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Gait adaptations in response to perturbations in adults with Down syndrome

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Abstract

Objectives—Ligamentous laxity, hypotonia and physiologic changes associated with aging lead to gait adaptations to increase control during comfortable unperturbed walking in adults with Down syndrome (DS). These changes appear at earlier ages than changes associated with aging in adults with typical development (TD)[1]. Here we describe gait adaptation and stability when gait is perturbed in relatively older adults with DS compared to their peers with TD.

Participants—A volunteer sample of 14 adults with DS and 14 adults with TD, all 35 to 65 years of age, participated.

Methods—We used 3-D motion analysis to capture walking patterns at self-selected pace and in seven environmentally relevant perturbation conditions. We tested for group differences in gait parameters and amount of variability by condition: specifically percent stance, step width and stride length, velocity and frequency. To quantify overall change in gait parameters and variability from baseline to each condition, we created summative parameters of the overall percent change from baseline to each condition for each dependent variable.

Results—Adults with DS and TD made small but complex adjustments in gait parameters and variability in response to perturbations.

Conclusions—Overall adults in both groups maintained group differences in gait patterns while adapting well to anticipated perturbations.

Keywords

Down syndrome; gait; aging; perturbations

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

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INTRODUCTION

Persons with Down syndrome (DS) now live well into adulthood. Median age at death is nearly 60 years [2,3]. Adults with DS show precocious age-related changes compared to adults with typical development (TD), both in physiologic function [4] and resulting motor performance. They demonstrate decreased ability to perform activities of daily living by 40 years of age [5]; 10 years earlier than adults with only intellectual disability [6]. They also experience premature problems with osteoarthritis [7], hearing loss [8], increased body weight [9] and dementia [10–12].

Gait patterns may be altered in response to internal or external changes. Maintaining stable walking while sensing and responding to changes becomes more challenging as adults with DS age. They experience the effects of aging in addition to the lifelong challenge of locomotor stability due to low tone and ligamentous laxity. Toddlers with DS show shorter stride length, slower velocity and a trend towards wider step width compared to their peers with TD [13]. In pre-adolescents, merely increasing step width is an adequate adaptation to provide the greater than normal stability needed to control comfortable walking [14,15]. As they experience the typical physiologic changes associated with aging, affecting their ability to sense and respond to perturbations, adults with DS show stability-enhancing adaptations in gait characteristics at a comfortable pace. They adapt in ways seen across the lifespan in those with DS (e.g. wider step width) and add strategies used by elderly adults with TD (e.g. shorter step lengths, increased double support and stance, slower velocity), although at a younger chronological age [1].

Unknown are the effects of many common environmental perturbations on the gait of adults with DS. Here we examine perturbations known to decrease gait stability and elicit adaptations in adults with TD in their 70's and older, including divided attention, low lighting, and irregular surface conditions [16–19]. We compared performance of adults with DS to their peers with TD in five single and two double sensori-motor perturbation conditions. Participants were 35 to 65 years of age. We hypothesized that adults with DS would adapt by making larger adjustments to gait than their peers with TD. As the same perturbation conditions were expected to be challenging for adults with DS but not TD, we anticipated adults with DS would show significant increases in amount of variability from baseline to all perturbation conditions, while adults with TD would show an increase only in the irregular surface condition. Our hypotheses derive from the theoretical perspective that there is an optimal amount of variability in a biological system that supports being stable yet adaptable. The system maintains a repertoire of movement strategies while avoiding both instability (one end of the continuum, too much variability) and rigidity (the other end, too little variability) [20]. Adults with TD are assumed to be near the ideal middle range of the continuum, while adults with DS are hypothesized to be on a different part of the continuum, toward too much variability and instability.

METHOD

Participants

Twenty-eight adults (14 with DS, 14 with TD) ages 35 to 65 years participated. Exclusion criteria were history of joint arthroplasty, fractures or sensori-motor deficits of the lower extremity. Adults with DS were recruited through masked area community groups, work programs and group homes for adults with disabilities in masked. Adults with TD were recruited from the masked clinical research volunteer website “masked”.

Procedures

Participants came to the masked for 2 hours. All procedures were approved by the masked Institutional Review Board. Prior to participation, we explained the purposes and procedures of our study to participants and caregivers/legal guardians. Participants signed an assent or consent form as appropriate, with consent for assenting adults provided by a legal guardian. Participants wore their own socks, close-fitting shorts and t-shirt. We provided standard lace-up walking shoes. During walking, they wore a harness adjusted to ensure their knees would not touch the ground if they fell. All participants were allowed 5 minutes to walk around the room to accommodate to the harness and shoes.

We applied infrared emitting diodes bilaterally at the iliac crest, knee, ankle, heel and toe. We used a 2-unit optoelectronic system (Optotrack; Northern Digital Corporation, Waterloo, Canada) with one system at either end of the walkway to collect data at 100 Hz.

Participants performed 4 repetitions of the unperturbed condition, walking along the flat 10 m walkway at their self-selected speed. Next, they completed a 4-repetition block of each perturbation condition, with conditions sequenced randomly. We described each condition, allowing participants to practice each task as needed. Adults with TD did not require practice; adults with DS sometimes required one practice trial. Perturbation conditions were:

Divided Attention—Participants with DS counted out loud by 1, then began to walk while counting. Sometimes we had to cue them to continue counting. Participants with TD followed the same instructions but counted by 4. Based on our previous work with adults with DS, counting tasks were chosen to provide a similar level of difficulty for both groups.

Distracting sounds—Prior to walking initiation, we began playing street corner sounds (cars and a scooter driving by, undistinguishable voices) in the background at moderate volume (64 dB).

Irregular surface—We arranged random prism-shaped pieces of wood (height = 1.5 cm, width = 3.5 cm, length = 6–16 cm) at a density of 26 pieces per meter² beneath a 1.5- by 10-m piece of industrial carpet.

Obstacle—An obstacle, made of blue construction paper 83 cm wide, 8 cm in high and 4 cm long, was placed in the middle of and parallel to the walkway.

Low light condition—Room lights were dimmed low (8.6 lux), allowing one to see the other end of the walkway but not object details. In all other conditions lighting was 400 lux, comparable to bright office space.

Two combination conditions: *Divided attention/low light combination*, *Irregular surface/distracting sounds combination*. These combinations involved multiple subsystems (cognitive/vision, proprioception/cognitive).

Participants completed the Berg Balance Scale, a standardized assessment [21,22] with demonstrated reliability for adults with DS [23]. Participants with DS completed the Timed Up and Go, an assessment that can discriminate fallers from non-fallers among community-dwelling older adults with TD [24]. For all participants, we measured height, weight, thigh, shank and foot lengths.

During an in-person interview, we asked about living arrangements, employment status and recreational activities. Participants/caregivers completed a survey addressing general health

and medication questions, fall status, and the Adaptive Behaviour Dementia Questionnaire, a dementia screen for adults with DS [25].

Data reduction

Real-time markers allowed us to ensure four trials per condition of visible markers. 3-D coordinates from Optotrak software were further analyzed using MATLAB. We analyzed data during steady state walking, when the pelvis marker velocity stabilized above 85% of trial's mean walking speed [26]. We calculated overall walking speed by taking the derivative of the anterior-posterior position of the pelvis marker.

To provide a comprehensive description of possible changes in participants' gait patterns, we calculated five gait parameters and five variability measures. Gait parameters, calculated based on heel markers, were percent stance, step width, stride length, stride velocity and stride frequency. All values except percent stance (which was already standardized) were converted to dimensionless values (see Appendix 1) and averages were calculated for each trial. We used dimensionless values to control for leg length differences. To represent amount of variability in the gait parameters, we calculated standard deviation (SD) of percent stance and the Coefficient of Variation (CV) of step width and stride length, velocity and frequency values. Using CV allowed us to standardize amount of variability between participants; we used SD for percent stance because it was already standardized among participants. An SD or CV was calculated for each of the four trials per condition. This again provided four "trial" averages per condition. For all dependent variables, we calculated a "condition" average of the four "trial" average values to obtain a steady overall description of performance by variable by condition.

To quantify overall change in gait parameters and variability, we created summative parameters of overall percent change from baseline to each condition, by dependent variable. This allowed us to compare amount of change among different parameters or variability measures while some increased and some decreased from baseline performance to conditions. For example, stride length was, on average, 5% larger in the divided attention as compared to the baseline condition for adults with DS.

Participants

Anthropometric measurement group means were: age = DS M 43.4, SD 7.3 years, TD M 48.5, SD 7.6 years; height = DS M 155.0, SD 9.3 cm, TD 166.7, SD 10.9 cm; weight = DS M 73.9, SD 18.2 kg, TD M 87.0, SD 29.4 kg. Seven adults with DS lived with their parents and 7 lived in supervised apartments/group homes. Nine worked part-time, ranging from 8–25 hours/week across 2–5 days/week.

Six adults with DS reported a history of falls and 8 did not. Three adults with DS had a loss of balance during data collection. One participant was able to regain stability with a large lateral step, while two required assistance. No adults with TD reported a history of falls, and none lost their balance during data collection. Adults with DS scored significantly lower than adults with TD on the Berg Balance Scale, indicating poorer performance [one-way ANOVA ($F[1, 26] = 13.58, p = 0.01$)], DS mean score 51.1, range 40–56, TD mean score 55.4, range 48–56]. In general, adults with DS lost points on the Berg Balance Scale because they performed tasks too slowly. Results from the Timed up and Go in adults with DS (M 9.3 s, range 5.3–14 s) were close to community-dwelling elder adults (M 8.4 s, range 6.4–12.6 s) [25].

Statistics

To test for differences in gait parameters we used a 2 (group) by 8 (condition) MANOVA with repeated measures on condition, Bonferroni and Huynh-Feldt corrections. Dependent variables were percent stance, normalized stride length, velocity, frequency and step width values. Gait variables were standardized to Z-scores, allowing comparison of changes across conditions of variables measured on different scales, with different amounts of fluctuation. To test for differences in variability measures we used a 2 (group) by 8 (condition) MANOVA with repeated measures on condition, Bonferroni and Huynh-Feldt corrections. Dependent variables were SD of percent stance and CV of stride length, velocity, frequency and step width.

RESULTS

Table 1 presents gait parameters before normalization. Group means and standard deviations are presented for percent stance, step width, stride length, stride velocity and stride frequency, by condition.

Group Gait Adaptations to Perturbation Conditions

For gait parameter statistical tests, group (Wilks' Lambda = 0.55, $F[5, 22] = 3.61$, $p = 0.02$, partial eta squared 0.45), and condition effects (Wilks' Lambda = 0.57, $F[35, 751] = 3.06$, $p < 0.01$, partial eta squared 0.11) were significant. The group by condition interaction was not (partial eta squared 0.03). Follow-up univariate analysis for the group effect revealed adults with DS demonstrated larger step widths ($F[1, 26] = 7.52$, $p = 0.01$) and slower stride velocity ($F[1, 26] = 7.01$, $p = 0.01$) than adults with TD. Follow-up pairwise comparisons for the condition effect demonstrated participants had lower stride frequency in the irregular surface and distracting sound combination ($p = 0.046$) than in baseline. Figure 1 presents percent change from baseline for each perturbation condition, by gait parameter.

For variability measure statistical tests, the multivariate group (Wilks' Lambda = 0.60, $F[5, 22] = 2.96$, $p = 0.03$, partial eta squared = 0.40) and condition effects (Wilks' Lambda = 0.61, $F[35, 751] = 2.97$, $p < 0.01$, partial eta squared = 0.09) were significant. The group by condition interaction was not (partial eta squared = 0.03). Follow-up univariate analysis showed group differences were largely due to adults with DS showing more stride velocity variability ($F[1, 26] = 4.54$, $p = 0.04$) and close to, but not significantly less, step width variability ($F[1, 26] = 3.18$, $p = 0.08$) than adults with TD. Follow-up pairwise comparisons for the condition effect suggested this was largely because adults in both groups produced more variability in stride frequency in the obstacle condition, compared to baseline ($p = 0.02$). Figure 2 illustrates percent change from baseline for each perturbation condition, by variability measure.

DISCUSSION

We hypothesized perturbation conditions would challenge adults with DS more and they would adapt by making larger adjustments in gait parameters and variability compared to adults with TD. Our results are somewhat surprising, though, in that all conditions elicited inconsistent combinations of small adjustments in gait parameters and variability in both groups. While adults with DS show age-related adjustments in gait at an earlier age than adults with TD [1], they adapt to anticipated perturbations quite well.

We did not find significant group by condition interactions, which would have indicated the groups responded differently overall to the conditions. Our summative parameters (Figures 1 and 2) illustrate the inconsistent nature of changes by variable and group, leading to the lack

of a group by condition interaction. We did, however, find significant overall group differences in gait parameter and variability measures.

Overall, gait parameter means for adults with DS were significantly different compared to their peers with TD, indicating adults with DS maintained stability enhancing adaptations used in baseline across perturbation conditions. They walked slower with wider strides than their peers with TD, consistent with masked [1].

Statistically significant group differences for amount of variability in gait parameters were largely due to adults with DS showing more stride velocity variability and close to, but not significantly less, step width variability than adults with TD. While the more common finding is increased variability in movement patterns in persons with DS as compared to their peers with TD [13,27], and increased step width variability in older as compared to younger adults [28,29], we observed this pattern does not hold for step width variability in adults with DS. Researchers have shown in passive dynamic robots and in-vivo studies that step width is more actively controlled than step length to provide medial-lateral stabilization [30,31]. As compared to their peers with TD, adults with DS use a wider step width to stabilize their center of mass and show here that they are less willing or able to adjust it.

Although not supported by statistical group by condition interactions, we would like to describe some interesting tendencies in the data. They align with our anecdotal observations and we believe they are worthy of prospectively-designed future study with an adequately powered larger sample. During the divided attention, low light and obstacle conditions adults with DS tended to adjust their gait differently than adults with TD. This is seen in Figure 1, where adults with DS and TD shift their gait parameters in opposite directions for most gait variables from baseline to the divided attention, low light and obstacle conditions. In the remaining conditions, the groups tended to shift gait parameters in the same direction. Anecdotally, differences in responses of adults with DS and TD in the distracted attention condition were that adults with DS were influenced by the rhythm of the counting task and synchronized their stepping and counting, increasing stride length (see Figure 1) and decreasing overall variability (see Figure 2). In the low light condition, adults with DS increased walking speed and stride length (see Figure 1), likely because darkness eliminated visual distractions. Results indicating the groups responded differently to the obstacle are consistent with earlier work where we observed that adults with DS, as compared to their peers with TD, used extended preparation time and more gradual adjustments in stride length and percent stance while approaching a 12-cm-high obstacle [1].

Overall, adults in both groups adapted their gait in response to the conditions. Although they showed adaptations, a few adults with DS demonstrated ultimate failure in their ability to adapt and remain stable; three adults with DS experienced loss of balance during testing while none of the adults with TD did. This result, combined with the fact that six out of fourteen adults with DS recruited from the community reported a fall within the past five years while five reported fear of falling, indicates this is a problematic area requiring future study. None of the TD adults in our sample reported a recent fall or reported a fear of falling.

Our study was not prospectively designed to study fallers vs. non-fallers; we did not know how many fallers with DS would participate. Future studies designed to address fallers, as well as to explore responses to unanticipated perturbations and the effects of practice on perturbation responses would help us better understand real-world control of gait and its relation to falls in older adults with DS.

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APPENDIX 1

Formulas for Normalization

$$\widehat{v} = \frac{v}{\sqrt{g l_o}}$$

$$\widehat{l}_{STRIDE} = \frac{l_{STRIDE}}{l_o}$$

$$\widehat{f}_{STRIDE} = \frac{f_{STRIDE}}{\sqrt{g/l_o}}$$

$$\hat{w}_{STEP} = \frac{w_{STEP}}{l_o}$$

where $\hat{v}$ (velocity), f_{STRIDE} (stride length), $\hat{f}_{STRIDE}$ (stride frequency), and $\hat{w}_{STEP}$ (step width) are converted gait variables, l_o is leg length (sum of thigh length and shank length) and g is acceleration due to gravity.

Figure 1.

Percent change from baseline to perturbation conditions, for adults with Down syndrome (DS) and typical development (TD). Conditions are: divided attention (DA), low light (LL), divided attention and low light combination (DA+LL), irregular surface (IRR), distracting sounds (S), irregular surface and distracting sounds combination (IRR+S) and obstacle (OBS). Figure 1a is stride length, (b) is stride frequency, (c) is step width, (d) is percent stance and (e) is stride velocity.

Figure 2.

Percent change in variability measures (CV and SD) from baseline to perturbation conditions, for adults with Down syndrome (DS) and typical development (TD). Conditions are: divided attention (DA), low light (LL), divided attention and low light combination (DA+LL), irregular surface (IRR), distracting sounds (S), irregular surface and distracting sounds combination (IRR+S) and obstacle (OBS). Figure 2a is stride length, (b) is stride frequency, (c) is step width, (d) is percent stance and (e) is stride velocity.

Table 1

Mean and standard deviation (SD) values by condition for gait parameters (as measured, not normalized) for adults with Down syndrome (DS) and typical development (TD)

Condition		Baseline			Divided Attention			Irregular Surface			Irregular Surface and Sound			Low Light			Low Light and Divided Attention			Obstacle			Distracting Sound		
		Mean	(SD)		Mean	(SD)		Mean	(SD)		Mean	(SD)		Mean	(SD)		Mean	(SD)		Mean	(SD)		Mean	(SD)	
Gait Parameters, by group																									
Stride Length (m)																									
DS	0.83	(0.07)		0.88	(0.07)		0.82	(0.07)		0.82	(0.06)		0.87	(0.07)		0.83	(0.07)		0.82	(0.08)		0.87	(0.07)		
TD	1.15	(0.09)		1.16	(0.08)		1.11	(0.07)		1.12	(0.09)		1.15	(0.07)		1.14	(0.09)		1.09	(0.12)		1.18	(0.08)		
Stride Frequency (s/stride)																									
DS	0.79	(0.05)		0.75	(0.05)		0.75	(0.06)		0.77	(0.07)		0.81	(0.05)		0.76	(0.06)		0.80	(0.09)		0.80	(0.05)		
TD	0.81	(0.04)		0.78	(0.05)		0.77	(0.05)		0.76	(0.05)		0.80	(0.04)		0.75	(0.07)		0.81	(0.08)		0.82	(0.04)		
Step Width (m)																									
DS	0.13	(0.03)		0.12	(0.03)		0.14	(0.03)		0.14	(0.03)		0.12	(0.03)		0.12	(0.03)		0.14	(0.03)		0.12	(0.03)		
TD	0.09	(0.03)		0.10	(0.03)		0.10	(0.03)		0.09	(0.03)		0.09	(0.03)		0.09	(0.03)		0.09	(0.02)		0.09	(0.03)		
Stride Velocity (m/s)																									
DS	0.67	(0.06)		0.69	(0.06)		0.66	(0.07)		0.63	(0.06)		0.72	(0.06)		0.66	(0.07)		0.67	(0.08)		0.72	(0.07)		
TD	0.95	(0.07)		0.92	(0.06)		0.86	(0.05)		0.88	(0.06)		0.94	(0.06)		0.88	(0.07)		0.89	(0.10)		0.99	(0.06)		
Percent Stance (%)																									
DS	71%	(4%)		70%	(4%)		68%	(5%)		67%	(4%)		70%	(4%)		70%	(4%)		72%	(5%)		70%	(4%)		
TD	69%	(4%)		64%	(4%)		69%	(4%)		68%	(4%)		71%	(4%)		69%	(5%)		70%	(5%)		69%	(4%)		