2-2019

Variability of spatiotemporal gait parameters in children with and without Down syndrome during treadmill walking

Matthew Beerse

Gena Henderson

Huaqing Liang

Toyin Ajisafe

Jianhua Wu

***4. Title Page (with authors and addresses)**

Variability of spatiotemporal gait parameters in children with and without Down syndrome during treadmill walking

Matthew Beerse [a,b†], Gena Henderson [a†], Huaqing Liang [a], Toyin Ajisafe [c], Jianhua Wu [a,d]*

[a] Department of Kinesiology and Health, Georgia State University, Atlanta, GA, USA

[b] Department of Health and Sport Science, University of Dayton, Dayton, OH, USA

[c] Department of Kinesiology, Texas A&M University Corpus Christi, Corpus Christi, TX, USA

[d] Center for Movement & Rehabilitation Research, Georgia State University, Atlanta, GA, USA

* Corresponding author:

Jianhua Wu, Ph.D.

Department of Kinesiology and Health, Center for Movement & Rehabilitation Research,

Georgia State University. 125 Decatur Street, Atlanta, GA 30302, USA.

Telephone: 1-404-413-8476; Fax: 1-404-413-8053; Email: jwu11@gsu.edu

† Contributed equally to this study.

Word count for Abstract: 284

Word count for Main Text: 2,995

Number of Tables: 2

Number of Figures: 2

This manuscript is submitted as an Original Article.

Acknowledgements

The authors are thankful to all the participants and their families for their participation in this study. This study was supported in part by the Jerome Lejeune Foundation.

Abstract

Background: Increasing walking speed and including bilateral external ankle load have been shown to improve aspects of the gait pattern of children with Down syndrome (DS). However, it is unknown if speed and ankle load improves the cycle-to-cycle variability in a similar way.

Research question: How do changes of walking speed and external ankle load impact spatiotemporal variability during treadmill walking in children with and without DS?

Methods: Thirteen children with DS (aged 7-10 years) and thirteen age- and sex-matched typically developing (TD) children participated in this study. Subjects completed two bouts of 60-second treadmill walking at two different speeds (*slow* and *fast*) and two load conditions (no load and ankle load equaling to 2% bodyweight at each side). Kinematic data was captured using a Vicon motion capture system. Mean and coefficient of variance of spatiotemporal gait variables were calculated and compared between children with and without DS.

Results and significance: Across all conditions, the DS group took shorter and wider steps than the TD group, but walked with a similar swing percentage, double support percentage, and foot rotation angle. Further, the DS group demonstrated greater variability of all spatiotemporal parameters, except for step width and foot rotation angle. Our results indicated that children with DS can modulate their spatiotemporal gait pattern accordingly like their TD peers when walking faster on a treadmill and/or with an external ankle load. Smaller step width variability in the DS group suggests that mediolateral stability may be prioritized during treadmill walking to safely navigate the treadmill and complete walking tasks. Similar temporal parameters but distinct spatial parameters in the DS group suggest that they may have developed similar rhythmic control but are confined by their spatial movement limitations.

Introduction

Individuals with Down syndrome (DS) typically present with hypotonia, joint hypermobility, reduced strength, and cognitive impairments [1-3]. These conditions are considered to underlie the often-termed "clumsy" movement patterns of individuals with DS characterized by poor balance control, reduced joint and muscle coordination, abnormal gait kinematics, delays in acquiring complex movement patterns, and abnormal variability of movement [4-8]. These impairments produce stereotypical alterations in both the gait patterns of individuals with DS and their ability to adapt to changing gait conditions [9-12].

When children with DS are challenged to walk faster on a treadmill they adapt similarly to typically developing (TD) children by increasing step length and decreasing step width [13]. The inclusion of external ankle load increased stride length and decreased cadence in children with DS similarly to their TD peers [10]. The combination of fast walking and ankle load demonstrated a more advanced gait pattern with an improved power spectrum and general muscular activation in children with DS [9, 10]. Although treadmill training is a common intervention for infants [14] and children with DS [9, 10], it is unknown to what degree walking speed and external ankle load affect cycle-to-cycle gait variability in children with DS.

All movement contains some degree of variability, which enables adaptation to new tasks and/or environments [15, 16]. However, too little or too much variability can be associated with movement dysfunction. When learning to walk, toddlers with DS display greater variability in step length and width and reduced these variabilities at a slower rate than their TD peers [17]. During treadmill walking, adults with DS demonstrate greater variability of center-of-mass, step width, and step length than healthy controls and these differences become greater at faster speeds [18]. Moreover, adults with DS increase stride velocity variability and decrease step width variability more than healthy controls when walking overground in more challenging conditions, and there is correlation between amount of variability and self-reported frequency of falls in adults with DS suggesting its clinical relevance and significance [19].

The purpose of this study was to investigate the acute effects of walking speed and external ankle load on spatiotemporal gait parameters and their variability patterns between children with and without DS. We hypothesized that children with DS will demonstrate a similar spatiotemporal adaptation pattern to their TD peers such that at faster speeds or wearing external ankle load, both groups will increase mean step length and swing percentage and decrease mean step width and double support percentage. Between the two groups, children with DS will show smaller step length and swing percentage and greater step width and double support percentage. In terms of gait variability, we hypothesized that a similar variability pattern will emerge for both groups such that variability of step length, swing percentage, and double support percentage will increase with speed and ankle load, and variability of step width will decrease. Between the two groups, children with DS will display greater variability in all the spatiotemporal variables.

Methods

Thirteen children with DS aged 7-10 years were recruited through local parent support groups and the Down Syndrome Association of Atlanta. Thirteen age- and sex-matched TD children also participated in the study. All participants were able to walk overground for 10-meters independently. Exclusion criteria included a history of medical conditions or the inability to walk independently. Anthropometric data were collected for each subject including body mass, height, and leg length. The children with DS were shorter in height but had similar body mass (Table 1). This study was approved by the institutional review board at the hosting university. Written informed consent was obtained from the parents or guardians of all the subjects before data collection.

Subjects completed treadmill walking at two different speeds and two load conditions for a total of four conditions. The treadmill speed conditions were set by the subject's preferred walking speed, calculated as the average speed of three 10-meter overground walking trials. Previous studies have shown that preferred treadmill walking speeds are lower than overground in children with DS, thus our treadmill speed conditions included a *slow* speed (75% of preferred) and a *fast* speed (100% of preferred) [4, 20]. The two load conditions included *no load* and *ankle load* equal to 2% of body weight on each side. This amount of ankle load increased the moment of inertia of the leg by 39%, which was tolerable in children with DS, but resulted in a modulated gait pattern [10]. We attached adjustable weight cuffs above each ankle and strapped them tightly to minimize any motion during walking. Sixty seconds of data was collected after the treadmill reached the condition speed and the subject visually appeared to be walking at a steady-state. Subjects completed two treadmill walking trials at each condition. Presentation of the conditions was randomized across subjects. Between trials the subjects were given adequate rest. A custom full-body 18 marker set was attached to each subject, including the heel, ankle, toe, knee, greater trochanter, shoulder, elbow, wrist, and temple bilaterally [10]. Kinematic data was captured using a 7-camera Vicon motion capture system (Denver, CO, USA) at a sampling rate of 100 Hz. Marker trajectories were filtered at a cutoff frequency of 6Hz. Custom MATLAB programs (Natick, MA, USA) were written for data analysis.

Gait events were determined using the anterior/posterior (AP) velocity of each heel marker [21]. A velocity change of the heel from positive to negative indicated a heel-strike event and a change from negative to positive indicated a toe-off event. To confirm the accuracy of this algorithm with our subjects, ten subjects were randomly chosen and manually labeled for heel-strikes and toe-offs and compared to the algorithm-generated gait events. Mean difference between the manually labeled and algorithm-generated heel-strike events was about one frame and thus deemed acceptable. However, the algorithm-generated toe-off event occurred, on average, three frames before those manually labeled. Therefore, three frames were added to the algorithm-generated toe-off events for each trial.

Step length was calculated as the AP difference between the ipsilateral heel marker at heel-strike and the contralateral heel marker at minimum AP position during stance phase. Step width was calculated as the medial/lateral (ML) difference between the heel markers at heel-strike. Both step length and width were normalized by leg length. Temporal variables included swing percentage of gait cycle, and double support percentage of gait cycle. Double support percentage was calculated for the first double support phase of a gait cycle. Foot rotation angle [22] was calculated as the angle between the line connecting the toe and heel markers of the current foot step (i.e., line of foot placement) and the line connecting the heel of the current and previous step from the same side (i.e., line of foot progression) [23]. A positive or negative FRA indicated an out-toeing or in-toeing position of the foot with respect to the line of foot progression, respectively. Spatiotemporal variables were calculated for each side and combined after no asymmetry was observed between the two sides for either group. To investigate the variability of spatiotemporal variables, coefficient of variation (CV) was calculated as the ratio of standard deviation to mean value for each variable within each trial. For FRA, we used absolute values when calculating the CV.

A three-way (2 group x 2 speed x 2 load) mixed ANOVA with repeated measures on speed and load was conducted on the spatiotemporal variables and their CV. Normality was assessed using the Shapiro-Wilk test. Variables found to violate normality were log transformed and reassessed using the Shapiro-Wilk test. This process sufficiently normalized our data. Post-hoc pairwise comparisons were completed when necessary. The statistical analysis was completed using the SAS 9.4 statistical software (Cary, NC). A significance level was set at $\alpha=0.05$.

Results

Some children with DS could not complete all four walking conditions; 11 completed the *fast* speed condition without ankle load, 10 completed the *slow* speed condition with ankle load, and 7 completed the *fast* speed condition with ankle load. No significant differences were found between those children with DS who were able to complete all conditions and those who were not, so both subgroups were combined for analysis. All 13 TD children completed all walking conditions.

Mean spatiotemporal variables

Both the TD and DS groups increased normalized step length and maintained normalized step width when increasing walking speed (Table 2). With additional ankle load, both groups maintained normalized step length; however, the TD group increased normalized step width while the DS group did not change step width. Statistical analysis demonstrated that there was a group by load interaction for normalized step length ($p=0.016$) and step width ($p<0.001$; see Table 2 for the details). Post-hoc analysis indicated that the DS group had a smaller step length and a greater step width than the TD group at each load condition, and the difference between the two groups became greater at the ankle load condition. There was also a speed effect for normalized step length across the two groups ($p<0.001$). In addition, FRA was similar between the two groups (between 0 and 5 degrees) and unaffected by speed and load conditions.

While walking faster, both groups displayed similar trends and values by increasing swing percentage but decreasing double support percentage (Table 2). With additional ankle load, both groups showed similar trends and values by increasing swing percentage but decreasing double support percentage. Statistical results demonstrated that there was a speed effect ($p<0.001$) and a load effect ($p=0.036$) for swing percentage, and a speed effect ($p<0.001$) and a load effect ($p=0.006$) for double support percentage. There was neither a group effect nor a group by speed/load interaction for both temporal variables.

Variability of spatiotemporal variables

Both groups decreased normalized step length variability but increased normalized step width variability from *slow* to *fast* speed condition (Fig. 1a-d). With the additional ankle load, both groups displayed no change in normalized step length variability but decreased normalized step width variability. Regardless of speed and load conditions, the DS group had greater step length variability and smaller step width variability than the TD group. For step length variability, there was a group effect ($F(1,18)=24.93$, $p<0.001$) and speed effect ($F(1,17)=8.44$, $p=0.010$). For step width variability, there was a group effect ($F(1,18)=8.91$, $p=0.008$), speed effect ($F(1,17)=6.82$, $p=0.018$), and load effect ($F(1,18)=36.22$, $p<0.001$). Both groups showed similar variability in FRA across the speed and load conditions with no significant statistical results (Fig. 1e-f).

Both groups decreased variability in swing and double support percentage from the *slow* to *fast* speed condition (Fig. 2a-d). The additional ankle load did not change variability in both swing and double support percentages. Regardless of the speed and load conditions, the DS group showed greater variability in both swing and double support percentages than the TD group. Statistical analysis showed that there was a group effect ($F(1,18)=26.85$, $p<0.001$) and a speed effect ($F(1,17)=41.95$, $p<0.001$) on swing percentage variability, and a group effect ($F(1,18)=21.84$, $p<0.001$) and a speed effect ($F(1,17)=9.10$, $p=0.008$) on double support percentage variability.

Discussion

Partially supporting out hypotheses, our results indicated that children with DS displayed some similar trends in spatiotemporal pattern and its variability as their TD peers while adapting to walking speed and ankle load but maintained group-level differences across all conditions. This is consistent with previous findings of an overall lack of stability control in individuals with DS [19]. In this study, modulating speed was found to induce similar acute adaptations in both groups and the DS group demonstrated greater improvement of stability by reducing variability in step length and swing percentage. Clinical interventions that involve modulating speed and external ankle load during treadmill training have been shown to improve some aspects of gait patterns of infants [14] and children with DS [9, 10]. Additionally, children with DS improve their overground gait patterns after treadmill walking practice [13]. Clinicians can use these findings to their advantage by modulating treadmill conditions to produce adaptations desired in overground walking. However, in this study, modulating ankle load was found to induce some unexpected compensations in both groups: strict step width control (lower variability) in the DS group and wider steps in the TD group. While these were acute adaptations, when developing clinical interventions, it is important to weigh positive effects with the potential motor compensations. Further research on prolonged treadmill training with changes in speed and external ankle load are required to quantify the potential long-term influence of motor compensations reported in this study.

In contrast to previous work in adults [24], both groups of children responded to the *fast* speed condition by decreasing the variability of step length, swing percentage, and double support percentage. When walking on a rapidly moving treadmill belt, both groups took longer steps, spent more time in swing phase and less time in double support. The consistent faster pace might have necessitated this adaptation and reduced the variability of these parameters to maintain a stable position in the middle of the treadmill belt. This suggests that a portion of gait variability can be reduced or optimized when adapting to a faster speed in children with and without DS. As excessive variability of stride velocity and limited variability of step width is correlated with fall risk in adults with DS [18], interventions which normalize variability may improve the overall stability and safety of individuals with DS. Our results suggest that treadmill training at a fast speed, which decreases step length variability but increases step width variability, may represent such an intervention.

Our results of unchanged mean step width and FRA are in opposition to previous studies [13, 25-27]. However, Agiovlasitis et al. [24] noted a lack of change in step width at faster speeds in young adults with DS during treadmill walking and proposed, as we speculated, that they might maintain stability at faster speeds by modulating step length alone. Methodologically, FRA is affected by both the degree of in-toeing or out-toeing of the foot relative to the line of progression and the placement of the foot in the ML direction. Our definition is different from previously reported angles, which were defined between the line of progression (i.e., the regression line of all the steps) and the placement of the foot [25, 26]. Also, the treadmill might substantially constrain the ML placement of the foot. Additionally, arch height has been shown to influence FRA in children with DS [5] and we did not control for the arch height of our subjects.

Interestingly, step width variability increased with the *fast* walking speed but decreased with ankle load for both groups. Individuals with DS have been found to value frontal plane stability, prioritizing equilibrium maintenance over forward progression during overground gait [8, 19, 28]. The increased consistency of wider steps during the ankle load condition suggests that the external ankle load might present an increased challenge to ML stability during gait, requiring strict control. The prioritization of maintaining step width variability might illustrate a posture-first strategy, which has been proposed to prevent falls during more complex walking tasks [19, 29]. However, while the ankle load potentially perturbed ML stability, children with DS increased swing percent and decreased double support percent, similar to the TD group. This result furthers the proposal that external ankle load might aid the unloading of the leg during the stance-to-swing transitions, and the increased moment of inertia most likely assisted the pendulum motion of the swing leg [9]. Therefore, while external ankle load might acutely improve temporal parameters associated with stability, there appeared a requirement to more strictly maintain spatial base of support (BOS). The increased step width found in the TD group was likely due to the added weight above the ankle, requiring more space during swing to safely pass the legs by each other. It may warrant further investigation on whether other unexpected compensations, such as circumduction, are utilized to accommodate the external load.

Previous studies have suggested that the more pronounced out-toeing demonstrated by young adults with DS during fast overground walking is an attempt to increase BOS and improve stability at the expense of efficiency [26]. Therefore, it is reasonable for modulation of FRA variability to also emerge as a strategy to increase stability. As previously noted, we believe that the ML constraints of the treadmill might have limited the capacity of both groups to alter FRA, resulting in preferential modulation of step width to increase BOS and improve ML stability. Further studies that examine the variability of FRA during fast walking overground are needed to explore this possible explanation.

Although both groups demonstrated similar mean temporal parameters across both speed conditions, the children with DS demonstrated increased variability of these parameters under all conditions. This increased variability may be a result of their inherently lower muscle tone and decreased ability to finely time movements [1]. However, the children with DS were able to successfully maintain similar rhythmic timing as their TD peers across both speed conditions. Black et al. [4] suggests that children with DS may recognize the inherent difficulty in controlling the excessive laxity of their movements and choose to only constrain variability that may negatively affect task performance. Our findings support this notion, as the increased temporal variability exhibited by the children with DS did not affect their ability to demonstrate similar temporal variables as their TD peers.

Some limitations of this study include our small sample size, exacerbated by the inability of some children with DS to complete all walking conditions. Additionally, the short length of our walking trials might have been insufficient for our subjects to accommodate to the task. Although we only collected data when subjects visually appeared to have achieved steady-state walking, more subtle compensations might have occurred. Further, subjects were not controlled for their experience with treadmill walking. Although the tasks presented were novel to most subjects, the actual degree of task novelty might have varied across the subjects. Finally, our results can only be generalized to children with DS and should be investigated in individuals with DS at different ages to determine if these adaptations are consistent across the lifespan.

References

[1] Block ME. Motor Development in Children with Down Syndrome: A Review of the Literature. Adapted Physical Activity Quarterly. 1991;8:179-209.

[2] Lott IT. Neurological phenotypes for Down syndrome across the life span. Prog Brain Res. 2012;197:101-21.

[3] Roizen NJ, Patterson D. Down's syndrome. Lancet. 2003;361:1281-9.

[4] Black DP, Smith BA, Wu J, Ulrich BD. Uncontrolled manifold analysis of segmental angle variability during walking: preadolescents with and without Down syndrome. Exp Brain Res. 2007;183:511-21.

[5] Galli M, Cimolin V, Rigoldi C, Pau M, Costici P, Albertini G. The effects of low arched feet on foot rotation during gait in children with Down syndrome. Journal of Intellectual Disability Research. 2014;58:758-64.

[6] Galli M, Rigoldi C, Brunner R, Virji-Babul N, Giorgio A. Joint stiffness and gait pattern evaluation in children with Down syndrome. Gait Posture. 2008;28:502-6.

[7] Palisano RJ, Walter SD, Russell DJ, Rosenbaum PL, Gemus M, Galuppi BE, et al. Gross motor function of children with down syndrome: creation of motor growth curves. Arch Phys Med Rehabil. 2001;82:494-500.

[8] Rigoldi C, Galli M, Mainardi L, Crivellini M, Albertini G. Postural control in children, teenagers and adults with Down syndrome. Res Dev Disabil. 2011;32:170-5.

[9] Wu J, Ajisafe T. Kinetic patterns of treadmill walking in preadolescents with and without Down syndrome. Gait & posture. 2014;39:241-6.

[10] Wu J, Ajisafe T, Beerse M. Children Display Adult-Like Kinetic Patterns in the Time Domain, But Not in the Frequency Domain, While Walking With Ankle Load. J Appl Biomech. 2015;31:292-308.

[11] Rigoldi C, Galli M, Albertini G. Gait development during lifespan in subjects with Down syndrome. Research in Developmental Disabilities. 2011;32:158-63.

[12] Ganley KJ, Powers CM. Gait kinematics and kinetics of 7-year-old children: a comparison to adults using age-specific anthropometric data. Gait & Posture. 2005;21:141-5.

[13] Smith BA, Kubo M, Black DP, Holt KG, Ulrich BD. Effect of Practice on a Novel Task—Walking on a Treadmill: Preadolescents With and Without Down Syndrome. Physical Therapy. 2007;87:766-77.

[14] Wu J, Looper J, Ulrich BD, Ulrich DA, Angulo-Barroso RM. Exploring effects of different treadmill interventions on walking onset and gait patterns in infants with Down syndrome. Developmental Medicine & Child Neurology. 2007;49:839-945.

[15] Fetters L. Perspective on variability in the development of human action. Phys Ther. 2010;90:1860-7.

[16] Vereijken B. The Complexity of Childhood Development: Variability in Perspective. Physical Therapy. 2010;90:1850-9.

[17] Looper J, Wu J, Barroso RA, Ulrich D, Ulrich BD. Changes in Step Variability of New Walkers With Typical Development and With Down Syndrome. Journal of motor behavior. 2006;38:367-72.

[18] Agiovlasitis S, McCubbin JA, Yun J, Pavol MJ, Widrick JJ. Economy and Preferred Speed of Walking in Adults With and Without Down Syndrome. Adapted Physical Activity Quarterly. 2009;26:118-30.

[19] Smith BA, Ashton-Miller JA, Ulrich BD. Gait adaptations in response to perturbations in adults with Down syndrome. Gait & posture. 2010;32:149-54.

[20] Ulrich BD, Haehl V, Buzzi UH, Kubo M, Holt KG. Modeling dynamic resource utilization in populations with unique constraints: Preadolescents with and without Down syndrome. Human Movement Science. 2004;23:133-56.

[21] Zeni JA, Richards JG, Higginson JS. Two simple methods for determining gait events during treadmill and overground walking using kinematic data. Gait & posture. 2008;27:710-4.

[22] Franz JR, Kram R. The effects of grade and speed on leg muscle activations during walking. Gait Posture. 2012;35:143-7.

[23] Angulo-Barroso RM, Wu J, Ulrich DA. Long-term effect of different treadmill interventions on gait development in new walkers with Down syndrome. Gait Posture. 2008;27:231-8.

[24] Agiovlasitis S, McCubbin JA, Yun J, Mpitsos G, Pavol MJ. Effects of Down syndrome on three-dimensional motion during walking at different speeds. Gait Posture. 2009;30:345-50.

[25] Galli M, Cimolin V, Pau M, Costici P, Albertini G. Relationship between flat foot condition and gait pattern alterations in children with Down syndrome. Journal Of Intellectual Disability Research: JIDR. 2014;58:269-76.

[26] Horvat M, Croce R, Zagrodnik J, Brooks B, Carter K. Spatial and temporal variability of movement parameters in individuals with Down syndrome. Percept Mot Skills. 2012;114:774-82.

[27] Kim B-S, Bang DY, Kim B-O. Gait characteristics in down's syndrome. Gait & Posture. 1995;3:84.

[28] Rigoldi C, Galli M, Cimolin V, Camerota F, Celletti C, Tenore N, et al. Gait strategy in patients with Ehlers-Danlos syndrome hypermobility type and Down syndrome. Research in Developmental Disabilities. 2012;33:1437-42.

[29] Kelly VE, Eusterbrock AJ, Shumway-Cook A. Factors influencing dynamic prioritization during dual-task walking in healthy young adults. Gait & Posture. 2013;37:131-4.

6. Table(s)

Table 1: Mean (SD) of subject characteristics, overground walking speeds, and ankle load at each side

Group	Age (yrs)	Sex	Height (m)	Body mass (kg)	Leg length (m)	Fast speed (m/s)	Slow speed (m/s)	Ankle load (kg)
DS	9.12 (1.43)	11M/2F	1.25 (0.09)	31.67 (5.98)	0.57 (0.06)	0.99 (0.36)	0.74 (0.27)	0.60 (0.09)
TD	9.31 (1.49)	11M/2F	1.34 (0.08)*	30.41 (5.50)	0.65 (0.06)*	1.33 (0.11)*	1.00 (0.08)*	0.59 (0.12)

TD: typically developing children; DS: children with Down syndrome. Fast speed: treadmill speed that was equal to the subject's preferred overground walking speed; Slow speed: treadmill speed that was equal to 75% of the subject's preferred overground walking speed. Symbol * denotes a significant difference between the two groups at $p<0.05$.

Table 2: Mean (SD) of normalized step length, normalized step width, swing percentage, double support percentage, and foot rotation angle.

Variable	Group	Slow Speed		Fast Speed		Statistical results
		No load	Ankle load	No load	Ankle load	
Normalized step length	TD	0.79 (0.09)	0.81 (0.10)	0.88 (0.10)	0.91 (0.10)	S: F(1,17)=112.17, p<0.001 G*L: F(1,18)=7.01, p=0.016
	DS	0.66 (0.12)	0.64 (0.13)	0.76 (0.12)	0.76 (0.15)	
Normalized step width	TD	0.19 (0.05)	0.21 (0.05)	0.18 (0.04)	0.21 (0.05)	G*L: F(1,18)=19.96, p<0.001
	DS	0.31 (0.07)	0.32 (0.07)	0.31 (0.08)	0.30 (0.05)	
Swing percentage (% gait cycle)	TD	62.43 (0.54)	62.05 (0.60)	61.53 (0.76)	60.87 (0.75)	S: F(1,17)=92.19, p<0.001 L: F(1,18)=5.16, p=0.036
	DS	64.46 (3.00)	64.49 (3.09	62.66 (2.90)	60.29 (1.88)	
Double support percentage (% gait cycle)	TD	12.54 (0.56)	12.16 (0.64)	11.56 (0.74)	10.92 (0.67)	S: F(1,17)=104.39, p<0.001 L: F(1,18)=9.50, p=0.006
	DS	13.81 (2.21)	14.07 (2.77)	12.47 (2.64)	11.85 (1.93)	
Foot rotation angle (deg)	TD	4.13 (8.56)	4.42 (8.53)	5.15 (6.84)	4.93 (8.47)	
	DS	1.38 (10.50)	2.36 (8.58)	-0.08 (10.73)	3.74 (10.87)	

In statistical results, S: speed effect; L: load effect; G*L: group by load interaction; at $p<0.05$.

Figure captions:

Figure 1: Mean and SD of coefficient of variation of spatial gait variables at the *Fast* and *Slow* treadmill speeds. Normalized step length (i.e., step length/leg length) for TD group (a) and DS group (b), normalized step width (i.e., step width/leg length) for TD group (c) and DS group (d), and foot rotation angle for TD group (e) and DS group (f). Slow treadmill speed was equal to 75% of the subject's preferred overground walking speed; Fast treadmill speed was equal to the subject's preferred overground walking speed. No Load denotes the no-ankle load condition. Ankle Load denotes the ankle-load condition, which was equal to 2% of body weight attached above each ankle. Symbol * indicates a significant load effect at p<0.05. Symbol + indicates a significant speed effect at p<0.05.

Figure 2: Mean and SD of coefficient of variation of temporal gait variables at the *Fast* and *Slow* treadmill speeds. Swing percentage (in % gait cycle) for TD group (a) and DS group (b) and double support percentage (in % gait cycle) for TD group (c) and DS group (d). Slow treadmill speed was equal to 75% of the subject's preferred overground walking speed; Fast treadmill speed was equal to the subject's preferred overground walking speed. No Load denotes the no-ankle load condition. Ankle Load denotes the ankle-load condition, which was equal to 2% of body weight attached above each ankle. Symbol * indicates a significant load effect at p<0.05. Symbol + indicates a significant speed effect at p<0.05.

Fig 1

Figure 1:

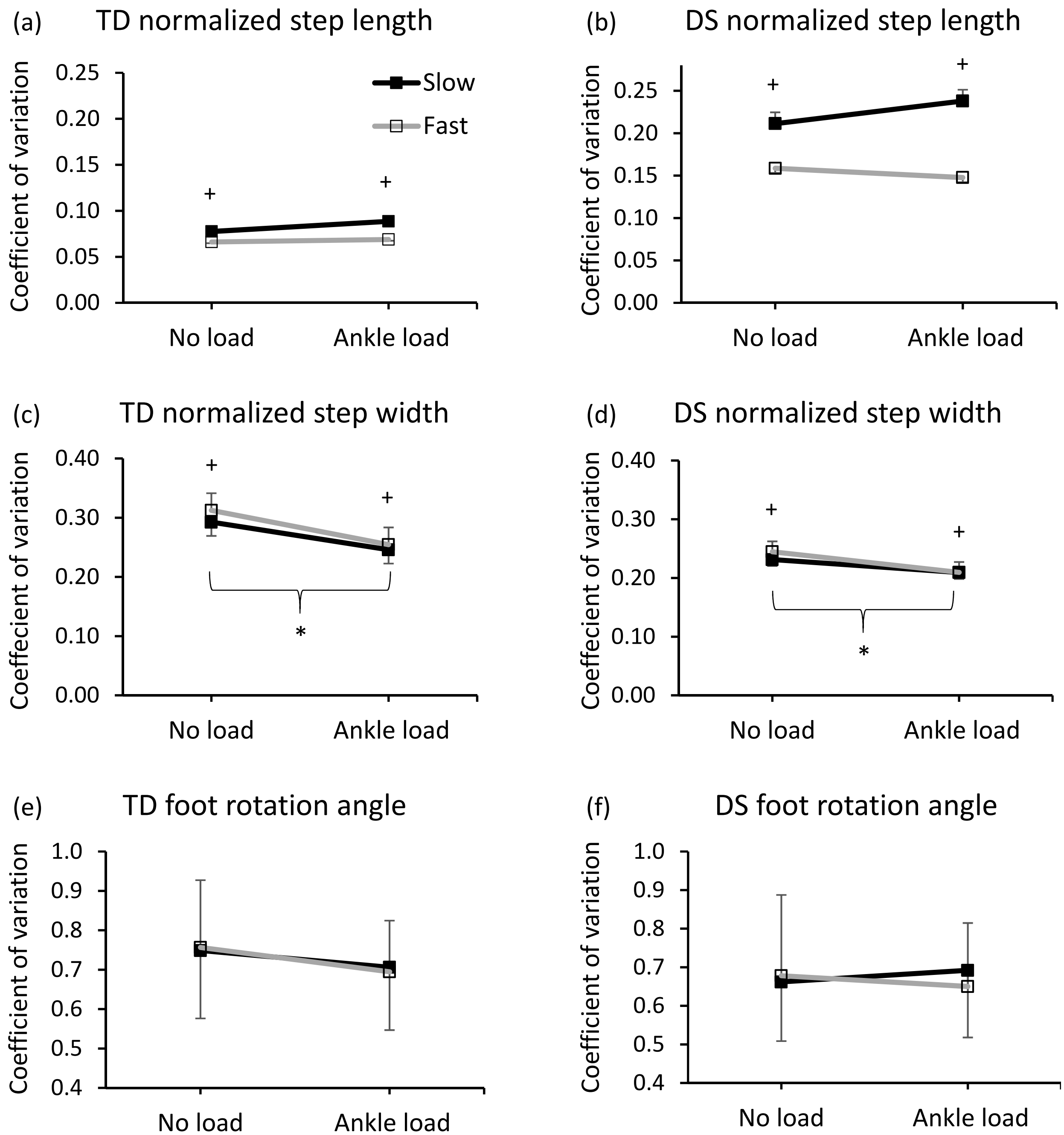
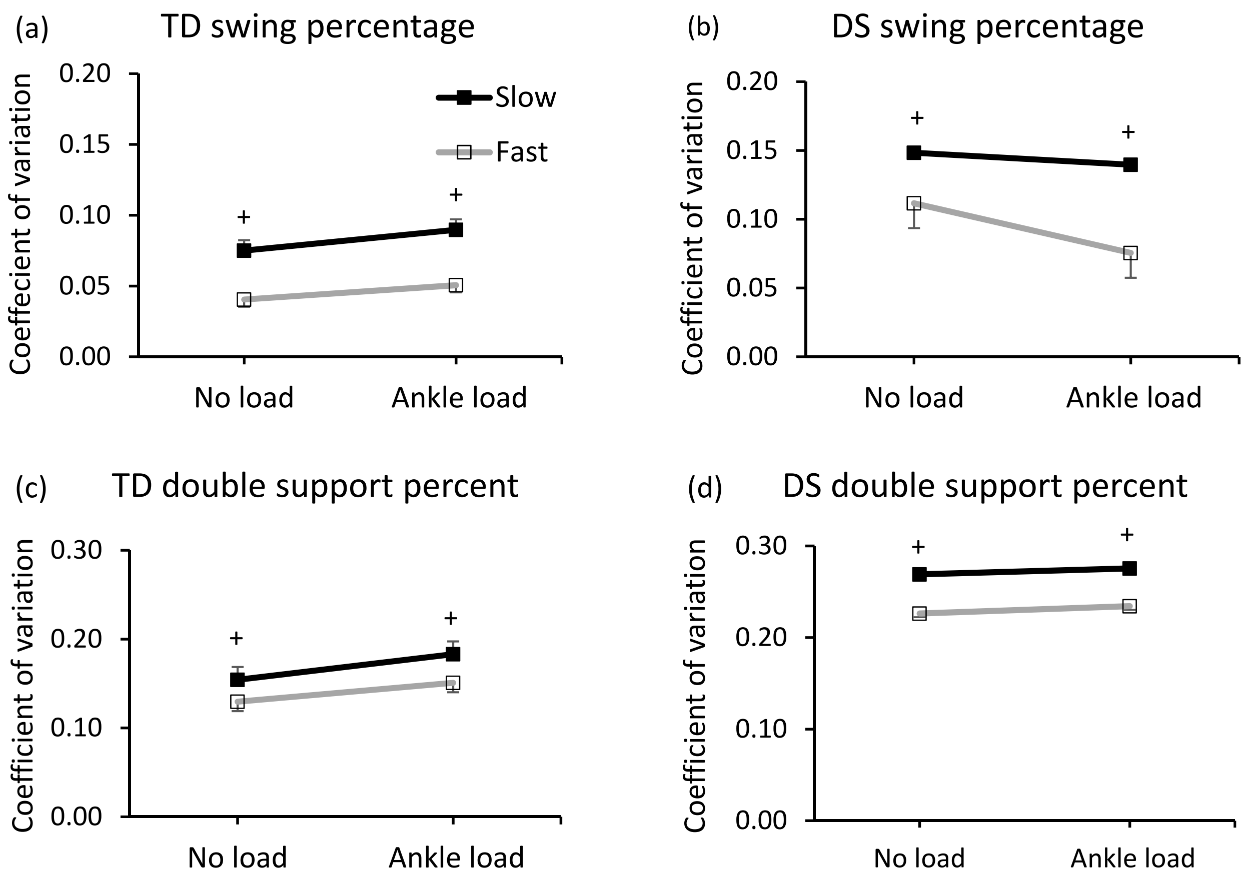


Fig 2

Figure 2:



Research Highlights:

1. We study gait variability of treadmill walking in children with DS and TD.
2. Children with DS showed similar spatiotemporal adaptions to speed and ankle load.
3. Children with DS produced longer and wider steps but similar temporal variables.
4. Children with DS displayed greater variability in most spatiotemporal variables.
5. Children with DS had less step width variability and may prioritize ML stability.