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A COMPARISON OF SPATIAL-TEMPORAL GAIT VARIABILITY IN OVER-GROUND AND TREADMILL WALKING IN CHILDREN WITH AUTISM

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ABSTRACT

Children with Autism Spectrum Disorder (ASD) experience an increased sedentary lifestyle which results in elevated risk for being overweight and obese. A low-cost and viable solution to increase physical activity while accommodating for social-behavioral barriers such as stereotypy, aggressive, or non-verbal characteristics, may be treadmill-related interventions. Gait variability during treadmill ambulation has not been extensively researched in the ASD population, therefore the aim of this study was to quantify the acute effects of treadmill usage on spatial-temporal gait parameter variability when compared to overground walking. Three-dimensional kinematic data were obtained through motion analysis where 5 children with ASD were outfitted with retroreflective markers on their lower extremities. Participants walked overground across a 10-meter walkway for 12 trials, then on a treadmill for 5-minutes continuously; both conditions were at self-selected pace. Variability was computed via coefficient of variation for step width, double limb support, and bilateral stride length and step length. Then variables of interest were assessed through dependent samples t-tests to identify significant differences between conditions (α=0.05). Analysis revealed no statistically significant differences were observed between overground and treadmill gait conditions, which contradicts previous findings. In neurotypical literature, gait modifications were observed during treadmill gait due to equilibrium maintenance from the change in external stimuli during gait whereas unchanged spatial-temporal gait variability in this ASD sample may suggest posture instability and a system that is less adaptable to perturbations as optimal levels of variability were fluctuating. Future research should focus on trip/fall risk as well as gait modulation to gain a better understanding as to why variability during TM gait may go unchanged in children with ASD.

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1. INTRODUCTION

Autism spectrum disorder (ASD) is classified as a developmental disability that can cause social, communicative, and behavioral challenges [1-3]. When compared to their peers, children with ASD are less physically active and fit [4-7], as well as more at risk for being overweight or obese [8]. This may be due to social skill impairment [9] and the social barriers experienced [1] causing an increase in sedentary behavior [5,10]. Children with ASD require a solution to increase physical activity and decrease the prevalence of obesity while accommodating for social-behavioral barriers such as stereotypy, aggressive, or non-verbal characteristics. Treadmill (TM) interventions may be a safe, viable, and low-cost intervention for children with ASD as research has shown TM walking does not increase the risk of tripping in children with ASD [11] and may result in similar gait regulations as seen within Parkinson's Disease patients [12]. However, no studies have observed spatial-temporal gait parameter variability in children with ASD during TM walking compared to over ground (OG) walking.

Gait mediation and modulation are the result of the interactions within a complex neuromuscular system, under the influence of sensory feedback [13]. Three brain structures have been researched in individuals with ASD: motor cortex, basal ganglia, and cerebellum [14-17] where researchers have examined their roles in motor function, acquiring new skills and action sequences; though results are inconclusive over the specific influence of these structures [14,17-22]. Although the cause is speculated, the general consensus is that individuals with ASD display motor delays [22], impaired postural control [23-25], lack of motor coordination [26], clumsiness [27], and deficits in fine and gross motor skills [28]. As such, the interest in gait analysis has been of heightened interest in this population to further the understanding of motor behavior. Previous OG gait mechanics literature comparing children with ASD to children with NT

development observed decreases in stride length [29,30] and hip and ankle range of motion [31,32], as well as increases in stance time [30], base of support [33], stride width variability [34,35], stride length variability [36], and cadence [37]. Weiss et al. [30] observed similar findings including decreases in velocity, step length and increases in the time spent in single limb support, double limb support, and stance phase in children with ASD when compared to children with NT development. Overall, these findings characterize individuals with ASD as having highly variable lower extremity gait patterns when compared with NT controls [30,34].

Gait variability is inherent within human systems and is viewed as a continuum where the magnitude of variability is dependent on neurological functioning capabilities of each individual [38]. Stergiou and colleagues [38] described decreased system variability as being less adaptable to perturbations, which may then characterize children with ASD as having a higher predisposition to injury based on their decreased variability during the terminal swing phase of gait [34]. In turn, it has been suggested that TM gait in NT populations may inhibit an individual's natural variability [39-41] creating a stable and possibly more predictable gait pattern [39], thus, utilizing TMs in clinical populations, such as children with ASD, may prove beneficial in examining gait variability. Previously, Kautz et al. [42] found that TM-based walking evoked distinctive gait deviations, therefore TM gait analysis may be best in detecting motor control deficits during gait. Stereotypy has been established as a prevalent motor characteristic of ASD that falls under the umbrella of restrictive, repetitive behaviors which are often associated with an underlying brain dysfunction [43]; restrictive, repetitive behaviors are characterized as having an inflexible component in nature [43,44]. These behaviors have also been associated with hyperactivation of a part of the brain responsible with attention allocation which [45] which could alter with their methods of regulating gait variability. Currently, there is

a paucity of studies examining spatial-temporal gait parameter variability in children with ASD comparing OG performance to TM performance. Further understanding how NT populations adapt gait during TM walking may provide a theoretical basis in developing gait interventions in clinical populations such as children with ASD. Before TM interventions are prescribed for children with ASD to combat physical inactivity, the acute effects on spatial-temporal gait parameter variability needs to be investigated. A greater understanding of variability responses during TM gait may give insight to their ability to modulate spatial-temporal gait parameter characteristics to different perturbations. As such, the purpose of this study was to quantify the acute effects of TM usage on spatial-temporal gait parameter variability when compared to OG walking. Based on the lack of gait modification needed during TM walking in preliminary results [11], it was hypothesized that TM gait variability in children with ASD would decrease when compared to OG gait.

2. METHODS

2.1 PARTICIPANTS

An *a priori* power analysis was performed using step length pilot data from children with ASD and children with NT [34]. A sample of 28 total participants, 14 in each group, was determined to provide sufficient statistical power due to an estimated effect size of 0.99, power of 0.80 and an alpha of 0.05. Therefore, our target was thirty children (15 with ASD and 15 with NT) between the ages of 8-15 years, but only five participants were recruited to participate in this study. To confirm ASD diagnosis, parents were required to bring a copy of their child's most recent Individualized Education Plan (IEP). Participants were required to ambulate without the use of assistive devices such as canes, crutches, or walkers. Children who were NT were age- and sex-matched to a study-enrolled participant with ASD and absence of any disorders was verbally confirmed by the parent. Prior to completing any laboratory activities, written parental consent and child assent were obtained via institutionally approved documentation (IRB# 1829668-1).

2.2 PROCEDURES

Once child assent and parental consent were obtained, participants' age, sex, height, and mass were measured and recorded. Participants were instructed to wear tight-fitting clothing to accurately represent segment movement during data collection and assist in the placement of motion capture retro-reflective markers. To track segmental movement, 14-mm retro-reflective markers were adhered bilaterally to the following anatomical landmarks with double sided hypoallergenic tape: anterior superior iliac spine, iliac crest, posterior superior iliac spine, medial and lateral femoral epicondyle, medial and lateral malleoli, the base of the second toe, and on the

calcaneus. An additional marker was placed on the sacrum to aid in tracking pelvic movement. Four four-marker clusters were placed bilaterally on the lateral aspect, mid-segment on the thighs and shanks secured with elastic wraps. Three-dimensional kinematic data were collected by a ten-camera three-dimensional motion capture system (200Hz, Vicon Motion Systems Ltd., Oxford, UK). Once all markers were adhered, participants were instructed to stand in a 'T-pose' within the capture volume for static calibration. Following static calibration, participants began OG trials. A total of 12 walking trials were collected at a self-selected velocity [30,34-37,46] along a 10-meter path, verbal cues will be given to remind participants to walk as normally as possible, when necessary. OG trials were collected first to act as participants' baseline.

After completing the OG trials, a five-minute rest break was given before beginning TM trials. TM trials were performed on an ActiveStep treadmill (Simbex, Lebanon, NH) interfaced to a computer running ActiveStep software to control the velocity of the TM. An aggregate mean velocity was computed from OG trials and used for the TM trials. TM velocity was modified if participants felt it was too fast, to ensure safety and comfortability. Participants were then instructed to walk for a total of five-minutes continuously where kinematic data were collected for five 30-second intervals: from 0-30 seconds, 1:00-1:30 minutes 2-2:30 minutes, 3-3;30 minutes, 4-4:30 minutes, and ended at 5 minutes.

2.3 DATA REDUCTION

Raw data were exported from Vicon Nexus to Visual 3D Biomechanical Software Suite (C-Motion, Inc., Germantown, MD, USA) for processing. A seven-segment model was constructed from the marker trajectories to include the pelvis, and left and right thigh, leg, and foot segments. Marker trajectories were filtered with low-pass Butterworth digital filter at a cutoff frequency of 6 Hz. Given that children with ASD demonstrate asymmetrical movement

patterns between contralateral limbs [34,35,46], limb data were not collapsed for comparisons. Variables of interest included stride length, step length, step width, and double limb support time. Variability was computed as coefficient of variation (CoV) and was used for analysis [47].

2.4 STATISTICAL ANALYSIS

Group mean and standard deviation values were calculated for each variable of interest then collated to a group average to create ASD and NT groups for comparisons. Means for stride length and step length were calculated independently for each limb to due to the established heterogeneity in children with ASD [30,34-37,46]. Dependent *t*-test (p=0.05) were used to test for significant differences in each variable of interest, comparing OG and TM CoV magnitudes. All statistical tests were performed in SPSS Software (v24 IBM Corp ©, Armonk, NY).

3. RESULTS

Participant anthropometric data are presented in **Table 1.** Individual means and standard deviation values of CoV magnitude for each variable for OG and TM conditions are presented in Table 2. Dependent t-tests yielded no statistical significance for left ($t(4)= -0.731$ $p= 0.505$) and right stride length ($t(4)= -0.021$ $p= 0.984$), left ($t(4)= 0.842$ $p= 0.447$) and right ($t(4)= 0.525$ $p= 0.628$), step width ($t(4)= 0.225$ $p= 0.833$), and double limb support time ($t(4)= 1.127$ $p= 0.323$) between OG and TM conditions in children with ASD. The aggregate CoV means **(Figures 1-3)** were not found to be statistically significant for the following variables of interest: left and right stride length, left and right step length, double limb support time, and step width.

Table 1
Subject Anthropometrics.

Subject	Height (m)	Mass (kg)	Gender	Age (yrs)
ASD_01	1.71	56.3	Male	15
ASD_03	1.72	82.7	Male	13
ASD_04	1.45	48.9	Male	11
ASD_05	1.71	103.1	Male	14
ASD_06	1.76	84.3	Male	14

Table 2
CoV mean and standard deviation values for spatiotemporal parameters.

	OG	TM	
	Mean (SD)	Mean (SD)	*p*-value
L Stride Length	4.59(±2.41)	6.54(±4.97)	0.505
R Stride Length	4.65(±2.49)	4.70(±3.24)	0.984
L Step Length	5.72(±3.46)	3.87(±2.24)	0.833
R Step Length	3.95(±1.81)	4.77(±1.96)	0.323
Double Limb Support Time	7.98(±4.23)	5.56(±1.60)	0.447
Step Width	10.19(±4.17)	9.75(±5.70)	0.628

Values represent CoV percentages for each variable. Mean ± standard deviation (SD) for each gait variable of interest are displayed. Asterisk (*) indicates a statistically significant difference between the two conditions at $p<0.05$.

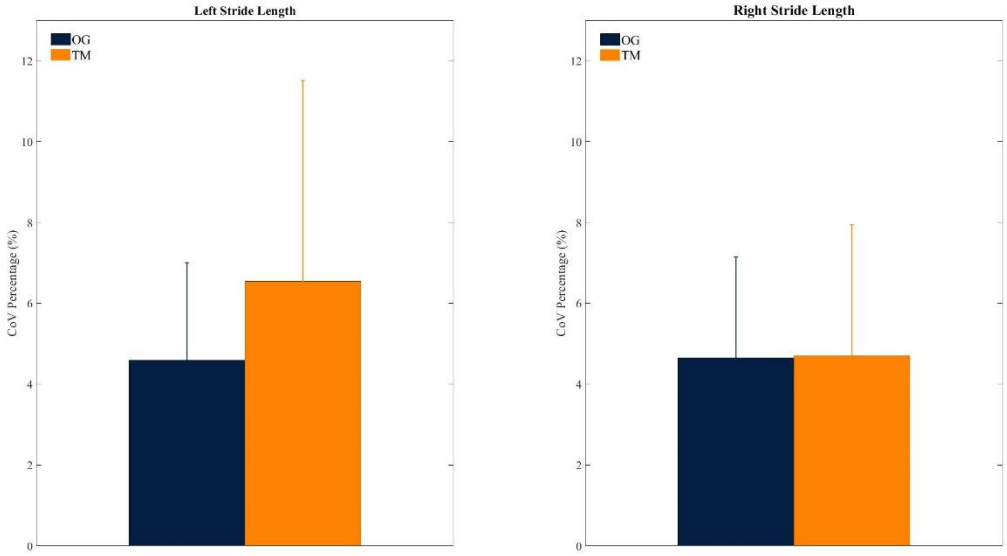

Figure 1. Left and Right limb CoV percentage means and standard values for stride length during OG and TM gait. Asterisk (*) indicates a statistically significant difference between the two conditions at p<0.05.

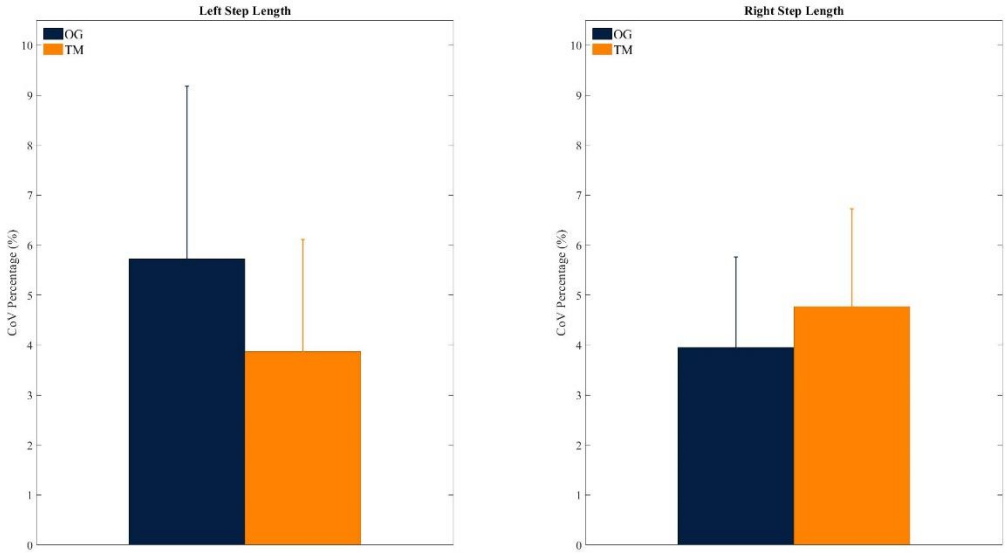

Figure 2. Left and Right limb CoV percentage means and standard values for step length during OG and TM gait. Asterisk (*) indicates a statistically significant difference between the two conditions at p<0.05.

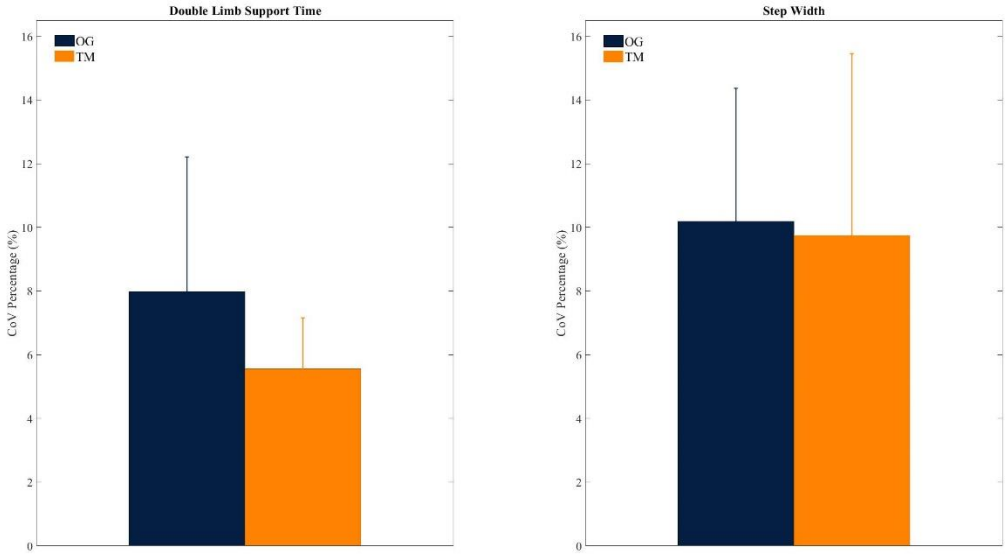

Figure 3. CoV percentage means and standard values for double limb support time and step length during OG and TM gait. Asterisk (*) indicates a statistically significant difference between the two conditions at $p<0.05$.

4. DISCUSSION

The purpose of this study was to quantify the acute effects of TM usage on spatial-temporal gait parameter variability when compared with OG walking. It was hypothesized that gait variability would decrease in the TM condition when compared with OG gait and was not supported in the current study. Prior research analyzing the effects of TM usage on spatial-temporal gait parameters when compared to OG gait discovered decreased variability during TM trials in NT populations [39-41,48], however children with ASD have displayed higher gait variability than NT children [30]. Previously, TMs have been implemented for individuals with Parkinson's or Huntington's Disease in a clinical setting with the aim to regulate and improve on decreased OG stride length and gait speed deficits [12,49]. Research revealed decreases in spatial-temporal variability during TM usage within these clinical populations and have been speculated to have similar methods of regulating gait as individuals with ASD [12,48,49]. Contrary to prior findings, the current study found that spatial-temporal variability was similar among conditions which may be due to the unchanging nature of the TM belt as it may not be enough of an external stimulus to overcome the inherent variability found within this sample.

The findings of the current analysis are not supported by earlier literature that has found significant increases in stride width variability [34,35], stride length variability [36], and double support time [30]. Gait modifications observed during TM gait in NT populations resulted, in part, due to equilibrium maintenance from the change in external stimuli during gait [50]. Similarly, NT children exhibited larger changes in step width than NT adults when comparing OG and TM gait [50]. **Figures 1-3** illustrate that variability was not different among variables between OG and TM conditions in children with ASD which could be associated with atypical cerebellar activation that has previously been associated with clumsiness and poor motor

coordination found within other studies [26,27,32,51]. Disruptions in cerebellar functioning may be at play during TM gait that facilitates similar spatial-temporal variability as seen during OG gait as the cerebellum is involved in motor function, acquiring new skills, and action sequencings [14-16].

Based on the results of this study, spatial-temporal variability found within this sample did not change during TM usage which coincides with prior literature that less than and more than optimal levels of variability create a system that is less adaptable to perturbations [38] which could directly affect stability during gait. Stability during TM usage is important as most commercial-grade TMs do not utilize a safety harness in case of slipping, so proper equilibrium and gait modifications during use is imperative for the safety of the user. If children with ASD are maintaining similar gait characteristics during TM usage, then there may be an increased risk of tripping, or stepping off the belt, during use. Disruptions within the motor cortex, basal ganglia, and cerebellum have been suggested to be the cause of fine and gross motor skill deficits in individuals with ASD [22,28,52,53], therefore, based on the results of this analysis, similar disruptions may result in no change observed in OG gait variability when compared to TM gait. Preliminary data suggests that TM use does not increase tripping risk in children with ASD as kinematic strategies for a safer gait were observed instead [11], however trip and fall risks were not measured or quantified to fully support the use of TMs in this sample.

4.1 STUDY LIMITATIONS

The current study analyzed data on five participants, leaving the study very underpowered. Assuring there is appropriate sample size could possibly yield statistically significant findings consistent with prior findings, while the current analysis did not reveal any statistically significant differences in CoV between OG and TM gait. Within this study there were significant

outliers, backed by large standard deviations, that could be attributed to the heterogeneity of children with ASD which presents increased variability when compared to their NT counterparts [30,34-36]. CoV is substantially affected by outliers [47,54], therefore, in conjunction with a small sample size, data may have been skewed due to these factors. Future studies should consider a group and single-subject comparison when analyzing ASD gait characteristics to account for the heterogeneity observed within the population. Additionally, single-subject analysis may have clinical significance as it would provide valuable insight on the individual's gait characteristics resulting in more individualized intervention plans.

5. CONCLUSION

This analysis is not supported by previous findings that TM usage negates the need for gait modification [11] and could help regulate gait variability to create a more stable gait [49]. The results of the current study do not fall in line with what has been previously found in literature about the effects of TM usage on their NT counterparts [39-41], furthermore children with ASD may utilize different kinematic strategies of gait regulation in general. Consequently, caution is needed when utilizing TMs as a possible intervention to counteract sedentary lifestyles as variability between conditions went unaltered. However, these findings are valuable as they serve as preliminary data for future studies to further examine gait mechanics in comparing TM walking to OG walking in this population. Additionally, the results of this study further build upon prior findings that motor deficits in children with ASD may be caused by disruptions within the motor cortex, basal ganglia, and cerebellum [22,28,52,53]. As such, a lack of necessary gait modifications needed to maintain equilibrium [50] and to keep appropriate levels of variability [38] may be linked to abnormal cerebellar activation during TM usage [38,50]. Future research should focus on the role these structures play in gait modulation to gain a better understanding as to why variability during TM gait may go unchanged in children with ASD.

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VITA

René Ubaldo Sanchez graduated from New Mexico State University in 2018 with a Bachelor of Science (B.S.) in Kinesiology. In Fall 2020, he enrolled in the University of Texas at El Paso's Masters in Kinesiology program. He was employed as a graduate teaching assistant under various professors of the program in subjects such as biomechanics, exercise physiology, and research methods. Additionally, he joined the Stanley E. Fulton Gait Research and Movement analysis (GAIT) laboratory under the supervision of Dr. Jeff Eggleston. During his time in the GAIT lab, he gained experience writing several IRB documents as well as lead data collections independently. Notably, he assisted in writing a Dodson Research Grant for a multifaceted study on individuals with Cerebral Palsy. He also led a small team of undergraduate students during the collection of kinetic and kinematic data of UTEP's women's Volleyball team to assess injury risk associated with jumping and landing. Rene's time in the lab equipped him the necessary skills that involved quantitative analysis of both clinical and athletic populations.