talking to the child about his or her interests, discussing imaginary games that could be conducted on the swing, and chatting about each task the child underwent. The child was instructed to sit on the swing with their legs crossed (although if they had a different preferred position, they were allowed to assume it at first) and hold on to the ropes. At the start of the therapy routine, the swing was swayed side to side, back and forth, and along both diagonals to
allow each child to become accustomed to the movement. Once the child was comfortable, the speed was slightly increased and the child was encouraged to try a few different positions, such as kneeling while holding onto the wooden bars above his or her head. If the child was comfortable shifting position while the swing was slowly moving, the researcher did not completely stop the swing to increase the challenge of the task. If the child consented, they were also twirled in both directions on the swing.

Next, the child was told to lie with their stomach on the swing with their legs trailing out behind them. A puzzle with 10 removable pieces was placed below the swing while the 10 pieces were placed far enough in front of the swing that the child had to perform a full body extension to reach them. The child was then instructed to complete the puzzle as the swing swayed forwards and backwards, reaching for pieces on the upswing and trying to fit them in their slots on the backswing. This task was modified to make it appropriately challenging for each child, depending on age, motor skill, and cognitive ability. After the puzzle, the child was instructed to sit back up on the swing and play a ball tossing game with the PI. The PI and the child played catch with several different types of ball and the PI also used a basket to provide a target for the child to throw small, Styrofoam cubes in. If all of these activities were completed before the 10 minutes were up, then the researcher engaged the child in a flashcard game that required cognitive skill and motor challenged for the duration of the time.
2.1.6 Study Protocol

Postural sway measurements during static standing were taken with a Bertec force platform (Model BP5050, Columbus OH). The balance plate measures the A/P and M/L COP collected at 1000 Hz. Collected data was transmitted to a laptop through a USB cable. The test re-test reliability for children who participate in posturography studies has been shown to be fair to excellent, with an intraclass correlation coefficient (ICC) between 0.62 and 0.80 [77]. Figure 2.4 depicts the balance plate and the balance plate with the foam padding added.

![Balance Plate With and Without Foam Padding](image)

Figure 2.4: Balance Plate With and Without Foam Padding

A trial consisted of 20 seconds of quiet standing upon the plate and the plate was zeroed before each trial [16, 42]. Although a trial duration of 30 seconds is more common in posturography studies, the 20 seconds duration was selected to increase the likelihood of subjects successfully completing it. Fournier et al., Kohan-Raz et al., and Radonovich et al. also utilized 20 second trials when conducting posturography studies with children who had ASD [11, 14, 17].
While on the balance plate, the subjects underwent a test based on the Modified Clinical Test of Sensory Interaction on Balance (mCTSIB), standing on the force plate under 4 different standing conditions: eyes open, eyes closed, eyes open on a foam pad, eyes closed on a foam pad [78]. The rationale behind the mCTSIB is to examine a subject’s postural control under a variety of sensory conditions. Eyes open on the flat, firm surface of the balance plate tests the subject’s ability to balance while he is receiving visual, vestibular and proprioceptive feedback. Eyes closed on the flat plate tests the subject while he is receiving only vestibular and proprioceptive feedback. The third and fourth conditions involve standing on the foam pad, a medium that is designed to significantly reduce the amount of proprioceptive feedback from the contact between a subject’s feet and the plate’s surface. The third condition required the subject to stand on the foam with eyes open, allowing the subject primarily visual and vestibular feedback to aid in standing. The fourth trial was conducted while the subject stood on the foam pad with closed eyes, allowing feedback primarily from the vestibular system. The foam pad utilized in the protocol was an Airex Balance Pad.

Subjects were tested barefoot and instructed to stand with their feet a comfortable distance apart. Subjects were also given an image to focus on while performing each balance trial, decreasing any potential sway produced by a subject looking around the room [79]. An image of a jungle animal was placed on the wall approximately 4 feet in front of the subject at face height. For each different balance trial, the image was switched out to a different animal to keep the subject interested. This was to give the subject an object to focus on Only four images were used and they
were used consistently for a specific balance trial (e.g. image 1 was always used during eyes open, flat plate testing for all subjects). Subjects were prompted to help in the process of trading out the animals, making them feel more involved in the process. A nonrestrictive blindfold was offered to any children who have trouble keeping their eyes closed for an entire trial. Additionally, an assistant researcher quietly counted to 20 for each trial to help the subjects maintain quiet standing. While on the balance plate the subject wore a safety belt in case they lost their balance during any part of the testing. A researcher also spotted them the entire time.

2.2 Posturography Analysis

The overall emphasis of the analysis was to compare the pre-therapy results to the post-therapy results. Calculations were done based on A/P and M/L COP data collected at 1000 Hz and downsampled to 100 Hz. Five sway parameters were used to analyze each subject’s data. The first four were traditional parameters based on linear analysis methods that measured the amount a subject sways. The fifth parameter, Sample Entropy (SampEn), was a non-linear analysis method measuring how the subject sways by identifying underlying patterns in the time series data [80]. Sway range, or how far a subject sways in any direction, and mean velocity (MV) of sway were chosen due to their prevalence of report in previous posturography studies that involved individuals with ASD [11, 14, 16, 55, 57]. Root mean square (RMS) was selected as it is measures the amount of variation within sway and would provide a counterpoint to the nonlinear measurement of variability. SampEn was selected as the nonlinear variable
rather than the closely related approximate entropy (ApEn) parameter due to the fact that SampEn does not have the bias towards regularity that ApEn has [51]. SampEn also has been reported to provide more consistent results [51]. For the traditional, linear sway parameters, a decrease would indicate increased postural stability. For the nonlinear parameters, however, the improvement would be gauged by whether or not a population’s SampEn shifted to be closer to that of a golden standard. As optimum variability is somewhere in the middle of the continuum, a healthy, ‘golden standard’ must be identified to evaluate the SampEn values of a specific population. For this study, the pre-therapy SampEn values of the TD children were used as the healthy standard.

2.2.1 Signal Processing of the Data

As the Bertec system only allows a data collection rate of 1000 Hz, the data must be processed to separate the true human movement from the signal noise and artifact. The first step in this process was to downsample, or reduce, the data. The idea behind downsampling data is to appropriately capture the movements of the subject by getting rid of extraneous ‘noise’ that can occur when data is collected at very high sampling rates. Data that is not downsampled is at risk of oversampling, which could lead to the introduction of artificial artifacts into the data, and data that is overly downsampled can result in eliminating meaningful data [51].

Before downsampling can occur, it is necessary to determine the underlying frequencies of human movement, as this information is required to identify an
appropriate downsampling rate. As mentioned previously, the force plate collects data at a rate of 1000 Hz. This is an extremely large sampling frequency, especially considering that basic human movements occur at much lower frequencies (for example, the highest frequency in human gait is 12 Hz) [51]. Per the Nyquist Theorem, the data should be sampled at twice the frequency of the greatest frequency present, which requires the determination of the greatest frequency [51]. One way to determine the underlying frequencies of human movement is to plot the power spectral density (PSD) of the data so the largest sample frequency can be identified for a specific data set, allowing for a the downsampling rate to be identified (a common biomechanics standard is to downsample to a rate usually 5-10x greater than the highest frequency rather than the minimum 2).

A MATLAB program obtained from Dr. Nick Stergiou’s Nonlinear Analysis Workshop held at the University of Nebraska at Omaha in 2013 was used to determine the frequency at which 99% of the power is contained, also referred to as the cutoff frequency, and can be found in appendix B. The software processed all M/L data points and A/P data points separately and generated a graph of Power vs. Frequency, an example of which can be seen in Figure 2.5.
Figure 2.5: Power Spectral Density Plot.
This particular PSD graph indicates an appropriate down sampling frequency of 8

Once the graph was generated, the point at which approximately 99% of the data points fall behind was identified. This is the cutoff frequency, or the highest frequency, and in the case of Figure 2.7, is approximately 4 Hz.

As the subjects had an average cutoff frequency close to 10 Hz for both M/L and A/P directions, a downsampling rate of 100 Hz. was selected. A MATLAB program titled DownSampling, also in Appendix B, was used to downsample the data, bringing it from 20,000 data points to 2,000 and better capturing the human movement within the time series.

2.2.2 Linear Postural Stability Data Analysis

As mentioned previously, the linear postural stability parameters included A/P sway range (APSR), medial-lateral sway range (MLSR), mean velocity (MV), and Root Mean Square (RMS). Once the data was appropriately downsampled, a custom MATLAB
program was used to determine the linear postural stability parameters. This program can be found in Appendix B and used the following equations to determine each parameter [81].

APSR is depicted in equation 2.1, where $y_n$ is each individual data point in the A/P direction.

$$\text{APSR} = |(y_n)_{max} - (y_n)_{min}| \quad (\text{Eqn 2.1})$$

MLSR is depicted in equation 3.2, where $x_n$ is each individual data point in the M/L direction.

$$\text{MLSR} = |(x_n)_{max} - (x_n)_{min}| \quad (\text{Eqn 2.2})$$

MV, the resultant of the A/P and M/L velocities, was calculated using both $y_n$ and $x_n$ values and is depicted in Eqn 2.3 where $N$ is the total number of data points, $n$ is the data point under analysis, and $T$ is the total time duration of the trial.

$$MV = \frac{\sum_{n=1}^{N-1} \sqrt{(y_{n+1} - y_n)^2 + (x_{n+1} - x_n)^2}}{T} \quad (\text{Eqn 2.3})$$

RMS is the root mean square distance of the subject’s COP—e.g. the magnitude that the COP varies with respect to the mean location. This calculation is shown in equation 2.4.
2.2.3 Nonlinear Postural Stability Data Analysis

The nonlinear postural stability parameter, SampEn, was calculated to quantify the degree of variability in an individual’s postural control data of length N. The sample entropy method was first introduced by Richman and Moorman in an attempt to address the inherent bias within ApEn [82]. Its use for postural control data has been described by Ramdani et al., Donker et al., and Stins et al. [83-85]. SampEn calculations result in a value between 0 and 1.5 that describes the probability of the system to be periodic (approaching 0), chaotic (approaching 1.5), or complex, somewhere between the two. A complex system is ideal, but different subject populations have different SampEn values, depending on age and/or the presence of pathology. Therefore, an ideal degree of complexity is generally identified by determining the SampEn of a similar healthy control group and then comparing it to the SampEn values of a group with a disorder or pathology. In the case of children with ASD, a population that has been found to be less posturally complex than TD children, an improvement should be characterized by an increase in complexity as represented by a larger SampEn value.

A summary of the SampEn calculation is as follows. When calculating SampEn, the time series is divided into vectors with a designated length of m. The vectors are then systematically compared to the corresponding elements in each subsequent vector, and considered similar if the differences are within the radius of a designated
tolerance, r. Once all the vectors of length m are compared to each other, this process is repeated with vectors of length m+1. Equations 2.5 through 2.8 depict this process [51].

The length of the vectors, m is used to determine the conditional probabilities, $C_i^m$ and $C_i^{m+1}$.

$$C_i^m = \frac{\text{Vectors of } m \text{ within the tolerance } r}{\text{Total vectors compared}} \quad \text{Eqn 2.5}$$

$$C_i^{m+1} = \frac{\text{Vectors of } m+1 \text{ within the tolerance } r}{\text{Total vectors compared}} \quad \text{Eqn 2.6}$$

Next, the averages of $C_i^m$ and $C_i^{m+1}$ must be calculated.

$$B^m(r) = \frac{C_1^m + C_2^m + C_3^m \ldots + C_{N-m}^m}{N \times m}$$

$$A^m(r) = \frac{C_1^{m+1} + C_2^{m+1} + C_3^m \ldots + C_{N-m}^{m+1}}{N \times m}$$

These log is then taken of both averages to obtain SampEn.

$$SampEn(m, r, N) = -\log \left[ \frac{A^m(r)}{B^m(r)} \right]$$

For this study, a vector length of 2 and a tolerance of 0.2 were selected as these fall within the recommendations for clinical data [53]. The data was broken into its M/L and A/P components and processed with a MATLAB program titled `samp_enBatch` which ran the above algorithms to calculate the sample entropy values.

A surrogate analysis was then conducted to determine whether the SampEn values were valid—i.e. whether the SampEn algorithms were based on underlying patterns within the data or simply picking up on random noise. A MATLAB program was used to run a surrogation algorithm that processed each dataset and randomized the order of the values 19 times for each trial, producing 19 data sets of N length. The
SampEn values were then calculated for each of the randomized 19 data sets and compared to the experimental SampEn value. Per the Ranking Test, a SampEn value was considered valid if it was either larger or smaller than all of the randomized SampEn values, with a convention that a minimum of 95% of the data had to be valid to be analyzable. Valid indicates that the actual data has SampEn values that are significantly different than a dataset that is random in nature, supporting the notion that the data has some degree of complexity and making it suitable for nonlinear analysis. Once the surrogation analysis was conducted, the pre-therapy and post-therapy SampEn values of the children with ASD were compared to the pre-therapy SampEn values of the TD children.

2.2.4 Statistical Analysis

Due to the small subject size, the main goal of this study was to identify trends observed between the pre-test and post-test. This was conducted as more of a case study to examine both individual changes, as well as the mean change for the subject group. Despite the small sample size, statistical analysis was performed to determine whether any changes that were observed were statistically significant. This was done for all six postural sway parameters but only for the condition of primary interest: eyes open, flat plate. Statistical analysis was performed in SPSS v. 20 (IBM Corp., Armonk, New York). Because only five individuals were included in the study, non-parametric statistics were performed. This was done in the way of a Two-Related-Samples Wicoxon Signed Rank Test with p<0.05. Due to the exploratory nature of these statistics, a Bonferroni correction for multiple comparisons was not applied.
A second goal of the study was to perform a post hoc power analysis to ascertain how many subjects would be required to obtain statistically significant results in future studies. This was done using G*Power statistical software v. 3.1 (University of Dusseldorf, Dusseldorf, Germany) to conduct a post-hoc power analysis to calculate the necessary sample size required to achieve a statistically significant difference between pre-test and post-test values for each variable (p<0.05 without correction for multiple comparisons), again for only the primary condition of interest: eyes open, flat plate. G*Power utilized Wilcoxon signed-rank test (matched pairs). Effect size was determined using mean and standard deviation values from the study, with a power of 0.90 and a correlation input based on the relationship determined during the course of the nonparametric, traditional statistics. For each variable the minimum number necessary for statistical significance in future studies was calculated and reported.

2.3 Gaze Testing Protocol

2.3.0 Subject Demographics

Four children with ASD and four TD children participated in the eye tracking protocol. The average age of the subjects with ASD was 8.67 ± .58 years, the average height was 53.5 ± 1.5 inches, the average weight was 65.47 ± 9.82 lbs., and the average age of diagnosis was 3.67 ± 1.5 years. The TD children had an average age of 7.0 ± 1.83 years, an average height of 52.4 ± 2.56 inches, and an average weight of 70.3 ± 12.16 lbs. One subject with ASD did not receive the swing therapy and served as a control.
This subject who did not receive the swing therapy, S8 was intended to be part of a control group. Due to recruiting difficulties, however, S8 ended up being the only control subject and is therefore excluded from the analysis. The same subject criteria, recruitment methods, and pre-tests that were used for the posturography protocol was used for the gaze tracking.

2.3.1 Eye Tracking Protocol

This gaze protocol utilized an Ultraflex mobile unit manufactured by Positive Science Eyetracker lent to the University of Dayton by Proctor and Gamble’s Market Research Division. The Ultraflex unit is comprised of a small, lightweight backpack connected to a pair of glasses with no lenses. A video camera fixed in front of the glasses records the movement of the subject’s eye (specifically the pupil and the corneal reflection). A second video camera looks outward and records the scene the subject is viewing. The two cameras are designated ‘Eye Camera’ and ‘Scene Camera’ respectively. Figure 2.6 depicts the glasses and Figure 2.7 portrays the backpack a subject would wear along with the glasses.
Figure 2.6: Glasses with Eye Camera and Scene Camera. The lower camera (circled) recorded images of the subject’s eye while the higher camera (circled) faced outwards and recorded the scene the subject was viewing.

Figure 2.7: Ultraflex Eye Tracking Backpack with External Battery. The two cameras were within the main section of the backpack.

For this protocol, the subject was fitted with the backpack and glasses. The backpack was adjusted so it fit securely and comfortably. The glasses were adjusted so they fit securely on the face and were comfortable to the subject. Once the backpack and glasses were on the subject, the two cameras were turned on and adjusted to ensure
that they were even and in-line with the subject’s eyes and the scene. The eye camera was adjusted so the subject’s eye was centered and the scene camera was adjusted to ensure the camera was not skewed with respect to the scene the subject was viewing.

The cameras were then set to record and were synchronized and calibrated. To synchronize the cameras, the subject was asked to look at the experimenter who then provided a brief camera flash. To calibrate the unit, the experimenter established five to nine calibration points by moving a toy of interest in a grid-like pattern across the subject’s field of vision. During the calibration process, the subject was instructed to follow the object with his eyes while keeping his head still. Figure 2.8 depicts screen shots from the videos when they were being played in Yarbus software. The screen shots were taken from video frames during the calibration process.

![Figure 2.8: Scene Camera Frames During the Calibration Process. The crosshairs represent where the subjects gaze was currently directed.](image)

After the calibration sequence, the researcher engaged the subject in play scenarios to record the subject’s socially relevant gaze fixations. The play scenarios were selected to be appropriate for the spectrum of children participating in the study and were based on the PI’s previous work with ABA therapy. The first play scenario involved a gross motor game and the second play scenario was a quieter, fine motor game. The child was
allowed to select a preferred gross and fine motor game from a list of options, reviewed
in Table 2, to buoy subject interest, and therefore, compliance. Trial 1 and Trial 3 were
the gross motor game, and Trial 2 and Trial 4 were the fine motor game. The child was
allowed to select the game for each trial and table 2 depicts the activities that were
offered. The same games that were played for trial 1 and trial 2 before the swing were
repeated in trial 3 and trial 4 after the swing therapy was conducted. Table 2.2 depicts
the games children were allowed to choose from.

Table 2.2: Socially Engaging Play Activities

<table>
<thead>
<tr>
<th>Play Activities</th>
<th>Gross Motor Games</th>
<th>Fine Motor Games</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tossing a ball</td>
<td></td>
<td>Puzzle</td>
</tr>
<tr>
<td>Playing with cars on the floor</td>
<td></td>
<td>Play-doh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Blocks</td>
</tr>
</tbody>
</table>

2.4 Eye Tracking Analysis

The data analysis for the vision tracking was broken into two steps. The first step
was to use Yarbus software to render the two gaze videos into a single video with gaze
overlay and an accompanying text file with gaze coordinates. This process requires
synchronization, calibration, and rendering of the eye and scene videos. The second
process was to use Semanticode software to calculate the number of times the gaze
coordinates aligned with socially relevant fixations such as a person’s face or eyes. This
process involved designating what constituted a socially relevant gaze fixation and
marking its coordinates in the video. The following sections discuss both steps in further
detail.
2.4.1 Rendering a Single Video

Both the eye movie and the scene movie were uploaded to Yarbus software to render a single video. To correct for potential differences in recording time, the videos were then synchronized. This was done by scrubbing through each video until camera flash was located. The movie frame that captured the camera flash was distinct as it was completely whited out in both the scene and the eye video. This point was then established as the ‘begin’ point for both videos. The ‘end’ point of the videos was either established in a similar fashion (e.g. a frame filled with the flash) or it was calculated from time-offsets. After the beginning and end points were determined for each video, the videos were synchronized and calibration points were established. This was done by selecting points for a location that the subject was looking at during the calibration session of the eye tracking protocol. The overall program calibration accuracy is based on these points as well as estimates from the corneal reflection (CR) of the subject. Yarbus used a homography method as it corrects for rotation offsets. Once a minimum of 5 calibration points were added, the videos are rendered as a single Quicktime movie file with gaze overlay. The rendering process also outputs a text file that contains point of regard (POR) coordinates, center of pupil (PU) coordinates, corneal reflection (CR) coordinates, record frame number, and timestamp.
2.4.2 Quantifying socially relevant gaze fixations

Semanticode software was used to quantify the number of socially relevant gaze fixations (e.g. any gazes at a person’s face or eyes) for each subject. The rendered video and accompanying text files were uploaded to Semanticode. There were three different points of interest the researchers identified: Face_eyes, Face_other, and Task. While Face_eyes was clearly the ‘ideal’ social fixation, Face_other was also seen as a positive outcome, if not as good as Face_eyes. To determine which frames held a point of interest, the researcher scrolled through each video frame by frame and identified any point of interest. Figures 2.9-2.12 are examples of how points of interest were identified. The crosshairs denote the visual fixation of the subject.

**Figure 2.9:** Two Examples of ‘Face_other’

**Figure 2.10:** Three Examples of ‘Face_Eyes’.
Once all of the points of interest were identified, total fixation count and total fixation duration were calculated for each trial and compared to each other. These values were then used to calculate total percent occurrence (e.g. what percentage of the video length did each subject spend either making eye contact or looking at the researcher’s face) and the pre-therapy and post-therapy trials were compared to each other. An post-therapy increase in eye contact of face gazing was considered to be an improvement.
CHAPTER 3

RESULTS

3.0 Results

3.1 Posturography Results

3.1.1 Functional Reach and BOT2 Bilateral Coordination Results

One child from each subject group was unable to fully perform the BOT2 bilateral coordination test. On the functional reach test, the children with ASD scored an average of 7.53 ± 2.31 inches and the TD children scored an average of 7.75 ± 2.11 inches. On the BOT2 bilateral coordination test, the children with ASD averaged an overall score of 17, indicating a bilateral coordination level similar to that of a child between the ages of 7.58 ± 3.33 years and 7.71 ± 3.38 years. The TD children averaged an overall score of 18.5 on the BOT2 test, indicating a bilateral coordination level similar to that of a child between the ages of 7.77 ± 2.88 years and 7.92 ± 2.9 years.

3.1.2 Results Selected for Analysis

Although two pre-trials (trials 1 and trial 2) and two post-trials (trials 3 and trial 4) were conducted, the analysis only included the results from trials 2 and 3. This was for several reasons. Trial was designed to provide a practice trial that would let the
children know what to expect, increasing their comfort and the likelihood of subject compliance. Trial 2 and 3 were only separated by the swing, allowing for a ‘cleaner’ comparison between the two. Although the author intended to compare trials 3 and 4 to determine whether the effect of the swing waned quickly, not all subjects took the same length of break between trials 3 and 4. Therefore, this approach was discarded due to the inconsistent amount of time between trials 3 and 4.

3.1.3 Posturography Results Interpretation

Before the results of the linear posturography are presented, it is important to understand how posturography data is commonly depicted. Figure 3.1 depict graphical representations of a stabilogram, a plot of the COPx and COPy data. It is a useful visual representation of the trajectory of an individual’s sway as it ‘traces’ the path of an individual’s COP as they stand quietly.

![Stabilogram](image)

**Figure 3.1:** A Stabilogram of a Subject Quietly Standing
The A/P and M/L sway can also be isolated and are depicted in Figures 3.2. Note how human produce a greater amount of sway in the A/P direction than the M/L.

![A/P and M/L Sway](image)

**Figure 3.2:** A Plot of the A/P and M/L Sway of a Subject Standing on a Flat Surface with Their Eyes Open

Although there are exceptions for certain pathologies that result in significantly smaller than usual linear sway parameters, a general rule of thumb for linear sway parameters is the higher the magnitude of a linear result, the less stable an individual is. In other words, a person with a very high sway range is swaying more than a person with a smaller sway range and is therefore more posturally unstable. Therefore, a post-therapy decrease of sway parameters would indicate that the children with ASD are experiencing beneficial effects. Nonlinear results are interpreted by gauging whether a subject demonstrates appropriate postural complexity or if the subject is too periodic or too chaotic. As stated in the methodology, the averaged SampEn of the TD children will be used as the standard by which to compare the SampEn of the children with ASD.
Based on previous literature, the children with ASD were expected to be overall less complex than the TD children, and therefore an increase in complexity would be viewed as a sign that the SI therapy provided beneficial effects.

### 3.1.4 Posturography Results for the NS-EO Condition

Subjects were tested under four different sensory conditions but because the children with ASD demonstrated the most marked changed in the NS-EO condition, all results for this condition will be presented first. The following section will review the results for the other conditions. Tables 3.1 and Figure 3.3 depict the APSR results for the NS-EO condition. The error bars present on each plot depict the standard deviation of the averaged values.

<table>
<thead>
<tr>
<th>APSR: NS-EO</th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>29.31</td>
<td>18.75</td>
</tr>
<tr>
<td>S2</td>
<td>59.03</td>
<td>50.87</td>
</tr>
<tr>
<td>S3</td>
<td>26.13</td>
<td>33.77</td>
</tr>
<tr>
<td>S4</td>
<td>21.60</td>
<td>23.87</td>
</tr>
<tr>
<td>S5</td>
<td>16.54</td>
<td>16.10</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>30.52±16.65</td>
<td>27.47±13.84</td>
</tr>
<tr>
<td>TD AVG</td>
<td>23.09±7.35</td>
<td></td>
</tr>
</tbody>
</table>
Three out of the five subjects demonstrated decreased A/P sway post-therapy for the NS-EO condition. On average individuals with ASD swayed less in the A/P direction after the swing therapy while standing in this condition.

Tables 3.2 and Figure 3.4 depict the MLSR results for the NS-EO condition.
Figure 3.4: MLSR Results for the NS-EO Condition

Three out of the five subjects demonstrated decreased M/L sway post-therapy for the NS-EO condition. On average individuals with ASD swayed less in the M/L direction after the swing therapy while standing in this condition.

Table 3.3 and figure 3.5 depict the MV results for NS-EO condition.

Table 3.3: MV Results for the NS-EO Condition

<table>
<thead>
<tr>
<th>MV: NS-EO</th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>17.16</td>
<td>11.49</td>
</tr>
<tr>
<td>S2</td>
<td>41.51</td>
<td>33.17</td>
</tr>
<tr>
<td>S3</td>
<td>15.19</td>
<td>13.74</td>
</tr>
<tr>
<td>S4</td>
<td>19.90</td>
<td>12.24</td>
</tr>
<tr>
<td>S5</td>
<td>18.76</td>
<td>12.53</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>22.50±10.77</td>
<td>17.09±9.16</td>
</tr>
<tr>
<td>TD AVG</td>
<td>14.21±1.31</td>
<td></td>
</tr>
</tbody>
</table>
All five subjects demonstrated decreased MV post-therapy for the NS-EO condition. On average individuals with ASD had decreased MV after the swing therapy while standing in this condition.

Table 3.4 and figure 3.6 depict the RMS results for NS-EO condition.

Table 3.4: RMS Results for the NS-EO Condition

<table>
<thead>
<tr>
<th></th>
<th>RMS: NS-EO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-swing</td>
</tr>
<tr>
<td><strong>S1</strong></td>
<td>9.32</td>
</tr>
<tr>
<td><strong>S2</strong></td>
<td>14.71</td>
</tr>
<tr>
<td><strong>S3</strong></td>
<td>14.71</td>
</tr>
<tr>
<td><strong>S4</strong></td>
<td>9.14</td>
</tr>
<tr>
<td><strong>S5</strong></td>
<td>7.12</td>
</tr>
<tr>
<td><strong>ASD AVG</strong></td>
<td>11.00±3.50</td>
</tr>
<tr>
<td><strong>TD AVG</strong></td>
<td>6.23±1.50</td>
</tr>
</tbody>
</table>
Three out of the five subjects demonstrated decreased RMS post-therapy for the NS-EO condition. On average individuals with ASD had decreased RMS after the swing therapy while standing in this condition.

Table 3.5 and Figure 3.7 depict the M/S SampEn results for NS-EO condition.

**Table 3.5: M/L SampEn Results for NS-EO**

<table>
<thead>
<tr>
<th>NS-EO, ML SampEn</th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.05</td>
<td>0.08</td>
</tr>
<tr>
<td>S2</td>
<td>0.13</td>
<td>0.06</td>
</tr>
<tr>
<td>S3</td>
<td>0.13</td>
<td>0.07</td>
</tr>
<tr>
<td>S4</td>
<td>0.06</td>
<td>0.09</td>
</tr>
<tr>
<td>S5</td>
<td>0.08</td>
<td>0.15</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>0.09 ± 0.037</td>
<td>0.09 ± 0.048</td>
</tr>
<tr>
<td>TD AVG</td>
<td>0.14 ± 0.037</td>
<td></td>
</tr>
</tbody>
</table>
Three out of the five subjects demonstrated increased M/L SampEn post-therapy for the NS-EO condition. On average individuals with ASD had increased M/L SampEn after the swing therapy while standing in this condition.

Table 3.6 and figure 3.8 depict the M/S SampEn results for NS-EO condition.

<table>
<thead>
<tr>
<th>A/P SampEn for NS-EO Condition</th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>S2</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>S3</td>
<td>0.09</td>
<td>0.04</td>
</tr>
<tr>
<td>S4</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>S5</td>
<td>0.18</td>
<td>0.11</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>.12±.04</td>
<td>.08±.03</td>
</tr>
<tr>
<td>TD AVG</td>
<td>.13±.05</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.7: M/L SampEn Results for NS-EO Condition

Figure 3.23 depicts A/P SampEn for the NS-EO condition.
Four out of the five subjects demonstrated decreased A/P SampEn post-therapy for the NS-EO condition. On average individuals with ASD had decreased M/L SampEn after the swing therapy while standing in this condition.

### 3.1.5 Posturography Post Hoc Power Analysis for NS-EO Condition

As the NS-EO condition demonstrated the most reliable trends, statistical analysis and a power analysis was conducted for all the parameters for this condition. When non-parametric statistics were performed to examine the differences between the pre-intervention results of the TD children and children with ASD, 3 parameters were significantly different. These parameters were MLSR (p = .043), RMS (p = .043), and M/L SampEn (p = .042).

Table 3.7 depicts the results of the power calculation for the posturography data. Power analysis revealed a minimum of 9 subjects needed to achieve statistically
significant differences between subjects for one postural stability parameter. A study seeking a minimum of two significant parameters between subjects would require an estimated 12 subjects. A study that incorporated 54 subjects would have 4 significantly different parameters between subjects. Both medial-lateral parameters MLSR and ML SampEn were so little affected by the swing that the total sample size needed to see statistical significance was impractical (15565 and 33526, respectively.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>APSR</td>
<td>54</td>
</tr>
<tr>
<td>MLSR</td>
<td>15565</td>
</tr>
<tr>
<td>MV</td>
<td>9</td>
</tr>
<tr>
<td>RMS</td>
<td>40</td>
</tr>
<tr>
<td>ML SampEn</td>
<td>33526</td>
</tr>
<tr>
<td>AP SampEn</td>
<td>12</td>
</tr>
</tbody>
</table>

When non-parametric statistics were performed only one parameter, MV, approached significance (P = 0.08).

### 3.1.6 Posturography Results for Conditions NS-EC, PS-EO, and PS-EC

The results of the remaining conditions are below. Table 3.8 and Figure 3.9 depict the APSR results for the NS-EC condition.
Table 3.8: APSR Results for the NS-EC Condition

<table>
<thead>
<tr>
<th>APSR: NS-EC</th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>33.91</td>
<td>23.13</td>
</tr>
<tr>
<td>S2</td>
<td>73.80</td>
<td>58.25</td>
</tr>
<tr>
<td>S3</td>
<td>33.77</td>
<td>33.77</td>
</tr>
<tr>
<td>S4</td>
<td>32.98</td>
<td>33.32</td>
</tr>
<tr>
<td>S5</td>
<td>21.84</td>
<td>24.90</td>
</tr>
<tr>
<td><strong>ASD AVG</strong></td>
<td><strong>39.26±19.97</strong></td>
<td><strong>34.67±14.03</strong></td>
</tr>
<tr>
<td><strong>TD AVG</strong></td>
<td><strong>34.67±15.83</strong></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.9: APSR Results for the NS-EC Condition

Two out of the five subjects demonstrated decreased A/P sway post-therapy for the NS-EC condition. On average individuals with ASD swayed less in the A/P direction after the swing therapy while standing in this condition.

Table 3.9 and Figure 3.10 depict the APSR results for the PS-EO condition.
**Table 3.9: APSR Results for the PS-EO Condition**

<table>
<thead>
<tr>
<th></th>
<th>APSR: PS-EO</th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>79.19</td>
<td>65.22</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>70.12</td>
<td>89.27</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>41.59</td>
<td>46.78</td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td>25.04</td>
<td>30.79</td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td>38.20</td>
<td>33.32</td>
<td></td>
</tr>
<tr>
<td>ASD AVG</td>
<td>50.83±22.84</td>
<td>53.08±24.41</td>
<td></td>
</tr>
<tr>
<td>TD AVG</td>
<td>30.56±6.73</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Two out of the five subjects demonstrated decreased A/P sway post-therapy for the PS-EO condition. On average individuals with ASD swayed more in the A/P direction after the swing therapy while standing in this condition.

Table 3.10 and Figure 3.11 depict the APSR results for the PS-EC condition.
Two out of the five subjects demonstrated decreased A/P sway post-therapy for the NS-EO condition. On average individuals with ASD swayed more in the A/P direction after the swing therapy while standing in this condition.

Table 3.11 and Figure 3.12 depict the MLSR results for the NS-EC condition.
Two out of the five subjects demonstrated decreased M/L sway post-therapy for the NS-EC condition. On average individuals with ASD swayed more in the M/L direction after the swing therapy while standing in this condition.

Table 3.12 and Figure 3.13 depict the MLSR results for the PS-EO condition.
Table 3.12: MLSR Results for the PS-EO Condition

<table>
<thead>
<tr>
<th></th>
<th>MLSR: PS-EO</th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td></td>
<td>58.40</td>
<td>55.41</td>
</tr>
<tr>
<td>S2</td>
<td></td>
<td>198.71</td>
<td>70.93</td>
</tr>
<tr>
<td>S3</td>
<td></td>
<td>91.62</td>
<td>33.11</td>
</tr>
<tr>
<td>S4</td>
<td></td>
<td>29.93</td>
<td>33.38</td>
</tr>
<tr>
<td>S5</td>
<td></td>
<td>22.01</td>
<td>17.70</td>
</tr>
<tr>
<td>ASD AVG</td>
<td></td>
<td>80.13±71.70</td>
<td>42.11±20.98</td>
</tr>
<tr>
<td>TD AVG</td>
<td></td>
<td>36.59±6.49</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.13: MLSR Results for the PS-EO Condition

Four out of the five subjects demonstrated decreased M/L sway post-therapy for the NS-EO condition. On average individuals with ASD swayed less in the M/L direction after the swing therapy while standing in this condition.

Table 3.12 and Figure 3.13 depict the MLSR results for the PS-EO condition.
Table 3.13: MLSR Results for the PS-EC Condition

<table>
<thead>
<tr>
<th></th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>62.43</td>
<td>83.83</td>
</tr>
<tr>
<td>S2</td>
<td>106.23</td>
<td>111.70</td>
</tr>
<tr>
<td>S3</td>
<td>47.20</td>
<td>43.30</td>
</tr>
<tr>
<td>S4</td>
<td>46.84</td>
<td>65.54</td>
</tr>
<tr>
<td>S5</td>
<td>52.89</td>
<td>42.53</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>63.12±24.91</td>
<td>69.38±29.22</td>
</tr>
<tr>
<td>TD AVG</td>
<td>46.39±20.80</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.13: MLSR Results for the PS-EC Condition

Two out of the five subjects demonstrated decreased M/L sway post-therapy for the PS-EC condition. On average individuals with ASD swayed more in the M/L direction after the swing therapy while standing in this condition.

Table 3.14 and Figure 3.15 depict the MV results for the NS-EC condition.
Table 3.14: MV Results for the NS-EC Condition

<table>
<thead>
<tr>
<th></th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>16.51</td>
<td>19.22</td>
</tr>
<tr>
<td>S2</td>
<td>31.73</td>
<td>32.44</td>
</tr>
<tr>
<td>S3</td>
<td>20.67</td>
<td>13.74</td>
</tr>
<tr>
<td>S4</td>
<td>20.68</td>
<td>17.79</td>
</tr>
<tr>
<td>S5</td>
<td>21.92</td>
<td>21.84</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>22.30±5.66</td>
<td>21.00±7.03</td>
</tr>
<tr>
<td>TD AVG</td>
<td>21.00±1.59</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.15: MV Results for the NS-EC Condition

Three out of the five subjects demonstrated decreased MV post-therapy for the NS-EC condition. On average individuals with ASD had decreased MV after the swing therapy while standing in this condition.

Table 3.15 and Figure 3.16 depict the MV results for the PS-EO condition.
### Table 3.15: MV Results for the PS-EO Condition

<table>
<thead>
<tr>
<th></th>
<th>MV: PS-EO</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-swing</td>
<td>Post-swing</td>
</tr>
<tr>
<td>S1</td>
<td>49.95</td>
<td>31.73</td>
</tr>
<tr>
<td>S2</td>
<td>76.34</td>
<td>48.67</td>
</tr>
<tr>
<td>S3</td>
<td>26.58</td>
<td>25.37</td>
</tr>
<tr>
<td>S4</td>
<td>20.77</td>
<td>19.40</td>
</tr>
<tr>
<td>S5</td>
<td>21.19</td>
<td>21.85</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>38.97±24.07</td>
<td>29.40±11.73</td>
</tr>
<tr>
<td>TD AVG</td>
<td>20.35±2.3</td>
<td></td>
</tr>
</tbody>
</table>

### Figure 3.16: MV Results for the PS-EO Condition

Three out of the five subjects demonstrated decreased MV post-therapy for the PS-EO condition. On average individuals with ASD had decreased MV after the swing therapy while standing in this condition.

Table 3.16 and Figure 3.17 depict the MV results for the PS-EC condition.
Table 3.16: MV Results for the PS-EC Condition

<table>
<thead>
<tr>
<th></th>
<th>MV: PS-EC</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-swing</td>
<td>Post-swing</td>
</tr>
<tr>
<td>S1</td>
<td>51.84</td>
<td>42.86</td>
</tr>
<tr>
<td>S2</td>
<td>89.79</td>
<td>78.49</td>
</tr>
<tr>
<td>S3</td>
<td>28.08</td>
<td>38.24</td>
</tr>
<tr>
<td>S4</td>
<td>30.22</td>
<td>45.28</td>
</tr>
<tr>
<td>S5</td>
<td>40.33</td>
<td>54.72</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>48.05±25.17</td>
<td>51.92±16.02</td>
</tr>
<tr>
<td>TD AVG</td>
<td>36.57±5.69</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.17: MV Results for the PS-EC Condition

Two out of the five subjects demonstrated decreased MV post-therapy for the PS-EC condition. On average individuals with ASD had increased MV after the swing therapy while standing in this condition.

Table 3.17 and Figure 3.18 depict the RMS results for the NS-EC condition.
Table 3.17: RMS Results for the NS-EC Condition

<table>
<thead>
<tr>
<th></th>
<th>RMS: NS-EC</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-swing</td>
<td>Post-swing</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>6.23</td>
<td>10.13</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>14.45</td>
<td>12.72</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>14.45</td>
<td>12.72</td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td>9.94</td>
<td>6.25</td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td>4.78</td>
<td>6.15</td>
<td></td>
</tr>
<tr>
<td>ASD AVG</td>
<td>9.97±4.50</td>
<td>9.59±3.28</td>
<td></td>
</tr>
<tr>
<td>TD AVG</td>
<td>9.59±2.33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.18: RMS Results for the NS-EC Condition

Three out of the five subjects demonstrated decreased RMS post-therapy for the NS-EC condition. On average individuals with ASD had decreased RMS after the swing therapy while standing in this condition. Table 3.18 and Figure 3.19 depict the RMS results for the NS-EC condition.
### Table 3.18: RMS Results for the PS-EO Condition

<table>
<thead>
<tr>
<th></th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>19.78</td>
<td>17.46</td>
</tr>
<tr>
<td>S2</td>
<td>34.18</td>
<td>21.41</td>
</tr>
<tr>
<td>S3</td>
<td>34.18</td>
<td>21.41</td>
</tr>
<tr>
<td>S4</td>
<td>7.51</td>
<td>9.50</td>
</tr>
<tr>
<td>S5</td>
<td>8.88</td>
<td>8.50</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>20.91</td>
<td>15.66</td>
</tr>
<tr>
<td>TD AVG</td>
<td>8.41</td>
<td></td>
</tr>
</tbody>
</table>

Three out of 5 of the subjects demonstrated decreased RMS post-intervention. This was also reflected in the overall average of the children with ASD. Table 3.19 and Figure 3.20 depict the RMS results for the PS-EC condition.
Table 3.19: RMS Results for the PS-EC Condition

<table>
<thead>
<tr>
<th></th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>16.46</td>
<td>21.63</td>
</tr>
<tr>
<td>S2</td>
<td>30.63</td>
<td>35.32</td>
</tr>
<tr>
<td>S3</td>
<td>30.63</td>
<td>35.32</td>
</tr>
<tr>
<td>S4</td>
<td>13.24</td>
<td>17.23</td>
</tr>
<tr>
<td>S5</td>
<td>16.06</td>
<td>16.84</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>21.41±8.51</td>
<td>25.27±9.37</td>
</tr>
<tr>
<td>TD AVG</td>
<td>14.23±3.13</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.20: RMS Results for the PS-EC Condition

All five subjects demonstrated increased RMS post-therapy for the PS-EC condition. On average individuals with ASD had increased RMS after the swing therapy while standing in this condition.

Table 3.20 and Figure 3.21 depict the M/L SampEn values for condition NS-EC.
Table 3.20: M/L SampEn Results for the NS-EC condition

<table>
<thead>
<tr>
<th></th>
<th>M/L SampEn Results for NS-EC</th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td></td>
<td>0.14</td>
<td>0.05</td>
</tr>
<tr>
<td>S2</td>
<td></td>
<td>0.10</td>
<td>0.07</td>
</tr>
<tr>
<td>S3</td>
<td></td>
<td>0.07</td>
<td>0.14</td>
</tr>
<tr>
<td>S4</td>
<td></td>
<td>0.11</td>
<td>0.15</td>
</tr>
<tr>
<td>S5</td>
<td></td>
<td>0.18</td>
<td>0.17</td>
</tr>
<tr>
<td>ASD AVG</td>
<td></td>
<td>0.12±0.04</td>
<td>0.10±0.03</td>
</tr>
<tr>
<td>TD AVG</td>
<td></td>
<td>0.13±0.04</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.21: M/L SampEn Results for NS-EC Condition

Two out of the five subjects demonstrated increased M/L SampEn post-therapy for the NS-EC condition. On average individuals with ASD had decreased M/L SampEn after the swing therapy while standing in this condition.

Table 3.21 and Figure 3.22 depict M/L SampEn for the PS-EO condition.
Table 3.21: M/L SampEn Results for the PS-EO Condition

<table>
<thead>
<tr>
<th>M/L SampEn Results for PS-EO</th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>S2</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>S3</td>
<td>0.02</td>
<td>0.08</td>
</tr>
<tr>
<td>S4</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>S5</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>.07±.03</td>
<td>.09±.03</td>
</tr>
<tr>
<td>TD AVG</td>
<td>0.08±.02</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.22: M/L SampEn Results for PS-EO Condition

Three out of the five subjects demonstrated increased M/L SampEn post-therapy for the PS-EO condition. On average individuals with ASD had increased M/L SampEn after the swing therapy while standing in this condition.

Table 3.22 and Figure 3.23 depict M/L SampEn for the PS-EC condition.
Table 3.22: M/L SampEn Results for the PS-EC Condition

<table>
<thead>
<tr>
<th></th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.09</td>
<td>0.06</td>
</tr>
<tr>
<td>S2</td>
<td>0.08</td>
<td>0.07</td>
</tr>
<tr>
<td>S3</td>
<td>0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>S4</td>
<td>0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>S5</td>
<td>0.06</td>
<td>0.10</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>.08±.01</td>
<td>.08±.01</td>
</tr>
<tr>
<td>TD AVG</td>
<td>.10±.03</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.23: M/L SampEn Results for PS-EC Condition

Three out of the five subjects demonstrated increased M/L SampEn post-therapy for the PS-EC condition. On average individuals with ASD had increased M/L SampEn after the swing therapy while standing in this condition.

Table 3.23 and Figure 3.24 depicts the A/P SampEn values the NS-EC condition.
Table 3.23: A/P SampEn Results for the NS-EC Condition

<table>
<thead>
<tr>
<th></th>
<th>A/P SampEn Results for NS-EC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td></td>
</tr>
<tr>
<td>S4</td>
<td></td>
</tr>
<tr>
<td>S5</td>
<td></td>
</tr>
<tr>
<td>ASD AVG</td>
<td></td>
</tr>
<tr>
<td>TD AVG</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.24: A/P SampEn Results for NS-EC Condition

Three out of the five subjects demonstrated decreased A/P SampEn post-therapy for the NS-EO condition. On average individuals with ASD had decreased M/L SampEn after the swing therapy while standing in this condition.

Table 3.24 and Figure 3.25 depict A/P SampEn for the PS-EO condition.
Table 3.24: A/P SampEn Results for PS-EO

<table>
<thead>
<tr>
<th></th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>S2</td>
<td>0.11</td>
<td>0.07</td>
</tr>
<tr>
<td>S3</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>S4</td>
<td>0.10</td>
<td>0.09</td>
</tr>
<tr>
<td>S5</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>0.09±.01</td>
<td>0.08±.01</td>
</tr>
<tr>
<td>TD AVG</td>
<td>0.11±.02</td>
<td></td>
</tr>
</tbody>
</table>

Four out of the five subjects demonstrated decreased A/P SampEn post-therapy for the PS-EO condition. On average individuals with ASD had decreased M/L SampEn after the swing therapy while standing in this condition.

Table 3.25 and Figure 3.26 depicts A/P SampEn for the PS-EC condition.
Table 3.25: A/P SampEn Results for the PS-EC Condition

<table>
<thead>
<tr>
<th></th>
<th>Pre-swing</th>
<th>Post-swing</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.12</td>
<td>0.07</td>
</tr>
<tr>
<td>S2</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>S3</td>
<td>0.04</td>
<td>0.08</td>
</tr>
<tr>
<td>S4</td>
<td>0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>S5</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>ASD AVG</td>
<td>.08±.03</td>
<td>.09±.02</td>
</tr>
<tr>
<td>TD AVG</td>
<td>.09±.01</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.26: A/P SampEn Results for PS-EC Condition

Three out of the five subjects demonstrated increased A/P SampEn post-therapy for the NS-EO condition. On average individuals with ASD had increased M/L SampEn after the swing therapy while standing in this condition.
3.2 Eye tracking Results

3.2.1 Functional Reach and BOT2 Bilateral Coordination Results

All subjects were able to complete the BOT2 Bilateral Coordination Test and the Functional Reach Test. The subjects with ASD scored an average of 6.89±3.02 in for the Functional Reach Test, while the TD subjects scored an average of 8.06±3.33 inches. For the BOT2 bilateral coordination test, the subjects with ASD had an average score of 21.67±2.08 inches, indicating a bilateral coordination level approximate to that of a child between the ages of 5.45±5.23 and 5.55±5.33 years. The TD children scored an average of 22±1.41, indicating a bilateral coordination level of a child that fell between the ages of 6.04±4.77 and 6.15±4.86 years.

3.2.3 Eye Tracking Results

Eye tracking data can be represented in terms of a total count of visual fixations, the sum of the duration of those fixations, and the percentage over the length of the entire video that the duration of the fixations occurred. Of the three visual fixations (eye contact, face gazing without eye contact, and task), the socially relevant fixations are reported below. Visual fixations on the task were not reported as it was not directly indicative of socially relevant behaviors. Additionally, as the subjects often looked down while engaged in the fine motor task, the eye tracker was unable to retain a lock on the pupil of the subject, resulting in an inconsistent collection of task gaze data while the subject looked at the task. Tables 3.26 and 3.27 represent the eye tracking data collected and analyzed for each gross motor, three minute play session for the subjects...
with ASD. Figures 3.28 and 3.29 examine the number of eye contact and face-gazing fixations separately pre- and post-therapy.

**Table 3.26:** Eye Tracking Results from the Gross Motor Game Pre-Therapy

<table>
<thead>
<tr>
<th>Subject</th>
<th>Fixation</th>
<th>Fixation Count</th>
<th>Fixation Duration (ms)</th>
<th>Percent of Occurrence (10e-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S6</td>
<td>Eyes</td>
<td>1</td>
<td>200</td>
<td>1.11</td>
</tr>
<tr>
<td>S6</td>
<td>Face</td>
<td>11</td>
<td>2536</td>
<td>14.089</td>
</tr>
<tr>
<td>S7</td>
<td>Eyes</td>
<td>3</td>
<td>468</td>
<td>2.60</td>
</tr>
<tr>
<td>S7</td>
<td>Face</td>
<td>20</td>
<td>4302</td>
<td>23.90</td>
</tr>
<tr>
<td>S9</td>
<td>Eyes</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S9</td>
<td>Face</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 3.27:** Eye Tracking Results from the Gross Motor Game Post-Therapy

<table>
<thead>
<tr>
<th>Subject</th>
<th>Fixation</th>
<th>Fixation Count</th>
<th>Fixation Duration (ms)</th>
<th>Percent of Occurrence (10e-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S6</td>
<td>Eyes</td>
<td>9</td>
<td>1433</td>
<td>7.96</td>
</tr>
<tr>
<td>S6</td>
<td>Face</td>
<td>20</td>
<td>3604</td>
<td>20.02</td>
</tr>
<tr>
<td>S7</td>
<td>Eyes</td>
<td>3</td>
<td>335</td>
<td>1.86</td>
</tr>
<tr>
<td>S7</td>
<td>Face</td>
<td>12</td>
<td>2135</td>
<td>11.86</td>
</tr>
<tr>
<td>S9</td>
<td>Eyes</td>
<td>4</td>
<td>701</td>
<td>3.89</td>
</tr>
<tr>
<td>S9</td>
<td>Face</td>
<td>3</td>
<td>467</td>
<td>2.59</td>
</tr>
</tbody>
</table>
When pre-therapy and post-therapy results were compared for the gross motor game, children with ASD demonstrated an overall average increase in instances of eye contact. This increase was demonstrated by two of the three of subjects.

When the pre-therapy and post-therapy visual fixation counts during the gross motor game were compared to each other, the children with ASD demonstrated an
average increase of instances of visual fixations on the face. Two of the three subjects did demonstrate increased facial fixations post-therapy.

Tables 3.28 and 3.29 represent the eye tracking data collected and analyzed for each fine motor, three minute play session for the subjects with ASD. Figures 3.29 and 3.30 examine the number of eye contact and face-gazing fixations separately pre- and post-therapy.

Table 3.28: Eye Tracking Results from the Fine Motor Game Pre-Therapy

<table>
<thead>
<tr>
<th>Subject</th>
<th>Fixation</th>
<th>Fixation Count</th>
<th>Fixation Duration (ms)</th>
<th>Percent of Occurrence (10e-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S6</td>
<td>Eyes</td>
<td>13</td>
<td>2502</td>
<td>13.90</td>
</tr>
<tr>
<td>S6</td>
<td>Face</td>
<td>5</td>
<td>1435</td>
<td>7.97</td>
</tr>
<tr>
<td>S7</td>
<td>Eyes</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S7</td>
<td>Face</td>
<td>1</td>
<td>133</td>
<td>0.74</td>
</tr>
<tr>
<td>S9</td>
<td>Eyes</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S9</td>
<td>Face</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 3.29: Eye Tracking Results from the Fine Motor Game Post-Therapy

<table>
<thead>
<tr>
<th>Subject</th>
<th>Fixation</th>
<th>Fixation Count</th>
<th>Fixation Duration (ms)</th>
<th>Percent of Occurrence (10e-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S6</td>
<td>Eyes</td>
<td>1</td>
<td>100</td>
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Figure 3.29: Eye Contact During the Fine Motor Game Pre- and Post- Therapy.

For the fine motor game, one child demonstrated a decrease, one demonstrated an increase, while the final subject experienced no change in eye contact.

Figure 3.30: Facial Fixations During the Fine Motor Game Pre- and Post- Therapy.

During the fine motor game, children with ASD demonstrated an average decrease of facial gazing post-therapy. Two subjects demonstrated a decrease and one subject did not change. Both the fine motor game and gross motor game demonstrated
a consistent trend: the TD children demonstrated more instances of eye contact and facial fixations than the children with ASD.
4.0 Discussion Overview

This chapter is broken into two parts, with the primary section focusing on the results of the posturography protocol and the second section discussing the findings of the eye tracking protocol. Each section will first review the pre-test results of the functional reach and BOT2 test and discuss how the subject’s performance could affect the findings and between-group comparisons. Then, the major findings will be discussed. These are:

- For the postural data, the greatest changes were demonstrated in the normal surface, eyes open (NS-EO) condition
- Children with ASD demonstrated decreased postural stability and complexity than the TD group before exposure to the swing therapy
- Post-therapy, children with ASD demonstrate overall improved postural control and increased dynamic complexity in the NS-EO condition although these trends were not significant and they were still not as stable as the TD children
• Future work is needed to address the limitations of this study

• The gaze tracking protocol used in this study did not indicate uniform post-therapy trends.

Each section will also include a review of the limitation of each protocol and provide suggestions for future studies.

4.1 Posturography

4.1.1 Subject Reach and Coordination: Pretest Results

The pretest used two different metrics, the Functional Reach Test and the BOT2 Bilateral Coordination Test, to examine the overall balance and coordination of both subject groups. When the Functional Reach scores of the two groups were compared, they were very close (the children with ASD scored an average of 7.53 ± 2.31 inches and the TD children scored an average of 7.75 ± 2.11 inches). The scores of the two group’s BOT2 tests reflected a similar trend, with the children with ASD scoring an average of 17±7.16 and the TD children scored an average of 18.5±4.93. When compared to a national standard, this indicated that the children with ASD had a bilateral coordination score similar to that of a child between the ages of 7.58 ± 3.33 years and 7.71 ± 3.38 years while the TD children performed on the level of children ages 7.77 ± 2.88 years to 7.92 ± 2.9 years. The similarity between the scores of both groups allows for a better comparison between them. Had there been a large disparity between the two groups, it would have been less meaningful to use the TD group as a ‘Golden Standard’ when conducting the nonlinear analysis. The similar scores also support the findings of
Minshew et al., who determined that, even though they had significantly lessened postural stability, individuals with ASD did not have significantly different motor control abilities than TD individuals [15]. Although the scores of both groups were similar, the average ages were not. The group with ASD had an average age of 9.2 ± .45 years, while the TD group had an average age of 7.4 ± 2.06 years. The fact that the children with ASD were underperforming in terms of their age group reflects the commonly reported symptom of motor coordination issues experienced by this population [18, 86, 87]. This is also one indicator that the children in the ASD group are a good representation of the overall ASD population.

4.1.2 Anticipated Results

It was anticipated that the children with ASD would demonstrate improved postural stability post-therapy, as the children’s sensory processing abilities would have benefitted as a result of the therapy. Additionally, the findings were expected to vary depending on the sensory condition (NS-EO, NS-EC, PS-EO, and PS-EC) in which the children were tested in. This assumption was based on the fact that each sensory condition provides a different range of sensory inputs. As NS-EO provided the largest degree of sensory input, the most significant changes were expected to occur in this condition. The other conditions all restricted at least one sensory input and were therefore expected to change, but perhaps not as considerably as NS-EO.

It was also expected that the postural stability of the children with ASD would potentially decline post-therapy in the condition that provided the least amount of
sensory input, PS-EC. This was anticipated due to the nature of the swing therapy—it was designed to provide vestibular sensory input which could potentially cause some disruption in the vestibular system. As the PS-EC conditions restricts visual and proprioceptive input, requiring the body to rely more heavily on the vestibular sensory system to maintain balance, any perturbations to this system could result in decreased postural control. Finally, it was anticipated that not all subjects would consistently generate the same trends. This assumption was based on the small sample size and that fact that ASD is a spectrum disorder with a varying range of impairment across the spectrum. Even though the subjects were all considered ‘high functioning’ they still exhibited a range of symptoms and abilities which could be reflected in their postural control. Although not all the children might react the same way, any changes would indicate something was occurring as a result of the 10 minute therapy session, indicating that the therapy did have an effect on sensory processing abilities.

4.1.3 Linear Posturography Results: Comparisons between TD and ASD groups

Before pre- and post-therapy results of the children with ASD were evaluated, an overall group comparison between the children with ASD and the TD group was conducted. The children with ASD demonstrated larger average APSR, MLSR, MV, and RMS than the TD children across all experimental conditions except PS-EC. Stated plainly, this means children with ASD swayed more in every direction, swayed at a faster rate, and in a more variable fashion that TD children. Overall, these results indicate that the children with ASD demonstrate decreased postural stability when compared to TD
peers. This reflects the findings of current literature, further indicating the group used for this study is an accurate representation of the overall population [11-18, 55-57]. This trend did not extend to the PS-EC condition, which supports a 1992 study conducted by Kohen-Raz et al. in which he determined children with ASD displayed decreased postural stability in all conditions but the most difficult [14]. This was referred to as a paradoxical postural stress response [14]. This paradoxical postural stress response is somewhat controversial, however, as several other studies refuted it and attributed it to an artifact introduced by a display of moving, flashing lights utilized in Kohen-Raz’s methodology [11, 15, 16].

The methodology used in this study was similar to that of Kohen-Raz’s in the respect that there was a degree of additional sensory inputs occurring during pre- and post-therapy testing (i.e. the researcher counting down and the image placed in front of each subject). This could explain this particular finding, though would not have affected the between-group differences since the efforts to improve compliance in completing the balance testing protocol were identical in both pre- and post-test.

The majority of studies that identified decreased postural stability as a hallmark of ASD also suggested this was a result of sensory processing deficits rather than motor impairments [11-18, 55-57]. As both groups in this study performed similarly on the motor tests, the findings of this study also imply that a mechanism other than motor impairments is the cause of the postural stability of children with ASD. Therefore, the postural trends demonstrated by the individuals with ASD appear to follow those found
by previous studies, namely individuals with ASD are more inherently unstable than TD individuals and it is likely due to sensory processing issues.

4.1.4 Linear Posturography Results: Pre- and Post-Therapy Comparisons

Because of the small number of subjects and the relatively large number of postural sway parameters and conditions examined, summarizing effectiveness was challenging. Though examining differences between average performance pre-test and average performance post-test often revealed changes, the individual subjects did not necessarily show the same, or consistent, improvement. For this reason, when the pre- and post-therapy linear posturography parameters were compared to each other, both the individual results of each subject and the overall average results were analyzed.

As anticipated by the author, NS-EO appeared to be the condition in which there was the most marked and consistent improvement and therefore will be the main focus of this discussion. The fact that the largest improvement was seen in the NS-EO condition could be because it is a ‘sensory heavy’ condition and thus the most likely to show improvements when an individual’s sensory processing abilities increase.

Of all the linear parameters, MV demonstrated the strongest trends. Firstly, changes in MV were the most consistent across all the subjects when compared to the other three parameters: for the NS-EO condition, all five subjects displayed an average MV decreased of $5.41 \pm 14.14$ mm/s, indicating a post-therapy improvement in postural stability. The difference between the TD children and children with ASD can give context to the whether this is a meaningful decrease. The TD demonstrated a MV of $14.21 \pm 1.31$
mm/s, and the MV of the children with ASD decreased from 22.50±10.77 mm/s to 17.09±9.16 mm/s post therapy. This change appears to be meaningful, and was even determined to be approaching significance (p = .08).

As MV appears to be the strongest affected parameter, it is necessary to better explore the connection between MV and sensory processing. MV has been proposed to be a result of a feedback control loop the body utilizes to maintain upright standing [88]. As the body sways in any direction, it receives sensory input from the visual, vestibular, and proprioceptive sensory systems. Once one or more of these symptoms start processing feedback that indicate the body has swayed too far in one direction, the direction of sway is reversed and postural stability is maintained [88]. A high rate of MV is often indicative of a body over-compensating for a delay in perceiving the need to correct the direction of sway. The sensory processing that occurs in this feedback loop is highly intricate. As all subjects demonstrated decreased MV, this is highly indicative that the swing was having a positive effect of postural control and therefore, sensory processing.

The trend seen for the MV parameter in the NS-EO condition held true across the other three linear parameters. When RMS was analyzed, 4 out of the 5 children with ASD demonstrated decreased RMS post-therapy for the NS-EO condition and the average RMS decrease post-therapy was 1.10±6.66, indicating that the amount of sway variability of the children with ASD decreased after exposure to the SI therapy. When compared to the RMS of the TD children, however, the change in RMS does not appear to be very large. Although a decrease of 1.10±6.66 was observed, it only lowered the
RMS to 9.90±5.67 (compared to the TD RMS of 6.23±1.50). The power analysis of this parameter, however, suggests that 40 subjects would be required to reach statistical significance. As this is actually a very common sample size for posturography studies, this indicates the change in RMS was more meaningful than it appears.

When APSR was examined, 3 of the 5 children with ASD displayed decreased APSR for the NS-EO condition, suggesting that exposure to the swing therapy improved their postural stability. Additionally, when the results of all five subjects were averaged, the group displayed a decrease in APSR of 3.05±21.65 mm for the NS-EO conditions. Although this decreased the APSR of children with ASD to 27.47±13.84 mm (a number that is still larger than the TD children’s APSR of 23.09±7.35 mm), the power analysis indicated that 54 subjects would be necessary for this parameter to reach statistical significance. Similarly to the RMS parameter, this sample size is not unreasonable for a posturography study, which implies the decrease in APSR is meaningful. For MLSR, 3 out of 5 of the subjects demonstrated decreased sway post-therapy for the NS-EO conditions. Additionally, when MLSR was averaged across all subjects, it also decreased post-therapy by 0.59±25.57 mm, which suggests that the SI therapy did have a consistent—if small—effect on postural stability. Considering that there was a pre-therapy MLSR difference of 13.99±12.21 mm, this decrease does not seem meaningful. The results of the power analysis support this, indicating that 15,565 subjects would be required for statistical significance. The trend seen in the MLSR parameter does have an interesting implication for the ASD population, as individuals with ASD have been found to show significantly larger MLSR than TD individuals [14, 55, 57]. Since this seems to be
a unique trait demonstrated by individuals with ASD, the fact that it is positively affected by the SI therapy could indicate that the SI therapy session had a beneficial effect on this population. As of now, however, it is hard to meaningfully interpret this result as such, because the results of the power analysis indicated such a large sample size would be required to achieve significance with this parameter. This suggests that the differences between pre- and post-therapy MLSR is either minimal or highly variable.

Some additional interesting trends involved the fact that the averages of both APSR and RMS decreased across all conditions except for PS-EC, in which both parameters increased post-therapy, indicating decreased postural stability. A potential reason this difference didn’t extend to the PS-EC condition could due to the fact that the therapy caused perturbations to the vestibular system, which would result in decreased performance for the condition that requires the largest degree of vestibular input. It could also be a result that the PS-EC condition provides the least amount of sensory input—which, in turn requires a lesser degree of sensory processing—and thus is less likely to show an immediate effect as a result of the therapy session. Another trend was that both the average RMS and MLSR improved in the PS-EO condition as well as the NS-EO condition. This could be due to the fact that both conditions provided visual input and children with ASD have been found to be more visually reliant than TD controls.
4.1.5 Nonlinear Results: Comparison between TD and ASD Group

The nonlinear results were analyzed by comparing the results of the children with ASD to the ‘golden standard’ of the pre-swing TD children. Therefore, rather than simply looking for an increase or decrease in postural stability as reflected in SampEn, the data from the children with ASD had to be examined to see if it shifts to become more like that of the TD group. When the pre-therapy results of both groups for the NS-EO condition were compared, the TD children demonstrated increased SampEn in both the M/L and A/P direction when compared to the children with ASD, supporting the current literature that identifies children with ASD as less posturally dynamic [57].

4.1.6 Nonlinear Results: Pre- and Post-Therapy Comparisons

When pre- and post-therapy results for the NS-EO condition were compared to each other, the children with ASD demonstrated an increase in M/L SampEn post-therapy by shifting. This shift, however, was very minor. Theoretically, these results indicate the children with ASD became more postural dynamic in the M/L direction post-therapy, and became more similar to the TD children. A shift towards complexity is a good thing as it allows an individual to better respond to internal events and external environmental factors, and this indicates the therapy did benefit the children with ASD. As system complexity requires a complicated feedback loop that is always integrating sensory information and prompting appropriate system responses accordingly, this also indicates the benefit experienced by the children was likely due to improved sensory processing that came about due to the therapy. Although this trend is promising, the
power analysis results make it difficult to state this meaningfully. The magnitude of change was extremely small. Moreover, the power analysis indicated that a minimum of 33526 subjects would be required for M/L SampEn to reach significance, which underscores how small this magnitude of change was.

When pre- and post-therapy results for the A/P SampEn in the NS-EO condition were compared to each other, the children with ASD demonstrated a decrease in A/P SampEn post-therapy of .12±.04 to .08±+.03. As TD children demonstrated an A/P SampEn of .13±.05, this is not favorable. This could indicate that the therapy caused the children to become more posturally periodic, but it could also be a result of sample size and/or variability. This result is difficult to interpret because it was expected that the swing would either help the child better sensory process and thus exhibit improved postural complexity, the swing would slightly ‘disorient’ the child’s sensory processing and thus make it more chaotic, or the swing would instigate no change at all. The power analysis indicated that this parameter requires a minimum of 12 subjects to be significant. As the magnitude of changes of A/P SampEn are similar to those of M/L SampEn, this supports that the high sample size required for the M/L SampEn variable is likely due to variability rather than magnitude of change.

4.1.7 Study Limitations and Direction for Future Work

The most notable limitation of the study was the limited sample size and the variable nature of the sample size. Although the small number of subjects did produce results that were not statistically significant, it was notable that the differences
approached statistical significance for the MV parameter. For such a small sample size, this indicates that a change is likely occurring and, in this instance, that change is beneficial. The sample size was also a reflection of the novelty of this research—a study had never been conducted to determine whether a SI therapy generated physiological results that could be indicative of actual improvements in sensory processing. Therefore, this pilot study had to be performed before a full scale study to explore whether this area of research would be able to offer insight into this issue. As the results of this study did suggest that SI therapy resulted in some beneficial postural changes, future research can easily overcome this limitation by conducting a full scale study. The results of this study provide new and unique contributions to the field of biomechanics and occupational therapy, and should be used as a springboard to more diverse therapeutic evaluative methods. These evaluative methods range from include general efficacy evaluations to client-specific evaluations for individual therapy plans.

A second limitation was the acute nature of the SI therapy. Subjects were only exposed to a 10 minute therapy session, while children in a SI therapy program often have weekly or biweekly 30 minute sessions over a period of time. Therefore, the results of an acute therapy program are anticipated to be less than those of a full scale SI therapy program. Conversely, the 10 minute swing protocol does mimic how a swing is used in a therapy regime, as OTs often only work with children on the swing for part of a session than moving onto other SI therapy protocols. Additionally, some SI therapy protocols are used for short period of times to generate a calming effect [89]. One example of this is how some children with autism in special education programs report
using SI therapy equipment such as swings or pressure devices between classes to help them focus better.

One limitation of this study was that results were examined mainly for beneficial changes, while it actually might be more appropriate to simply look for overall post-intervention shifts. Any shift in posturography indicates a change occurred and that the change was a result of the sensory processing systems being affected by the SI therapy intervention. This phenomenon is often seen in physical therapy (PT) interventions—where immediately post-intervention patients exhibit a decrease in postural stability due to system fatigue (which, in the case of an SI intervention, would due to sensory overload). After continued exposure to a PT intervention, however, patients exhibit an overall increase in postural stability. Therefore, future work could address this by examining the immediate effect of an intervention but then compare it to the longitudinal effect.

Another limitation was the fact that not enough information was collected that provided explanations for why some children displayed varying postural control results. While this suggests that the therapy is more beneficial for some children than others, it limits the author from drawing specific conclusions concerning the rationale behind this. This limit could be addressed in future studies in several ways. Additional tests such as the Childhood Autism Rating Scale or the Repetitive Behavior Scale-Revised could be conducted to rate the symptom severity of this children with ASD. Another issue stemmed from the fact that, although posturography studies usually perform multiple trials then average them, this study only analyzed a pre- and post-therapy trial.
Although this study did conduct two pre- and post-therapy trials, the first and last trial were discarded due to the inconsistency of the break times between trial 1 and 2, and trial 3 and 4. Although the PI had planned on maintaining a strict break time of 3 minutes between trials, this was not possible for all of the children. Because the time between trials was not consistent across all the subjects, the two trials were not averaged in the analysis. This did offer two potential benefits—of offering a ‘practice’ trial and only examining the immediate effects of the therapy, which would make for a ‘cleaner’ analysis if the effects of the swing fade quickly. Another potential limitation was the fact that no outliers were identified. This was due to the small sample size and because, other than one or two specific conditions, no subjects demonstrated markedly different magnitudes of postural sway than others.

Several additional limitations were created by the introduction of several strategies intended to improve subject compliance. These included providing an image for the subjects to focus on during the trials and a countdown so the subject knew how long they had to stand still. Both of these strategies are not ideal and have been known to slightly improve a TD individual’s postural stability as it provides a point to focus on. There is, however, the possibility that providing additional sensory input in the form of a image would result in the postural performance of a child with ASD being additionally impaired. However, the image was necessary when working with children with ASD and any advantageous or disadvantageous effect was alleviated due to the nature of the study: the subjects were all equally exposed to these strategies and they were compared to themselves, which would theoretically cancel out the effect. Future studies...
could explore additional ways to improve subject compliance, such as seated posturography. The scope of the study was another limitation—only a single SI therapy protocol was examined when in reality OTs often employ a wide range of protocols in a single session. This can be addressed by future studies that examine multiple therapy protocols, both alone and in conjunction with others.

The results of this study indicate the children with ASD do experience improved postural stability after exposure to the SI therapy protocol. Therefore, future work is strongly suggested to explore this work with larger scope and with more subjects. Future studies should include a larger sample size of at least 12 children to obtain statistically significant results, work with children with varying degrees of symptom severity, examine multiple SI tools and protocols, incorporate additional compliance-inducing measures into the methodology, and explore both acute and longitudinal effects of multiple therapies. All of these suggested studies would require a larger sample size than the current study. Based on the results of the linear parameters, the author suggests utilizing them for future studies as they all demonstrated interesting trends. Of all the parameters, MLSR could be cut because the observed power requires a large sample size. The fact that both the nonlinear parameters had opposite trends and such varying degrees of power prompt the author to suggest also exploring them in a full scale study. A homogenous population could aid in decreasing variability and potentially lowering the required sample size for significance.

The clinical utility of these findings should also be determined by examining if some children benefit more from this therapy than other, and whether these results
extend to behavioral changes. OTs could explore the possibility of using posturography data as a standard by which to judge therapy progress or to determine which protocol has a stronger effect for a specific child. The postural variability demonstrated by children with ASD (i.e. not all children demonstrated the same degree of improvement post-therapy) need to be explored to determine if certain subsets of ASD require a different or more intense therapeutic approach.

The meaningfulness of the improvements must also be determined. Studies could address this by conducting posturography tests and coupling the results with those of various behavior or academic test, which would allow a researcher to gauge whether an improvement in sensory processing as denoted by improved posturography extends to decreased undesirable behaviors such as self-harm, social withdraw, and repetitive behaviors.

4.2 Gaze Tracking Results

The data was broken into two sections for this discussion—a section focusing on the results from the fine motor game and those from the gross motor game. It was anticipated that the children with ASD would demonstrate increased socially relevant fixations post-therapy in accordance to the results from studies that suggest some children with ASD demonstrated improved social behaviors after a SI therapy protocol [29, 89-92].
4.2.1 Subject Reach and Coordination: Pretest Results

The pretest results for the children who underwent the gaze tracking protocol were similar to the findings of the posturography protocol. Namely, the Functional Reach scores were very close (approximate within 1.2 inches of each other) and the BOT2 Bilateral Coordination scores were close (approximately a difference of .5 years between groups). This boded well for between group comparisons, as both groups demonstrated similar physiological abilities. Conversely, however, both groups underperformed for their age groups. The average age of the TD child was 7.0 ± 1.83 years, almost a full year older than their BOT2 score. The group with ASD had an average age of 8.75 ± .5 years, which was over 3 years older than their BOT2 score. While the slight performance lag of the TD children cannot be readily explained, the delay demonstrated by the children with ASD is consistent with motor deficiencies reported by this population.

4.2.2 Fine Motor Results

There were no marked trends post-therapy demonstrated by the children with ASD during the fine motor game. One child displayed increased eye contact, one child displayed decreased eye contact, and one remained unchanged. The control subject who did not receive the swing therapy demonstrated increased eye contact, which would not have been expected. The magnitude of these changes were very also small—an increase of occurrence of .00075%, a decrease of .00056%, and 0% respectively.
For the facial fixations, two children demonstrated decreased facial fixations while one remained unchanged. Like the eye contact results, the changes in percentage of occurrence were small in magnitude: the subjects 6 and 7 demonstrated decreases of percentage of occurrence of .00797% and .00074%, and subject 9 remained unchanged. Due to the lack of trends and small magnitudes change, it is not possible to draw a concrete conclusion from the eye tracking data collected during the fine motor game. Although the lack of eye contact form the subjects with ASD could be explained by the fact that they were looking down at the game for much of the time, the TD control all demonstrated much more eye contact for the fine motor task than the children with ASD.

4.2.3 Gross Motor Results

The data collected during the gross motor game demonstrated slight trends, but still seemed somewhat inconclusive, especially considering the small degree of change demonstrated after the swing therapy. Post-therapy, two children with ASD demonstrated increased percent occurrences of eye contact (.00686% and .00389%, respectively) post-therapy, while the other demonstrated decreased percentage occurrences of eye contact by .00074%. The results of the instances of facial gazing was similar. Two subjects experienced an increase in percent occurrence of facial fixations post-therapy of .0059% and .0026%. The other subject displayed a decreased percentage of occurrence of facial fixations of .012%.
Based on the gross motor results, it does appear that two children experienced improved eye contact. It is difficult to establish how the slight trend exhibited by the two subjects in the gross motor game meshes with the lack of gaze trends for the fine motor game, especially because the two subjects who demonstrated the improvements in the gross motor game displayed either a decrease or unchanged number of visual fixations for the fine motor game. One potential cause of this could be the fact that the gross motor game was conducted immediately after the swing therapy, while the fine motor game was conducted after the closer to 10 minutes post-therapy. It is possible that any social effect of the 10 minute vestibular therapy wanes quickly, thus the children only demonstrated an immediate improvement. This improvement, however, was very minimal.

4.2.4 Study Limitations and Suggestion for Future Work

There were several limitations of this study. The first was sample size, but as this study was exploratory in nature the author wanted to ascertain the usefulness of an eye tracker as a tool to measure physiological changes post-therapy before conducting a full scale study. This approach was, to a certain extent, validated by the lack of meaningful results obtained from this protocol. Another limitation was the acute nature of the therapy. A 10 minute therapy might not have enough of an impact to cause a change in something as significant as how a child with ASD perceives others socially. Future studies could explore whether eye contact and facial fixations would change after long-term exposure to SI therapy, as the results of this study do not suggest an acute benefit.
Another limitation was the fact that the children wearing the mobile tracker struggled to refrain from touching the apparatus during testing. This could be alleviated by using a slightly smaller, more child-sized mobile eye tracking unit. Based on the results, the author does not currently recommend using the eye tracker in this application for similar future studies, although it could provide beneficial information when utilized in longitudinal studies.

4.3 Study Conclusions

The results of this study indicate that children with ASD experienced improved postural stability and dynamic postural complexity after undergoing a 10 minute SI therapy. This improvement indicates that a change in sensory processing is occurring as a result of the protocol although the results were not significant. Despite this improvement, the children with ASD were still not as stable or dynamic as their TD peers post-therapy. The eye tracking results did not demonstrate a strong trend and do not appear to be overly useful in this application. It is recommended that a full scale study be conducted to further explore the trends seen in this pilot study and determine whether posturography can be used to explore therapeutic efficacy and identify best evidence based practices.
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APPENDIX A:

Postural Stability Protocol Consent Form

Eye Tracking Protocol Consent Form

Subject Health Checklist
TITLE OF STUDY: A Pilot Study of the Effect of a Swing Therapy on Postural Stability (i.e. Balance) of Children with Autistic Spectrum Disorders

Your child is asked to participate in a research study conducted by Senia Smoot, the principal investigator and a mechanical engineering graduate student at the University of Dayton. Your child’s participation in this study is voluntary and is not related to his or her current sensory integration treatment. Read the information below, and ask questions about anything you do not understand, before deciding whether or not to allow your child to participate.

PURPOSE OF THE STUDY

The point of this study is to evaluate the effect a vestibular (or platform) swing routine has on a child’s postural stability (balance).

PROCEDURES

If you volunteer your child to participate in this study, we would ask you to do the following things:
1. Read, understand (please do not hesitate to ask any questions), and sign the informed consent form.
2. Inform the researcher of the child’s age and previous sensory integration therapy experience.
3. Remain in the lab for the duration of the study (approximately 120 minutes).
4. Allow the researcher to defer to you should your child express any unsuitable behaviors.

If you volunteer your child to participate in this study, we would ask your child to do the following things:
1. Listen to instructions and give verbal consent.
2. Allow researchers to measure and record his or her height and weight.
3. Take a reach test and a coordination test.
4. Stand on a balance plate (or a specialized scale) for 30 seconds under the following conditions: eyes open, eyes closed, eyes open on a foam pad, eyes closed on a foam pad.
5. Participate in a 5 minute platform swing routine (if your child is randomly selected to be a control they will not participate in this swing routine).

The study will go as follows: first, your child will be weighed and measured. He or she will participate in a reach test in which he/she sees how far he/she can lean forward while keeping his/her balance. He or she will then participate in a
coordination test to test his or her motor coordination. The coordination test requires your child to do the following: touch his or her nose with eyes closed, perform jumping jacks, jump in place, perform the “Itsy Bitsy Spider” motion, and tap feet and fingers in sync and out of sync.

Your child’s postural stability (balance) will then be measured by a balance plate, or a specialized scale that records your child’s downward force. Your child will stand on the balance plate for thirty seconds at a time. The researcher will measure your child’s balance under four conditions: eyes open, eyes closed, eyes open on a foam pad, eyes closed on a foam pad. If your child has difficulty keeping his or her eyes shut during the two ‘eyes closed’ balance test, he will have the option of wearing a loose blindfold. This will be repeated then your child will get a three minute break. After the break, your child will repeat the balance test (all data will be collected twice).

After balance has been measured, the researcher will engage your child in a five minute platform swing routine. If your child is randomly selected to be a control they will not participate in this swing routine. The routine will be basic and will include forward/backward motion, side to side motion, using the swing while sitting/standing/lying down, and incorporating pretend games while swinging. After the swing routine, your child will perform two more postural stability (balance) tests. Each test will be repeated twice and there will be a three minute break in between. This will conclude the study.

POTENTIAL RISKS AND DISCOMFORTS

This study is very low risk. The balance plate is approximately 1.5” tall, it is completely stationary, and your child will wear a safety belt while standing on it. Additionally, the researcher will stand next to your child while he or she is on the balance plate. The platform swing is suspended 6”-8” above the ground, its movements will be controlled by the researcher, and a gym mat is placed underneath it.

ANTICIPATED BENEFITS TO PARTICIPANTS

This research has no direct benefits for your child. However, the long term ramifications could potentially increase knowledge of sensory integration therapy treatments thus benefitting a wide range of individuals with ASD.

PAYMENT FOR PARTICIPATION

There is no payment for participation in this study.

IN CASE OF RESEARCH RELATED ADVERSE EFFECTS
This study is not a medical treatment and is not intended to replace or supplement any therapies your child is undertaking. There are no anticipated adverse effects of this study. However, if your child experiences any kind of discomfort as a result of your participation in this study, you may contact Senia Smoot at 304-533-6378 or Dr. Kimberly Bigelow at 937-229-2918.

CONFIDENTIALITY

When the results of the research are published or discussed in conferences, no information will be included that would reveal your child’s identity. Before any photographs are taken for this study, your permission will be obtained. Furthermore, the face and any identifying features of your child will be blurred and/or blacked out. All personal information will be coded. Any data connected to your child will be assigned to a pseudonym such as ‘Subject A.’ Any documents linking your child’s name and code will be destroyed when data collection is complete.

PARTICIPATION AND WITHDRAWAL

Your child’s participation in this research is voluntary. If you or your child chooses not to participate, that will not affect your relationship with the University of Dayton or other services to which you are otherwise entitled. If you and your child decide to participate, you are free to withdraw your consent and discontinue participation at any time without prejudice or penalty. The investigator may withdraw you from participating in this research if circumstances arise which warrant doing so.

IDENTIFICATION OF INVESTIGATORS

If you have any questions about this research, please contact one of the investigators listed below:

Senia Smoot, Principal Investigator, University of Dayton, Mechanical Engineering Department, 304-533-6378, senia.smoot@gmail.com

Dr. Kimberly Bigelow, Faculty Advisor, University of Dayton, Mechanical Engineering Department, 937-229-2918, kbigelow1@udayton.edu

RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your child’s rights as a research participant, you may contact the Chair of the Institutional Review Board (IRB) at the University of Dayton: Dr. Mary Connolly, (937) 229-3493, MConnolly1@udayton.edu.
SIGNATURE OF PARENT or LEGAL GUARDIAN

I have read the information provided above. I have been given an opportunity to ask questions and all of my questions have been answered to my satisfaction. I have been given a copy of this form. I certify that I am at least 18 years of age.

Name of Parent/Legal Guardian (please print)
________________________________________

Address
_____________________________________________________________________

Signature of Legal Guardian
________________________________________Date___________

SIGNATURE OF WITNESS

My signature as witness certifies that the legal guardian of the participant signed this consent form in my presence.

Name of Witness (please print)
____________________________________________________

Signature of Witness
____________________________________________

Date___________

(Must be same as participant signature date)

CONSENT TO USE IMAGES OR RECORDINGS FROM RESEARCH
(Parent or legal guardian)

I consent and give permission for the researcher to use any photographs taken during the course of this research. Your child’s identity will be protected or disguised by the researcher prior to publication or use in presentations of their results. By signing below, I acknowledge that I understand that these images or recordings may compromise the confidentiality of my child’s participation in this research.

Name of Participant (please print)
UNIVERSITY OF DAYTON - CONSENT TO PARTICIPATE IN RESEARCH

TITLE OF STUDY: A Pilot Study of the Effect of a Swing Therapy on Gaze Patterns of Children with Autistic Spectrum Disorders

Your child is asked to participate in a research study conducted by Senia Smoot, the principal investigator and a mechanical engineering graduate student at the University of Dayton. Your child’s participation in this study is voluntary and is not related to his or her current sensory integration treatment. Read the information below, and ask questions about anything you do not understand, before deciding whether or not to allow your child to participate.

PURPOSE OF THE STUDY

The point of this study is to evaluate the effect a vestibular (or platform) swing routine has on a child’s gaze patterns.

PROCEDURES

If you volunteer your child to participate in this study, we would ask you to do the following things:

1. Read, understand (please do not hesitate to ask any questions), and sign the informed consent form.
2. Inform the researcher of your child’s age and previous sensory integration therapy experience
3. Remain in the lab for the duration of the study (approximately 120 minutes)
4. Allow the researcher to defer to you should your child express any unsuitable behaviors

If you volunteer your child to participate in this study, we would ask your child to do the following things:

1. Listen to instructions and give verbal consent
2. Allow researchers to measure and record his or her height and weight
3. Take a reach test and a coordination test
4. Wear an eye tracker unit that consists of a pair of glasses and a lightweight backpack while your child participates in play activities including: play dough, tossing a ball, building blocks, card game, puzzle, coloring, cars, book
5. Participate in a 5 minute platform swing routine (if your child is randomly selected to be a control they will not participate in this swing routine.)

The study will go as follows: first, your child will be weighed and measured. He or she will participate in a reach test in which your child will see how far he or she can lean forward while keeping his or her balance. Your child will then participate in a coordination test to test his or her motor coordination. The coordination test requires your child to do the following: touch his or her nose with eyes closed, perform jumping jacks, jump in place, perform the “Itsy Bitsy Spider” motion, and tap his or her feet and fingers in sync and out of sync.

The next step will be the two gaze tracking trials. A trial consists of your child being fit with the eye tracker backpack and glasses, synchronizing the two cameras with a light flash, calibrating the cameras by having your child look at specific objects, and your child and the researcher engaging in a three minute play activity. After the first play activity, your child will be given a three minute break. Then a second eye tracking trial, identical to the first, will take place. After his or her gaze patterns have been measured twice, the researcher will engage your child in a five minute platform swing routine. If your child is randomly selected to be a control they will not participate in this swing routine. The routine will be basic and include forwards/backwards motion, side to side motion, using the swing while sitting/standing/lying down, and incorporating pretend games. After the swing routine, your child will participate in two more gaze trials with a three minute break in between. This will conclude the study.

**POTENTIAL RISKS AND DISCOMFORTS**

This study is very low risk. As long as your child is comfortable wearing the eye tracker glasses and lightweight backpack and engaging in play with the researcher, there should be no safety issue. The swing procedures will be conducted in a safe and professional manner. The platform swing will only be suspended 6”-8” off the ground, a gym mat will be placed under the swing, and the researcher will control all movements of the swing while your child is on it.

**ANTICIPATED BENEFITS TO PARTICIPANTS**

This research has no direct benefits for your child. However, the long term ramifications could potentially increase knowledge of sensory integration therapy treatments thus benefitting a wide range of individuals with ASD.

**PAYMENT FOR PARTICIPATION**
There is no payment for participation in this study.

**IN CASE OF RESEARCH RELATED ADVERSE EFFECTS**

This study is not a medical treatment and is not intended to replace or supplement any therapies your child is undertaking. There are no anticipated adverse effects of this study. However, if your child experiences any kind of discomfort as a result of your participation in this study, you may contact Senia Smoot at 304-533-6378 or Dr. Kimberly Bigelow at 937-229-2918.

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**SIGNATURE OF PARENT or LEGAL GUARDIAN**

I have read the information provided above. I have been given an opportunity to ask questions and all of my questions have been answered to my satisfaction. I have been given a copy of this form. I **certify that I am at least 18 years of age.**

Name of Parent/Legal Guardian (please print)
________________________________________

Address
_____________________________________________________________________

*Signature of* Parent/Legal Guardian
___________________________________Date___________

**SIGNATURE OF WITNESS**

My signature as witness certifies that the Parent/Legal Guardian of the participant signed this consent form in my presence.

Name of Witness (please print)
____________________________________________________

*Signature of Witness* _______________________________________

Date___________

*(Must be same as participant signature date)*

**CONSENT TO USE IMAGES OR RECORDINGS FROM RESEARCH**

*(Parent or legal guardian)*

I consent and give permission for the researcher to use any photographs taken during the course of this research. My child’s identity will be protected or disguised by the
researcher prior to publication or use in presentations of their results. By signing below, I acknowledge that I understand that these images or recordings may compromise the confidentiality of my child’s participation in this research.

Name of Parent/Legal Guardian (please print)
________________________________________

Address
_____________________________________________________________________

Signature of Parent/Legal Guardian
___________________________________Date___________
Parent/legal guardian’s name:

Child’s name:

Child’s birth date:

Has your child received a diagnosis of autism or Asperger’s disorder from a physician or psychologist? How old was your child when he or she received this diagnosis?

Has your child had any medication changes during the last 6 weeks?

Does your child have any of the following conditions? (Check all that apply)

___ 1. Any diseases, disorders, injuries or other conditions that would prevent him or her from walking at a moderate pace for up to 3 minutes at a time and for a total of 30 minutes

___ 2. Any diseases, disorders, injuries, or other conditions that have caused a physician to restrict or caution against physical activity

___ 3. Any known gait (or walking) disorders, including foot drop

___ 4. Problems walking

___ 5. Any known balance disorders, including inner ear problems, including ear infections

___ 6. Any known neurological disorders, including Multiple Sclerosis, Huntington’s Disease, or Parkinson’s Disease

___ 7. Any known orthopedic disorders such as arthritis
8. Any cardiac (heart) problem that restricts ability to participate in physical activity
9. A history of seizures
10. A history of fainting
11. A history of dizziness within the last year
12. Diagnosed muscles weakness of the legs
13. Vision impairment or blindness
14. Numbness of the feet
15. Any significant surgery within the last 6 months
16. Is your child likely to become upset enough to self-injure or injure others when in a routine therapy setting?

Parent/legal guardian signature: -
-----------------------------------------------
APPENDIX B: MATLAB Code

FFT Program

Down Sample Command

Posturography Program

SampEn Program

Surrogate Analysis Program
%Original Code by Dr. Nick Stergiou’s Lab, modified by Senia Smoot

%%Fourier Transform

close all;clc;clear;

%Get the data from the file and subtract the mean
[filename,path]=uigetfile('*.dat','DAT file');
data=dlmread([path filename]);

%Prompt User to Enter Sampling Frequency
prompt = {'Enter Sampling Frequency'};
dlg_title = 'Enter Sampling Frequency';
num_lines = 1;
def = {'60'};
answer = inputdlg(prompt,dlg_title,num_lines,def);
Fs = str2double(answer{1});

%Set the sampling frequency of the data
% Fs = 240;

%Calculate the FFT
T = 1/Fs;
L = length(data);
t = (0:L-1)*T;
NFFT = 2^nextpow2(L);
Spect = fft(data,NFFT)/L;
f = Fs/2*linspace(0,1,NFFT/2+1);
data2=2*abs(Spect(1:NFFT/2+1));

% Plot Power Spectrum
bar(f,data2)
axis([0 20 0 (max(abs(data2)))]
title('PowerSpectra using fft function')
xlabel('Frequency (Hz)')
ylabel('Power')
Down Sample Command

%Original Code by Dr. Nick Stergiou, modified by Senia Smoot
%Matr = data set
%specify a downsampling rate, m
m = 10;
%Downsample the data
Matr = downsample(Matr,m);
Posturography Program

%Postural stability data analysis

clc; close all; clear all;

%read the data from the file
fid = fopen('PosturalSwayData.txt');
Matr = fscanf(fid, '%f', [6,inf]);
%transpose it to get it in the correct format
Matr = transpose(Matr);
%specify a downsampling rate, m
m = 10;
%Downsample the data
Matr = downsample(Matr,m);
%Assign column names
t = Matr(:,1);
Fz = Matr(:,2);
Mx = Matr(:,3);
My = Matr(:,4);
COPx = Matr(:,5)*1000;
COPy = Matr(:,6)*1000;

%calculate N
n= length(t);

% Shifts graph to 0
x_bar = mean (COPx);
y_bar = mean(COPy);

for ii = 1: length(COPx)
    y_n(ii) = COPy(ii) - y_bar;
    x_n(ii) = COPx(ii) - x_bar;
end
%apply 4th order low-pass Butterworth Filter
Fs = 1/mean(diff(t));
Fcutoff = 5;
fnorm = Fcutoff/(Fs/2);
[b,a] = butter(4,fnorm);
y_nF = filtfilt(b,a,y_n);
x_nF = filtfilt(b,a,x_n);

T = (max(t)-min(t));

% A/P Sway Range (mm)
AP_Sway = abs(max(y_nF) - min(y_nF))

% M/L Sway Range (mm)
ML_Sway = abs(max(x_nF) - min(x_nF))

Mean_Vel_loop = 0;
for ii = 1:n-1
    Mean_Vel_loop = (Mean_Vel_loop + sqrt((x_nF(ii+1)-...
    x_nF(ii))^2+(y_nF(ii+1)-y_nF(ii))^2));
end

Mean_Vel = Mean_Vel_loop/T;

%RMS (mm)
RMS = sqrt((sum(y_n.^2+x_n.^2))/n);

%Confidence Ellipse
sig_x = sqrt((sum(x_n.^2))/n);
sig_y = sqrt((sum(y_n.^2))/n);
sig_xy = (sum(x_n.*y_n))/n;
CoVa = [sig_x.^2 sig_xy; sig_xy sig_y.^2];
[EigV,Eig] = eig(CoVa);
a = 1.96*sqrt(Eig(1,1));
b = 1.96*sqrt(Eig(2,2));
Confidence_Interval = a*b*pi;

x1 = EigV(1,1);
x2 = EigV(2,1);

% Angular deviation from AP Sway (deg)
\[
\theta_{dev} = \text{acosd}(x_1/\sqrt{x_1^2 + x_2^2}) - 180;
\]

% Mean Frequency (Hz)
MF = Mean_Vel/(2*pi*sum(sqrt(x_nF.^2+y_nF.^2))/n);

% M/L Mean Velocity (mm/s)
ML_MV = sum(abs(diff(x_nF)))/T

% AP Mean Velocity (mm/s)
AP_MV = sum(abs(diff(y_nF)))/T

SampEn Program sampen_Batch with subFunctions sampenc_1 and sampleentropy

%Original Code by Dr. Nick Stergiou, modified by Senia Smoot
%sampenc_1
function e = sampenc_1(y,M,r);
sampenc_1(y,M,r);
%Input
% y input data
%M maximum template length
% r matching tolerance
%Output
% e sample entropy at M
n=length(y);
lastrun=zeros(1,n);
run=zeros(1,n);
A=zeros(M,1);
B=zeros(M,1);
p=zeros(M,1);
e=zeros(M,1);
for i=1:(n-1)
j=n-i;
y1=y(i);
for jj=1:nj
j=jj+i;
if abs(y(j)-y1)<r
run(jj)=lastrun(jj)+1;
M1=min(M,run(jj));
for m=1:M1
A(m)=A(m)+1;
if j<n
B(m)=B(m)+1;
end
end
else
run(jj)=0;
end
end
for j=1:nj
lastrun(j)=run(j);
end
end
N=n*(n-1)/2;
B=[N;B(1:(M-1))];
p=A./B;
e=-log(p);
e= e(M);

% sample entropy
function output = sampentropy(data, m, r)
r = .2*std(data);
output = sampenc_1(data,m,r);

% sampen_Batch
% To compute Sampen
clear all
clc
close all
warning off

% if you need to change any parameters do so right here (M,r):
m = 2;
r = 0.2;

directory_name=uigetdir(pwd,'Select data directory');
directory_name=(
directory_name '
');
addpath(directory_name)
files=dir([directory_name,'*dat']);
if isempty(files)
    msgbox('No raw files in this directory')
end

FileName=[];
for i=1:length(files)
    filename=files(i).name;
    data=load(filename);
    filename=filename(1:end-4);
    FileName=[FileName; cellstr(filename)];
    Sampen_value(i)=sampentropyp(data, m, r);
    figure
    plot(data, 'r.'
    hold on
    plot(data)
    hold off
    title(num2str(filename(1:end)))
end

output=[Sampen_value' ;
header={'Filename' 'Sampen'} ;
range=['A2:A',num2str(length(files)+1)];
xlswrite('SampenOutput',header,'A1:B1')
xlswrite('SampenOutput',FileName,range)
range2=['B2:B',num2str(length(files)+1)];
xlswrite('SampenOutput',output,range2)
Surrogate Analysis Program

%Original Code by Dr. Nick Stergiou, modified by Senia Smoot
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Program for producing Phase randomized surrogate time series.
%The following will run the program >>surrogate11
%Your data and surrogate11.m need to be in the same directory
%Your input file should be of the following format:
% (i.e. in my Subject 1 folder, my file is laid out like: T1_OPENflat_COPy,
% a file name that stand for trial 1, under the eyes open/flat plate condition, and the
% COPy data)
%This program will return/create an output file s1c1t1_theiler.dat which is a phase
%randomized surrogate.
%Compute the ApEn value for the original and surrogated time series.
%If they are statistically different then you have a chaotic time series.
%Last edited: MJK 12/15/03
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

directory_name=uigetdir(pwd,'Select subject folder');
directory_name=[directory_name '\'];
files=dir([directory_name '*.dat']);

for i_files=1:length(files)
    filename=files(i_files).name;
s=load([directory_name,filename]);

    for sub=1:19;
        outputfile=([filename(1:end-4), '_',num2str(sub),'_theiler', '.dat']);
        
    end

end
N=length(s);
im=sqrt(-1);
twopi=2*pi;
half=fix((N+1.1)/2);

%Sort the original series.
%Randomize phases of the series s.
z=fft(s);
for i=2:half;
    r=rand*twopi;
    z(i)=z(i)*(cos(r)+im*sin(r));
end
for i=2:half
    z(N+2-i)=conj(z(i));
end
zz=ifft(z);
xx=real(zz);
save (outputfile, 'xx', '-ascii');
end;
end;