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Graded forward and backward walking at a matched intensity on cardiorespiratory responses and postural control

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ABSTRACT

Background: While several studies compare backward walking (BW) and forward walking (FW) in terms of heart rate (HR) and rating of perceived exertion (RPE), workload (VO_2) was not matched to control for intensity levels (Hooper et al. [1]). Moreover, acute effects of inclined BW on postural control and ankle musculature has not been investigated. This study was designed to compare cardiovascular, metabolic and perceptual responses, changes in center of pressure (COP) motion, and muscle activation of tibialis anterior (TA) and gastrocnemius (GM) to control quiet stance posture immediately following inclined BW and FW at a matched intensity.
Methods: Seventeen healthy young adults completed three lab sessions 7–14 days apart. Session one, maximal oxygen consumption (VO_{2max}) was measured using open-circuit spirometry for each participant. Session two, participants performed BW for 15-min. Session three, participants performed FW for 15-min at matched intensity of BW. Surface electromyography (SEMG) measured the muscular activity of the TA and GM during bilateral stance on a force plate for 30 s prior to and immediately following BW and FW under both eyes open (EO), and eyes closed (EC) conditions.
Results: HR, VCO_2, RER and RPE were significantly greater during BW compared to FW. Increased muscle activation and COP motion was elicited immediately following BW compared to FW under EO and EC.
Conclusion: Results of this study indicate BW requires greater cardiovascular, metabolic, perceptual and neuromuscular demands than FW, which may cause postural instability particularly to those with compromised balance. While there are benefits to BW in rehabilitation settings, these factors should be considered when prescribing BW for training and/or rehabilitation exercise program (Duffell et al. [2], Warnica et al. [3]).

1. Introduction

Since the 1980s, backward walking (BW) has gained popularity as a tool for lower limb physical rehabilitation [4]. BW requires longer muscular activation in the legs than forward walking (FW) and has been shown to provide neuromuscular and cardiovascular benefits [1,5,6]. Furthermore, improvements in postural control were seen among school-aged boys over a 12-week training period of BW [7]. Other studies indicate that BW increases cardiorespiratory responses compared to FW and can maintain fitness levels while reducing forces on the lower extremity joints [1,6]. Hooper et al. [1] has demonstrated that inclined BW increased O_2 uptake by 17%–20% compared to FW at the same speed and incline levels [1]. Because of these benefits, prescribing BW has increased in clinical settings. These studies have examined the cardiovascular, biomechanical, and metabolic responses of BW compared to FW at a matched speed and/or incline however, intensity level was not standardized and therefore dissimilar [1,6,8].

Changes in postural motion occur immediately following a variety of different walking tasks under both maximal and submaximal cardiovascular intensities [9–11]. Results of these investigations indicate that the type of exercise (treadmill vs cycling), intensity level, and vision conditions (eyes open vs eyes closed) all influenced postural motion of young adults during bilateral quiet stance. Treadmill walking at a high intensity produced the greatest amount of change in postural motion compared with cycling however, these responses were transient and baseline values returned within 5–10 min [9–11]. While the intensity of exercise has been shown to have an impact on postural motion during forward treadmill walking, the impact that BW has on postural control has not yet been investigated, particularly at intensities that may provide cardiovascular training benefits.

The aim of this study was to identify the impact of BW on an inclined treadmill compared to FW at a matched moderate intensity (40–59% VO_2 Reserve; VO_2R) [12] on heart rate (HR), rate of CO_2 production (VCO_2), respiratory exchange rate (RER) and rate of

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perceived exertion (RPE). A secondary aim was to compare acute changes in postural motion and subsequent muscular activity in the GM and TA during quiet stance following BW and FW on an inclined treadmill. We hypothesized that BW compared to FW, at a matched moderate intensity, would introduce greater challenge to the cardiovascular, metabolic and neuromuscular systems of healthy young adults under similar workloads.

2. Methods

2.1. Participants

Seventeen young adults (7 males; age 19.4 ± 1.1 yr., height 172.1 ± 8.5 cm, weight 70.3 ± 12.4 kg, BMI 23.6 ± 3.1 kg·m^{-2}, VO_{2max} 47.0 ± 7.53 ml·kg^{-1} min^{-1}) participated in this study. All participants completed a physical activity readiness questionnaire (PAR-Q) [12] and a medical history questionnaire prior to activity. Participants were free of any health issues that would influence fitness and balance control. The College Institutional Review Board approved the study and written informed consent was obtained from participants.

2.2. Procedures

Participants completed three separate lab sessions, seven to fourteen days apart. In all three sessions, expired respiratory gases were collected and analyzed for O_2 and CO_2 concentration at 30-second (s) intervals (mini CPX by Vacumed; Ventura, California, USA) to determine oxygen consumption (VO_2). Second and third sessions were experimental conditions in which subjects walked backward (BW) and forward (FW) on the treadmill at a matched moderate intensity. In session one, participants completed a Bruce Protocol VO_{2max} test [13] on a motorized treadmill (TrackMaster, Full Vision Inc., Wichita, Kansas, USA). VO_{2max} was defined as the averaged VO_2 in the last 30 s of the exercise. Session two, participants walked backward on the treadmill (BW) for 15 min at 67 m min^{-1} and 10% grade to elicit a moderate intensity exercise. For session three, participants walked forward on the treadmill (FW) for 15 min at a similar intensity as that of the BW. In the FW trial, intensity was computed utilizing the American College of Sports Medicine (ACSM) metabolic equations by controlling for the speed at 67 m· min^{-1} and varying the grade [12]. When needed, as indicated by live readings from the metabolic cart, the grade was fine-tuned to match the moderate intensity of the BW trial (Table 2). A Polar® monitor (Polar E-600, Polar Electro Inc., Kempele, Finland) was used to determine heart rate (HR), and participants provided their RPE using the Borg Scale [14] for all three sessions. During BW and FW sessions, HR, VO_2, VCO_2, RER, and RPE were measured, and VO_2R was computed and recorded during the last ten minutes of exercise to allow the participant to achieve steady state exercise.

Surface electromyography (SEMG) taken from the tibialis anterior (TA) and the lateral head of the gastrocnemius (GM) (sampled at 1000 Hz) recorded muscular activation during quiet stance before and immediately after BW and FW. Pre-gelled, Ag/AgCl electrodes (SX230-1000, Biometrics, Ltd., UK) were attached over the belly of the selected muscles. SEMG was amplified using a Biometrics DataLINK amplifier (DLK900 DataLINK, Biometrics, Ltd., UK) interfacing with a desktop computer via USB.

Before and immediately following each walking condition (BW, FW), center of pressure (COP) forces were assessed using a Bertec force plate (Model 5050, Bertec Corp., Columbus, OH) and sampled at 1000 Hz. For all postural assessments, participants stood on a pliable surface (Airex® foam pad) for 30 s with eyes closed (EC) and eyes opened (EO). The foam surface provided a postural challenge to the bilateral stance of healthy young adults. Participants were instructed to adopt a comfortable, bilateral stance with their feet hip-distance apart on the foam. EO and EC conditions were alternated between participants to control for order effect.

2.3. Data reduction and analysis

COP data were filtered using a 2nd order low-pass Butterworth filter (cutoff frequency 30 Hz) and normalized. The dependent measures calculated included: COP excursion for both anterior-posterior (AP) and medio-lateral (ML) directions (e.g., mean, standard deviation (SD), and maximal sway range), COP velocity, and total COP motion (path length and 95% ellipse area). COP velocity involves the total displacement of the COP in the ML and AP directions, divided by the length of the trial (COP velocity = total excursion/time). Path length identifies the total length of the COP excursion and is approximated by the sum of the distances between two consecutive points on the COP path in both the AP and ML axes. The 95% confidence ellipse sway area (ESA) was calculated using the equation by Prieto et al. [15] where the area of the 95% bivariate confidence ellipse includes 95% of the points within the sway pathway.

SEMG data were full-wave rectified and filtered using a 2nd order low-pass Butterworth filter (cutoff frequency 400 Hz) to create a linear envelope. Each EMG data point during quiet stance was divided by the peak value for the muscle (amplitude value/peak amplitude *100) to establish a percent of maximal activation (% $Peak_{task}$) [16]. COP and SEMG data were processed using custom designed software programs in Matlab version 7.8 (R2015a, Mathworks, Inc., Natick, MA).

Approximate Entropy (ApEn) analysis was used to assess the regularity of the COP data. This analysis measures the level of repetition between m and m + 1 vectors within a tolerance range of the standard deviation (r) of a time series. This analysis returns a value between 0–2 with lower values reflecting vectors of length m are more likely to be close (within the tolerance range) to the next incremental comparisons (m + 1), thus indicating greater regularity (less structure) in the time series. A perfect sine wave or a straight line with no deviation produces an ApEn score close to zero. Higher ApEn values represent lower repeatability of the vectors m and m + 1 and represent greater irregularity (decreased structure) in the time series. Increases in ApEn have been interpreted as an increase in the signal’s time domain complexity [17].

2.4. Statistical analysis

Means and standard deviation were used to describe the physical characteristics of the participants (Table 1). Individual dependent *t*-tests were used to evaluate differences between speed, grade, HR, VO_2, VCO_2, RER, RPE, and VO_2R between trials (Table 2). A Pearson product-moment correlation coefficient was computed to assess the relationship between VO_2 and COP data. Statistical analyses were performed using statistical software (SPSS, Version 22.0, SPSS, Inc., Chicago, IL, USA). A General Linear Model (GLM) with repeated measures was used for analysis on the COP and SEMG dependent variables. Within subject factors included walking condition (BW, FW), vision condition (EO, EC), and trial (baseline, post-walking). Where significant interactions were observed, Bonferroni corrections were conducted to determine the differences. Statistical analyses for SEMG and COP data were performed using statistical software (SAS Institute Inc., Cary, NC, USA). Level of significance for all variables was set at $p < 0.05$.

Table 1
Descriptive characteristics of participants.

Variable	Mean ± SD
Age	19.41 ± 1.12
Height (m)	1.72 ± 0.08
Weight (kg)	70.30 ± 12.36
BMI (kg m^{-2})	23.64 ± 3.13

BMI = Body Mass Index.