International Journal of EXERCISE SCIENCE

Original Research

Cardiovascular, Metabolic and Perceptual Responses to Preferred Walking Speed at Different Inclines and Post Exercise Postural Control in Healthy College Age Adults

MEIR MAGAL‡1, S. LEANNA. FANN*1 and KATHLEEN S. THOMAS‡2

[1]Department of Exercise Science, North Carolina Wesleyan College, Rocky Mount, NC, USA; [2]Department of Health, Physical Education and Exercise Science, Norfolk State University, Norfolk, VA, USA

*Denotes undergraduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 15(2): 113-124, 2022. Although several studies investigated heart rate (HR) and metabolic responses to preferred walking speed (PWS), there is a limited amount of data on PWS responses during varying inclines. Further, there is no data pertaining to the impact of PWS at various inclines on postural control. The purpose of the study was to measure cardiovascular, metabolic, perceptual, and postural impacts of walking at PWS at various inclines. Twenty-one participants completed two lab sessions, seven days apart. On day one, PWS on the treadmill and maximal oxygen consumption ($\dot{V}O_{2max}$) were established for each participant. On day two, using a counter balanced design, participants completed three, 15-minute walking sessions at their PWS at 0, 4, and 8% inclines. During the sessions, HR, $\dot{V}O2$, rating of perceived exertion (RPE), $\dot{V}O_2$ reserve ($\dot{V}O_2R$) and HR reserve (HRR) were measured and recorded. Center of Pressure (COP) motion was recorded while standing upon a force plate immediately following each walking bout with eyes closed (EC) and eyes open (EO). The results of the study demonstrated a significant difference ($p < .05$) in the independent variables across the different inclines excluding HR, RPE and HRR at 4% incline. While there were no significant differences in sway amplitude between the different walking bouts, there was a significant increase in sway with EC compared to EO vision condition ($p < .05$). Still, Approximate Entropy values decreased (increased regularity) from baseline measures ($p < .05$). These findings suggest that PWS at different inclines impact measures of exertion and signal regularity but not sway amplitude or velocity.

KEY WORDS: Physical activity (PA), relative exercise intensity, muscular fatigue postural dynamics

INTRODUCTION

Habitual participation in physical activity (PA) has been shown to have many health benefits including but not limited to lower risk of numerous cardiovascular and metabolic diseases, improved musculoskeletal health and reducing all-cause mortality (22). PA has been defined as any activity that leads to an increase in caloric expenditure due to the activity of skeletal muscle.

(13). Walking, which is a form of PA, has been shown to be one the most preferred outdoor recreational activities. Further, it does not require any special skills, nor does it involve any costly expense and the volume of activity can be regulated by the exerciser (2, 3).

Generally, individuals have a preferred walking speed (PWS), a "self-selected" walking speed that is used during recreational activities. Previous studies have measured PWS in different populations including normal weight and obese individuals (9, 29, 30, 33), younger and older individuals (41), and in both males and females (30, 41). Further, studies have also used different settings to assess PWS such as above ground indoor (29, 30, 42) or outdoor (9) walking or treadmill walking (33). Although some of these studies measured aerobic capacity (8, 9, 24, 33, 36) and one may expect to see an increase in cardiovascular and metabolic measures when incline varies, limited data is available to demonstrate the perceived or measured relative intensity of PWS. In particular, walking at PWS while utilizing different inclines.

One of the outcomes of PA is muscular fatigue which is commonly defined as a failure to maintain the needed or expected force output, or a momentary decrease in the ability to perform physical activities (4, 9). This fatigue which affects the distal muscles of the lower limb (e.g., tibialis anterior, gastrocnemius) may lead to greater postural sway in both the Anterior-Posterior (AP) and Medial-Lateral (ML) directions and an increase in sway velocity. Therefore, straining the postural control system to maintain quiet stance (18, 23, 38). Several studies have investigated the effect of muscle fatigue on postural stability following moderate intensity PA and demonstrated changes in postural control because of fatigue (21, 45, 47). However, changes in postural sway due to walking at various inclines is limited. Changes in the amplitude and variability of COP can contribute to increased injury potential and/or risk of falls (21, 23).

Therefore, the current investigation has two objectives: 1) to identify the impact of walking at PWS at 0, 4, and 8% incline on heart rate (HR), oxygen consumption ($\dot{V}O_2$), rate of perceived exertion (RPE), oxygen consumption reserve ($\dot{V}O_2R$) and heart rate reserve (HRR) and 2) to compare the acute changes in postural dynamics during quiet stance following the three bouts of activity. We hypothesized there would be a direct relationship between the intensity of the exercise and the responses of the cardiovascular, metabolic, perceptual and neuromuscular systems of healthy college age adults.

METHODS

Participants

Twenty-one healthy college age adults, 11 males and 10 females (age = 21.38 ± 2.25 yr, height = 175.0 ± 9.0 cm, weight = 80.60 ± 16.62 kg, BMI = 26.24 ± 4.35 kg·m^{-2}, $\dot{V}O_{2max}$ = 46.57 ± 8.66 ml·kg^{-1}·min^{-1}, PWS = 1.11 ± 0.07 m·s^{-1}) free of any cardiovascular, metabolic, neurological, or physical impairment were recruited to participate in the study. Each participant completed a physical activity readiness questionnaire (PAR-Q+) (7), a medical history form, received detailed explanation of both the benefits and the risks of the study and gave their written informed consent. All data collection took place in the Exercise Science Laboratory at North Carolina Wesleyan College (NCWC) and were approved by the NCWC Institutional Review Board for

Human Participants Experimentation. Further, all experimental procedures followed the ethical standards set by the International Journal of Exercise Science (31).

Protocol

Participants attended two lab sessions at least seven days apart. On day one, documentation was completed, and anthropometric measures were collected. Following that, PWS was established and maximal oxygen consumption ($\dot{V}O_{2max}$) was measured on a treadmill. Finally, participants were introduced to the measurements of postural stability. On day two, postural stability was recorded prior to and immediately following three 15-minute walking sessions (at 0, 4 and 8% incline) at PWS. PWS was the same for all walking sessions.

Anthropometry: Body mass was measured to the nearest 20 g (Ohaus Champ II Model CH 150 R11, Ohaus Corporation, Florhan Park, New Jersey, USA) and height was measured to the nearest 0.1 m using a stadiometer.

PWS establishment: Participants were asked to choose a comfortable speed, which was increased and decreased by approximately 0.1-0.2 miles $\cdot hr^{-1}$ per input from each participant. Determining PWS was completed without any leading questions, but by merely asking the test participant, "how that feels in comparison to your normal walking speed".

HR, Metabolic, and RPE measurements: On both days, HR was obtained and measured continually via heart rate monitor (Polar E-600, Polar Electro Inc., Kempele, Finland) and O_2 and CO_2 concentration were collected via expired respiratory gases at 30-second (s) intervals (mini CPX by Vacumed; Ventura, California, USA) to determine oxygen consumption ($\dot{V}O_2$). On day one, participants completed a $\dot{V}O_{2max}$ test using the Bruce Protocol (10) on a motorized treadmill (TrackMaster, Full Vision Inc., Wichita, Kansas, USA). Maximal oxygen consumption was defined as the averaged $\dot{V}O_2$ in the last 30 s of the exercise upon volitional fatigue. Rate of perceived exertion was measured at the last 10 seconds of each completed stage and the end of the test. On day two, participants completed three, 15-minute walking sessions at their PWS at 0, 4, and 8% inclines. The order of the inclines was counterbalanced and separated by a 10-minute rest period to allow HR and metabolic variables to return to baseline. The first five minutes of each walking session allowed participants to achieve steady state exercise. Steady state HR, $\dot{V}O_2$ and RPE were recorded every minute during the last 10 minutes of each session. The presented data were the average of each of these variables.

Balance measurements: Balance protocols were completed in both lab sessions, however, day one served as a familiarization session which let participants stand on the force plate with a pliable surface with no actual data recording. The second lab visit, center of pressure (COP) force was assessed using a Bertec force plate (Model 5050, Bertec Corp., Columbus, OH) before and immediately following each walking session. These were sampled at 1000 Hz. For all postural assessments, participants stood on a pliable surface (Airex® foam pad) for 30 s under eyes closed (EC) and eyes opened (EO) conditions. The foam surface provided a postural challenge to the bilateral stance of the participants. 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. All COP data were processed using customized software programs in Matlab version 7.8 (R2015a, Mathworks, Inc., Natick, MA). COP data were filtered using a 2nd order low-pass Butterworth filter (cutoff frequency 30 Hz).

COP measures: Dependent measures included COP excursion (e.g., mean, standard deviation (SD), and maximal sway range), COP velocity, and total COP motion (path length). COP velocity was calculated as the total displacement of the COP in both the medio-lateral (ML) and anterior-posterior (AP) directions, divided by the length of the trial (COP velocity = total excursion/time). Path length includes the total length of the COP excursion and is estimated by the sum of the distances between two consecutive points on the COP path in both the A-P and M-L axes. (35).

COP signal regularity was assessed using Approximate Entropy (ApEn) analysis. This analysis measures the conditional probability of the likelihood that any given data point (n) in the time series that is close for m observations, remains close at the next incremental comparison ($m + 1$). This is calculated by the level of repetition that occurs between m and $m + 1$ vector within a tolerance range of the standard deviation (r) of a time series. This is shown as a value between 0-2. Lower values reflect 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 would produce an ApEn score close to zero. Higher ApEn values correspond to lower repeatability of the vectors m and $m + 1$ and represent greater variability in the time series (34).

Statistical Analysis

The physical characteristics of the participants were described by way of means and standard deviation. A one-way analysis of variance (ANOVA) was used to analyze the differences between HR, $\dot{V}O_2$ and RPE and HRR and $\dot{V}O_2R$ across the different treatments (Table 1). A Bonferroni correction was used to eliminate the possibility of type I errors in the consequent pairwise comparison. To analyze sway (Figures 1 and 2), a Mixed General Linear Model (GLM) and two-way ANOVA with repeated measures was used for statistical analysis of each dependent variable. The major dependent variables that were focused upon were COP excursion, including mean and maximal sway ranges, COP velocity, and total COP motion. COP velocity was determined by dividing total ML and AP displacement by the trial length in terms of time. Total COP motion was calculated by an equation in which 95% of the bivariate confidence ellipse is expected to include 95% of the point within the total sway pathway (35). Effect size were calculated and classified using η^2 (small = 0.01, medium = 0.06, and large > 0.14) (15). Statistical significance was set at $p < .05$ for this investigation. All statistical analyses were performed using a statistical software package (SPSS, Version 27.0, SPSS, Inc., Chicago, IL).

RESULTS

Energy Costs Due to Incline Walking: Differences in HR, $\dot{V}O_2$, RPE, $\dot{V}O_2R$ and HRR between the different walking sessions are presented in Table 1. Generally, the results of the study demonstrated a significant difference ($p < .05$) in the independent variables across the different inclines excluding HR, RPE and HRR at 4% incline. Further, there was a large effect size in all the variables across the different inclines.

Table 1. Differences in HR, $\dot{V}O_2$, RPE, $\dot{V}O_2R$ and HRR between the different walking sessions.

Variable/Percent	0	4	8	0 vs 4 *p*	0 vs 8 *p*	Effect
HR (bpm)	91.76 ± 13.90	98.95 ± 12.75	113.29 ± 16.64	0.34	< .001*	0.29
$\dot{V}O_2$ (ml ·kg^{-1} ·min^{-1})	12.29 ± 1.16	14.98 ± 1.19	19.65 ± 1.55	< .001*	< .001*	0.85
RPE	6.88 ± 1.10	7.49 ± 1.69	8.91 ± 2.43	0.85	0.02*	0.19
$\dot{V}O_2R$ (%)	18.22 ± 5.51	24.96 ± 6.67	36.61 ± 8.65	.009*	< .001*	0.55
HRR (%)	20.22 ± 11.97	26.25 ± 11.01	38.30 ± 13.72	0.35	< .001*	0.28

*Significant differences between walking sessions, $P \leq .05$.

Impact of Incline Walking on Postural Control: The raw COP data between the 3 conditions under both the EO and EC vision conditions are illustrated in Figure 1.

A main effect for vision was indicated for all the COP variables ($p < 0.001$; $\eta^2 = 0.66$) with the EC condition producing greater amounts of sway compared to EO (Figure 1). A significant main effect for trial ($p = 0.006$; $\eta^2 = 0.58$) was revealed in the structure (ApEn) of COP motion in the ML direction. Walking on the treadmill elicited greater regularity in the signal (lower ApEn) compared to that at baseline but no significant main effect ($p > 0.05$) was seen due to the different incline conditions in the path length ($p = 0.831$; $\eta^2 = 0.010$), COP excursion ($p = 0.990$; $\eta^2 = 0.0005$) or structure (ApEn) in either ML ($p = 0.199$; $\eta^2 = 0.09$) or AP ($p = 0.081$; $\eta^2 = 0.14$) directions (Table 2).

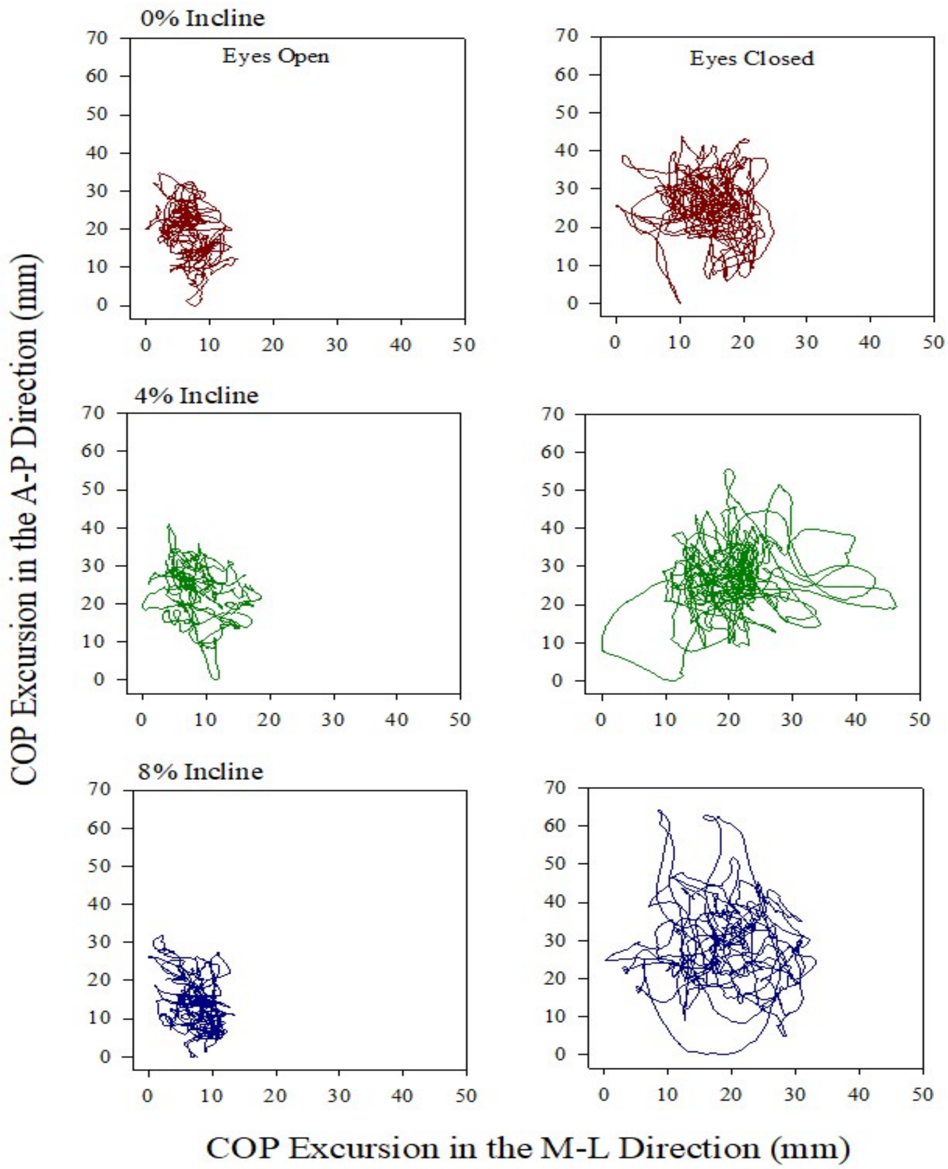

Figure 1. COP traces for each incline level under EO and EC conditions.

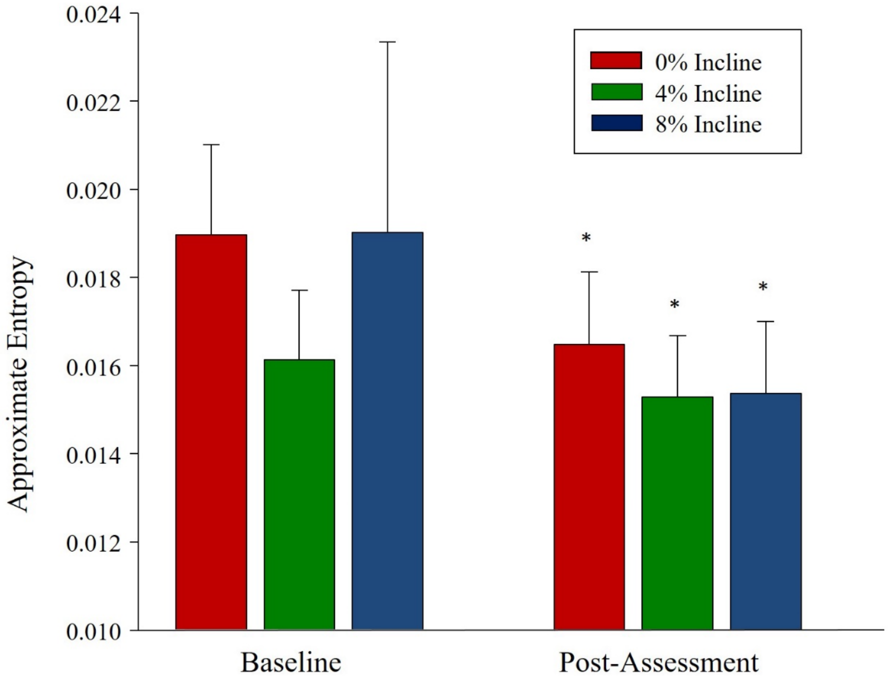

Figure 2. Approximate entropy values-ML direction. *Significant difference between Baseline and Post-walking assessment in ML COP ApEn values across the different inclines.

Table 2. Mean ± Standard Deviation for COP motion.

COP Variable	Baseline		0 % Incline		4 % Incline		8 % Incline	
	EO	EC	EO	EC	EO	EC	EO	EC
Mean Velocity (mm/s)	11.7 ± 2.0	27.4 ± 7.4	14.0 ± 4.3	25.6 ± 5.8	13.4 ± 2.6	26.40 ± 7.1	13.9 ± 2.8	26.1 ± 4.7
Mean ML (mm)	8.5 ± 4.2	16.9 ± 6.2	14.3 ± 4.2	18.8 ± 7.3	13.3 ± 7.5	16.9 ± 4.5	14.6 ± 7.3	21.5 ± 9.6
Mean AP (mm)	16.1 ± 4.0	28.9 ± 7.1	19.5 ± 6.3	28.2 ± 8.0	18.5 ± 6.2	30.0 ± 8.4	17.7 ± 7.1	29.2 ± 9.0
CV – ML (%)	34.6 ± 6.2	36.3 ± 10.7	36.4 ± 9.7	34.8 ± 6.7	36.4 ± 7.2	36.1 ± 6.2	35.2 ± 8.2	32.2 ± 7.0
CV – AP (%)	39.1 ± 9.4	33.8 ± 5.9	35.4 ± 7.0	34.8 ± 4.9	36.0 ± 7.0	35.9 ± 4.1	38.0 ± 11.2	35.8 ± 4.3
Range ML (mm)	16.0 ± 6.1	34.0 ± 10.0	27.5 ± 19.3	37.4 ± 11.8	25.2 ± 10.4	35.2 ± 8.7	27.9 ± 12.0	42.8 ± 20.5
Range AP (mm)	33.4 ± 7.0	56.6 ± 12.9	39.5 ± 12.1	54.9 ± 13.5	35.7 ± 9.9	63.4 ± 13.7	35.2 ± 10.8	61.7 ± 17.7
95% ESA (mm^2)	292.3 ± 76.3	1017.2 ± 314.3	608.8 ± 590.2	1083.9 ± 418.3	561.6 ± 332.9	1207.4 ± 535.4	573.1 ± 352.7	1357.5 ± 836.0

DISCUSSION

The aim of this study was twofold: 1) to identify the impact of walking at PWS on 0, 4, and 8% incline on HR, $\dot{V}O_2$, RPE, $\dot{V}O_2R$ and HRR and 2) to compare the acute changes in postural dynamics during quiet stance following the three bouts of activity. The results of the study demonstrated a significant difference in the independent variables across the different inclines excluding HR, HRR and RPE at 4% incline and a large effect size for all variables. Further, a significant difference with effect size of 0.62 was demonstrated between EO and EC vision conditions at all three inclines. Lastly, a significant difference and an effect size of 0.58 was seen in the COP structure in the mediolateral direction following the walking activities regardless of the incline level.

Previous reports have identified the cardiovascular, metabolic, and perceptual responses of PWS in different populations (8, 9, 24, 33, 36), yet these studies have not teased out the effects of PWS at different inclines. The current study showed that HR, $\dot{V}O_2$, and RPE responses, while walking at PWS, yielded a direct relationship with the incline of the treadmill. Although the effect size was large, the $\dot{V}O_2$ was significantly greater at both the 4% and the 8% inclines when compared to baseline while HR and RPE showed similar trends at the 4% incline but were only significant at the 8% incline (Table 1). The effects of these various bouts of PA on the cardiovascular and metabolic systems are not surprising. The increase in the incline of the treadmill challenges the different body systems to cope with the increasing demands of the PA, produce more energy and deliver more blood to the working skeletal muscles (26, 39). The relationship to RPE is not surprising either considering that the RPE of any given PA bout reflects the feed forward mechanism indicating the level of stress from the various body mechanisms such as the metabolic and cardiovascular systems (5, 20).

A major purpose of the current investigation was to measure the relative intensity responses of walking at PWS at different inclines by examining both $\dot{V}O_2R$ (%) and HRR (%). Both variables demonstrated large effect size and were significantly higher across the different inclines excluding HRR at 4% incline (Figure 1). Yet and although not significant, HRR at 4% was higher than the HRR at 0% and lower than the HRR at 8% therefore conforms to the predictable trend of directly relating to the treadmill incline. The current study demonstrated that the percent $\dot{V}O_2R$ of walking at PWS at 0% grade is much lower (Table 1) than previously reported. Browning and Kram (9) found that the $\dot{V}O_2R$ of walking at PWS at 0% grade is 51% and 36% for obese and normal weight participants, respectively. Although the participants in the current study may be defined as overweight based on BMI measures (28) and therefore expected to have higher $\dot{V}O_2R$ than normal weight participants, this was not the case. The current finding may be explained by differences in maximal aerobic capacity values ($\dot{V}O_{2max}$). The participants in the current study had ~45% and ~17% higher aerobic capacity when compared to the obese and normal weight participants (9). Vollaard and colleagues (46) have demonstrated that individuals with higher $\dot{V}O_{2max}$, had a significantly lower absolute $\dot{V}O_2$ and HR responses for a given submaximal exercise intensity. In agreement with others (1, 37, 40), they have suggested that these improvements may be related to better metabolic and hormonal control and greater dependence on lipids metabolism (46).

It is important to note that although there was an increase in the relative intensity [$\dot{V}O_2R$ (%) and HRR (%)] with the increasing treadmill inclines, the intensity of these bouts were perceived as very light and light (Table 1), as defined by the American College of Sports Medicine (ACSM) (22, 28). This finding may be important especially when one considers the implication of walking at PWS, even at different inclines, and the health-related benefits of such an activity in this population. In the recently published *2018 Physical Activity Guidelines Advisory Committee Report,* the authors of the publication have concluded that although any PA, regardless of intensity may provide health benefits, moderate-to-vigorous PA (MVPA) may provide more substantial health benefits (17). While the health benefits of walking at PWS at different inclines may have less than optimal effects on the current cohort of participants, this may not be the case with other population such as older, cardiovascular disease (CVD) patients, and obese participants. In these populations, individuals have lower $\dot{V}O_{2max}$ and higher relative $\dot{V}O_2$ for a given task (9, 24, 25, 29, 32, 43). Therefore, walking at PWS, with or without incline, may be MVPA in these populations. Yet, the current investigation did not assess these cohorts and therefore this assumption is purely speculative.

Our investigation has also demonstrated that COP variables were affected by vison and that the EC condition produced greater amounts of sway compared to EO (Figure 1). However, the differences in amplitude of sway between visual conditions was not surprising. It has been well documented that humans with sight are heavily reliant on vision. As in many previous studies, closing the eyes increases the amount of sway compared to having the eyes open (6, 12, 16, 27, 45).

While no significant differences were revealed in the amplitude and/or velocity of sway following walking at any of the three different incline levels (Table 2), a statistically significant difference with an effect size of .582 was seen in the COP structure in the mediolateral direction following the walking activities (Figure 2). It was hypothesized there would be an increase in sway amplitude due to the increased treadmill incline however, this was not indicated in the current study. In contrast, previous studies have reported increases in sway due to changes in walking speed and inclines (6, 11, 44, 45). The reason for this could be due to the lower intensity level even with the increases in incline levels (19).

Changes in the COP timeseries in the ML direction following treadmill walking indicates there is less-randomness in the structure (lower ApEn) compared to baseline values. This increased signal regularity has been identified in previous research as an attempt to further control postural sway through increased co-contraction of the lower extremity musculature (14, 34) indicating that even a low-level exercise poses some challenges to the postural control system. It is important to point out that such changes to COP can contribute to increased risk of injury due to falls mainly in older and more frail populations.

Overall, the results of the current investigation suggest there was a direct relationship between HR, $\dot{V}O_2$, RPE, $\dot{V}O_2R$ and HRR and the incline of the treadmill while walking at PWS. However, in the current cohort the differences between the inclines elicited intensities found to be below the recommended MVPA for optimal health benefits. Additionally, while current findings indicate that the act of treadmill walking at PWS does cause mild disruption to postural sway, the levels of incline used did not prove to further increase the amplitude or velocity of sway. The changes in the structure of the signal due to the PA aligns with the changes indicated in increased HR, $\dot{V}O_2$, RPE, $\dot{V}O_2R$ and HRR in this healthy young college-aged population.

Limitations: There is one limitation to the study. In the current protocol, the participants completed three, 15-minute walking sessions at their PWS at 0, 4, and 8% inclines separated by a 10-minute rest period. Following that, balance measurements commenced. Although one may assume that the balance measures may be different if each trial (0, 4, 8%) would have been completed on different day, precautions were taken to limit this possibility. First, the 10-minute rest period was added to allow HR and metabolic variables to return to baseline to limit the effect on the balance measurements. Second, the order of the inclines was counterbalanced. Therefore, such an assumption is possible but unlikely.

REFERENCES

1. Achten J, Gleeson M, Jeukendrup AE. Determination of the exercise intensity that elicits maximal fat oxidation. Med Sci Sports Exerc 34 (1): 92-97, 2002.

2. Ball K, Bauman A, Leslie E, Owen N. Perceived environmental aesthetics and convenience and company are associated with walking for exercise among Australian adults. Prev Med 33 (5): 434-440, 2001.

3. Barton J, Hine R, Pretty J. The health benefits of walking in greenspaces of high natural and heritage value. J Integr Environ Sci 6 (4): 261-278, 2009.

4. Bigland-Ritchie B, Furbush F, Woods J. Fatigue of intermittent submaximal voluntary contractions: central and peripheral factors. J Appl Physiol 61 (2): 421-429, 1986.

5. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14 (5): 377-381, 1982.

6. Bove M, Faelli E, Tacchino A, Lofrano F, Cogo CE, Ruggeri P. Postural control after a strenuous treadmill exercise. Neurosci Lett 418 (3): 276-281, 2007.

7. Bredin SS, Gledhill N, Jamnik VK, Warburton DE. PAR-Q+ and ePARmed-X+: new risk stratification and physical activity clearance strategy for physicians and patients alike. Can Fam Physician 59 (3): 273-277, 2013.

8. Browning RC, Baker EA, Herron JA, Kram R. Effects of obesity and sex on the energetic cost and preferred speed of walking. J Appl Physiol 100 (2): 390-398, 2006.

9. Browning RC, Kram R. Energetic cost and preferred speed of walking in obese vs. normal weight women. Obes Res 13 (5): 891-899, 2005.

10. Bruce R, Blackmon J, Jones J, Strait G. Exercising testing in adult normal subjects and cardiac patients. Pediatrics 32 (4): 742-756, 1963.

11. Caron O. Effects of local fatigue of the lower limbs on postural control and postural stability in standing posture. Neurosci Lett 340 (2): 83-86, 2003.

12. Caron O. Is there interaction between vision and local fatigue of the lower limbs on postural control and postural stability in human posture? Neurosci Lett 363 (1): 18-21, 2004.

13. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public health rep 100 (2): 126-131, 1985.

14. Cavanaugh JT, Guskiewicz KM, Giuliani C, Marshall S, Mercer VS, Stergiou N. Recovery of postural control after cerebral concussion: new insights using approximate entropy. J Athl Train 41 (3): 305, 2006.

15. Cohen J. Statistical power analysis for the behavioral sciences. Academic press; 2013.

16. Collins J, De Luca C. The effects of visual input on open-loop and closed-loop postural control mechanisms. Exp Brain Res 103 (1): 151-163, 1995.

17. Committee PAGA. Physical Activity Guidelines Advisory Committee Scientific Report; ODPHP. US Department of Health and Human Services: Washington, DC, USA 779, 2018.

18. Corbeil P, Blouin J-S, Bégin F, Nougier V, Teasdale N. Perturbation of the postural control system induced by muscular fatigue. Gait Posture 18 (2): 92-100, 2003.

19. Egerton T, Brauer SG, Cresswell AG. Dynamic postural stability is not impaired by moderate-intensity physical activity in healthy or balance-impaired older people. Hum Mov Sci 29 (6): 1011-1022, 2010.

20. Eston R. Use of ratings of perceived exertion in sports. Int J Sports Physiol Perform 7 (2): 175-182, 2012.

21. Fox ZG, Mihalik JP, Blackburn JT, Battaglini CL, Guskiewicz KM. Return of postural control to baseline after anaerobic and aerobic exercise protocols. J Athl Train 43 (5): 456-463, 2008.

22. Garber CE, Blissmer B, Deschenes MR et al. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. Med Sci Sports Exerc 53 (1): 124-130, 2011.

23. Gribble PA, Hertel J. Effect of lower-extremity muscle fatigue on postural control. Arch Phys Med Rehabil 85 (4): 589-592, 2004.

24. Jones LM, Waters DL, Legge M. Walking speed at self-selected exercise pace is lower but energy cost higher in older versus younger women. J Phys Act Health 6 (3): 327-332, 2009.

25. Kurl S, Laukkanen JA, Rauramaa R, Lakka TA, Sivenius J, Salonen JT. Cardiorespiratory fitness and the risk for stroke in men. Arch Intern Med 163 (14): 1682-1688, 2003.

26. Lavie CJ, Arena R, Swift DL et al. Exercise and the cardiovascular system: clinical science and cardiovascular outcomes. Circ Res 117 (2): 207-219, 2015.

27. Lepers R, Bigard AX, Diard J-P, Gouteyron J-F, Guezennec CY. Posture control after prolonged exercise. Eur J Appl Physiol Occup Physiol 76 (1): 55-61, 1997.

28. Liguori G, American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. Lippincott Williams & Wilkins; 2022.

29. Mattsson E, Larsson UE, Rössner S. Is walking for exercise too exhausting for obese women? Int J Obes 21 (5): 380-386, 1997.

30. Melanson EL, Bell ML, Knoll JR et al. Body mass index and sex influence the energy cost of walking at self-selected speeds. Med Sci Sports Exerc 35 (5): S183, 2003.

31. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12 (1): 1, 2019.

32. Ogawa T, Spina RJ, Martin 3rd W et al. Effects of aging, sex, and physical training on cardiovascular responses to exercise. Circulation 86 (2): 494-503, 1992.

33. ÖhrstrÖm JH, Mats Ekelund, Margareta. Energy expenditure during treadmill walking before and after vertical banded gastroplasty: A one-year follow-up study in 11 obese women. Eur J Surg 167 (11): 845-850, 2001.

34. Pincus SM, Goldberger AL. Physiological time-series analysis: what does regularity quantify? American Journal of Physiology-Heart and Circulatory Physiology 266 (4): H1643-H1656, 1994.

35. Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM. Measures of postural steadiness: differences between healthy young and elderly adults. IEEE Trans Biomed Eng 43 (9): 956-966, 1996.

36. Ralston HJ. Energy-speed relation and optimal speed during level walking. Int Z Angew Physiol 17 (4): 277-283, 1958.

37. Ramsbottom R, Williams C, Fleming N, Nute M. Training induced physiological and metabolic changes associated with improvements in running performance. Br J Sports Med 23 (3): 171-176, 1989.

38. Reimer III RC, Wikstrom EA. Functional fatigue of the hip and ankle musculature cause similar alterations in single leg stance postural control. J Sci Med Sport 13 (1): 161-166, 2010.

39. Rivera-Brown AM, Frontera WR. Principles of exercise physiology: responses to acute exercise and long-term adaptations to training. PM R 4 (11): 797-804, 2012.

40. Romijn J, Coyle E, Sidossis L, Rosenblatt J, Wolfe R. Substrate metabolism during different exercise intensities in endurance-trained women. J Appl Physiol 88 (5): 1707-1714, 2000.

41. Samson MM, Crowe A, De Vreede P, Dessens JA, Duursma SA, Verhaar HJ. Differences in gait parameters at a preferred walking speed in healthy subjects due to age, height and body weight. Aging 13 (1): 16-21, 2001.

42. Spyropoulos P, Pisciotta J, Pavlou K, Cairns M, Simon S. Biomechanical gait analysis in obese men. Arch Phys Med Rehabil 72 (13): 1065-1070, 1991.

43. Sui X, LaMonte MJ, Blair SN. Cardiorespiratory fitness as a predictor of nonfatal cardiovascular events in asymptomatic women and men. Am J Epidemiol 165 (12): 1413-1423, 2007.

44. Thomas KS, Magal M. How does physical activity impact postural stability. J Nov Physiother 4 (206): 2, 2014.

45. Thomas KS, VanLunen BL, Morrison S. Changes in postural sway as a function of prolonged walking. Eur J Appl Physiol 113 (2): 497-508, 2013.

46. Vollaard NB, Constantin-Teodosiu D, Fredriksson K et al. Systematic analysis of adaptations in aerobic capacity and submaximal energy metabolism provides a unique insight into determinants of human aerobic performance. J Appl Physiol 106 (5): 1479-1486, 2009.

47. Vuillerme N, Hintzy F. Effects of a 200 W–15 min cycling exercise on postural control during quiet standing in healthy young adults. Eur J Appl Physiol 100 (2): 169-175, 2007.