Gait & Posture 41 (2015) 180–184

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

# Gait characteristics of adults with Down syndrome explain their greater metabolic rate during walking

Stamatis Agiovlasitis [a,*], Jeffrey A. McCubbin [b], Joonkoo Yun [c], Jeffrey J. Widrick [d], Michael J. Pavol [c]

[a] Department of Kinesiology, Mississippi State University, 233 McCarthy Gym, PO Box 6186, Mississippi State, MS 39762, United States
[b] Colorado State University, College of Health and Human Sciences, 201A LL Gibbons Building, 1501 Campus Delivery, Fort Collins, CO 80523-1501, United States
[c] Oregon State University, School of Biological and Population Health Sciences, Women's Building, Corvallis, OR 97331, United States
[d] Boston Children's Hospital, Division of Genetics and Genomics, 300 Longwood Avenue, CLS 15030.2, Boston, MS 02115, United States

ARTICLE INFO

*Article history:*
Received 11 June 2014
Received in revised form 30 September 2014
Accepted 4 October 2014

*Keywords:*
Gait
Kinematics
Energetic cost
Down syndrome

ABSTRACT

The altered gait patterns of adults with Down syndrome (DS) may contribute to their higher net metabolic rate (net-MR) during walking than adults without DS, leading to mobility limitations. This study examined the extent to which gait characteristics explain differences in net-MR during walking between adults with and without DS. Fifteen adults with DS (27 ± 8 years) and 15 adults without DS (28 ± 6 years) completed two testing sessions in which expiratory gases and kinematic data were collected, respectively, during treadmill walking. Participants walked at six, randomly-presented dimensionless speeds, ranging from slow to fast. Hierarchical and stepwise regressions were used to determine the proportion of the variance in net-MR explained by gait variables that differed between groups, after controlling for variance due to walking speed. Positive work rate, the range of the body center of mass (COM) mediolateral position and its square, variability in the time-course of COM anteroposterior velocity, and the variability of step length, step width, and step time significantly predicted net-MR ($p < .05$). These variables collectively explained 73.9% of the variance in net-MR that was explained by DS but not by walking speed. After accounting for shared variance among predictors, step length variability made the greatest unique contribution (10.6%) to the higher net-MR in adults with DS, followed by the range of COM mediolateral motion (6.3%), step width variability (2.8%), and variability in COM anteroposterior velocity (0.7%). Therefore, the gait characteristics of adults with DS appear to largely explain their higher net-MR during walking.


## 1. Introduction

Adults with Down syndrome (DS) experience disparities in metabolic and functional health [1–3] that might be alleviated or prevented with properly-designed physical activity programs. Walking is a commonly performed activity in adults with DS [4] and could be used to improve their health. However, most adults with DS do not perform adequate amounts of health-promoting physical activity [4,5]. A contributor to this may be the fact that adults with DS have a higher net metabolic rate (net-MR) during walking than those without DS [6,7]. This increased energetic cost, when combined with their very low aerobic fitness [2], may limit the extent to which adults with DS walk. Therefore, identifying factors that increase net-MR during walking in adults with DS may lead to interventions to improve their mobility and health.

One contributor to the increased net-MR during walking in adults with DS may be their gait pattern, as theoretical and empirical support exists for a relationship between gait characteristics and net-MR. A major energetic cost during walking is the positive work needed to redirect the sagittal motion of the body center of mass (COM) during step-to-step transitions, and the rate of this work increases with increases in step length and step frequency [8,9]. Similarly, there is an energetic cost to redirecting the mediolateral motion of the COM, and this cost appears directly related to step width and the range of COM mediolateral motion [10,11]. Active stabilization of the body through the modulation of step width and step length, as reflected in the between-step

* Corresponding author. Tel.: +1 662 325 4772.
*E-mail addresses:* sagiovlasitis@colled.msstate.edu (S. Agiovlasitis), jeff.mccubbin@colostate.edu (J.A. McCubbin), jk.yun@oregonstate.edu (J. Yun), jeffrey.widrick@childrens.harvard.edu (J.J. Widrick), mike.pavol@oregonstate.edu (M.J. Pavol).

http://dx.doi.org/10.1016/j.gaitpost.2014.10.004

variability of these parameters, is also associated with an energetic cost [12,13]. Together, the energetic costs of step-to-step transitions and active stabilization may explain almost 50% of net-MR during preferred walking [8,14]. Differences in gait pattern between adults with and without DS would thus be expected to have an effect on net-MR during walking. Such differences exist, most likely due to such factors as the central control deficits, joint laxity, hypotonia, mitochondrial dysfunction, and low fitness characteristic of persons with DS [2,15–17]. We previously found that adults with DS walked with greater and more variable COM mediolateral motion, and more variable COM anteroposterior velocity and COM vertical motion than adults without DS [18]. Adults with DS also exhibited higher step frequencies and more variable step lengths, step widths, and step times. However, effects of these differences on net-MR had not been quantified.

This study therefore examined the extent to which differences in gait variables between adults with and without DS are associated with differences in net-MR between groups. Because differences in gait variables and in net-MR between adults with and without DS depend on walking speed [6,7,18], it was necessary to account for effects of walking speed. We hypothesized that, after controlling for walking speed, the gait patterns of persons with DS would explain much of their higher net-MR during walking.

## 2. Methods

### 2.1. Participants

Fifteen adults with DS and 15 adults without DS participated in this study. The groups were matched for sex (eight men, seven women). Participants with and without DS did not differ in age (mean $\pm$ SD of DS vs. non-DS group: 27.1 $\pm$ 7.6 vs. 28.2 $\pm$ 5.7 years) or body mass (66.1 $\pm$ 10.4 vs. 70.2 $\pm$ 13.4 kg), but those with DS were shorter (150.1 $\pm$ 8.1 vs. 171.1 $\pm$ 11.7 cm; $p < .05$) and had greater body mass indices (29.2 $\pm$ 3.5 vs. 23.8 $\pm$ 2.9 kg/m$^2$; $p < .05$). The relevant Institutional Review Board approved this study. Written informed consent was obtained from all participants with and without DS and from the legal guardians of those with DS.

### 2.2. Procedures

The procedures have been described in detail previously [6,18]. Briefly, participants attended multiple laboratory sessions over 2–4 weeks. Treadmill familiarization took place during the first two sessions of participants with DS and during the first session of participants without DS, providing them with 60 and 35 min of treadmill practice, respectively. The subsequent two sessions were devoted to metabolic and kinematic data collection, respectively.

During each session, participants completed one treadmill walking trial at each of a set of dimensionless speeds $\{= v/\sqrt{gL}$, where $v$ is walking speed (m/s), $g$ is the acceleration of gravity (9.81 m/s$^2$), and $L$ is leg length (m)$\}$ [9,19]. Participants walked at dimensionless speeds of 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6. Those without DS also walked at a dimensionless speed of 0.7, but their data at that speed were not included in the present analyses.

Metabolic data were collected with open-circuit spirometry (TrueMax 2400, Parvo Medics, Salt Lake City, UT) for 6 min of quiet standing and during walking trials in the corresponding testing session. The pneumotachometer and gas analyzers were calibrated prior to testing. The walking trials were 6 min in duration and were performed without hand-rail support in a randomized order. Participants sat for 5 min between trials.

Whole-body three-dimensional kinematic data were collected with a nine-camera motion-capture system (Vicon, Los Angeles, CA) during the final session. Participants wore tight-fitting clothing and 35 reflective markers were attached to their arms, legs, torso, and head using the Vicon Plug-In-Gait marker set. Following a trial of quiet standing, participants performed the walking trials in the same randomized order as in the previous session, with 3 min of rest between trials. At each speed, marker position data were collected at 60 Hz for 30–35 steps following 4 min of walking. Anthropometric measurements required for Plug-In-Gait were also made.

### 2.3. Data analyses

Average gross metabolic power over the last 2 min of each trial of the metabolic testing session was determined in Watts using the Weir method [20]. Net metabolic power during walking was then calculated by subtracting the standing from the gross metabolic power. To account for between-group differences in body size, net metabolic rate was expressed in dimensionless form [net-MR $= P/(mg\sqrt{gL})$, where $P$ is net metabolic power (Watts), $m$ is body mass (kg), and $g$ and $L$ are as defined earlier] [9]. Net-MR was the dependent variable.

Kinematic data from the final session were filtered with a fourth-order, no-lag Butterworth low-pass filter at a cut-off frequency of 9 Hz. The Vicon Plug-In-Gait software was then used to determine the position of the whole-body COM, based on a 15-segment model with assumed inertial properties [21]. For each walking trial, we determined the mean range of COM mediolateral position across strides. The variability of the COM mediolateral position, COM vertical position, and COM anteroposterior velocity were also computed as the root-mean-square value, over the stride, of the between-stride standard deviations about the participant's mean trajectory. Additionally, between-step variability in step length, step width, and step time were determined for each trial. Finally, the dimensionless positive work rate during each trial was estimated [Work rate = $1/8 \cdot f^3 \cdot s^4$, where $f$ is mean step frequency normalized by pendular frequency ($\sqrt{g/L}$) and $s$ is mean step length normalized by leg length] [9]. These gait variables were considered as potential predictors of net-MR.

Influences of walking speed and DS on net-MR within the pooled data from all participants and speeds were examined using hierarchical regression. Linear and quadratic terms for normalized walking speed were entered as the first set of predictors of net-MR; DS status (0 = non-DS; 1 = DS) and its interaction with normalized walking speed were added as the second set of predictors, and the associated $R^2$ were determined ($R^2_{\text{Speed}}$ and $R^2_{\text{Speed+DS}}$, respectively). The proportion of variance in net-MR explained by DS but not walking speed was:

$$sR^2_{\text{DS/Speed}} = R^2_{\text{Speed+DS}} - R^2_{\text{Speed}}$$

Using stepwise regression, a set of gait variables that jointly predicted net-MR across all participants and walking speeds was identified. The pool of predictors included the eight gait variables described above and quadratic terms for the range of COM mediolateral position and for step time variability, as these latter two variables exhibited curvilinear relationships with net-MR. Cut-off probabilities of 0.05 and 0.1 were used for variable entry and exit, respectively. Pearson correlations were computed between gait variables included in the final stepwise model. Effects of between-group differences in gait on net-MR at a dimensionless speed of 0.5, representative of preferred walking speed [6], were also predicted from the model and the corresponding mean values of the gait variables for the DS and non-DS groups.

Another hierarchical regression was then performed, identical to the first, except the gait variables from the final stepwise model were added to the first set of predictors (yielding $R^2_{\text{Speed+Gait}}$ and