Exploring effects of different treadmill interventions on walking onset and gait patterns in infants with Down syndrome

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Two cohorts of participants were included to investigate the effects of different treadmill interventions on walking onset and gait patterns in infants with Down syndrome (DS). The first cohort included 30 infants with DS (17 males, 13 females; mean age 10mo [SD 1.9mo]) who were randomly assigned to either a lower-intensity-generalized (LG) training group, or a higher-intensity-individualized (HI) training group. A control (C) group from another study, who did not receive treadmill training, served as the control (eight males, seven females; mean age 10.4mo [SD 2.2mo]). Mean age at walking onset was 19.2, 21.4, and 23.9 months for the HI, LG, and C groups respectively. At walking onset the HI group was significantly younger than the C group (*p*=0.011). At the gait follow-up that was conducted between 1 and 3 months after walking onset, three groups significantly different in overall gait patterns (*p*=0.037) were examined by six basic gait parameters including average velocity, stride length, step width, stride time, stance time, and dynamic base. Post-hoc analyses demonstrated that stride length was the gait parameter largely contributing to this overall group difference (*p*=0.033), and the HI group produced a significantly longer stride length than the C group (*p*=0.030). In conclusion, the HI treadmill intervention significantly promoted earlier walking onset and elicited more advanced gait patterns (particularly in stride length) in infants with DS.

Down syndrome (DS) is one of the disabilities that causes moderate to severe mental retardation* and significant motor delays.[1] For example, infants with DS usually start walking independently about 1 year later than their peers with typical development (TD).[1,2] As walking is a fundamental motor skill that facilitates infants to interact with the environment and helps develop motor, social, and cognitive skills,[3] it is highly desirable to promote walking onset in infants with DS to facilitate their development and to relieve the stress that parents face when this delay persists.

Over the past several decades, early interventions have been conducted in infants with DS, but motor outcomes have been mixed.[4] For instance, earlier attainment of most gross- and fine-motor milestones was achieved in infants with DS who received an intervention combining gross motor activities and sensory stimulation.[5] In contrast, negligible effects on motor development were reported for infants with DS who received a neurodevelopmental treatment.[6]

Recently, a treadmill intervention was reported to decrease significantly the age at walking onset in infants with DS by about 3.5 months.[2] The training protocol used in that study [2] was 8 min/day, 5 day/week at a belt speed of 0.2m/s for every participant throughout the training. As children with DS usually show larger individual differences in performing motor tasks than their peers with TD,[1,4] an individualized treadmill training design should provide a protocol that better fits the unique developmental trajectory of each individual participant. Meanwhile, early interventions with higher intensities have been advocated to produce more positive outcomes.[7] With respect to a relatively low level of intensity implemented in Ulrich et al.'s study,[2] increasing training intensity should elicit more positive motor outcomes in infants with DS. The increase in training intensity can be implemented by increasing both daily training duration and belt speed to increase the stepping repetitions per day,[7] and by adding small weights at participants' ankles to strengthen their leg muscles and facilitate the practice of pendulum-like leg swing patterns.[8]

In addition to promoting early walking onset, a potentially more relevant question arises as a result of treadmill training; that is, does treadmill training produce more advanced gait patterns than without treadmill training? This question has not been addressed thus far. Children with DS usually walk at a slower speed, and produce a shorter step length and a wider step width.[9,10] This is due to their musculoskeletal and neuromuscular deficits such as decreased muscle strength,[11] hypotonia,[12] and increased muscle burst onset latencies.[13] As infants with DS can repeatedly practice alternating stepping patterns (a pattern similar to that of overground walking) and improve their leg muscle strength and limb coordination during treadmill training, they should produce more advanced gait patterns within a certain period after the training ends.

The goal of this study was to manipulate treadmill interventions applied in infants with DS and explore training effects on both the attainment of walking onset and the development of gait patterns between 1 and 3 months after walking onset. Because the intervention had to be implemented for ethical reasons to all participants in the new cohort, a historical control cohort was used for comparison. Our hypotheses were

*UK usage: learning disability.

that: (1) infants with DS who received treadmill training would walk earlier and generate more advanced gait patterns (e.g. faster walking speed and longer stride length) than those without training; and (2) a higher-intensity-individualized (HI) training protocol would lead to more positive motor outcomes on both walking onset and gait patterns than a lower-intensity-generalized (LG) protocol.

Method

PARTICIPANTS

Two cohorts of participants from two studies were included (see Fig. 1 for details). The first cohort is our current study, where infants with DS were recruited when they produced six steps per minute while being supported on a treadmill. Participants were recruited from parent support groups located in Lower Michigan. They were randomly assigned to either a LG training group or a HI training group. The control (C) group came from another study,[2] who did not receive treadmill intervention and were recruited when they could sit alone for 30 seconds. These participants were recruited from parent support groups and DS clinics in Indianapolis, Cincinnati, and surrounding areas. Neither race nor sex precluded infants from enrolling in these two studies. Exclusion criteria included the presence of a seizure disorder, uncorrectable vision problems, and any other medical conditions that would severely limit the infant's participation in either study. The sample sizes for these two cohorts were calculated separately on the basis of previous studies[2,8,14,15] to provide 80% power for each study at an alpha level of 0.05. At least 10% more participants were recruited for each cohort due to possible participant dropout. The randomization procedure was conducted by the fourth investigator for the two cohorts separately via a table of random numbers.

Participants stopped treadmill training when they could walk three steps independently on the ground, the operational definition of walking onset (item 62 of the Bayley Scales Infant Development, 2nd edition; BSID-II). All the participants in both cohorts received regular pediatric therapy services. Research staff visited all the participants biweekly throughout the pre-walking phase to take anthropometric measures, record 5 minutes of treadmill stepping, and monitor the compliance of training when appropriate. The recording of 5 minutes of treadmill stepping was used to determine if the training

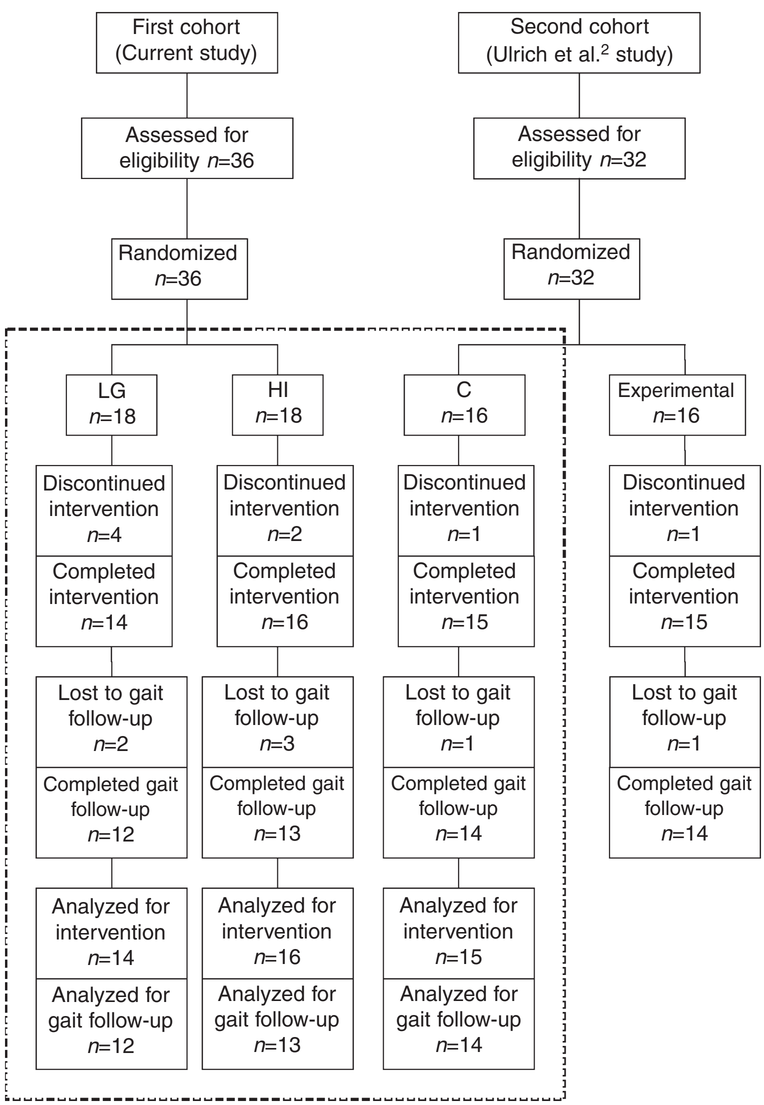

Figure 1: *Flow of participants through the trial for the cohorts in two studies. Lower-intensity-generalized (LG), higher-intensity-individualized (HI), and control (C) groups (included in the broken-line box) were investigated in the article. Participants in the LG and HI groups (first cohort) were recruited from Lower Michigan, and participants in the second cohort were recruited from Indianapolis, Cincinnati, and surrounding areas. Reasons for 'discontinued intervention' included non-compliance with protocol (n=4) and medical reasons (n=2). Reasons for 'lost to gait follow-up' included family circumstances (n=2) and medical reasons (n=4).*

intensity needed to be increased for the HI group. A gait follow-up was conducted between 1 and 3 months after walking onset. Parents of all the infants gave written informed consent before entering the study. Study procedures were approved by the Institutional Review Boards at Indiana University (C group) and the University of Michigan.

TREADMILL INTERVENTION

We provided families in the LG and HI groups with small, motorized, custom-designed treadmills and trained parents to appropriately administer training in their homes.[2] Parents held their infant upright on the treadmill at the front of the belt. The belt of the treadmill, when turned on, moved the infants' legs backward and elicited forward stepping. Whenever infants did not generate steps, parents repositioned the infant to the front of the belt. Table I presents the intended and actual training protocols for the LG and HI groups. Infants in the LG group received the same protocol throughout the training, which was administered about 6 min/day, 5 day/week at a belt speed of 0.18m/sec. Infants in the HI group also trained 5 day/week; however, training protocol was individualized for each infant on the basis of the step frequency they produced in the training sessions (see Table I for details). Besides progressively increasing belt

Table I: Details of the lower-intensity-generalized (LG) and higher-intensity-individualized (HI) treadmill intervention protocols

Group	*Protocol*	*Step frequency (step/min)*	*Belt speed (m/s)*	*Training duration (min/day)*	*Ankle weights (% calf mass)*	*Range of ankle weights (g)*[a]
LG	Intended	All	0.15	8	0	–
	Actual	All	0.18	6.1	0	–
HI	Intended	<10	0.15	8	0	–
		10–19	0.20	8	50	–
		20–29	0.25	10	75	–
		30–39	0.30	12	100	–
		≥40	0.30	12	125	–
	Actual	<10	0.18	6.0	14	0–150
		10–19	0.18	6.2	43	117–162
		20–29	0.19	6.2	74	125–238
		30–39	0.20	6.8	88	232–334
		≥40	0.22	8.9	115	311–470

[a]Note that the amount of ankle weights was calculated individually as a percentage of the participant's calf mass. A regression equation[16] was used to estimate the calf mass on the basis of the participant's bodyweight, shank length, and circumference. We bilaterally placed an elastic cloth pocket with weights inside around the participant's ankle and secured it with Velcro. Sometimes when we increased ankle weights for some infants, they reduced their step frequency so that we had to decrease ankle weights to the previous amount and, then increase weights later whenever appropriate.

Table II: Baseline characteristics in control (C), lower-intensity-generalized (LG), and higher-intensity-individualized (HI) groups at entry into study

Characteristics	*C (n=15)*	*LG (n=14)*	*HI (n=16)*
Sex, male:female	8:7	5:9	12:4
Subtype of DS, *n*	Trisomy 21 (15)	Trisomy 21 (13) Mosaic (1)	Trisomy 21 (15) Mosaic (1)
Chronological age, mo[a]	10.4 (2.2)[b]	10.4 (2.2)	9.7 (1.6)
Step frequency, step/min	9.1 (7.6)	10.9 (6.7)	12.9 (9.7)
BSID-II raw motor score[c]	37.8 (1.0)	41.5 (4.8)	40.9 (6.6)
Crown-heel length, cm	69.6 (2.7)	68.6 (3.5)	69.1 (2.9)
Thigh length, cm	12.2 (0.7)	14.1 (1.2)	13.5 (1.6)
Mid-thigh circumference, cm	24.2 (2.3)	25.2 (2.7)	24.6 (2.2)
Shank length, cm	12.2 (0.8)	11.6 (0.9)	12.1 (1.1)
Mid-shank circumference, cm	16.8 (1.4)	17.2 (1.5)	17.6 (1.2)
Weight, kg	8.1 (0.9)	8.5 (1.2)	8.5 (1.1)

[a]Chronological age was corrected if participant was born >2wks before due date. [b]Mean (SD). [c]Bayley Scales of Infant Development, 2nd edition (BSID-II).[17] Note that three groups (n=45 in total) were not significantly different for any baseline measures (all $p>0.05$) except for sex distribution ($p<0.05$). To ensure the equivalence in these baseline measures among the three groups was preserved for those who completed both treadmill intervention and gait follow-up (n=39 in total; LG, n=12; HI, n=13; C, n=14; see Fig. 1 for details), a series of analyses of variances were conducted on each baseline characteristic at entry for these 39 participants. No group difference was found to be significant for any baseline measure (all $p>0.05$) except for sex. DS, Down syndrome.

speed and daily training duration, we attached to the infants' ankles a small amount of weight that was proportional to their estimated calf mass,[16] and increased the weight over the course of training. Treadmill training terminated when participants walked three steps independently, our operational definition for walking onset.

GAIT FOLLOW-UP

A gait follow-up was conducted between 1 and 3 months after walking onset (see Fig. 1). Gait follow-ups for the C group were conducted in the participants' homes about 1 month after walking onset. Infants walked at a self-selected speed over an 8-foot walkway covered with a long strip of 3-foot-wide butcher paper (sturdy paper sold in large rolls). Two pieces of moleskin with tempera paint were placed on the frontal and heel sections respectively of the sole of each foot. When infants walked across the walkway, the moleskin left marks on the paper, from which gait parameters were calculated thereafter. A video camera was placed at the right side of the walkway to record walking trials, and an average of three walking trials was collected.

Both the LG and HI groups came to our laboratory for the gait follow-up after parents reported to us that their child could walk eight to 10 steps independently, which occurred about 3 months after walking onset. We used a GAITRite mat (CIR Systems, Havertown, USA) and a six-camera Peak Performance (Vicon Peak, Lake Forest, USA) motion analysis system to collect data. Participants wore only a diaper during the data collection. Reflective markers were attached bilaterally to the temporomandibular joint, acromion process, lateral epicondyle of humerus, greater trochanter, lateral epicondyle of femur, lateral malleolus, and second metatarsal head. Participants walked at a self-selected speed on the GAITRite mat, and an average of four walking trials was collected.

DATA ANALYSIS

Six basic gait parameters were examined including average velocity, stride length (distance between heel strikes on the same foot), stride time (duration between heel strikes on the same foot), stance time (duration from heel strike to toe-off within one stride), step width (lateral distance between feet), and dynamic base[18] (angle formed by one stride and the next step). For the C group, average velocity was estimated based on the length of walkway, the length of walking path traced from the video screen, and the corresponding video time. Stride length, step width, and dynamic base were calculated manually from the paint marks on the butcher papers, and stride time and stance time were obtained from the behavioral coding of videotapes. For the LG and HI groups, all the gait parameters were calculated by the GAITRite system except dynamic base, which was calculated from the Peak data using a customized MATLAB program (Mathworks, Natick, USA). Because the GAITRite mat has been shown to generate gait parameters that are highly consistent and reliable with both the spatial measures from a paper-and-pencil method and the temporal measures from a video-based method,[19] we concluded that any difference observed in gait patterns among the three groups should be due to treadmill intervention rather than due to the different gait data collection methods.

We did not aim to investigate sex effects on treadmill training in two studies. Thus, sex was not used as a restriction while recruiting and randomizing participants. However, to examine possible sex differences in the outcome measures, we conducted 3 (Group) x 2 (Sex) analyses of variance (ANOVAs) on age at walking onset, the elapsed time from entry to walking onset, age at the gait follow-up, the elapsed time from walking onset to gait follow-up, and each of the six gait parameters. Neither a sex difference nor a sex by group interaction was significant for any of these measures (all $p>0.05$). We therefore pooled the data across male and female participants in each group for further analyses.

The SAS statistical software was used throughout this study for statistical analyses. The General Linear Model procedure was used: (1) to conduct ANOVA for outcome measures of treadmill intervention; (2) to conduct multivariate analysis of covariance (MANCOVA) for the set of six basic gait parameters; and (3) to conduct analysis of covariance (ANCOVA) for each gait parameter (more details in Results). Post-hoc pair-wise comparisons with Bonferroni adjustments were conducted whenever appropriate. Statistical significance was set at $p<0.05$ level.

Table III: Mean (SD) of variables at walking onset and at gait follow-up for control (C), lower-intensity-generalized (LG), and higher-intensity-individualized (HI) groups

	C	*LG*	*HI*	p^a	$\omega^{2\,b}$
Treadmill intervention	$n=15$	$n=14$	$n=16$		
Age at walking onset, mo	23.9 (4.7)	21.4 (4.7)	19.2 (2.8)[d]	0.011	0.153
Elapsed time from entry to walking onset, mo	13.4 (4.4)	11.0 (3.8)	9.6 (3.3)[c]	0.037	0.103
Gait follow-up	$n=14$	$n=12$	$n=13$		
Age at gait follow-up, mo	24.5 (4.7)	24.9 (5.1)	21.8 (3.1)	0.162	–
Elapsed time from walking onset to gait follow-up, mo	0.9 (0.7)	3.3 (1.2)[d]	2.7 (0.9)[d]	<0.001	0.545
Leg length, cm	30.7 (2.1)	30.2 (2.9)	31.1 (3.1)	0.728	–

[a]Note that p values were presented for one-way (Group) analysis of variance tests. [b]Omega-square (effect size) $\omega^2 = (SS_{FACTOR} - (k-1)\,MS_{ERROR}) / (SS_{total} + MS_{ERROR})$, where SS is the sum of squares, MS is mean square, and k is number of groups. According to Cohen,[20] ω^2 represents a large effect size when greater than 0.15, a medium effect size when 0.06 to 0.15, and a small effect size when less than 0.06. Leg length was sum of shank and thigh lengths. [c,d]Training group was significantly different from C group at $p<0.05$ and $p<0.01$ respectively. No significant difference was found between LG and HI groups in any of these measures.

Results

The flow of participants through the trial is presented in Figure 1. Forty-five participants completed treadmill training (LG, *n*=14; HI, *n*=16) or observation (C, *n*=15), and 39 of them completed the gait follow-up (C, *n*=14, seven males, seven females; LG, *n*=12, four males, eight females; HI, *n*=13, 10 males, three females).

BASELINE CHARACTERISTICS

Baseline characteristics at entry are presented in Table II. Although the entry criterion was different between the two studies (producing six step/min on a treadmill versus sitting alone for 30s), mean chronological age at entry was about 10 months of age for all three groups, which was not significantly different (ANOVA, $p>0.05$). Also, all three groups produced about 10 steps/min while being supported on a treadmill at entry, and no group difference was found ($p>0.05$). In addition, no significant difference was found for anthropometric measures and BSID-II motor scores among the three groups (all $p>0.05$). Sex distribution was different among the three groups ($p<0.05$), but none of our dependent variables differed between males and females (as mentioned in the Data analysis section).

TREADMILL INTERVENTION OUTCOMES

Table III presents age at walking onset and the elapsed time from entry into the study to walking onset for the three groups, who did not drop out of the study during the treadmill

Table IV: Estimated mean difference, 95% confidence interval values, effect sizes (Cohen's *d*), and power between control (C), lower-intensity-generalized (LG), and higher-intensity-individualized (HI) groups

Variable	*Group*	*Mean difference*	*Confidence interval*	*p value*	*Effect size, d*	*Power*
Treadmill intervention						
Age at walking onset, mo	LG – C	–2.64	–5.76 to 0.49	0.096	0.55	0.27
	HI – C	–4.76	–7.78 to –1.74	0.003	1.21	0.89
	HI – LG	–2.12	–5.20 to 0.95	0.171	0.55	0.32
Elapsed time from entry to walking onset, mo	LG – C	–2.28	–5.16 to 0.60	0.118	0.56	0.32
	HI – C	–3.67	–6.46 to -0.88	0.011	0.94	0.73
	HI – G	–1.39	–4.23 to 1.45	0.329	0.39	0.18
Gait follow-up						
Walk-experience adjusted stride length, m	LG – C	0.07	–0.01 to 0.16	0.095	0.79	0.54
	HI – C	0.10	0.03 to 0.18	0.010	1.13	0.78
	HI – LG	0.03	–0.03 to 0.09	0.383	0.32	0.09

Note that *p* values were presented for pair-wise group comparisons without Bonferroni adjustments. In mean differences and confidence intervals, negative values for both age at walking onset and elapsed time from entry to walking onset represent improvements in these two variables, i.e. younger at walking onset and shorter time spent from entry to walking onset. Positive values for walking-experience adjusted stride length represent improvements, i.e. increased stride length. In the calculation of effect size and power, the pooled SD was used, which was equal to the root mean square of the two SDs. According to Cohen,[20] *d* represents a large effect size when greater than 0.8, a medium effect size when 0.5 to 0.8, and a small effect size when less than 0.5. **Bold type denotes the two phases in the study.**

Table V: Mean (SD) of raw and walking-experience adjusted gait parameters for the control (C), lower-intensity-generalized (LG), and higher-intensity-individualized (HI) groups at the gait follow-up

	Gait parameter	*C (n=14)*	*LG (n=12)*	*HI (n=13)*
Raw values	Velocity (m/s)	0.33 (0.08)	0.47 (0.12)	0.50 (0.18)
	Stride length (m)	0.27 (0.06)	0.36 (0.06)	0.39 (0.09)
	Step width (m)	0.20 (0.02)	0.20 (0.03)	0.20 (0.03)
	Stride time (s)	0.87 (0.10)	0.84 (0.16)	0.82 (0.09)
	Stance time (s)	0.52 (0.12)	0.52 (0.10)	0.50 (0.08)
	Dynamic base (°)	123.5 (7.9)	128.1 (7.0)	128.8 (9.4)
Walking-experience adjusted values	Velocity (m/s)	0.38 (0.18)	0.43 (0.16)	0.49 (0.14)
	Stride length (m)	**0.28 (0.10)**	**0.36 (0.09)**	**0.38 (0.08)**[a]
	Step width (m)	0.19 (0.04)	0.20 (0.04)	0.20 (0.03)
	Stride time (s)	0.82 (0.16)	0.88 (0.14)	0.83 (0.12)
	Stance time (s)	0.49 (0.13)	0.54 (0.12)	0.51 (0.10)
	Dynamic base (°)	122.4 (11.2)	129.0 (10.1)	129.1 (8.7)

[a]Training group produced a significantly different gait parameter adjusted with walking-experience than C group at $p<0.05$. No significant difference was found between LG and HI groups. **Bold type denotes the significant result (stride length).**

intervention phase (see more details of dropout in Fig. 1). One-way (Group) ANOVAs conducted for these two variables revealed a significant group effect for age at walking onset ($F[2,42]=5.06$, $p=0.011$; ω^2 [omega-square[20]] $=0.153$), and for the elapsed time ($F[2,42]=3.58$, $p=0.037$; $\omega^2=0.103$). Post-hoc analyses showed that only the HI group was younger at walking onset ($p=0.011$; Cohen's d[20]$=1.213$) and spent shorter time from entry to walking onset ($p=0.028$, Cohen's $d=0.980$) than the C group. No significant difference was found between the LG and HI groups. Detailed group comparisons between the three groups are presented in Table IV, corroborating the aforementioned findings.

GAIT PATTERNS IN NEW WALKERS

Age at the gait follow-up, elapsed time from walking onset to the gait follow-up (walking experience), and leg length are presented in Table III for three groups. One-way (Group) ANOVAs conducted for these three variables demonstrated no significant difference in age at the gait follow-up and leg length (all $p>0.05$) but significant difference in walking experience ($F[2,36]=24.40$, $p<0.001$, $\omega 2=0.545$) among the three groups. Post-hoc analyses indicated that the C group had significantly shorter walking experience than both the LG group ($p<0.001$, Cohen's $d=2.518$) and the HI group ($p<0.001$, Cohen's $d=2.294$). As basic gait parameters have been reported to depend on walking experience in newly walking toddlers,[18] walking experience was used as a covariate in the following analyses of gait parameters.

Raw values of the six basic gait parameters are presented in Table V for three groups. A MANCOVA with walking experience as a covariate was conducted for the six gait parameters. A significant group difference was found among three groups (Wilk's lambda=0.447, $F[12,50]=2.07$, $p=0.037$). One-way (Group) ANCOVAs with walking experience as a covariate were conducted for each gait parameter. Table V also presents the estimates of walking experience-adjusted gait parameters. Only stride length significantly differentiated the three groups ($F[2,35]=3.76$, $p=0.033$, $\omega^2=0.102$) such that the HI group produced a significantly longer walking experience-adjusted stride length than the C group ($p=0.030$, Cohen's $d=1.133$). No significant difference was found between the LG and HI groups. Detailed group comparisons for walking experience-adjusted stride length are presented in Table IV.

Discussion

The significant earlier onset of independent walking achieved by the HI group compared with the C group replicates empirical evidence that treadmill intervention can be an effective early intervention for infants with DS.[2] Our results suggest that a treadmill training protocol with an increased training intensity and an individualized design significantly advances the attainment of walking onset in infants with DS, but lowering training intensity reduces such benefit when compared with no treadmill intervention. As Badke and DiFabio suggested,[21] the effectiveness of intervention in the physical domain lies mainly in the repetition of targeted movement patterns. In contrast to no or LG treadmill training, the paradigm of the HI treadmill intervention best fits this task-specific intervention concept, and provides enhanced repetitive stimuli through the continuously moving belt. The backward stretch of the leg on the treadmill elicits hip extension and facilitates the unloading of the leg at the end of stance phase, both of which are critical in initiating forward leg swing[22,23] even for infant stepping.[24] The increased intensity due to increased daily training duration, belt speed, and ankle weights in the HI training protocol elicits further repetitions of treadmill stepping, facilitates more practice of pendulum-like leg swing, and potentially further strengthens leg muscles. In addition, an individualized training intensity suits the training program best to the developmental trajectory of each individual participant. We argue that these factors are potential explanations for the earlier onset of walking via this kind of intervention. However, further research is necessary to corroborate this proposal.

Regarding the effectiveness of the HI training, it is important to discuss the timing of starting a treadmill intervention to achieve the optimal training outcomes in infants with DS. It has been shown that after 1 month of daily treadmill training, 3-month-old infants with TD whose alternating stepping patterns were inconsistent and variable at the beginning of the training, significantly increased step frequency on a treadmill, while 7-month-olds whose alternating stepping patterns were quite consistent and stable at the beginning of the training, made only small improvements.[25] These data suggest that treadmill training has to be implemented when the targeted movement patterns are still inconsistent and unstable for better motor outcomes to be achieved. Infants with DS were reported to produce only 13 steps/min at 11 months of age while being supported on a treadmill.[14] This suggests that infants with DS do not produce maximal (typically 40–50 steps/min) and stable treadmill stepping at 11 months of age. Furthermore, infants with DS could produce treadmill stepping patterns as early as 8 months old but showed a wide range of ages.[15] Thus, the criterion of starting treadmill training in the LG and HI groups, i.e. the participant could produce six steps/min while being supported on a treadmill, ensured that the participant was ready to practice treadmill stepping at a young age (about 10mo of age for the LG and HI groups). The stepping pattern was still unstable to elicit maximal training outcomes in the percentage of alternating stepping pattern and the step frequency of alternating steps. This criterion also precluded the situation where treadmill training was provided too early and, therefore, infants and caregivers could become frustrated because the child was not responding to the treadmill.

The HI group produced a significantly longer stride length than the C group at the gait follow-up. This indicates that the HI treadmill training not only advanced the earlier attainment of walking onset in the infants with DS, but also produced a positive effect on gait development. Although only one (stride length) out of six basic gait parameters produced a significant difference between the HI and C groups, this result is still encouraging in that it matches the directional sequence of infant gait development within the first year after walking onset, which suggests that step/stride length develops earlier than step width or other gait parameters. For example, newly walking toddlers, including TD and DS with and without treadmill training, were found to reduce their larger step length variability while maintaining their smaller step width variability in the first several months after walking onset; and then step width variability started to increase and became larger than step length variability.[26] This trend suggests that new walkers develop control of their step/stride length before step width. The significant difference in stride length but not in step width between the HI and C groups implies that the HI group developed their gait patterns at a faster rate than the C group at the very first few months after walking onset. As new walkers improve their gait patterns dramatically within the first 5 to 6 months after walking onset,[18,27] a longer period of gait follow-up should allow us to observe the possible gait difference between the HI and C groups.

In contrast to the positive outcomes produced by the HI group, the LG group was not significantly different from the C group in age at walking onset and gait patterns. In the Ulrich et al. study,[2] 8 minutes of practice per day with a belt speed of 0.2m/s was used for treadmill training. Exercise provided by the LG training protocol in this study was about 30% less than that of the study.[2] This smaller amount of treadmill training may account for the insignificant outcomes between the LG and C groups (although medium size effects were found when comparing these two groups). It also implies that a certain amount of treadmill exercise may be required to achieve positive outcomes in walking onset and gait development. Despite that, the LG group was not statistically significantly different from the HI group in age at walking onset and gait development, all the results were in favor of the HI group. The intended HI training protocol was proposed to be largely different from the LG protocol. But the actual daily training duration and belt speed were not different between two protocols (Table I). It appears, therefore, that ankle weights used in the HI intervention contributed most to the advantages observed in the HI group.

One of the limitations in this study is that the compliance of treadmill training was relatively low, particularly in the HI group. Since parenting a child with disability is stressful and requires tremendous attention and the time commitment to implementing treadmill training is enormous (5d/wk for about 10mo), a variety of circumstances account for the low compliance, such as family vacations, child and caregiver illness, and busy personal schedules. Meanwhile, manipulating daily training duration, belt speed, and ankle weights all together in the HI training may be too complex for the parents to administer. We thus suggest that future studies may reduce the complexity of the HI training protocol and concentrate on manipulating one or two training conditions. Another limitation of this study is that the power values reported are relatively low except for the comparison between the HI and C groups (see Table IV). Small sample size may account for the low power values in the comparisons between the LG and C groups and between the LG and HI groups. However, as discussed earlier, the relatively low compliance of treadmill training may also explain these small power values. Both sample size and the compliance of training should be considered for future studies to optimize the treadmill training protocol.

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