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ORIGINAL ARTICLE

Inverse association between changes in energetic cost of walking and vertical accelerations in non-metastatic breast cancer survivors

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Abstract

Purpose With accelerometry, the utility to detect changes in physical activity are predicated on the assumption that walking energetics and gait mechanics do not change. The present work examined associations between changes (Δ) in walking energetics, exercise self-efficacy, and several accelerometer-derived metrics.

Methods Secondary analyses were performed among a sub-sample ($n = 29$) of breast cancer survivors participating in a larger randomized trial. During 4 min of treadmill walking (0.89 m s^{-1}, 0% grade), indirect calorimetry quantified steady-state energy expenditure (EE), wherein, participants were fitted with a heart rate monitor and hip-worn triaxial accelerometer. Exercise self-efficacy was measured using a 9-item questionnaire, while vector magnitude (VM) and individual planes (e.g., mediolateral, vertical, and anteroposterior) of the movement were extracted for data analyses. Evaluations were made at baseline and after 3 months.

Results From baseline to 3 months, the energetic cost of walking (kcals min^{-1}) significantly decreased by an average of − 5.1% ($p = 0.001$; $d = 0.46$). Conversely, VM significantly increased ($p = 0.007$; $d = 0.53$), exclusively due to greater vertical accelerations (acc) (+ 5.7 ± 7.8 acc; $p = 0.001$; $d = 0.69$). Changes in vertical accelerations were inversely and positively associated with Δwalking EE ($r = -0.37$; $p = 0.047$) and Δexercise self-efficacy ($r = 0.39$; $p = 0.034$), respectively.

Conclusion Hip-worn accelerometers do not appear well-suited to correctly detect changes in ease of walking as evidenced by reduced energetic cost. Further research should determine if a divergence between measured EE and vertical accelerations could contribute to erroneous inferences in free-living physical activity.

Keywords Cardiovascular · Energy expenditure · Exercise training · Non-metastatic · Physical activity

Introduction

Recent evidence indicates there are more than 3.5 million women living in the United States with a history of breast cancer (Miller et al. 2016). Earlier detection and advances in targeted therapies have largely contributed to an expanding population where 5-year survival rates reach 90% (Siegel et al. 2018). As cancer incidence increases with age (Rowland 2008), treatment-related comorbidities, including systemic deconditioning, correspond with an elevated risk of functional impairment (Deimling et al. 2009). Regrettably, even the most mundane tasks of daily-living can become troublesome, as declining skeletal muscle strength and cardiorespiratory fitness necessitate greater utilization of physiologic reserve. While the known health consequences attributed to a sedentary lifestyle are well-defined, many breast cancer survivors (BCS) are insufficiently active (Mason et al. 2013). This, in turn, elevates the risk of cardio-metabolic dysregulation and poor weight management (Elme et al. 2013). As such, increasing physical activity adherence among BCS is essential for interventions designed to enhance health outcomes in this population (Troeschel et al. 2018).

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Multiple randomized controlled trials over the last two decades have shown structured exercise training favorably influences general health/well-being in cancer populations (Speck et al. 2010). Consistent with the extensive phenotypic changes of habitual exercise, we have previously shown a modest reduction in oxygen cost of walking associated with greater free-living physical activity in BCS (Carter et al. 2018). Given the known synchrony between physiological and psychological constructs, it is reasonable to suspect that improved ease of walking (i.e., ↓difficulty) similarly contributes to greater exercise self-efficacy/confidence. Indeed, fitness-related improvements may invoke a positive perception whereby individuals may feel less constrained by their physical capacities, and thus, more capable of independent-living. To our knowledge, no prior work has determined if the energetics of walking relate to confidence levels as evidenced by changes in exercise self-efficacy among BCS (Rogers et al. 2006). A clearer understanding of this relationship could inform innovative exercise strategies designed to encourage greater physical activity by optimizing the energetic cost of walking.

Technological advancements have improved user-interface wherein the determination of physical activity under free-living conditions has been simplified. Hip-worn triaxial accelerometers, in particular, correlate moderately with the established criterion (doubly-labeled water) for estimating activity-related energy expenditure (EE) (Van Remoortel et al. 2012), however; the generalizability of reported outcomes like weekly minutes of moderate-to-vigorous physical activity are less straight-forward (Pedisic and Bauman. 2015). From a translational perspective, data interpretation can become problematic as indirect calorimetry reveals the energetic cost of non-graded walking varies from 12 to 25% between-individuals (Hunter et al. 2011). Moreover, it is uncertain whether fitness-related changes in the energetics of walking alter accelerometry-derived detection of the mediolateral, vertical, and anteroposterior planes. Given the propensity for weight gain in BCS (Gross et al. 2015), effective weight management necessitates accurate knowledge of factors governing ambulatory bioenergetics and accurate field-based monitoring/measurement.

Therefore, in the present pilot study we sought to examine the following among a sub-sample of post-primary treatment BCS participating in a randomized trial: (1) evaluate whether changes (Δ) in energetics of walking associated with Δaccelerometer-derived metrics during a standardized treadmill task and; (2) determine if Δenergetics of walking associated with Δconfidence levels as measured by exercise self-efficacy. It was hypothesized that: (1) Δenergetic cost of walking would positively associate with Δaccelerometer-derived estimates of EE and; (2) Δenergetic cost of walking would negatively associate with Δexercise self-efficacy.

Methods

Design

The present investigation is a secondary analysis from a sub-sample enrolled in a two-armed, randomized study testing a 3-month physical activity behavior-change intervention *vs.* control group (Rogers et al. 2012), supplemented to examine additional outcomes (Carter et al. 2018). Participants from both study groups (i.e., 17 received a 3-month physical activity behavior-change intervention focused on walking and 12 received written materials related to physical activity) were pooled for the purposes of this pilot study focusing on associations among change scores (i.e., deltas) related to the standardized walking task.

Inclusion/exclusion criteria

Briefly, participants were English-speaking females from 18 to 70 years. Inclusion criteria were limited to ambulatory participants not currently receiving chemo-/radio-therapy. Based on self-report, only participants performing < 60 min of moderate-intensity *or* < 30 min of vigorous-intensity physical activity per week were included. Exclusion criteria were: [1] without physician's clearance (e.g., possible contraindication to perform regular physical activity); [2] metastatic or recurrent breast cancer; [3] dementia or cognitive disorders preventing full study participation; [4] participation in an on-going exercise study; and [5] planned travel. An IRB-approved telephone script was used for initial screening purposes, after which, interested participants were scheduled for an orientation visit. Protocols/expectations were covered in-detail. Written informed consent was obtained from those committed to study involvement and scheduled for a baseline assessment. In compliance with the guidelines established by the Declaration of Helsinki, all study procedures were approved by the local Institutional Review Board. Group allocation was determined at random using a computer-based number generator in blocks of 4. Each number was stored in a sealed, opaque envelope until completion of baseline measures. Research staff were blinded to the participant study group allocation.

Participants

Participants randomly assigned to the intervention (INT; $n = 17$) completed 12 supervised exercise sessions during the initial 6 weeks with a certified cancer exercise trainer. The exercise sessions tapered to home-based workouts in the concluding 6 weeks. Each participant received a heart rate (HR) monitor (Polar Electro, Kempele, Finland) for identification of target HR during supervised and unsupervised workouts. Exercise prescription was advanced progressively from baseline fitness-level with the aim of performing ≥ 150 min of moderate-intensity exercise per week. In the closing 4 weeks of the intervention, intensity-level was adjusted to elicit 40–60% of HR reserve (American College of Sports Medicine 2010). Treadmill exercise was the mode of exercise used during the supervised exercise sessions; however, following the sixth week participants were free to engage in other forms of exercise provided they adhered to specified intensity and duration. At the end of each workout, participants executed a total body stretching routine to support joint mobility and range-of-motion. During the final 6 weeks of the intervention, at 2-week intervals, participants attended (in-person or by telephone) counseling sessions designed to address exercise progression, barriers, and goal setting. Attendance at six discussion group sessions was also required (covered topics such as time management, stress management, behavioral modification strategies, etc.). Additional materials were provided including information on healthy nutrition, exercise safety, and sheets to track exercise training progress. Participants randomized to the control (CON; $n = 12$) group were furnished with publicly available written materials concerning physical activity guidelines from the American Cancer Society. Separate recommendations concerning physical activity and/or exercise training were not provided.

Assessment protocols

Assessments were conducted on two separate visits at baseline and immediately following a 3-month period. For standardization, testing was performed in morning hours after an overnight-fast. Self-report was used to collect: age, cancer stage, months since cancer diagnosis, current hormonal therapy, employment/marital status, history of chemo-/radio-therapy, smoking status, and alcohol use. Exercise self-efficacy was determined from 9-item inventory that queried participants on how confident they were to exercise in different situations (e.g., bad weather, tired). For example, participants were asked, *"How confident are you that you can exercise when you are fatigued?"* In agreement with Bandura (Bandura. 1977), Likert-type responses of 0% (not at all confident) to 100% (extremely confident) in 10% intervals were used. General headings were provided for reference: 0–20%, not at all confident; 20–40%, slightly confident; 40–60%, moderately confident; 60–80%, very confident; and 80–100%, extremely confident (Rogers et al. 2006).

Total body water

Body composition was determined from total body water (TBW) using deuterium dilution techniques as previously described (Goran et al. 1995). In short, a dose of deuterated water was administered orally after a baseline urine sample. Isotope loading was based on measured body mass (54 g if ≤ 60 kg; 63 g if 60.1–75 kg; 74 g for 75.1–95 kg; and 89 g for > 95 kg). Post-dose urine samples were collected at + 3 h and + 4 h to permit isotopic equilibrium. Urine samples were stored at − 20 °C until measured in duplicate by isotope ratio mass spectrometry. Total body water (TBW) was calculated: dose of tracer/ (isotope enrichment of post-dose sample − isotope in pre-dose sample). Fat-free mass (g) = TBW (g)/0.73. Fat mass = body mass (g) − fat-free mass (g).

Standardized walking task

A standardized (non-graded, 0.89 m s^{-1}), 4-min walking task was used to determine the energetic cost of walking via indirect calorimetry (MAX II, Pittsburgh, PA). Prior to walking, participants were outfitted with a HR monitor and accelerometer (Actigraph GT3X, Penscola, FL) secured about the anterior superior iliac crest. Following the equilibration period, breath-by-breath $\dot{V}O_2$ and carbon dioxide ($\dot{V}CO_2$) production were collected in 30-s aggregates wherein the average of the concluding 2 min were used for subsequent analyses. Of note, $\dot{V}O_2$ data were plotted against time to confirm steady-state. Calculation of energy expenditure (EE) was performed by multiplying $\dot{V}O_2$ (L min^{-1}) by the thermal equivalent of O_2 at the corresponding measured respiratory quotient (RQ) using the equation described by Lawler and White (Lawler and White. 2003): kcals $min^{-1} = (B)(4.686) + [1.23\,(RQ - 0.707)]$; where B is $\dot{V}O_2$.

Actigraphy

A single, triaxial accelerometer was fastened about the non-dominant hip (anterior superior iliac crest) and worn throughout the duration of the standardized treadmill task. Similar to the approach described by Hall and colleagues (Hall et al. 2013), the time of day was recorded at the start of each walking assessment to ensure accurate synchronization between measured EE and accelerometry-derived metrics over the same period. Accelerations in the range of 0.05–2.0 g were recorded in mediolateral, vertical, and anteroposterior planes. Vector magnitude (VM), according to manufacturer details, represents a composite of the three orthogonal planes and calculated as the square root of the sum of the squares of each axis of data. Fundamentally, as exercise intensity-level rises there is a simultaneous increase in activity "counts" detected by the device. Acceleration data were exported to a Microsoft Excel® spreadsheet in 1-s bins.

Data were subsequently gathered into 30-s averages to correspond with the sampling frequency of measured EE. Note data from the final 2 min of the walking task were used for analyses.

Statistical analyses

Data are presented as means and standard deviations unless noted otherwise. Parametric and non-parametric tests were used where appropriate. Deltas (Δ) were determined for variables of interest (i.e., energetic cost of walking, accelerometry-based metrics) by calculating the difference between 3-month follow-up and baseline data. Two-tailed, bivariate correlations were used for exploratory purposes, wherein subsequent multiple linear regressions were used to examine independent associations. Collinearity of diagnostics for all variables was within acceptable limits with variable inflation factors for each analysis less than 2.82. All data were analyzed using the Statistical Package for the Social Science (SPSS version 24.0; IBM, Armonk, NY). Substantive differences were determined with Cohen's *d* as a measure of effect size: 0.1 as trivial; 0.2 as small; 0.5 as moderate; and 0.8 as large (Thomas et al. 1991). Statistical significance level was set at $\alpha \leq 0.05$.

Results

Descriptive characteristics are shown in Table 1. Significant between-group differences were not observed at baseline. Shown in Table 2, assessments at the 3-month follow-up revealed a significant decrease (− 0.7 mLO_2 kg^{-1} min^{-1}) in overall measured energetic cost of walking, which corresponded with a concurrent − 5.1% average reduction in measured EE. Alternatively, VM and vertical accelerations were significantly increased, which in isolation, suggests the standardized treadmill task was performed with greater intensity (as opposed to the lower intensity evidenced by ↓EE). In fact, the average ΔVM and Δvertical accelerations increased by + 13% and + 31%, respectively. These changes were reflected by + 22% average increase in accelerometry-derived estimates of EE. Of note, there were no differences ($p = 0.667$; $d = 0.08$) in step rate between assessments. To account for potential confounding from body composition at the 3-month follow-up, multiple linear regression was used to determine the independent effects of fat mass and fat-free mass on vertical accelerations during the walking task (Table 3). Fat-free mass (surrogate of strength) was found to account for nearly 20% of the variance in vertical accelerations, suggesting increased vertical COM accelerations positively associated with greater fat-free mass independent of fat mass. Consistent with the parameters of treadmill walking, differences were not observed among mediolateral or anteroposterior planes. Interestingly though, Δwalking energetics (kcals min^{-1}) and Δvertical accelerations were inversely associated ($r = -0.37$; $p = 0.047$), such that greater vertical COM accelerations coincided with *less* EE (Fig. 1). Given the inextricable link between muscle–tendon elasticity and mechanical output, these findings appear indicative of improved synchrony/coordination in gait. Moreover, Δexercise self-efficacy was positively associated

Table 1 Descriptives ($n = 29$)

Variables	Overall
Age (yrs)	55 ± 7
Race	
European American	18 (62%)
African American	11 (38%)
Height (m)	1.61 ± 0.06
Body Mass (kg)	83.6 ± 24.2
Fat mass (kg)	40.6 ± 17.4
Fat-free mass (kg)	43.1 ± 7.8
Body mass index (kg/m^2)	32.2 ± 9.1
Waist circumference (cm)	90 ± 20
Hip circumference (cm)	115 ± 18
Waist-to-hip ratio	0.80 ± 0.06
Peak VO_2 ($mL{\bullet}kg^{-1}{\bullet}min^{-1}$)	20.5 ± 4.8
Barriers Self-Efficacy (au)[a]	47.3 ± 24.1
Employed (yes) [no. (%)]	16 (55%)
Marital status [no. (%)]	
Married or living with sig other	17 (59%)
Other	12 (41%)
Cancer stage [no. (%)]	
DCIS	2 (7%)
1	9 (31%)
2	14 (48%)
3	4 (14%)
Months since breast cancer diagnosis	53 ± 61
History of chemotherapy (yes) [no. (%)]	19 (66%)
History of radiation (yes) [no. (%)]	17 (59%)
Current hormonal therapy	
Aromatase inhibitor (yes)	9 (31%)
Estrogen receptor modulator (yes)	4 (14%)
Menopause [no. (%)]	
Pre-menopausal	4 (14%)
Unsure	2 (7%)
Post-menopausal	23 (79%)
Current smoker (yes) [no. (%)]	2 (6%)
Alcohol (yes) [no. (%)]	11 (38%)

Values are shown as means and standard deviations unless noted otherwise. Fat mass and fat-free mass were determined by deuterium dilution

Peak VO_2 peak oxygen uptake, *DCIS* ductal carcinoma in situ

[a]Evaluated using a 9-item questionnaire

Table 2 Baseline and 3-month responses to a fixed-speed (0.89 m s^{-1}) treadmill task ($n=29$)

Variables	Baseline	3-month follow-up	*p* value	*d*
VO_2 (mL kg^{-1} min^{-1})	9.9 ± 1.4	9.2 ± 1.2	*< 0.001*	0.73
Energetic cost (kcals min^{-1})	3.9 ± 1.3	3.7 ± 1.1	*0.001*	0.46
Vector magnitude (acc)	40.3 ± 10.9	45.6 ± 14.4	*0.007*	0.53
Mediolateral accelerations (acc)	18.1 ± 6.9	19.9 ± 7.7	0.125	0.29
Vertical accelerations (acc)	18.1 ± 10.0	23.7 ± 10.3	*0.001*	0.69
Anteroposterior accelerations (acc)	28.4 ± 9.4	28.2 ± 18.2	0.933	0.02
Accelerometer estimated energetic cost (kcals min^{-1})	1.8 ± 0.8	2.2 ± 1.5	0.100	0.34
Step rate (steps min^{-1})	65 ± 19	66 ± 17	0.667	0.08

Values are shown as means and SD. VO_2, oxygen uptake (via indirect calorimetry)

Statistically significant *p* values are in italic

acc acceleration data, *d* Cohen's effect size

Table 3 Model estimation for vertical accelerations during a fixed speed (0.89 m s^{-1}) treadmill task at the 3-month follow-up ($n=29$)

	Model *R*	R^2	Partial *r*	*p* value
Vertical accelerations	0.74	0.54		
Fat-free mass (kg)			0.447*	*0.017*
Fat mass (kg)			0.172	0.381

kg kilograms

Statistically significant *p* value is in italic

*p value < 0.05

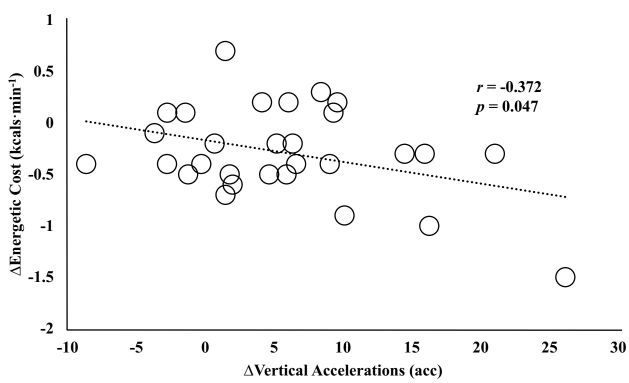

Fig. 1 Unadjusted scatterplot showing an inverse association between the changes (Δ) in energetic cost of walking (0.89 m s^{-1} at 0% grade) and Δvertical accelerations. Note that participants who performed the task with more vertical accelerations tended to expend less energy (kcals) while walking ($n=29$)

($r=0.39$; $p=0.034$) with Δvertical accelerations, which was not observed for any other accelerometry-derived metric (Table 4). Illustrated in Fig. 2, greater vertical accelerations associated with increased exercise self-efficacy. Further analyses of this relationship revealed that Δvertical accelerations exhibited a positive association ($r=0.401$; $p=0.034$) with Δexercise self-efficacy independent of Δwalking energetics (kcals min^{-1}), in part, suggesting enhanced walking mechanics (i.e., timing and muscle activation) relate to improved confidence.

Discussion

Advances in wearable-technology have made it increasingly feasible for researchers to examine patterns of physical activity under free-living conditions. Consensus indicates accelerometers have the advantage of minimal burden and impartiality, however; notable uncertainty exists regarding best practices for data processing/analyses (Lee and Shiroma. 2014). In contrast to our first hypothesis, we report a significant *inverse* association between Δmeasured EE during walking and Δvertical accelerations detected by accelerometry. Specifically, greater vertical COM accelerations associated with *less* EE. We also noted Δvertical accelerations positively associated with Δexercise self-efficacy. Thus, within the context of this pilot study, our results appear suggestive of: (1) hip-worn (about the iliac crest) accelerometers are not be sensitive to changes associated with improved ease of walking (i.e., evidenced by ↓VO_2) and; (2) sole reliance on vector magnitude as an indicator of physical activity pattern may conceal subtle changes in energetic cost/walking mechanics and, in doing so, could lead to erroneous inferences concerning patterns of free-living physical activity.

Improved neural-muscle activation notwithstanding (Sawicki et al. 2009), use of elastic energy during walking may be a source of disconnect between measured EE and accelerometer-derived estimates of EE. Each step during non-graded walking is characterized by vertical COM acceleration wherein considerable transfer exists between potential energy and kinetic energy (Cavagna et al. 1977). Owing to the muscle–tendon unit, potential energy is briefly stored then returned like an elastic recoil (i.e., stretch–shortening cycle) during push-off to augment forward locomotion.

Table 4 Correlation matrix for changes (Δ) from baseline to 3-month follow-up during a fixed-speed (0.89 m•s^{-1}) treadmill task ($n = 29$)

Variables	ΔVM	ΔMediolateral	ΔVertical	ΔAnteroposterior
ΔEnergetic cost	– 0.20	– 0.04	– 0.37*	0.14
ΔExercise self-efficacy[a]	0.26	0.06	0.39*	– 0.03

Energetic cost measured via indirect calorimetry (kcals min^{-1})

VM vector magnitude

*p value < 0.05

[a]Evaluated using a 9-item self-report questionnaire

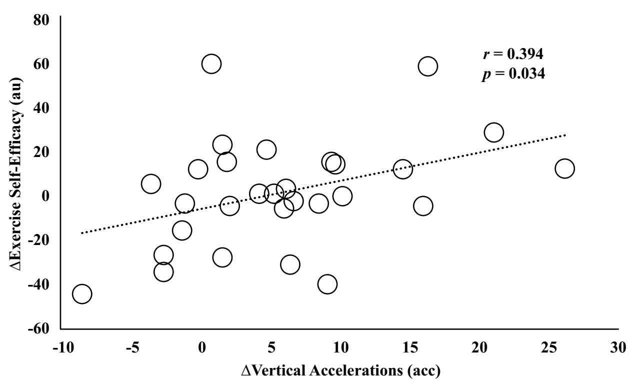

Fig. 2 Unadjusted scatterplot showing a positive association between the changes (Δ) in exercise self-efficacy and Δvertical accelerations during a walking (0.89 m s^{-1} at 0% grade) task. Note that participants who exhibited greater vertical accelerations reported higher exercise self-efficacy ($n = 29$)

Simply, stretch–shortening cycle potentiation (SSCP) is an intrinsic locomotive strategy harnessed during the stance phase where elastic energy increases mechanical output during push-off. Hence, energy savings (required for mechanical output) is reduced because gravity is used to stretch the muscle–tendon unit, which is then immediately returned during the push-off phase. This, in turn, diminishes the degree of concentric muscle contraction(s) needed for locomotion—thus reducing the energetic cost of walking (i.e., ↓$\dot{V}O_2$). It is possible that increasing leg strength would act favorably to enhance movement economy (Hunter et al. 2015) by enabling individuals to better profit from the elastic recoil (evidenced by ↑vertical accelerations) to lower EE. Consistent with this speculation, fat-free mass (surrogate of strength) positively associated with vertical accelerations, independent of fat mass. As such, we can reasonably posit that increased vertical COM accelerations may have been due to the combined effects of improved locomotor strength and coordinated utilization of muscle–tendon elasticity, both of which, lower the energetic cost of walking. For these reasons, we would anticipate more pronounced gains in strength and SSCP with resistance training (Carter et al. 2016).

Since physical activity is known to preserve cardio-metabolic health and moderate disease progression, accurate/precise monitoring of physical activity in free-living conditions is of vital importance. As demonstrated by the divergence in measured and estimated EE in the present study, questions are raised as to the capability of accelerometers to delineate between meaningful changes in physical activity and artefact attributed to gait modifications. In the present study, determination in physical activity changes solely based on VM may be vulnerable to overestimation, as indicated by the + 13% average increase while performing the same standardized task. Nevertheless, previous research comparing triaxial accelerometers to doubly-labeled water has revealed correlations of 0.59 and 0.61 with activity-related EE and total EE, respectively (Van Remoortel et al. 2012). Simply put, accelerometry-derived estimates account for just 35% and 37% of the variance in free-living EE. Based on the present work, it seems probable that these correlations could be readily strengthened with appropriate individual-calibration that accounts for underlying biomechanical factors (i.e., SSCP) that govern movement economy.

With respect to the extensive literature characterizing physical activity patterns among BCS (Irwin et al. 2003; Mason et al., 2013; Pinto et al. 2002), there is a shortage of information elucidating the functional limitations imposed by obesity and lower-extremity dysfunction to execute tasks of daily-living. Indeed, increased fat mass associates with aberrant walking mechanics, both of which, necessitate greater absolute EE for a given walking speed compared to individuals of normal-weight (Browning and Kram 2005; Browning et al. 2006). Since many daily tasks are performed at relatively low intensity, even modest improvements related to submaximal fitness and/or walking ease may produce meaningful benefit to independent-living (Carter et al. 2018). In the present study, we reasoned that improved ease of walking would relate to increased confidence level as evidenced by favorable changes in exercise self-efficacy. Consistent with our hypothesis, we detected a positive association between Δexercise self-efficacy and Δvertical accelerations independent of Δenergetic cost of walking. Therefore, it seems increased vertical COM accelerations (possibly indicative of coordinated SSCP utilization) may have invoked a positive shift in perception, in which, participants felt more confident in their ability to exercise under varied conditions. In other words, our results demonstrate participants who literally had more *'spring in their step,'* as evidenced by greater vertical COM accelerations while walking, also reported greater self-efficacy. Though speculative, it is intriguing to consider the interaction between improved physiological functioning and confidence, both of which, may promote overall adaptability/mobility.

We must acknowledge several limitations of this present investigation. First, the study sample was purposely limited to women with a history of non-metastatic breast cancer. As specified by group mean data, participants were generally overweight/obese, such that, extrapolation of these findings to other demographics should be applied with caution. Second, it is important to note that the inverse association between the Δmeasured EE during walking and Δvertical accelerations occurred at a single workload. We offer reasoned speculation that SSCP could be involved though changes in locomotor synchrony/coordination should not be discounted. Indeed, neural afferents (e.g., Ia, Ib, and II) are involved in the scaling of muscle activation to execute the timing for proper use of elastic energy in the Achilles tendon (Ishikawa and Komi. 2008). Whereas previous work has indicated that accelerometers are less accurate at slow walking speeds (Van Remoortel et al. 2012), our results further underscore the need to perform calibration studies targeting BCS and other chronic disease populations with limited mobility. Given the clinical utility of walking speed (Middleton et al. 2015), combining accelerometry with a set of standardized tasks may increase the sensitivity to detect, monitor, and predict health outcomes and intervention responsiveness. Strengths of the present work include an indirect calorimetry to measure EE and deuterium dilution to measure fat mass and fat-free mass.

Here, we report a significant inverse association between the Δmeasured EE during walking and Δvertical accelerations detected by accelerometry. These results indicate greater vertical COM accelerations associated with less EE during a standardized walking task that may have resulted from improved locomotor synchrony/coordination and/or utilization of SSCP. It is also notable that Δvertical accelerations positively associated with Δexercise self-efficacy. Taken together, accelerometers do not appear well-suited to correctly distinguish the reduced energetic cost of non-graded treadmill walking. Further research should determine if a divergence between measured EE and vertical accelerations could contribute to erroneous inferences in free-living physical activity.

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Author contributions SJC, LQR, HRB, LAN, and GRH participated in the execution of the study including, data analyses, drafting, review, and final approval of the manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

American College of Sports Medicine (2010) ACSM's Guidelines for Exercise Testing and Prescription. Lippincott, Williams, and Wilkins, Baltimore

Bandura A (1977) Self-efficacy: toward a unifying theory of behavioral change. Psychol Rev 84:191–215

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

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

Carter SJ, Herron RL, Rogers LQ, Hunter GR (2016) Is 'high-intensity' a bad word? J Physiother 62:175. https://doi.org/10.1016/j.jphys.2016.05.017

Carter SJ, Hunter GR, Norian LA, Turan B, Rogers LQ (2018) Ease of walking associates with greater free-living physical activity and reduced depressive symptomology in breast cancer survivors: pilot randomized trial. Support Care Cancer 26:1675–1683. https://doi.org/10.1007/s00520-017-4015-y

Cavagna GA, Heglund NC, Taylor CR (1977) Mechanical work in terrestrial locomotion: two basic mechanisms for minimizing energy expenditure. Am J Physiol 233:R243–R261. https://doi.org/10.1152/ajpregu.1977.233.5.R243

Deimling GT, Arendt JA, Kypriotakis G, Bowman KF (2009) Functioning of older, long-term cancer survivors: the role of cancer and comorbidities. J Am Geriatr Soc 57(Suppl 2):S289–S292. https://doi.org/10.1111/j.1532-5415.2009.02515.x

Elme A, Utriainen M, Kellokumpu-Lehtinen P et al (2013) Obesity and physical inactivity are related to impaired physical health of breast cancer survivors. Anticancer Res 33:1595–1602

Goran MI, Carpenter WH, McGloin A, Johnson R, Hardin JM, Weinsier RL (1995) Energy expenditure in children of lean and obese parents. Am J Physiol 268:E917–E924. https://doi.org/10.1152/ajpendo.1995.268.5.E917

Gross AL, May BJ, Axilbund JE, Armstrong DK, Roden RB, Visvanathan K (2015) Weight change in breast cancer survivors compared to cancer-free women: a prospective study in women at familial risk of breast cancer. Cancer Epidemiol Biomarkers Prev 24:1262–1269. https://doi.org/10.1158/1055-9965.EPI-15-0212

Hall KS, Howe CA, Rana SR, Martin CL, Morey MC (2013) METs and accelerometry of walking in older adults: standard versus measured energy cost. Med Sci Sports Exerc 45:574–582. https://doi.org/10.1249/MSS.0b013e318276c73c

Hunter GR, McCarthy JP, Bamman MM, Larson-Meyer DE, Fisher G, Newcomer BR (2011) Exercise economy in African American and European American women. Eur J Appl Physiol 111:1863–1869. https://doi.org/10.1007/s00421-010-1816-9

Hunter GR, McCarthy JP, Carter SJ et al (2015) Muscle fiber type, Achilles tendon length, potentiation, and running economy.

J Strength Cond Res 29:1302–1309. https://doi.org/10.1519/JSC.0000000000000760
Irwin ML, Crumley D, McTiernan A et al (2003) Physical activity levels before and after a diagnosis of breast carcinoma: the Health, Eating, Activity, and Lifestyle (HEAL) study. Cancer 97:1746–1757. https://doi.org/10.1002/cncr.11227
Ishikawa M, Komi PV (2008) Muscle fascicle and tendon behavior during human locomotion revisited. Exerc Sport Sci Rev 36:193–199. https://doi.org/10.1097/JES.0b013e3181878417
Lawler JP, White RG (2003) Temporal responses in energy expenditure and respiratory quotient following feeding in the muskox: influence of season on energy costs of eating and standing and an endogenous heat increment. Can J Zool 81:1524–1538
Lee IM, Shiroma EJ (2014) Using accelerometers to measure physical activity in large-scale epidemiological studies: issues and challenges. Br J Sports Med 48:197–201. https://doi.org/10.1136/bjsports-2013-093154
Mason C, Alfano CM, Smith AW et al (2013) Long-term physical activity trends in breast cancer survivors. Cancer Epidemiol Biomarkers Prev 22:1153–1161. https://doi.org/10.1158/1055-9965.EPI-13-0141
Middleton A, Fritz SL, Lusardi M (2015) Walking speed: the functional vital sign. J Aging Phys Act 23:314–322. https://doi.org/10.1123/japa.2013-0236
Miller KD, Siegel RL, Lin CC et al (2016) Cancer treatment and survivorship statistics, 2016. CA Cancer J Clin 66:271–289. https://doi.org/10.3322/caac.21349
Pedisic Z, Bauman A (2015) Accelerometer-based measures in physical activity surveillance: current practices and issues. Br J Sports Med 49:219–223. https://doi.org/10.1136/bjsports-2013-093407
Pinto BM, Trunzo JJ, Reiss P, Shiu SY (2002) Exercise participation after diagnosis of breast cancer: trends and effects on mood and quality of life. Psychooncology 11:389–400. https://doi.org/10.1002/pon.594
Rogers LQ, Courneya KS, Verhulst S, Markwell S, Lanzotti V, Shah P (2006) Exercise barrier and task self-efficacy in breast cancer patients during treatment. Support Care Cancer 14:84–90. https://doi.org/10.1007/s00520-005-0851-2
Rogers LQ, McAuley E, Anton PM et al (2012) Better exercise adherence after treatment for cancer (BEAT Cancer) study: rationale, design, and methods. Contemp Clin Trials 33:124–137. https://doi.org/10.1016/j.cct.2011.09.004
Rowland JH (2008) Cancer survivorship: rethinking the cancer control continuum. Semin Oncol Nurs 24:145–152. https://doi.org/10.1016/j.soncn.2008.05.002
Sawicki GS, Lewis CL, Ferris DP (2009) It pays to have a spring in your step. Exerc Sport Sci Rev 37:130–138. https://doi.org/10.1097/JES.0b013e31819c2df6
Siegel RL, Miller KD, Jemal A (2018) Cancer statistics, 2018. CA Cancer J Clin 68:7–30. https://doi.org/10.3322/caac.21442
Speck RM, Courneya KS, Masse LC, Duval S, Schmitz KH (2010) An update of controlled physical activity trials in cancer survivors: a systematic review and meta-analysis. J Cancer Surviv 4:87–100. https://doi.org/10.1007/s11764-009-0110-5
Thomas JR, Salazar W, Landers DM (1991) What is missing in p < .05? Res Q Exerc Sport 62:344–348
Troeschel AN, Leach CR, Shuval K, Stein KD, Patel AV (2018) Physical activity in cancer survivors during "re-entry" following cancer treatment. Prev Chronic Dis 15:E65. https://doi.org/10.5888/pcd15.170277
Van Remoortel H, Giavedoni S, Raste Y et al (2012) Validity of activity monitors in health and chronic disease: a systematic review. Int J Behav Nutr Phys Act 9:84. https://doi.org/10.1186/1479-5868-9-84