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Comparing Functional Motor Control and Gait Parameters in Children with Autism to those of Age-Matched Peers who are Typically Developing

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COMPARING FUNCTIONAL MOTOR CONTROL AND GAIT PARAMETERS IN CHILDREN WITH AUTISM TO THOSE OF AGE-MATCHED PEERS WHO ARE TYPICALLY DEVELOPING

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ABSTRACT

The purpose of this study was to compare motor performance of children with Autism Spectrum Disorder (ASD) to that of age-matched peers who are typically developing (TD) on motor control tasks plus symmetry and variability of gait parameters across four walking conditions. A sample of convenience of children with ASD (n=6) and peers who are TD (n=6) were recruited. Motor control was assessed using initiation and completion times on the Timed Up and Go (TUG) test. Gait parameters were collected using a computerized walkway under four trial conditions: 1) walking at self-selected velocity (SSV); 2) walking during a tray-carrying task (dual tasking); 3) walking over a visible obstacle (feed-forward control); and 4) walking over an unexpected obstacle (feedback control). Independent t-tests were used to test for between-group differences in TUG initiation and completion times and gait parameters and variability by condition. Paired t-tests were used to assess within-group symmetry by condition. Findings showed that ASD and TD groups had similar TUG times, gait parameters across the four conditions, and variability in gait (all $p>.05$). Parents of children with ASD perceived their children as moving differently than their peers, but parents of children in the TD group did not ($p=.014$). The TD group had significant asymmetry of right versus left single limb support time ($p=.034$) in the dual task condition, while the ASD group demonstrated significant asymmetry of heel-to-heel distance in the feedback condition ($p=.049$). Children with ASD may benefit from being given a dual-task with an external focus and from delaying the introduction of unanticipated perturbations until skilled movement patterns have been established. Future research should focus on variability and motor tasks that are less repetitive than gait is warranted.

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INTRODUCTION

Autism Spectrum Disorder (ASD) is now identified as the most common pediatric diagnosis in the United States[1], affecting one in 68 children,[2] though estimated prevalence varies according to race and ethnicity.[3] Medical expenditures for children with ASD have been reported as being 4.1 to 6.2 times greater than those of children without ASD.[3,4] The cost of ASD over the lifespan is estimated at 3.2 million dollars per person in the United States including direct medical costs of interventions and social costs such as lost work productivity and care of adults with ASD[5], while the lifetime cost to care for an individual with cerebral palsy (CP) is estimated at one million dollars.[2]

Although the costs and many other factors related to ASD and CP differ, these conditions share some important commonalities, not the least of which is the heterogeneity which clouds the ability to understand its causes, the mechanisms through which it expresses itself within individuals that become barriers to function, and the pathway to improve function through intervention.[6,7,8] In fact, there have been over 100 different genetic variations associated with ASD.[9] When these genetic factors get sorted out and aligned with clinical presentation, the presence of three specific characteristics seems to differentiate one from the others: epilepsy or seizure activity, motor impairment, and sleep disturbance.[10]

The heterogeneity of individuals with autism is especially problematic because at present, the diagnosis of autism is made exclusively via clinical presentation based on criteria found in the Diagnostic and Statistical Manual of Mental Disorders (DSM-V)[11] since there are no widely accepted biological tests to diagnose autism. The DSM-V identifies the criteria for a clinical diagnosis of ASD as including problems with social communication and interaction seen in multiple environmental contexts resulting in failed communication; stereotyped patterns of repetitive behaviors with early childhood symptomology that interferes with school, work and social activities, that cannot be attributed to another clear cause such as global or cognitive developmental delays.[11,12] These criteria have been applied to the International Classification of Functioning, Disability, and Health (ICF)[13] to provide an understanding of how having these types of clinical signs and symptoms actually impacts the life of individuals with autism during early childhood.[14] Experts retained 39 items at the level of activity/participation, 11 items at the level of body functions, and 19 environmental factors in the ICF core set for ASD.

Although motor impairment was recognized as one of the major features distinguishing one ASD phenotype from another, none of the items in the ICF core set for ASD are related to mobility and difficulty with fine hand use is the only fine motor activity identified. Five items are classified as sensory functions that are problematic for individuals with autism including being able to focus on a single task, being able to handle or sequence multi-task commands, carrying out daily routines, handling stress, and managing one's own behavior.

It is interesting that although the experts did not include any functional mobility activities in the ASD core set, early parental concerns characterizing children with autism include limited play interests, motor hyperactivity, and lack of ability to adapt to changing conditions.[15] Descriptions of providers and professionals are similar to those of parents in differentiating social and communicative behaviors of children with ASD from those who are typically developing (TD) and include either over- or under-activity, guardedness or awkward interactions, rigidity, and repetitive nature of behaviors without variance.[16]

The impressions of parents and service providers who work with children with ASD seem to be borne out in the work of scientists conducting neuroimaging studies on children with ASD. Among the areas of the brain identified as being different in ASD compared to those of children who are TD include basil ganglia, cerebellum and the primary motor cortex. Additional parental anecdotal reports and observational studies of children with ASD demonstrating clumsy or uncoordinated movement patterns.[17,18,19] In teasing out some of the underlying factors contributing to these characterizations, Shetreat-Klein et al[18] noted that, during walking, children with ASD have exhibited a lack of consistency, smoothness and coordination compared to children who are TD. Other gait abnormalities described in children with autism include a wide base of support and apraxia.[17]

Numerous studies have highlighted specific changes in brain structure and white matter connectivity that support the idea that individual with autism also experience delayed or disordered motor development. Using fMRI, Rinehart et al[17] identified significant differences in the basal ganglia and cerebellums of children with ASD compared to their peers who are TD. These areas are responsible in large part for motor initiation and regulation, and movement termination, respectively, which was corroborated with behavioral observations of poor coordination during primarily fine motor tasks. Marko et al[20] also found structural changes in the cerebellum of children with ASD and associated these changes behaviorally with slower motor learning from visual feedback and enhanced motor learning following proprioceptive feedback. Nebel et al[21] found that the organization of the primary motor cortex of the brain, responsible for controlling the execution of coordinated movement, was significantly different in children with and without ASD, with the areas represented by upper and lower limbs demonstrating significantly different levels of connectivity.

It is important that the impact of activity limitations and impairments of body structure or function related to motor skill development be better understood because the contribution of motor experience and skilled movement on other areas of development has been well documented from the time of Piaget to the contemporary cognitive and movement scientists. Further, it appears that there may be particularly strong connections between motor activity and early efforts toward communication as evidenced by the fact that early motor activity within the brain precedes or occurs concurrently with infant attempts at communication.[12] In looking at the extensive body of literature describing the developmental issues seen in ASD and current accounts of characteristics across the domains, there are some common themes that emerge. Across the domains we find some evidence of delayed initiation or hyperactivity of behavioral responses, awkwardness, lack of flexibility or ability to adapt to changing conditions, and the type of variability usually seen in emerging rather than skilled behaviors. So, we began to wonder whether acquiring a better understanding of the patterns seen in the functional movement characteristics seen in children with ASD might provide insight into the problems seen in communication and social behaviors and the contribution of motor control challenges to early learning in other developmental domains. Thus, the purpose of this study was to compare motor performance of children with ASD compared to that of their same-age peers on aspects of motor control for task initiation and the symmetry and variation of gait parameters during varying conditions.

METHODS

Participants

A sample of convenience of children with ASD (n=6) or TD (n=6) was recruited via advertisement and word-of-mouth from the community-at-large and organizations that represent or serve this population. Eligible children were four to eight years old, had either a documented medical diagnosis of ASD or a history of TD, without any additional diagnoses of intellectual impairment or musculoskeletal disease, and were able to walk without assistance from another person. This study was approved by the Biomedical Institutional Review Board for human subject research at the University of Nevada, Las Vegas (Protocol #: 1310-4604).

Design

This study was completed using a nested cross-sectional design in which all measurement tools were administered within a single session to answer research questions comparing performance of children with ASD compared to children who are TD on walking tasks involving motor control under conditions that require initiation and termination of movement (TUG test) and adaptation to a variety of conditions.

Instrumentation

The Timed Up and Go (TUG) test is a commonly used test of motor control and was used to measure timing of initiation of movement and functional motor control in the sample. The TUG has been shown to be a reliable measurement to assess functional mobility in children as young as 3 years, as well as for children with and without physical disabilities.[22,23] In this study, the TUG was measured using an instrumented stool that calculated the participants weight while sitting and determined when 90% of their weight was removed, providing us with the start of the test.[24] used for the TUG assessment. A weight scale and measuring tape were used to obtain anthropometric measures from each participant. A reliability study on this TUG instrumented stool has been shown to be an acceptable timing method for the test compared to the standard method of using a handheld stop watch.[24]

Mobility Lab™ (Ambulatory Parkinson's Disease Monitoring, Inc., Portland, OR) was utilized to measure joint kinematic and gait symmetry properties. Six inertial sensors were placed on each participant: bilateral wrists, ankles, chest and waist (near center of mass) to track motion. Repeated technical difficulties resulted in insufficient data collection therefore analysis of this data could not be computed.

A GAITRite® Instrumented Walkway (CIR Systems Inc., Clifton, NJ, USA) was used in conjunction with the Mobility Lab™ to collect spatio-temporal gait characteristics including velocity, step and stride length, step and stride time, single support, double support, stance time, heel-heel BOS, and cadence. The GAITRite® has been shown to be a reliable tool for recording gait characteristics in children with neurodevelopmental disabilities.[25] These particular parameters were chosen because they demonstrated the highest reliability when using the GAITRite® in this population. [26] Participants carried a wooden tray with a small plastic cup on top for dual-tasking trials. An optical light source projected onto the floor was used as the obstacle to step over for the feed forward/feedback trials.

Procedure

Data were collected at the University of Nevada, Las Vegas within the UNLV Physical Therapy Gait and Balance Laboratory. Parental permission and child assent were both obtained before proceeding with data collection. To assist with keeping the children engaged throughout the data collection process, each participant was given a personalized paper star to which they could add a sticker of their choice following each completed tasked. Children were then weighed and measured for height and bilateral leg length. Mobility Lab™ sensors were then placed in the above listed locations.

We based our strategies for giving instructions to all child participants on a literature review of learning styles of and teaching strategies that work well with children with ASD. Of the many strategies discussed, among those most consistently named were manipulating the environment to bring about the desired response, modeling the desired response, and providing positive reinforcement.[27,28,29] For our study specifically, we set up the laboratory with one task at a time to improve focus and lessen distractions, modeled behaviors for all walking conditions on the GAITRite mat, and rewarded the completion of tasks with stickers.

Motor Control

Motor initiation time was collected using the TUG test with an instrumented stool. Participants began seated on the stool to calculate their weight, then on the verbal command "go" to walk three meters around a cone and return back to sitting on the stool. Initiation time was defined as the time between when the examiner gave the verbal command, "go" and pressed a timer-switch connected to the TUG software; and the time when 90% of the child's body weight was lifted off the stool, as recorded by the TUG software. Completion time began when 90% of the child's body weight was lifted from the stool; included the time it took for the child to walk a three-meter distance, turn around a cone and return to the stool, and ended when 90% of the child's body weight returned to the stool.

Gait Parameters: Symmetry and Variability

Walking data were collected during four conditions: walking at a self-selected velocity (SSV) without added distractions, walking while dual tasking, walking over an obstacle that was visible in advance of beginning to walk (feed-forward), and walking over an obstacle that appeared after beginning to walk (feedback control). All trials were completed by walking over the GAITRite® while being instrumented with the Mobility Lab™ sensors attached as previously described. For all passes, participants were instructed to complete each trial by starting to walk off the walkway and not stopping until stepping off the other end of the walkway of the GAITRite®. Four acceptable trials (two passes over the walkway) were completed for each condition for each participant. A script for trial instructions was prepared in order to maintain as much consistency between participants as possible. However, if a child required more or varied instruction from the script in order to comprehend the task being asked of them, this was provided.

The dual-tasking trials required children to carry a wooden tray, as mentioned previously, with a small plastic cup placed on top. Children were instructed to walk across the walkway as during the SSV trial while carrying the tray and keeping the cup upright. To assist with child engagement and participation, children were allowed to select their favorite cup from a variety of color and character options.

The obstacle used for the anticipatory and reactionary control conditions was a beam of light projected horizontally across the GAITRite® walkway by two PowerPoint slides created for this purpose. This obstacle allowed for the most control and manipulation by researchers without posing a physical risk to the child participants. Each participant was allowed one practice run of these trials to reduce the risk of task novelty interfering with their performance to assess control. For the feedback control trials, there were two potential locations the beam of light could appear to reduce predictability. In addition, these beams of light were shown onto the walkway 87 cm before the child reached it in order to standardize the allotted distance and reaction time between participants. This distance was calculated using research that stated the average cadence and reaction time of children in this age group.[30,31]

Outcome Variables

The outcome variables used to assess symmetry and variability included spatio-temporal gait parameters: velocity, step and stride length, step and stride time, single support, double support, stance time, heel-heel BOS, and cadence.

Statistics

All statistical tests were performed using SPSS 22.0 for Windows (Chicago, IL). The *a´ priori* alpha level was set at .05.

Participant Characteristics

Descriptive data were collected to characterize categorical demographic, developmental, and clinical characteristics. Groups were compared for between-group differences with categorical variables to assist in identification of potential confounding variables. These data are presented as frequencies and percentages. Between-group differences were analyzed using chi-square (X^2) to calculate p-values and 95% confidence intervals.

Motor Control

A one-tailed paired t-test was performed to analyze two different aspects of the TUG test because we hypothesized that the children with ASD would have longer initiation and completion times.[32] We analyzed initiation time as defined above, and completion time for the entire TUG at a three-meter distance.

Gait Parameters: Symmetry and Variability

SSV, dual task, and obstacle negotiation (feed-forward and feedback) yielded continuous data and were analyzed separately using appropriate measures of central tendency and variance. Inferential related to gait characteristics were separated into data suitable for parametric versus nonparametric analyses. Parametric tests were performed on continuous data meeting criteria for normal distribution. Statistical design included independent t-tests to analysis between group differences and paired t-tests to assess symmetry within each group. To assess variability, we calculated the Coefficient of Variation (CoV) for each child for each walking condition, then conducted independent T-tests using those CoV values to determine if between-group differences in variability were present on the gait parameters.

RESULTS

Participant Characteristics

Six children with ASD (mean age = 5.8 ± 1.5 years) and six TD children (mean age = 5.5 ± 1.6 years) participated in the study (n = 12; 10 males, 2 females). The mean age at which subjects were reported to begin sitting independently was 6.4 ± 1.8 months for children with ASD compared to 7.5 ± 1.9 months for children who are TD (p = .204). Reported age at which subjects began walking was 14.5 ± 5.5 months for children with ASD compared to 13.0 ± 3.7 months for children who are TD (p = .328). No significant differences were found between groups from X^2 test for age, gender, race, or ethnicity (p > .05). Significant between-group differences were discovered regarding parent perception of their child's gait: 100% of parents of children with ASD reporting that their child walked differently than their peers, while 0% of parents of children who are TD reported having that perception ($p=.014$). A significant between-group difference was also found in the presence of the diagnosis of ASD ($p=.001$). A significant within-group difference in severity of ASD with more children reporting a diagnosis of moderate ASD or Asperger's syndrome ($p \leq .035$). See Table 1 for details.

Motor Control

The independent T-tests showed no significant between-group differences for the time it took to initiate movement on the TUG (ASD 1.67 ± 1.69 seconds, TD 0.64 ± 0.15 seconds; $p = .196$). There were also no significant between-group differences on completion time for the three-meter TUG test (ASD = 9.98 ± 3.60 seconds, TD = 7.59 ± 1.20 seconds; $p =.176$). See Table 2 for details.

Walking Conditions

Independent t-tests were used to compare movement patterns in children with ASD to those who are TD. There were no significant between-group differences on any of the selected gait parameters tested under the self-selected velocity (see Table 3), dual task condition (see Table 4) or the anticipated/feed-forward obstacle condition (see Table 5), or the reactive/feedback obstacle (see Table 6).

Symmetry (Within Group)

Paired t-tests were used to compare performance right versus left sides for each selected gait parameter in each of the four gait conditions. There were no significant asymmetries found in either group for any of the selected gait parameters in the self-selected velocity condition (see Table 7). However, there was a significant difference between the right and left sides indicating asymmetry in the TD group on single limb support during the dual task condition with right leg (36.930 seconds ±3.026) able to maintain single limb stance longer than the left (37.761 seconds ±5.099; p=.034), (see Table 8). There were no significant differences in either group during the feedforward obstacle walking condition (see Table 9), but significant asymmetry was identified in the ASD group during the feedback walking condition for the heel-to-heel distance parameter with the left heel being further away from the line of trajectory (10.886cm ±2.241) than the right (10.420cm +2.040; p=.049), (Table 10).

Coefficient of Variation

An independent t-test was used to compare between-group differences in variability using the Coefficient of Variation to quantify variability on the identified gait parameters for each of the walking conditions. There were no significant differences found in any of the gait parameters during the self-selected velocity (Table 11), dual-task (Table 12), feed-forward obstacle (Table 13), or feedback obstacle conditions (Table 14).

DISCUSSION

There was a statistically significant difference in parent perception of their child's gait between children with ASD and children who are TD. The questionnaire asked parents if they thought their child walked differently compared to their peers, and parents of children with ASD agreed with this statement more than parents of their age-matched peers. This finding is consistent with previous research that parents and healthcare providers alike perceive gait and movement patterns of children with ASD to appear clumsy and uncoordinated.[15,16]

Our results showed motor control, when tested using the TUG test, the performance of four to eight year old children with ASD in our sample was not significantly different from that of children who are TD. These results are inconsistent our hypothesis that there would be a significant between-group difference in initiation time and time to complete the TUG test, but this was not the case with our subject sample. Although times for children with ASD appear to be longer for TUG initiation and completion, the difference in values did not reach statistical significance. These results are also inconsistent with neural imagining studies that suggested motor control would most likely be impaired in children with ASD because areas of the brain influential in motor control including the primary motor cortex and cerebellum have been seen as different in children with ASD compared to their age-matched peers .[17,18] Possible explanations for this finding include scores within the ASD group cancelling each other out and having low statistical power. It is also possible that because we followed educational best practices while giving children instructions for this task, the manner in which instructions were given allowed the children with ASD to be more successful with this test than they had been previous studies.[27,28,29]

During the dual-task condition, children with autism demonstrated significantly better symmetry than the children who are TD on the single limb support gait parameter, meaning that the children who are TD spent more time in single limb stance on the right than on the left. One possible explanation to increased symmetry in gait parameters during the dual task condition may be that there is an improvement in motor planning when an external focus is added (the tray and the light beam, respectively). We hypothesize that by adding an additional task to the SSV walking condition, whether it was dual task or feed-forward in which they anticipated negotiating a seen obstacle, it allowed the children with ASD to externally focus on completing that task than actually walking.[33,34] Previous research has supported hypersensitivity to sensory information that could be leading to increased distractibility.[17,20] Thus, giving the child a specific task to focus on may have resulted in a more symmetrical, consistent walking pattern than just walking alone.

In the feedback walking condition during which children were asked to react to a projected obstacle, children with autism demonstrated significant asymmetry in distance between each heel and the line of trajectory of their gait. That is, they took a wider stance on the left side than on the right side. This was consistent with what we expected to find based on neural imagining studies mentioned above in which the primary motor cortex and cerebellum of children with ASD were seen as significantly different then that of TD peers, resulting in presumably impaired coordination.[21] This finding was also consistent with one of the social challenges faced by children with ASD when their repetitive behaviors are interrupted by other people or events in their immediate environment..[35] In fact, we had expected all gait parameters to be similarly disrupted in this condition, which was not the case.

We had hypothesized that variability of motor control and gait parameters across conditions would be different than that of their age matched peers. The bases for this hypothesis came partly from the literature describing movements of children with ASD as poorly coordinated and lacking skill and partly from the literature describing other behaviors and movements of children with ASD as highly repetitive and stereotypical.[11,12,16-19] Clinically, the lack of adaptation within changing conditions and lack of using feedback effectively to allow the child to seek alternative solutions to a motor problem also influenced this hypothesis. So, it was very surprising that there were no significant between-group differences on any motor control tasks or gait parameters across the changing walking conditions. It is possible that both are true – that is, some children may have had high variability, while others low variability so that their values cancelled each other out. Perhaps looking at the patterns using the model statistic or other individualized approach to research design or analysis may have been a more appropriate approach.[36] It is also true that there are statistical approaches to calculating variance, and that the CoV was not sensitive enough to detect differences even when they were present.

LIMITATIONS

The bulk of literature describing neural imaging and motor development of children with ASD suggests that there are significant differences between their movement skills and those of their age-matched peers. In our study there were no significant differences in motor control and few differences in the gait parameters selected only under specific circumstances. Several factors may account for these results. The developmental and clinical heterogeneity of individuals with ASD is well known, but our sample was quite homogenous with regard to many characteristics and developmental milestones.[37,38] In addition, three of the children who are TD were siblings of subjects with ASD, who may have made the TD group more similar to the group with ASD.[39] Finally, sorting out the many and varied findings of this population relative to genetics, clinical phenotypes and neural imaging studies such a large noise to signal ratio across a broad spectrum of research findings in this population.[9]

Another factor that could have contributed to the lack of additional significant findings was that of low statistical power resulting in a possible Type II error. In addition, many of the children with ASD had difficulty following the instruction to keep feet on the three-foot wide GAITRite® computerized walkway. This required elimination of numerous steps by researchers in order to validate a complete walking trial. Although we were able to gather sufficient data to complete the above analyses, the equipment we had available proved to be difficult with this patient population.

CONCLUSION

In summary, this cross-sectional pilot study demonstrated that parents of children with ASD regard their children as walking differently than other children their age. However, we could not verify that perception with two exceptions. Children with ASD walked with a more symmetrical pattern of single limb stance than the children who are TD during the dual task condition. Children with ASD also demonstrated greater asymmetry on heel-to-heel distance than the children who are TD during the feedback, reactive condition. There were no findings of significant differences in motor control or variability between children with and without ASD.

While this was an observational study, it is possible that this study may point to future intervention strategies. For example, allowing children with autism to focus on an outside task when learning a new skill, with gradual weaning from that focus as skills develop may be a helpful in facilitating skilled motor function in children with ASD. Another possible strategy for individuals providing services to children with ASD may be to consider that requiring children with ASD to react to perturbations may be very challenging for them and could interfere with development of skilled behaviors if introduced during the early stages of motor learning.

Although ASD has a high prevalence and most likely includes delayed and disordered motor development, from a physical therapy perspective, this population may well be underserved, in part due to findings like ours.[25] Larger studies enrolling a range of participants that better reflects the heterogeneity seen in individuals with ASD and exploring the use of different measurement strategies should be completed to get a better picture of the motor control and gait difficulties seen in children with ASD and perceived by their parents. In particular, taking a closer look at variability remains justifiable based on descriptions of the behavioral descriptions and neural imaging studies of children with ASD. It is also true that looking at less repetitive and more complex motor tasks than walking may provide further insights. Indeed, sorting out the heterogeneity of this population found in both genotypes and phenotypes is an important and ongoing direction for future investigations.[9,10,37,40]

APPENDIX A – TABLES

Table 1.
Demographic, developmental, & clinical characteristics of participants

Characteristics	All participants (Total)	Participants with ASD diagnosis	Participants with TD	Differences between groups from *X*2
	N (% of total)	n (% of group)	n (% of group)	p value (95% CI)
Gender				0.121
Male	10 (83.3%)	6 (60%)	4 (40%)	
Female	2 (16.7%)	0	2 (100%)	
Age (mean)		(5.8 years)	(5.5 years)	0.856
8	2 (16.7%)	1 (50%)	1 (50%)	
7	2 (16.7%)	1 (50%)	1 (50%)	
6	1 (8.3%)	1 (100%)	0	
5	4 (33.3%)	2 (50%)	2 (50%)	
4	3 (25%)	1 (33.3%)	2 (66.7%)	
Race				0.273
White	7 (58%)	3 (42.9%)	4 (57.1%)	
Asian	2 (16.7%)	2 (100%)	0	
Mixed	2 (16.7%)	0	2 (100%)	
Not given	1 (8.3%)	1 (100%)	0	
Ethnicity				0.505
Hispanic/Latino	3 (25%)	2 (66.7%)	1 (33.3%)	
Not Hispanic/Latino	9 (75%)	4 (44.4%)	5 (55.6%)	
Reported to trip over own feet				0.036*
Yes	5 (41.7%)	4 (80%)	1 (20%)	
No	6 (50%)	1 (16.7%)	5 (83.3%)	
Not given	1 (8.3%)	1 (100%)	0	
Reported falls frequency				0.187
Very often (>1x/day)	2 (16.7%)	2 (100%)	0	
Often (1x/day)	1 (8.3%)	1 (100%)	0	
Sometimes (1-2x/week)	4 (33.3%)	2 (50%)	2 (50%)	
Never	5 (41.7%)	1 (20%)	4 (80%)	
Involvement in team sports				1.000
No	8 (66.7%)	4 (50%)	4 (50%)	
Yes	4 (33.3%)	2 (50%)	2 (50%)	
Involvement in individual sports				0.505
No	9 (75%)	5 (55.6%)	4 (44.4)	
Yes	3 (25%)	1 (33.3%)	2 (66.7%)	
Parent perception of child's gait				0.014*
Walks differently than	4 (33.3%)	4 (100%)	0	

age peers				
Walks like same-age peers	8 (66.7%)	2 (25%)	6 (75%)	
Diagnosis				0.001*
ASD	6 (50%)			
TD	3 (25%)			
TD sibling (TDS) of child w/ ASD	3 (25%)			
ASD type/ severity				0.035*
Moderate		2 (33.3%)		
Mild		1 (16.7%)		
Aspberger's		2 (33.3%)		
PDDNOS		1 (16.7%)		

Table 2.
Initiation time and time to complete TUG test between ASD and TD groups

	n	Mean	p-value
Initiation time (sec)			0.196
ASD	6	1.67 ± 1.69	
TD	5	0.64 ± 0.15	
Time to complete (sec)			0.176
ASD	6	9.98 ± 3.60	
TD	5	7.59 ± 1.20	

Table 3.
Independent t-test comparing movement patterns in children with and without Autism during SSV condition.

	Children with ASD (n=6)			Children with TD (n=6)			
Movement variable	Left Mean ± SD	Right Mean ± SD	Mean ± SD	Left Mean ± SD	Right Mean ± SD	Mean ± SD	p-value
GAITRite® - SSV							
Velocity (cm/s)			125.944 ±30.102			107.255± 15.932	0.209
Step Time (s)	0.530± 0.273	0.425± 0.068		0.496± 0.081	0.480± 0.069		L=0.775 R=0.195
Stride Length (cm)	122.445 ±47.732	102.241± 12.987		102.656 ±7.641	101.630 ±8.571		L=0.340 R=0.925
Step Length (cm)	60.309± 25.256	52.295± 6.825		51.560± 4.227	50.141± 4.281		L=0.422 R=0.527
H-H Base (cm)	9.453± 3.264	9.594± 1.600		8.513± 0.822	8.281± 0.949		L=0.521 R=0.115
Single Support	39.857± 10.288	63.473± 51.942		40.048± 3.668	39.357± 1.441		L=0.967 R=0.307
Double Support	18.324± 6.124	39.202± 48.911		21.950± 2.053	21.098± 2.693		L=0.199 R=0.407
Cycle Time (s)	1.034± 0.486	0.851± 0.128		0.969± 0.151	0.980± 0.142		L=0.758 R=0.130

Table 4.
Independent t-test comparing movement patterns in children with and without Autism during DT condition.

	Children with ASD (n=6)			Children with TD (n=6)			
Movement variable	Left Mean ± SD	Right Mean ± SD	Mean ± SD	Left Mean ± SD	Right Mean ± SD	Mean ± SD	p-value
GAITRite® - DT							
Velocity (cm/s)			89.438± 25.684			82.258± 22.992	0.621
Step Time (s)	0.522± 0.089	0.546± 0.114		0.572± 0.100	0.549± 0.100		L=0.386 R=0.965
Stride Length (cm)	91.722± 18.184	89.395± 17.117		87.932± 15.257	87.596± 15.333		L=0.704 R=0.852
Step Length (cm)	44.160± 8.697	46.946± 9.750		44.391± 8.136	43.125± 7.249		L=0.963 R=0.459
H-H Base (cm)	9.607± 2.027	9.226± 2.159		8.581± 1.263	8.894± 0.932		L=0.318 R=0.736
Single Support	37.909± 3.118	40.491± 6.379		36.930± 3.026	37.761± 3.526		L=0.593 R=0.381
Double Support	24.158± 6.017	25.941± 5.160		26.562± 5.109	26.303± 5.099		L=0.473 R=0.905
Cycle Time (s)	1.073± 0.204	1.046± 0.204		1.119± 0.201	1.120± 0.196		L=0.697 R=0.546

Table 5. Independent t-test comparing movement patterns in children with and without Autism during feed - forward condition.							
	Children with ASD (n=6)			Children with TD (n=6)			
Movement variable	Left Mean ± SD	Right Mean ± SD	Mean ± SD	Left Mean ± SD	Right Mean ± SD	Mean ± SD	p-value
GAITRite® - Feed-forward							
Velocity (cm/s)			107.933 ±12.505			96.555± 18.398	0.239
Step Time (s)	0.464± 0.033	0.443± 0.052		0.528± 0.063	0.552± 0.043		L=0.050 R=0.003
Stride Length (cm)	93.640± 19.349	97.011± 12.936		102.761± 15.202	103.523 ±16.143		L=0.385 R=0.459
Step Length (cm)	48.676± 5.177	48.126± 7.772		50.924± 7.488	51.386± 8.179		L=0.559 R=0.495
H-H Base (cm)	10.111± 1.520	10.584± 1.576		8.843± 2.298	8.993± 2.066		L=0.286 R=0.164
Single Support	38.690± 3.724	40.385± 3.123		38.817± 3.432	38.241± 2.536		L=0.952 R=0.221
Double Support	25.766± 9.344	22.285± 3.582		22.591± 5.866	22.622± 6.072		L=0.497 R=0.909
Cycle Time (s)	0.908± 0.066	0.908± 0.075		1.094± 0.085	1.100± 0.078		L=0.002 R=0.001

Table 6. Independent t-test comparing movement patterns in children with and without Autism during feedback condition.							
	Children with ASD (n=6)			Children with TD (n=6)			
Movement variable	Left Mean ± SD	Right Mean ± SD	Mean ± SD	Left Mean ± SD	Right Mean ± SD	Mean ± SD	p-value
GAITRite® - Feedback							
Velocity (cm/s)			82.294± 26.358			90.008± 13.838	0.540
Step Time (s)	0.550± 0.102	0.558± 0.147		0.556± 0.054	0.529± 0.071		L=0.903 R=0.664
Stride Length (cm)	87.415± 17.123	85.821± 16.767		96.617± 12.110	95.757± 9.845		L=0.308 R=0.236
Step Length (cm)	42.556± 9.503	44.216± 8.264		49.272± 6.183	45.806± 4.976		L=0.177 R=0.695
H-H Base (cm)	10.886± 2.241	10.420± 2.040		9.388± 2.950	9.358± 3.532		L=0.345 R=0.538
Single Support	37.653± 3.349	38.603± 4.386		37.733± 3.387	41.347± 2.425		L=0.968 R=0.210
Double Support	24.569± 8.400	24.361± 9.049		20.804± 2.616	20.616± 2.838		L=0.335 R=0.356
Cycle Time (s)	1.126± 0.245	1.121± 0.253		1.099± 0.117	1.088± 0.120		L=0.815 R=0.780

Table 7. Paired T-test comparing symmetry in movement between right and left sides in children with and without Autism during SSV condition.						
	Children with Autism (N=6)			Children without Autism (N=6)		
Movement Variable	Left Mean ±SD	Right Mean ±SD	p-value	Left Mean ±SD	Right Mean ±SD	p-value
GAITRite® - SSV						
Double limb support (s)	18.324±6.124	39.202±48.911	0.381	21.951±2.053	21.098±2.693	0.284
Single Support	39.857±10.288	63.473±51.942	0.384	40.048±3.668	39.357±1.441	0.621
Stride Length (cm)	122.444±47.732	102.241±12.987	0.348	102.656±7.641	101.630±8.571	0.295
Step Length (cm)	60.309±25.257	52.295±6.825	0.465	51.560±4.227	50.141±4.281	0.350
Step time (s)	0.530±0.273	0.425±0.068	0.378	0.496±0.081	0.480±0.069	0.358
Cycle Time (s)	1.034±0.486	0.842±0.129	0.369	0.969±0.151	0.980±0.142	0.128
H-H Base (cm)	9.453±3.264	9.594±1.600	0.872	8.513±0.822	8.281±0.950	0.217

Table 8. Paired T-test comparing symmetry in movement between right and left sides in children with and without Autism during dual-task condition.						
	Children with Autism (N=6)			Children without Autism (N=6)		
Movement Variable	Left Mean ±SD	Right Mean ±SD	p-value	Left Mean ±SD	Right Mean ±SD	p-value
GAITRite® - DT						
Double limb support (s)	24.158±6.017	25.941±5.160	0.147	26.562±5.109	26.303±5.099	0.078
Single Support	37.909±3.118	40.491±6.379	0.225	36.930±3.026	37.761±3.526	0.034
Stride Length (cm)	91.722±18.184	89.395±17.117	0.074	87.932±15.257	87.596±15.333	0.375
Step Length (cm)	44.160±8.697	46.946±9.750	0.066	44.391±8.136	43.125±7.249	0.229
Step time (s)	0.522±0.089	0.546±0.114	0.096	0.572±0.100	0.549±0.100	0.057
Cycle Time (s)	1.073±0.204	1.048±0.204	0.066	1.119±0.201	1.120±0.196	0.868
H-H Base (cm)	9.607±2.027	9.226±2.159	0.404	8.581±1.263	8.894±0.932	0.156

Table 9. Paired T-test comparing symmetry in movement between right and left sides in children with and without Autism during Feed-forward condition.						
	Children with Autism (N=6)			Children without Autism (N=6)		
Movement Variable	Left Mean ±SD	Right Mean ±SD	p-value	Left Mean ±SD	Right Mean ±SD	p-value
GAITRite® - Feed-forward						
Double limb support (s)	25.766±9.344	22.285±3.582	0.340	22.591±5.866	22.622±6.072	0.917
Single Support (s)	38.690±3.724	40.385±3.123	0.540	38.817±3.432	38.241±2.536	0.638
Stride Length (cm)	93.640±19.349	97.011±12.936	0.401	102.761±15.202	103.523±16.143	0.140
Step Length (cm)	48.676±5.177	48.126±7.772	0.761	50.924±7.488	51.386±8.179	0.712
Step time (s)	0.464±0.033	0.443±0.053	0.383	0.528±0.063	0.552±0.043	0.465
Cycle Time (s)	0.908±0.066	0.908±0.075	0.977	1.094±0.085	1.100±0.078	0.458
H-H Base cm)	10.111±1.520	10.584±1.576	0.089	8.843±2.298	8.993±2.066	0.416

Table 10.
Paired T-test comparing symmetry in movement between right and left sides in children with and without Autism during Feedback condition.

	Children with Autism (N=6)			Children without Autism (N=6)		
Movement Variable	Left Mean ±SD	Right Mean ±SD	p-value	Left Mean ±SD	Right Mean ±SD	p-value
GAITRite® - Feedback						
Double limb support (s)	24.569±8.400	24.361±9.049	0.886	20.804±2.616	20.616±2.838	0.601
Single Support (s)	37.653±3.349	38.603±4.386	0.627	37.733±3.387	41.347±2.425	0.076
Stride Length (cm)	87.415±17.123	85.821±16.767	0.082	96.617±12.110	95.757±9.545	0.472
Step Length (cm)	42.556±9.503	44.216±8.264	0.391	49.272±6.183	45.806±4.976	0.094
Step time (s)	0.550±0.102	0.558±0.147	0.840	0.556±0.054	0.529±0.071	0.206
Cycle Time (s)	1.126±0.245	1.121±0.253	0.716	1.099±0.117	1.088±0.120	0.129
H-H Base (cm)	10.886±2.241	10.420±2.040	0.049	9.388±2.950	9.358±3.532	0.941

Table 11.
Independent t-test comparing CoVs in children with and without Autism during SSV condition.

	Children with ASD (n=6)			Children with TD (n=6)			
Movement variable	Left Mean ± SD	Right Mean ± SD	Mean ± SD	Left Mean ± SD	Right Mean ± SD	Mean ± SD	p-value
GAITRite® - SSV							
Velocity CoV			17.937± 19.034			12.726± 7.194	0.545
Step Time CoV	20.189± 19.650	13.072± 12.220		8.762± 5.928	10.824± 6.240		0.222 0.697
Stride Length CoV	17.099± 19.943	8.291± 10.231		4.735± 3.043	5.773± 3.396		0.191 0.580
Step Length Cov	16.980± 20.744	7.026± 8.182		4.882± 1.962	6.522± 3.858		0.213 0.894
H-H Base CoV	8.201± 4.95	8.010± 8.360		16.726± 12.614	17.021± 13.940		0.170 0.204
Single Support CoV	18.203± 23.659	21.293± 28.318		5.273± 5.476	6.529± 3.025		0.221 0.259
Double Support CoV	24.571± 21.384	30.957± 29.268		14.589± 6.221	10.788± 3.639		0.298 0.153
Cycle Time CoV	20.975± 19.925	11.015± 12.501		8.874± 5.377	10.255± 6.306		0.203 0.898

Table 12.
Independent t-test comparing CoVs in children with and without Autism during dual task condition.

	Children with ASD (n=6)			Children with TD (n=6)			
Movement variable	Left Mean ± SD	Right Mean ± SD	Mean ± SD	Left Mean ± SD	Right Mean ± SD	Mean ± SD	p-value
GAITRite® - Dual Task							
Velocity			15.486± 10.718			16.063± 11.255	0.929
Step Time	10.414± 6.476	10.501± 4.859		9.049± 5.587	7.643± 3.399		L=0.704 R=0.265
Stride Length	11.857± 9.108	10.519± 8.856		8.713± 5.839	9.335± 5.883		L=0.493 R=0.780
Step Length	10.668± 6.268	13.991± 11.832		9.968± 5.563	8.677± 6.503		L=0.842 R=0.358
H-H Base	11.760± 10.867	14.906± 9.615		16.300± 10.880	11.985± 4.818		L=0.486 R=0.521
Single Support	7.057± 3.310	10.656± 8.230		5.973± 3.436	6.020± 4.261		L=0.590 R=0.248
Double Support	12.472± 10.861	19.199± 10.003		12.766± 8.930	12.797± 8.738		L=0.960 R=0.265
Cycle Time	10.487± 6.934	8.895± 5.155		7.913± 3.660	8.345± 3.585		L=0.446 R=0.834

Table 13.
Independent t-test comparing CoV s in children with and without Autism during feed-forward condition.

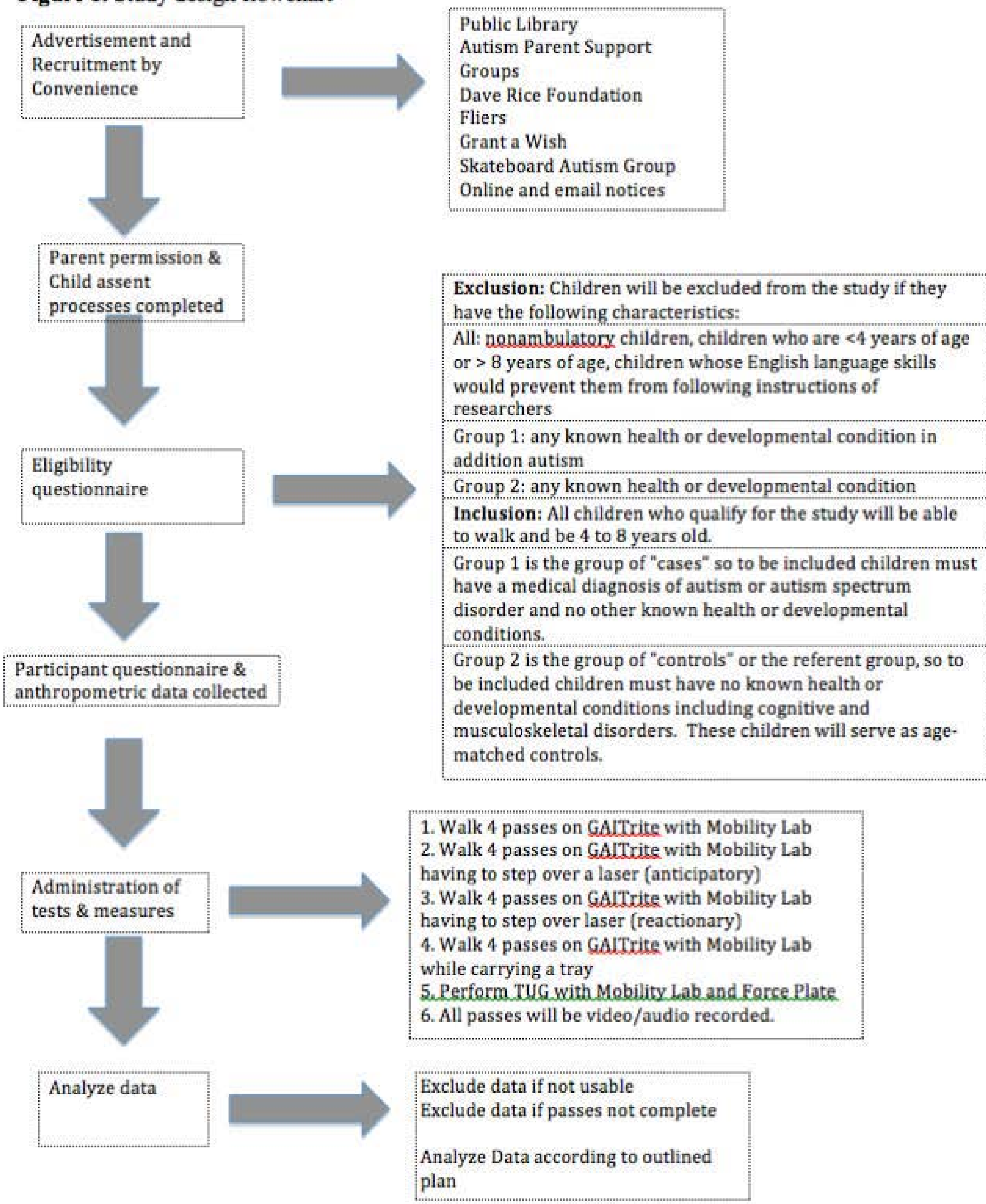
	Children with ASD (n=6)			Children with TD (n=6)			
Movement variable	Left Mean ± SD	Right Mean ± SD	Mean ± SD	Left Mean ± SD	Right Mean ± SD	Mean ± SD	p-value (two-tailed)
GAITRite® -Feed-Forward							
Velocity			14.108± 7.820			15.913± 8.826	0.716
Step Time	9.928± 6.180	13.849± 9.466		6.871± 2.001	14.818± 12.143		L=0.276 R=0.881
Stride Length	10.758± 3.622	11.289± 5.119		11.632± 6.312	11.260± 4.709		L=0.775 R=0.992
Step Length	12.592± 2.673	11.943± 7.852		13.093± 5.605	11.722± 6.249		L=0.847 R=0.958
H-H Base	14.832± 6.191	15.036± 6.368		20.036± 7.078	8.010± 4.529		L=0.205 R=0.195
Single Support	8.767± 5.858	8.010± 4.529		7.005± 4.581	10.976± 6.452		L=0.575 R=0.378
Double Support	31.867± 27.38	22.320± 11.119		18.677± 12.770	21.556± 12.779		L=0.310 R=0.914
Cycle Time	10.225± 6.812	11.267± 6.957		10.855± 6.862	11.482± 6.066		L=0.876 R=0.956

Table 14.
Independent t-test comparing CoVs in children with and without Autism during feedback condition.

	Children with ASD (n=6)			Children with TD (n=6)			
Movement variable	Left Mean ± SD	Right Mean ± SD	Mean ± SD	Left Mean ± SD	Right Mean ± SD	Mean ± SD	p-value
GAITRite® - Feedback							
Velocity			8.522± 4.648			11.0347± 7.784	0.513
Step Time	11.267± 8.651	9.389± 3.329		10.875± 6.078	9.047±4. 862		L=0.929 R=0.890
Stride Length	5.868± 3.302	7.250± 5.583		5.769± 4.032	5.737± 4.162		L=0.964 R=0.606
Step Length	9.844± 4.083	9.468± 9.026		6.903± 4.351	7.939± 5.428		L=0.255 R=0.730
H-H Base	11.739± 9.455	12.851± 8.659		15.997± 9.644	11.495± 4.971		L=0.458 R=0.746
Single Support	11.146± 8.474	7.282± 5.180		4.950± 3.298	6.185± 2.776		L=0.126 R=0.660
Double Support	16.966± 8.832	16.967± 10.40		9.183± 5.665	6.922± 6.931		L=0.99 R=0.77
Cycle Time	9.029± 5.261	9.515± 5.113		10.170± 5.114	10.150± 4.686		L=0.711 R=0.827

APPENDIX B – FIGURES

Figure 1. Study design flowchart



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    - Acute physical therapy
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- Nevada Physical Therapy Association (NPTA) member since 2012.

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Professional Leadership

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    - Student Investigator

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    - Doctor of Physical Therapy. Expected Degree: May 2015
- California State University San Marcos: San Marcos, California.
    - Bachelor of Science in Kinesiology, Minor in Psychology. May 2011.

Clinical Experience

- Providence Medical Group Family Medicine: Olympia, Washington. January-April 2015.
    - Clinical Internship
    - Outpatient orthopedics in primary care setting
- Memorial Health University Medial Center: Savannah, Georgia. October-December 2014.
    - Clinical Internship
    - Inpatient rehabilitation setting
- Veterans Affairs Hospital Sierra Nevada: Reno, Nevada. July-September 2014.
    - Clinical Internship
    - Acute care, intensive care unit, and geriatrics extended care
- Physiotherapy Associates: Colorado Springs, Colorado. June-August 2013.
    - Clinical Internship
    - Outpatient orthopedic and sports medicine

Certifications

- American Heart Association CPR and AED Certification since 2012.

- CITI Training Completion. February 2013.

Professional Association Membership

- American Physical Therapy Association (APTA) member since 2012.
- Nevada Physical Therapy Association (NPTA) member since 2012.

National Conference Attendance

- APTA Combined Sections Meeting: Las Vegas, Nevada. January 2014.
- APTA National Student Conclave: Louisville, Kentucky. October 2013.
- APTA Combined Sections Meeting: San Diego, California. January 2013.

Professional Leadership

- UNLV Class of 2015 Graduate Assistant. September 2013-May 2014.

Scholarships and Awards

- Physical Therapy Academic Scholarship January of 2013, 2014 and 2015.
- UNLV Graduate College Student Grant Award Spring Semester of 2013, 2014, and 2015.

Research in Progress

- Comparing functional motor control and gait parameters in children with autism to that of typically developing age-matched peers
    - Student Investigator

Christopher Ancell, SPT, BS

Education

- University of Nevada, Las Vegas: Las Vegas, Nevada
  - Doctor of Physical Therapy. Expected degree: May 2015
- University of Nevada; Las Vegas: Las Vegas, NV
  - Bachelor of Science in Kinesiology. May 2011.

Clinical Experience

- Child Find: Las Vegas, Nevada. January-March 2015
  - Clinical internship
  - Pediatric outpatient physical therapy
- Summerlin Rehabilitation Hospital: Las Vegas, Nevada. October-December 2014
  - Clinical internship
  - Inpatient rehabilitation
- St. Rose Sienna: Henderson, Nevada. July-September 2014.
  - Clinical internship
  - Acute physical therapy
- Physiotherapy Associates; Rainbow: Las Vegas Nevada. June-August 2013.
  - Clinical internship
  - Adult outpatient physical therapy

Professional Association Membership

- American Physical Therapy Association (APTA) member since 2012
  - Memberships: Geriatric, Pediatric and Neurology Sections
- Nevada Physical Therapy Association (NPTA) member since 2012

- Memberships: Student Special Interest Group (SSIG)

- American Heart Association Healthcare Provider CPR and AED Certification since 2013

National Conference Attendance

- APTA Combined Sections Meeting: Las Vegas, Nevada. January 2014.
- APTA Combined Sections Meeting: San Diego, California. January 2013.

Research in Progress

- Comparing functional motor control and gait parameters in children with autism to that of typically developing age-matched peers
  - Student Investigator