2020-01-01

Sensory Integration And Its Role In Behavioral Plasticity In Children Diagnosed With Autism Spectrum Disorder

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SENSORY INTEGRATION AND ITS ROLE IN BEHAVIORAL PLASTICITY IN CHILDREN DIAGNOSED WITH AUTISM SPECTRUM DISORDER

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by

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Kinesiology

THE UNIVERSITY OF TEXAS AT EL PASO

May 2020

ACKNOWLEDGEMENTS

The following work would not have been possible without the support and patience of my mentor Dr. Jason B. Boyle, Dr. Harry Meeuwsen, and Dr. Rhonda Manning. Thank you for giving me this opportunity to work with and learn from this special population. I appreciate the respect given to the work, to the population, and to me. The first step to being capable of achieving something is having someone else believe you're capable.

Thank you to the Graduate School of The University of Texas at El Paso for supporting this project with the Dodson Research Grant.

ABSTRACT

Although commonly characterized by communicative and social impairments, Autism Spectrum Disorder (ASD) presents a number of developmental deficits related to movement planning and action. The extent of these deficits to the entire neuromuscular system, as well as the individual input/output loops are still not well understood. Given the dynamic interplay between our plans, actions and outcomes lay the foundation for later mature motor behavior, it is critical to understand the unique motor learning processes these nervous systems face while a higher level of training plasticity may be present. A recent study examined the kinematics (acceleration, velocity, smoothness, etc.) of upper extremity target movements in high functioning children with ASD compared to age matched neurotypical (NT) peers (Gamez et al., 2020). Although significantly different from their NT peers in the initial pre-test assessment, the study found that the children with ASD were capable of significantly enhancing the kinematic profile of their movement on the target task (post-test) after a brief training paradigm of reciprocal sine wave tracking. Although interesting, the sensory specifics of the training should be considered given the population. The purpose of this study was to further the understanding of this unique motor system, as well as provide insight in to future therapeutic directions by isolating sensory inputs of vision and proprioception with the original sine wave design. The results showed that measures of movement time (MT) were significantly faster after training in the Sine Wave condition compared to their pretest measures, suggesting that the sine wave effect was replicated. Following lifted restrictions of COVID-19, this study will continue to investigate the importance of visual and proprioceptive sensory input in children with ASD.

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CHAPTER 1 INTRODUCTION

1.1 Autism Spectrum Disorder (ASD)

Autism Spectrum Disorder (ASD) refers to a diagnosis of a widespread range of conditions commonly characterized by social skill impairments, repetitive behaviors, and sensory issues (American Psychiatric Association, 2013). It wasn't until 2013, the American Psychiatric Association used ASD as an umbrella term to describe four subtype diagnoses: autism disorder, childhood disintegrative disorder, pervasive developmental disorder-not otherwise specified (PDD-NOS), and Asperger syndrome (American Psychiatric Association, 2013). These neurodevelopmental disorders are often characterized by challenges in communication, social deficits, repetitive behaviors, interests and activities, speech and nonverbal communication delays, and cognitive inflexibility (American Academy of Pediatrics, 2001; American Psychiatric Association, 2018; Brambilla et al., 2003; & Schaafsma & Pfaff, 2014). Depending on the severity, which is based on impairments in social communication and restricted, repetitive behavior, the symptoms may be noticeable as early as the first few months after birth and ASD may be diagnosed as early as the first two years of life (American Psychiatric Association, 2013; Itzchak, Lahat, & Zachor, 2011; Landrigan, 2010).

According to research within the past 70 years, no known specific cause for ASD has been determined; however there are theories which justify its development. A controversial theory has been the proposed link between vaccines and Autism; however, there is no concrete evidence that suggests an association (Landrigan, 2010; Lundy-Ekman, 2013). Most accepted theories of association refer to genetics, environmental factors, or a combination of both; and developmental abnormalities of brain structure and function, environmental factors such as parental ages and child's birth weight (Brambilla et al., 2003; Itzchak, Lahat, & Zachor, 2011). The brain structure differences include reduced communication between cerebral areas, a larger amygdala during childhood, and an abnormal shape of the caudate and putamen (Dawson & Murias, 2009). The motor, social, and communication impairments correlate with the unusual shapes of the caudate and putamen (Qui et al., 2010).

1.2 Prevalence and Costs

With an estimation of 1 in 54 children diagnosed, ASD is currently one of the most prevalent neurodevelopmental disorders, with increasing rates every year (American Academy of Pediatrics, 2001; Baio et al., 2018; Maenner, 2020). A survey conducted by the National Survey of Children's Health (NSCH) in 2016, revealed that the parent-reported prevalence of ASD was 1 in 40 children (Kogan et al., 2018). The United States prevalence in 2016 estimated 1 in 68 children diagnosed with ASD (Christensen, 2016). These rapid increases suggest there is either: 1. an underestimation of the real prevalence of the population, or 2. the ASD population will continue to rapidly increase. Exceeding the cost of stroke and hypertension, the annual economic burden (direct medical, direct non-medical, and productivity costs) of ASD was estimated to be $268 billion in 2015 (Leigh & Du, 2015). As this estimate was similar to the recent estimates for diabetes and attention deficit and hyperactivity disorder (ADHD), ASD costs are expected to exceed diabetes and ADHD by 2025, if the prevalence of ASD continues to increase (Leigh & Du, 2015).

CHAPTER 2 ASD MOTOR CONTROL

2.1 Motor Deficits

Although ASD has been commonly characterized by repetitive behaviors and impairments in social and communicative interactions, recent work has shown distinct motor impairments across the autism spectrum (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Provost, Lopez, & Heimerl, 2007; Sacrey et al., 2014). These motor deficits can be seen not only in reaching and grasping, but also in the kinematic composition of the actual movement, such as: decreased velocity, decreased accuracy, irregular smoothness, etc. Children diagnosed with ASD show signs of motor development delays, and motor deficits, either gross, fine, or both (Provost, Lopez, & Heimerl, 2007). Since motor differences can be seen within the first two years of age, it has been suggested that motor delays occur before social and communicative delays (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010).

Gross motor impairments are often found within Asperger Syndrome and high-functioning Autism (Dawson & Watling, 2000). Children with ASD show motor deficits in gait and balance (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010). More gross motor impairments have been found when using an evaluation relying on postural control and mobility (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010).

2.2 Movement Structure

Investigating whether motor deficits exhibited in children with ASD were due to motor planning dysfunction (Glazebrook, Elliott, & Lyons, 2006) or motor control deficits (Mari, Castiello, Marks, Marraffa, & Prior, 2003), a study conducted by Forti et al. (2011) concluded that ASD children show impairments in control processing and/or are only capable of planning the first phase of a moment but may not contain the full capacity to execute the secondary phase of a movement due to the presence of additional sub-movements. The children with ASD in this study showed higher velocities in the secondary phase and an increase in sub-corrective movements, compared to normally developing children. However, there were no differences between the two groups in accuracy, which shows children with ASD may trade time for accuracy. This tradeoff was also seen in a study conducted by Glazebrook, Elliott, & Lyons (2006), where rapid aiming movements, at different levels of task difficulty (ID), were performed by typically developing young adults and young adults with ASD. Participants with ASD showed slower preparation and execution of movements, with greater spatial and temporal variability, in the initial phase of the movement, compared to the control group. It was suggested that there is a compensation for initial impulses to minimize spatial variability occurring in the online movement control phase.

A study by Papadopoulos et al. (2012) examined the kinematic movement profiles of children with High Functioning Autism (HFA) and Asperger's Disorder (AD) and compared them to typically developing (TD) controls. Using a reciprocal Fitts' aiming task, there were four levels of task difficulties (ID), manipulated by varying target size and distances between targets. Movement time, constant error, and variable error were measured. The results showed that children with HFA produce greater constant and variable error in reciprocal aiming tasks, compared to TD children, similar to the findings of Forti et al. (2011). The findings also showed that differences in neuromotor profiles exist between HFA and AD children. There were no differences in movement time when comparing the children with ASD and TD children. Because of increased dispersed movements at the end point of the task, the authors suggested the ASD children have an incomplete movement plan, which may be due to feed-forward control impairments (Bastian, 2016).

When it comes to executing movements, children with ASD have shown impairments in online motor control, and they do not use a feed-forward mode of control, thus relying heavily on proprioceptive feedback (Schmitz, Martineau, Barthelemy & Assaiante, 2003). Furthermore, other studies have shown impairments in offline processes, which does not allow the child to use the visual feedback of a previous movement to improve the motor plan of a future movement (David et al., 2009; David et al., 2012). These impairments may occur when time-delayed feedback signals are greatly relied on (Bastian, 2006). The lack of ability to utilize visual feedback in both online and offline processes may result in the greater reliance on proprioceptive feedback when executing a movement; these deficits may also be the result of cerebellar dysfunction.

CHAPTER 3 ASD MOTOR LEARNING

3.1 Fitts' Law

In early studies regarding goal directed movement, Woodworth (1899) studied the accuracy of voluntary movement, where he found a speed-accuracy trade off. While having participants draw a horizontal line between two fixed targets, accuracy and consistency were examined between levels of difficulty; spatial and temporal characteristics were also measured. It was concluded that goal-directed movements were composed of two phases to reach accuracy: an initial impulse, which is preprogrammed, and a feedback-based corrective phase. The speed-accuracy trade-off is due to the decreased amount of time there is to make corrective adjustments in the feedback-based phase. It is in the second phase where the participant processes sensory information, which allows the participant to make adjustments as needed, based on the visual and proprioceptive feedback. Woodworth's findings were not implemented until the 1950's and are still influential now as much as it was then.

Following Woodworth's research, Fitts (1954) studied how task difficulty affected the execution of rapid, goal-directed arm movements using a reciprocal aiming task. He found increases in distance (D) and/or decreases in target width (W) resulted in a greater average movement time (MT); accuracy depends on target width and the distance between the targets due to increased attention demands. Fitts theorized a calculation as a linear function for an index of difficulty (ID) by the equation $ID=\log_2(2D/W)$, where D is the distance between the centers of the two targets and W is the width of the target areas. ID represents the minimum amount of information required to successfully and accurately produce a movement at the desired level of precision between two targets. In addition to the index of difficulty equation, movement time can be found by the equation MT = a + b (ID), where MT represents the time it takes to complete the movement.

Compared to low ID movements, high ID movements tend to result in higher MT, due to the greater time it takes to process feedback and formulate corrections (Boyle, Kennedy, & Shea, 2012). Furthermore, if the rate at which information is processed is constant, an increase in MT is needed to make up for increases in amplitude and/or decreases in target width. This is due to the correlation between MT and the bits of information to be processed, whereas MT increases more bits of information are needed to process (Boyle, Kennedy, & Shea, 2012).

Goal directed movements consist of an initial (pre-planned) and secondary phase (online), which operate under different cognitive processing (Meyer, Abrams, Kornblum, Wright, & Keith Smith, 1988). In the secondary phase, Meyer and colleagues (1988) found that visual and proprioceptive feedback control the execution of the movement. As difficulty increases, the increase in kinematic variables (total time, primary-submovement durations, standard deviation of primary-submovement endpoints, relative frequencies of secondary submovements, mean secondary submovement durations, and error rates) suggest this is the result of noise in the neuromotor system (Meyer et al., 1988).

In discrete tasks, participants aim for a single target, where in serial tasks participants aim between two targets repetitively. Movement time in a serial task is typically measured as the total time between two targets; dwell time measures the time spent reversing direction to the next target. When looking at dwell times in reciprocal tasks, Adam and Paas (1996) found an inverse relationship between movement time and dwell time. Whether reciprocal (Adam & Paas, 1996) or discrete, goal directed movements of the limbs typically show a speed-accuracy trade-off as difficulty increases (Fitts, 1954; Fitts & Peterson, 1964; Woodworth, 1899).

Recent studies have shown similar results as Woodworth's two-compartment model of limb control, where the initial movement phase is preprogrammed dependent on motor planning processes (Beggs & Howard, 1970; Carlton, 1981). In a speed and accuracy experiment, Beggs & Howart (1970) interrupted the visual feedback loop, which proved the initial movement phases to be an online movement. The results from a study conducted by Carlton (1981) demonstrated lower error rates in a vision sample compared to no vision, suggesting that the secondary phase relies on visual feedback.

3.2 Sine Wave Tracking

Although a speed-accuracy tradeoff (Fitts) has been well established, Boyle and colleagues (2013) found that a Sine wave training protocol resulted in not only a faster movement time, but a more harmonic movement pattern. While flexing and extending their right arm in the horizontal plane, participants' performance on a post-test Fitts target task improved. Smooth movement patterns were observed at no cost of a faster movement time. However, in another study conducted by Boyle and colleagues (2012), 20 days of practicing Fitts protocols using different IDs resulted in reduced endpoint variability, but no improvements in MT with practice. It was hypothesized that the insignificant improvements in MT may be due to a great deal of previous experience in wrist and arm movements in daily living; improvements in performance would be greater in earlier practice compared to mid to late practice (Boyle, Kennedy, & Shea, 2012). Tracing a novel sine wave template has shown to enhance aiming performance, even at high IDs (Boyle et al., 2012, 2014, 2015).

In a recent experiment, Gamez et al. (2020) examined behavioral plasticity of upper extremity coordination in children diagnosed with high functioning ASD. Children with ASD completed an upper extremity Fitts target task, where total time, dwell time, movement time, and percent time to peak velocity were measured. After a brief training protocol of tracking a harmonic template of a Sine wave, the children with ASD significantly improved their motor ability, compared to continuing the Fitts target task.

3.3 Sensory Integration and ASD

When learning a new motor skill, it has been found that individuals with ASD rely on visual and proprioceptive feedback (Glazebrook et al., 2009); however, in 2016 a study found that individuals with ASD rely less on visual feedback when learning a motor sequence compared to healthy controls (Sharer et al.). No differences in the reliance on proprioceptive feedback between participants with ASD and healthy controls were found (Fuentes et al., 2011; Sharer et al., 2016). In contrast, a study conducted by Izawa and colleagues (2012) found that participants with ASD relied more on proprioception compared to typically developed children, with no differences in vision between the groups. There may be under-responsiveness and over-responsiveness to different sensory inputs in children within the Autism spectrum (Bhat et al., 2011). Understanding a child's preferred sensory feedback will help clinicians teach or enhance new motor skills to children with ASD. For example, if a child relies more on visual feedback, a clinician can use a visual model of the steps involved in learning a task, compared to physically guiding the child through the action sequence (Bhat et al., 2011).

CHAPTER4 PURPOSE OF STUDY

The purpose of the following study was twofold. First, it was designed to replicate a study by Gamez et al., (2020) which included sine wave tracing and Fitts tasks in 12 children with ASD. Second, the study aimed to further the sine wave effect in children with ASD by investigating if training in isolated sensory inputs results in any learning differences of therapeutic value. Specifically, it was aimed to identify whether training in isolated sensory inputs of proprioception or vision would show enhancements in performance similar to the ones seen in the original sine wave training (Boyle et al., 2012, 2015; Gamez et al., 2020).

CHAPTER 5 METHODS

5.1 Participants

Children between the ages of 6-12 years were recruited from the local El Paso community. The population was made up of 7 high-functioning children diagnosed with ASD and 4 neurotypical children (NT). Recruitment was conducted through social media, targeted at individuals who participated in ASD groups on Facebook, by Dr. Rhonda Manning, a physical therapist in the El Paso community with over 13 years of specialization with this population.

The clinical site for the experiment was The University of Texas at El Paso (UTEP) Virtual Reality and Motor Control lab, under the direction of Dr. Jason Boyle. The procedure took at most 1.5 hours of a single session in the lab, and guardians of the children were asked to stay present at all times. Because of the children's age, guardians were responsible for reading and signing the informed consent. Participants were encouraged to visit the lab prior their testing session, in order to become familiar with the facility. If at any time the guardian or participant wanted to leave, they were advised that they were free to do so at no penalty to them.

5.2 Apparatus

A custom-built arm bar system was used to collect kinematic data of upper limb aiming movements (Figure 1-left). The system was fastened to a table with adjustable tracks to position the arms in a comfortable position matching the participant's limb structure. The arms were constructed from aluminum, cushioned with foam padding and wrapped with a soft cloth material for comfort of the participants. A soft ergonomically designed grip was fastened at the end of the bars. The arms moved freely in the horizontal plane and were positioned with safety rods to prevent the arm bar from moving too close or far away from the participant. A height adjustable chair was also used to allow the participant an optimal posture for the execution of the arm movements.

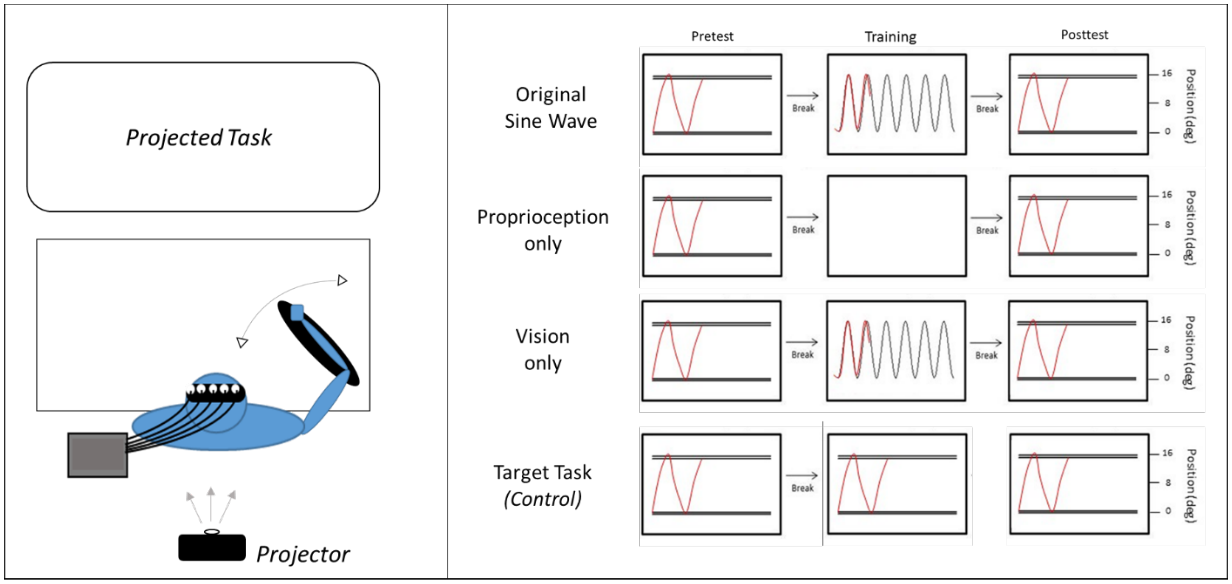

Figure1. Visual depiction of Fitts and Sine wave tasks.

5.3 Procedure

Participants, based upon their initial classification (ASD, NT), were randomly assigned to a training protocol (Vision, Proprioception, Original Sine Wave, Fitts Target Task). Before beginning, all participants first observed a lab member demonstrate an example of the target task requirements. Following the example, the participants were seated at the table with their arms comfortably resting on the levers. Participants were instructed to flex and extend the right lever in the horizontal plane in order to move a cursor in and out of two clearly defined target areas (Figure 1). The participants were instructed to complete this task as quickly and accurately as they could. A single trial lasted approximately 10 seconds and the participants completed a total of 15 trials. The last 5 of the 15 trials were analyzed as the baseline movement production and labeled as Pretest.

In the Visual condition, children were seated with their right arm positioned comfortably on the lever with no movement. A board was placed on the table to occlude vision of the limbs. The children were instructed to pay attention to the video projected on the screen in front of them. A visual depiction of the sine wave template being actively traced by a red cursor at 100%

accuracy was presented to the children. Each trial lasted approximately 12 seconds and a total of 30 trials were observed. In the proprioception condition, children were seated with their right arm placed on the lever. A board was placed on the table to occlude vision of the limbs, and no template of a visual task was provided. Following the same path with 100% accuracy, the right lever was actively moved through the 16 degree motion of tracing the sine wave automatically. Unlike passive assistance, in the 30 trials of proprioception, the children were encouraged to actively flex and extend with the lever instead of passively being moved. In the control conditions, participants replicated the original sine wave experiment.

Following the training conditions, participants completed 15 additional trials at the Fitts task again (Posttest). Although the experiment was completed within 45 minutes by most participants, a 2-hour time window was set to ensure the participants were as comfortable as possible during the session.

5.4 Measures and Data Analysis

The kinematic data were measured with a three-point central difference algorithm to calculate velocity of the limb. Dependent measures were analyzed on a half-cycle basis. Peak velocity (PKVEL) and time of peak velocity (TPV) were determined during each half-cycle of limb movement (i.e. limb extension vs limb flexion). The onset of movement was determined by tracing backward from TPV to a value 2.5 % of that half-cycle PV. Movement offset was calculated by tracing forward from TPV to a value 2.5 % PV. For each half-cycle, there was a single movement onset *(Figure 2- Green dot*), peak velocity *(Figure 2- Red dot*), and movement offset (*Figure 2- Blue dot*). Total time of movement (TT) was calculated as the difference of the summation of movement onset plus one and movement onset. Movement time (MT) was calculated as the difference of movement offset and movement onset. Dwell time in the target at movement reversal (DT) was calculated as the difference of movement onset plus one and movement offset. Percent time-to-peak velocity (%TPV) was calculated by the ratio of the difference of TPV and movement and the difference of movement offset and movement onset multiplied by 100.

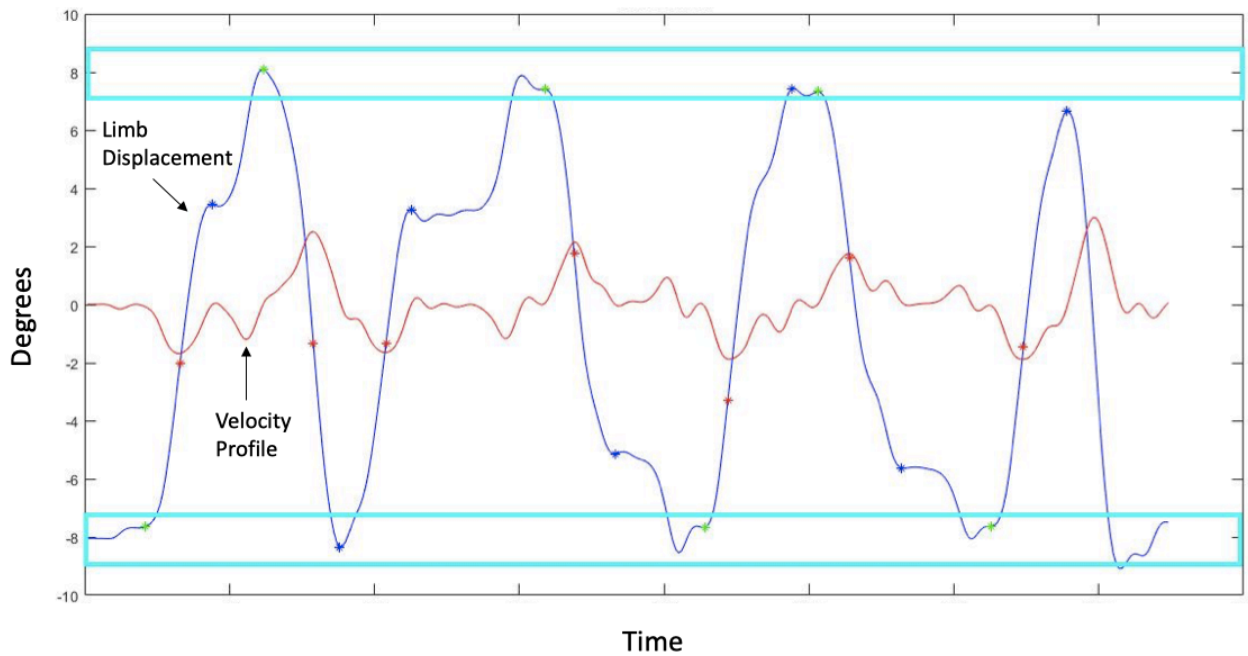

Figure 2. Kinematic Measures

Dependent test variables of MT, TT, DT, PKVEL, and %TPV were analyzed in separate Condition (Fitts, Sine Wave, Proprioception, Vision) × Group (ASD, NT) × Test (Test 1, Test 2) linear mixed model analyses of variance (ANOVAs) with repeated measure on Test. Simple main effects analyses were utilized when appropriate as post hoc procedures to follow-up on significant interactions. Isolated by Group (ASD or NT), dependent test variables of MT, TT, DT, PKVEL and %TPV were analyzed in separate Condition (Fitts, Sine Wave, Proprioception, Vision) × Test (Test 1, Test 2) analyses of variance (ANOVAs) with repeated measure on Test. Paired sample t-tests were run to investigate ASD Test differences. Finally, single subject differences from Test 1 to Test 2 were examined using the Model Statistical procedure (Barry, 1996). An $\alpha = .05$ was used for all tests.

CHAPTER 6 PRACTICAL RELEVANCE

Through simple tasks such as the one presented, it was the investigators hope that future adaptations to the protocol are developed and implemented unique to this population and ultimately improve quality of life. Ultimately the goal was to narrow down the specific movement construction issues, isolate sensory systems in the development of motor programs, and further the understanding of the neural-behavior processes of children with ASD.

CHAPTER 7 RESULTS

7.1 Linear Mixed Model ANOVA (All participants)

7.1.1 Total Time (TT)

The analysis indicated a within subjects effect for TT, $F(1,3) = 11.096$, $p = .045$, $\eta 2p = .787$, with consistently faster TTs on Test 2 (1051.5 ms) compared to Test 1 (1261.81 ms). The analysis failed to detect any TT x Group ($p = .678$), TT x Condition ($p=.402$) or TT x Condition x Group interactions ($p = .615$). The analysis also failed to detect any between subjects effects for Condition ($p=.923$), Group ($p=.586$) or Condition x Group interactions ($p=.917$).

7.1.2 Movement Time (MT)

The analysis indicated no significant within subjects effect for MT ($p = .568$), MT x Group ($p = .246$), MT x Condition ($p=.514$) or MT x Condition x Group interactions ($p = .780$). The analysis also failed to detect any between subjects effects for Condition ($p=.844$), Group ($p=.925$) or Condition x Group interactions ($p=.830$).

7.1.3 Dwell Time (DT)

The analysis indicated no significant within subjects effect for DT ($p = .057$), DT x Group ($p = .639$), DT x Condition ($p=.581$) or DT x Condition x Group interactions ($p = .585$). The analysis also failed to detect any between subjects effects for Condition ($p=.907$), Group ($p=.414$) or Condition x Group interactions ($p=.895$).

7.1.4 Peak Velocity (PV)

The analysis indicated no significant within subjects effect for PV ($p = .712$), PV x Group ($p = .554$), PV x Condition ($p=.908$) or PV x Condition x Group interactions ($p = .954$). The analysis also failed to detect any between subjects effects for Condition ($p=.912$), Group ($p=.224$) or Condition x Group interactions ($p=.765$).

7.1.5 Percent Time to Peak Velocity (%TPV)

The analysis indicated no significant within subjects effect for %TPV (p = .478), %TPV x Group (p = .553), %TPV x Condition (p=.497) or %TPV x Condition x Group interactions (p = .205). The analysis also failed to detect any between subjects effects for Condition (p=.965), Group (p=.543) or Condition x Group interactions (p=.937).

7.2 Repeated Measures ANOVA (Only ASD)

7.2.1 Total Time (TT)

The analysis indicated no significant within subjects effect for TT (p = .103) or TT x Condition interaction (p=.265). The analysis also failed to detect a between subjects effect for Condition (p=.814).

7.2.2 Movement Time (MT)

The analysis indicated no significant within subjects effect for MT (p = .565) or MT x Condition interaction (p=.394). The analysis also failed to detect a between subjects effect for Condition (p=.197).

7.2.3 Dwell Time (DT)

Although trending towards significance, the analysis indicated no significant within subjects effect for DT (p = .055) or DT x Condition interaction (p=.442). The analysis also failed to detect a between subjects effect for Condition (p=.717).

7.2.4 Peak Velocity (PV)

The analysis indicated no significant within subjects effect for PV (p = .848) or PV x Condition interaction (p=.906). The analysis also failed to detect a between subjects effect for Condition (p=.604).

7.2.5 Percent Time to Peak Velocity (%TPV)

The analysis indicated no significant within subjects effect for %TPV ($p = .916$) or %TPV x Condition interaction ($p=.431$). The analysis also failed to detect a between subjects effect for Condition ($p=.845$).

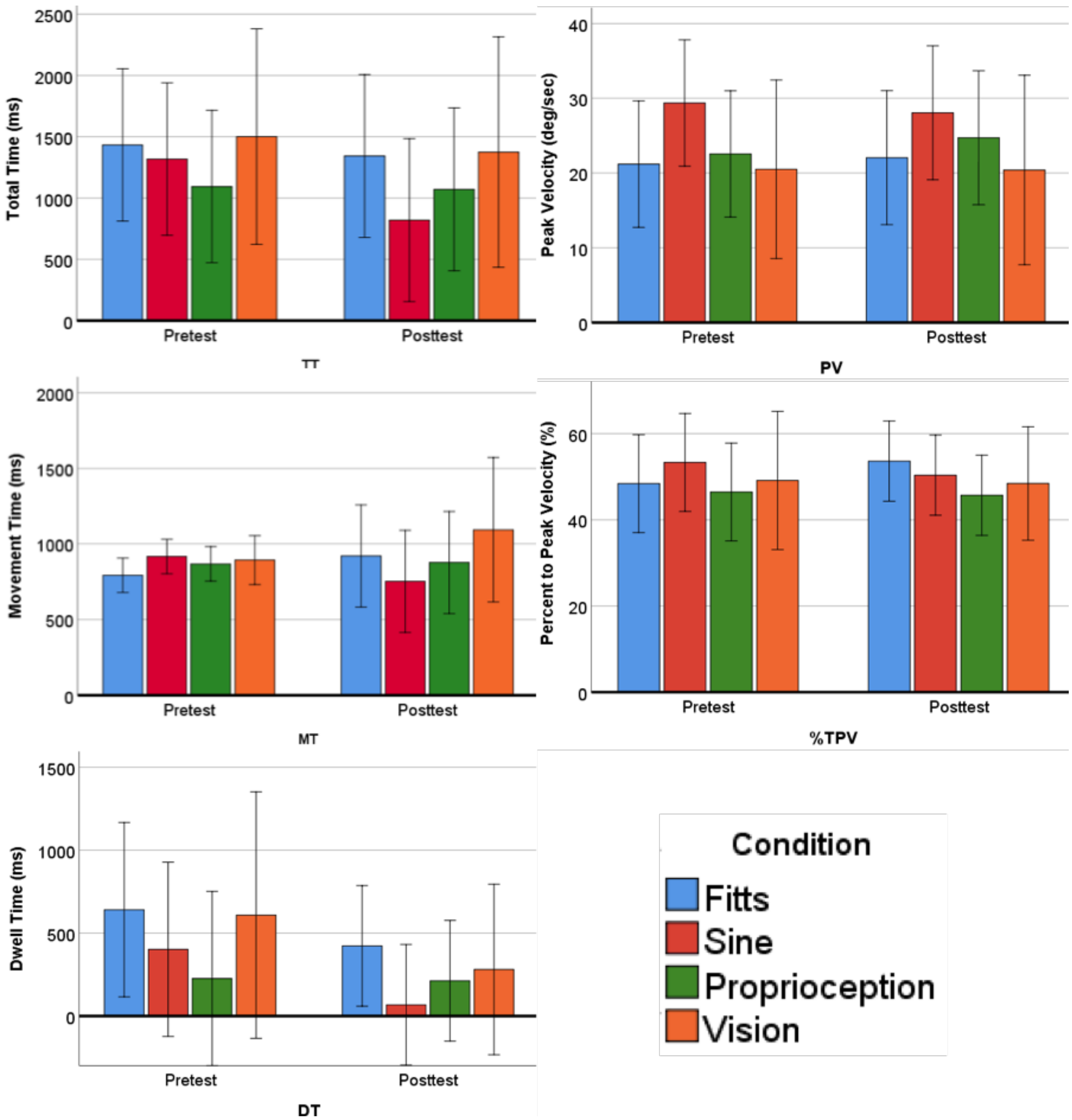

Figure 3. Repeated Mixed ANOVA (ASD)

7.3 Paired Sample T-Tests (ASD: Conditions)

*Vision condition not included due to n=1

Table 1. Paired Sample T-Tests (ASD: Conditions)

Fitts	**Mean**	**Std. Dev**	**Std. Err**	**95% CI**	**t**	**df**	**Sig.**
TT1-TT2	-127.4	78.74	55.68	-834.9 – 580.01	-2.2	1	.262
MT1-MT2	90.6	137.7	97.3	-1146.4 – 1327.8	.931	1	.523
DT1-DT2	218.1	216.4	153.05	-1726.5 – 2162.9	1.42	1	.389
PV1-PV2	-.86	2.02	1.43	-19.03 – 17.3	-.605	1	.654
%TPV1-%TPV2	-5.2	3.9	2.82	-41.09 – 30.65	-1.84	1	.316
Sine	**Mean**	**Std. Dev**	**Std. Err**	**95% CI**	**t**	**df**	**Sig.**
TT1-TT2	163.47	164.26	116.15	-1312.4 – 1639.35	1.407	1	.393
*MT1-MT2	498.42	43.7	30.9	105.72 – 891.12	16.12	1	.039
DT1-DT2	334.95	207.9	147.05	-1533.61 – 2203.51	2.27	1	.263
PV1-PV2	1.31	2.26	1.6	-19.02 – 21.64	.820	1	.563
%TPV1-%TPV2	2.96	6.03	4.24	-50.98 – 56.91	.699	1	.612
Proprioception	**Mean**	**Std. Dev**	**Std. Err**	**95% CI**	**t**	**df**	**Sig.**
TT1-TT2	-8.89	234.53	165.84	-2116.09 – 2098.30	-.054	1	.966
MT1-MT2	22.8	317.71	224.66	-2831.79 – 2877.39	.101	1	.936
DT1-DT2	13.77	108.57	76.77	-961.71 – 989.26	.179	1	.887
PV1-PV2	-2.16	7.94	5.61	-73.51 – 69.18	-.385	1	.766
%TPV1-%TPV2	.757	2.57	1.82	-22.41 – 23.93	.415	1	.750

The analysis indicated only a single significant finding in dependent measure MT, with the Sine trained participants in Test 1 (915.93ms) moving faster in Test 2 (752.46ms). All other comparisons failed significance.

7.4 Single Subject Model Statistics Procedure (ASD)

Table 2: Single Subject TT (ASD)

Total Time (TT)								
Participant	**Cond**	**M1**	**SD1**	**SE1**	**M2**	**SD2**	**SE2**	**Sig**
1	Fitt	964.29	353.93	158.28	970.97	231.58	103.57	p >.05
2	Fitt	1902.72	224.73	100.50	1714.66	579.10	258.98	p >.05
*1	Sine	1131.27	246.34	110.16	663.75	69.86	31.24	p <.05
*2	Sine	1505.43	134.02	59.94	976.10	182.45	81.59	p <.05
*1	Prop	908.48	173.77	77.71	661.02	101.93	45.58	p <.05
2	Prop	1279.49	130.25	58.25	1481.35	231.93	103.72	p >.05
1	Vision	1500.98	132.62	59.31	1374.74	131.68	58.89	p >.05

Table 3: Single Subject MT (ASD)

Movement Time (MT)								
Participant	**Cond**	**M1**	**SD1**	**SE1**	**M2**	**SD2**	**SE2**	**Sig**
1	Fitt	723.37	102.86	46.00	795.17	138.34	61.87	p >.05
*2	Fitt	861.62	98.77	44.17	1044.78	67.05	29.99	p <.05
*1	Sine	911.48	221.23	98.94	631.85	67.19	30.05	p <.05
2	Sine	920.38	144.08	64.43	873.07	117.97	52.76	p >.05
*1	Prop	797.20	133.58	59.74	640.26	90.68	40.55	p <.05
*2	Prop	937.75	91.91	41.11	1112.49	100.37	44.89	p <.05
*1	Vision	892.53	169.61	75.85	1094.19	45.08	20.16	p <.05

Table 4: Single Subject DT (ASD)

Dwell Time (DT)								
Participant	**Cond**	**M1**	**SD1**	**SE1**	**M2**	**SD2**	**SE2**	**Sig**
1	Fitts	240.92	272.51	121.87	175.79	119.83	53.59	p >.05
2	Fitts	1041.11	308.41	137.93	669.87	542.77	242.73	p >.05
*1	Sine	219.79	83.67	37.42	31.90	48.00	21.47	p <.05
*2	Sine	585.05	179.59	80.31	103.04	68.24	30.52	p <.05
*1	Prop	111.28	52.97	23.69	20.74	24.83	11.10	p <.05
2	Prop	341.73	97.06	43.41	404.73	195.64	87.49	p >.05
*1	Vision	608.44	240.94	107.75	280.56	126.99	56.79	p <.05

Table 5: Single Subject PV (ASD)

Peak Vel. (PV)								
Participant	**Cond**	**M1**	**SD1**	**SE1**	**M2**	**SD2**	**SE2**	**Sig**
1	Fitts	23.24	1.79	0.80	22.67	2.50	1.12	p >.05
*2	Fitts	19.14	1.50	0.67	21.44	1.46	0.65	p <.05
1	Sine	36.39	7.83	3.50	33.48	5.82	2.60	p >.05
2	Sine	22.35	2.95	1.32	22.63	3.20	1.43	p >.05
*1	Prop	22.46	3.58	1.60	30.23	5.20	2.33	p <.05
*2	Prop	22.66	2.51	1.12	19.20	1.93	0.86	p <.05
1	Vision	20.50	1.57	0.70	20.40	1.40	0.63	p >.05

Table 6: Single Subject %TPV (ASD)

%Time to Peak Vel. (%TPV)								
Participant	**Cond**	**M1**	**SD1**	**SE1**	**M2**	**SD2**	**SE2**	**Sig**
1	Fitt	51.98	3.52	1.57	54.38	6.46	2.89	p >.05
2	Fitt	44.79	15.66	7.00	52.83	4.00	1.79	p >.05
1	Sine	52.43	2.41	1.08	53.71	1.59	0.71	p >.05
2	Sine	54.18	7.78	3.48	46.96	7.92	3.54	p >.05
1	Prop	55.54	1.89	0.85	52.95	3.56	1.59	p >.05
2	Prop	37.33	1.81	0.81	38.40	11.18	5.00	p >.05
1	Vision	49.11	6.35	2.84	48.41	6.43	2.87	p >.05

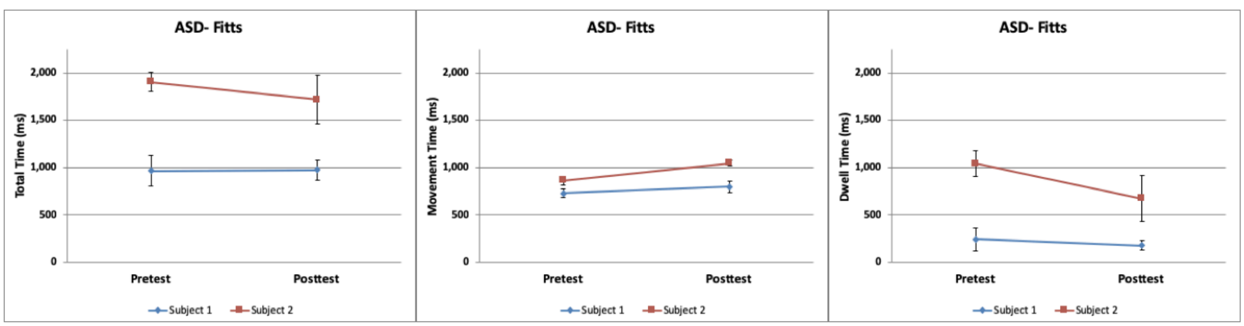

Figure 4. ASD Fitts Single Subject (TT, MT, DT)

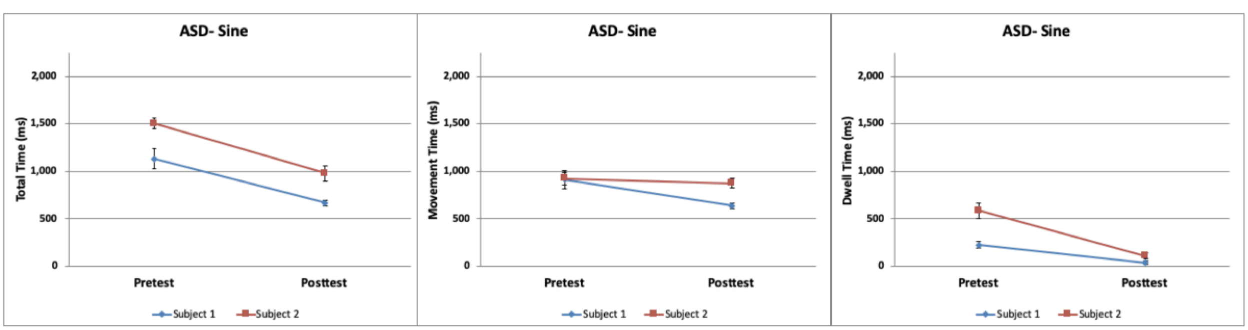

Figure 5. ASD Sine Single Subject (TT, MT, DT)

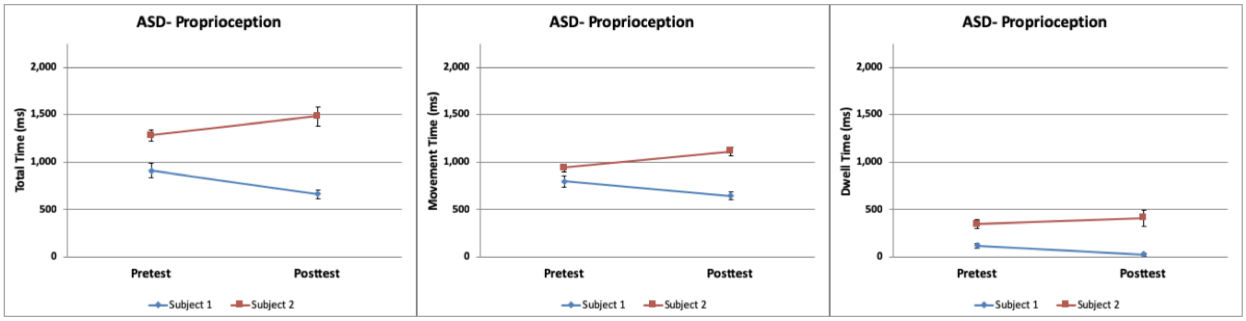

Figure 6. ASD Proprioception Single Subject (TT, MT, DT)

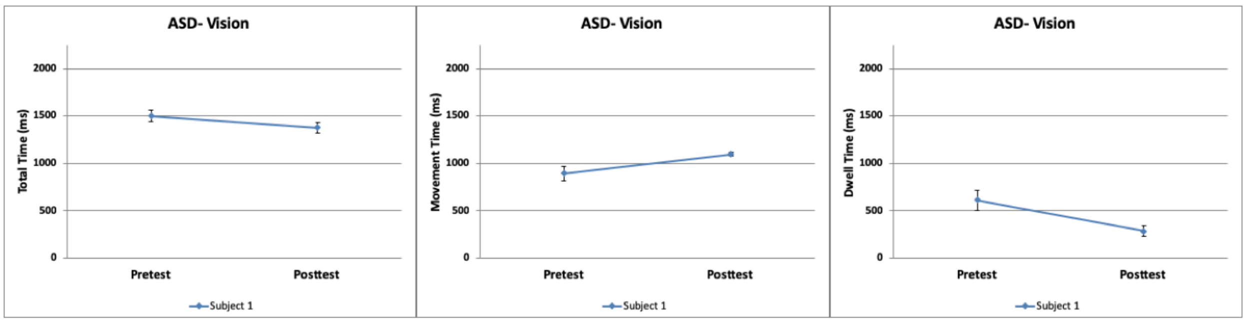

Figure 7. ASD Vision Single Subject (TT, MT, DT)

CHAPTER 8 DISCUSSION

The purpose of the thesis was twofold. First, the study by Gamez et al., (2020) is a recent publication based on a sample size of 12 children with ASD and warranted replication. Second, this study aimed to further investigate the sine wave effect in this population by isolating the sensory inputs experienced during the training to expose any potential learning differences of therapeutic value. Specifically, it was the investigator's aim to determine whether an isolated proprioceptive or visual experience of the training would provide performance enhancements similar to the ones seen in the original sine wave training (Boyle et al., 2012, 2015; Gamez et al., 2020). Although there is evidence of the sine wave replication as well as unique single subject enhancements following isolated sensory trainings, at this point, the conclusions drawn in this thesis are tentative and likely to evolve as this project is cleared to resume human subject recruitment following COVID-19 quarantine (Centers for Disease Control and Prevention, 2019). These conclusion interpretations, acknowledgment of study limitations and future directions will be described in the subsequent sections. Additionally, given the Repeated Mixed Model revealed no Group (ASD vs NT) statistical significance, the following results sections will be described with respect to between and within subject changes in the ASD population only.

Repeated measures revealed no significant findings related to children who trained in the Fitts control condition. With respect to the single subject analysis, a significant result from Pretest to Posttest was seen with participant 2 with their MT values becoming slower after continuing the Fitts task during training.

It was hypothesized that the children in the Sine Wave condition would show improvements in faster TT and MT, as well as a harmonic movement pattern after training. In a study conducted by Gamez et al. (2020), 12 children with ASD completed a similar protocol to the present study. Identical to this design, all of the children performed 15 trials of a Fitts target task before randomly being assigned to a training condition of either continuing the Fitts target task (control) or tracing a sine wave template for 30 trials. Following the training period, all of the children were retested on the Fitts target task for an additional 15 trials. Their results concluded that children who performed the 30 trials in the Sine Wave condition produced overall faster and more harmonic movement times compared to their own pretest measures on the target task as well as the Fitts control group on Test 2. The faster movement times were analyzed by kinematic measures of TT and MT, while the conclusions of harmonicity were drawn from measures of %TPV moving from averages near 35% TPV towards a value closer to 50%, demonstrating equal acceleration and deceleration movements. The authors describe the results as evidence that this population, although presenting slower pretest movement times compared to their NT peers, are capable of modifying their motor programs and/or synergistic activation patterns in a way that allows them to move smoother and faster.

In the present experiment, the repeated measures analysis, with only the ASD data, revealed that Posttest measures of movement time (MT) were significantly faster compared to Pretest only for the children who trained in the Sine Wave condition. Further single subject analysis confirmed that the two participants in the Sine Wave training condition were both significantly faster in Posttest compared to Pretest. Although non-significant in the paired sample t-tests of TT and DT, the single subject statistics of the Sine Wave trained group reveals significant differences from Pretest to Posttest for measures of TT and DT. These results, although tentative, would suggest that the Sine wave effect as shown by Gamez et al., was replicated in the present study (Specific aim 1).

Paired sample t-tests of TT, MT, DT, PV, and %TPV showed no significant differences between pre and posttests in the Proprioception condition. Further single subject analysis showed mixed results between both participants. There were significantly improved TT, MT, and DT in Participant 1 between Pretest and Posttest; however, Participant 2 showed a significant increase in MT and a decreased PV in Posttest compared to Pretest. Although not significant, the increased DT may have contributed to the increased MT, revealing the participant spent more time planning and executing the movement. This suggests the Proprioception condition is capable of enhancing the speed of executing a movement and decreasing the amount of time planning for the next movement. It can be inferred that Participant 1 successfully used proprioceptive feedback, independent of vision, to control the execution of movement in the online movement control phase.

Single subject statistics of the Vision trained condition revealed significant differences from Pretest to Posttest for measures of MT and DT. There was an increase in MT, but a significant decrease in DT. This implies that the participant may have been adopting a more harmonic approach but couldn't execute at a faster speed because of the lack of proprioception affecting the ability to fine tune the specific muscle synergy and intrinsic movement plan (Sarlegna & Sainburg, 2009). Since there was only one participant in this condition, it is likely that the results do not represent the population as a whole.

The %TPV and PV values were abnormally high in the present study. Although a commonly used measure to describe changes to movement smoothness, PV and %TPV currently do not provide much clarity to the discussion, but provide more confusion. It was hypothesized that the %TPV values would start below 50% in the Pretest and increase to a value closer to 50% in the Posttest, as demonstrated in the previous study (Gamez, 2020). However, in the current study, many of the children with ASD present values near or over a harmonic score of 50%TPV. Further investigation is necessary to determine if these differences were due to a small sample size.

A study conducted in 2009 found that individuals with ASD use both visual and proprioceptive feedback during an arm movement; however, visual information wasn't processed as quickly as proprioceptive information (Glazebrook et al., 2009). The study examined how young adults and adolescents with ASD used vision and proprioception to compete either eye movements and/or reaching movements; these movements were performed with and without vision. With greater variability during eye and hand movements, the ASD group displayed accuracy of landing on the target, with and without vision; there was less variability when they used proprioceptive feedback during their movement. Although the results of the present study did not show differences between proprioceptive and visual feedback, the results indicate that there is potential to see enhancements in both proprioception and vision training.

A number of limitations exist in the present thesis. First, the subject pool of ASD and NT children is uneven and poorly powered. With many underpowered statistical designs, an addition to the analysis pool has greater potential to highlight the most accurate findings. Given the challenges in recruiting a vulnerable minor population as well the shutdowns related to COVID-19, this study will continue through my advisor Dr. Jason Boyle as well as other collaborating faculty and Doctor of Physical Therapy students at UTEP throughout the next year. Similar to the proposal value, the target recruitment value is set at N=20, allowing 5 per training condition. Another limitation that must be considered is the engagement, comprehension and cognitive abilities of our small participant pool. No measure of executive functioning (e.g. Tower of

London) or handedness was administered prior to the experimental protocol. These measures will be implemented in future data collection sessions.

A potential limitation to the following results is the consistency of auditory input the participants take in during the task. The servomotors that created the proprioception condition emitted a rhythmical auditory signal, which potentially might have provided an augmented feedback or a CNS processing hindrance to the participants. Future studies could further the understanding of this scenario by investigating if children with ASD are able to benefit from auditory templates or not.

CHAPTER 9 CONCLUSION

The results of the present study suggest sensory integration of vision and proprioception in children with ASD during a goal-directed task needs to be explored further. Several studies have supported that individuals with ASD use both visual and proprioceptive feedback during movement; however, there are conflicting results as to which is relied on more heavily. Although tentative, the results of this study revealed that the Sine wave effect was successful in demonstrating a smoother and faster movement pattern following sine wave tracing. Sensory integration of proprioception and vision demonstrated a potential enhancement in smoother and faster movement patterns. With further investigation and an increased sample size, future studies will help highlight the most accurate findings.

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VITA

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Ms. Diaz became involved with the Virtual Reality and Motor Control Laboratory, under the supervision of Dr. Jason B. Boyle, since her first year of graduate school and has participated in research since. Upon starting this present thesis, Ms. Diaz was awarded the Dodson Research Grant from the Graduate School of the University of Texas at El Paso. The research in the present study was accepted to be presented at the North American Society for the Psychology of Sport and Physical Activity by Ms. Diaz in June 2020. Ms. Diaz hopes to present her research at American Physical Therapy Association's Combined Sections Meeting in February 2021.

While pursuing her Master's degree, Ms. Diaz was awarded a Teaching Assistant position by the Department of Kinesiology. In addition to assisting professors with grading assignments, Ms. Diaz taught an exercise physiology lab to undergraduate kinesiology students. Additionally, Ms. Diaz continues to help her parents run a small landscaping business, where she is in charge of bookkeeping and clerical work.

Ms. Diaz will continue her education in physical therapy after graduating with her master's. After researching and working with children with ASD, Ms. Diaz would love to pursue her physical therapy career with this population; however, she is also interested in all populations ranging from athletes to geriatrics to animals.

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