Gait & Posture 74 (2019) 162–168

Contents lists available at ScienceDirect

Gait & Posture

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

Full length article

Comparison of forward and backward gait characteristics between those with and without a history of breast cancer

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ARTICLE INFO

Keywords:
Gait variability
Postural control
Balance
Cancer survivors
Fall risk

ABSTRACT

Background: Decreased muscular strength and poorer postural stability impact the physical function of breast cancer survivors (BCS) and increases their risk of falls. Gait assessment, particularly in the backward direction, is often used as an indicator of fall risk in several populations. However this information is unknown in BCS.
Research question: What are the differences in forward, backward, and accelerated forward walking in BCS in comparison to individuals without a prior cancer diagnosis?
Methods: 17 postmenopausal BCS (mean age: 58.5 (8.5) years) and 17 age-matched women without a prior cancer diagnosis (mean age: 59.11 (5.55) years) completed 5 trials each of forward, backward, and fast forward walking conditions. Absolute (Means) and variability (Coefficient of variation) estimates were obtained for spatio-temporal gait parameters. Lower body, upper body and handgrip strengths were measured.
Results: For absolute estimates of gait, significant group main effects indicated that BCS had 7% shorter step length ($P = 0.019$) and 8% slower gait speed ($P = 0.048$). For variability estimates of gait, there was a significant interaction for stance time ($P = 0.035$). BCS had greater stance time variability during forward and fast forward conditions, but lesser variability during backward condition. Averaged across all the conditions, BCS had 38% greater step length variability ($P = 0.043$), 50% greater gait speed variability ($P = 0.028$), and 28.5% greater single support time variability ($P = 0.004$). Averaged across both the groups, all the variables except for swing time variability were significantly different among the conditions (all $P < = 0.013$). BCS also had significantly reduced upper body strength ($P = 0.036$).
Significance: Slower and shorter steps while walking both forwards and backwards could be indicative of a more cautious gait strategy by BCS. Also, BCS possibly focused on controlling spatial parameters during forward walking but temporal parameters while backward walking. Whether these alterations are related to an increased fall risk within BCS needs to be determined.

1. Introduction

Breast cancer is the most common cancer in women with 266,120 new cases projected in 2018 [1]. Although 5-year survival rates from breast cancer are reported at approximately 91% due to early detection and advancements in treatment strategies, breast cancer survivors (BCS) encounter several treatment-induced side effects [1–5]. These include changes in body composition, particularly the loss of lean body mass with the concurrent increase in fat mass that are further exarcebated by fatigue-related reductions in physical activity levels [4,6,7]. This ultimately negatively impacts the muscular strength of BCS as it has been reported that sedentary BCS were 17% and 29% weaker in upper and lower body strength than sedentary cancer free postmenopausal women [2,3,8].

These decrements in muscular strength impact the physical function of BCS and increase the risk of falls [9,10]. In a long term study, Sweeney et al. (2006) found that 42% of 1068 long-term BCS reported the inability to perform heavy household work while 26% were unable to walk half a mile and 9% could not walk up and down a flight of stairs [10]. The risk of experiencing a fall is also greater after a cancer diagnosis and the incidence of falls can be twofold in cancer survivors compared to age-matched adults without a prior cancer diagnosis [11,12]. In fact, Winters-Stone et al. (2009) found an association between lower leg strength and incidence of falls in BCS [13].

In addition to impaired muscular strength, BCS have been reported to have impaired postural stability compared to healthy age-matched women, which further contributes to their higher risk of experiencing a fall [14]. Increased fall risk among BCS has also been characterized by

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https://doi.org/10.1016/j.gaitpost.2019.09.004
Received 7 March 2019; Received in revised form 11 August 2019; Accepted 4 September 2019

poorer postural stability and functional balance. In particular, BCS have been shown to exhibit faster center of pressure movement, lower equilibrium scores during sensory organization tests, slower timed up and go performance, and lower scores on the Fullerton Advanced Balance Scale [14,15]. While there are several ways to measure fall risk, very few studies have examined gait and its variability in BCS as potential tools. Recently, Monfort et al. (2019) showed decreased gait stability was associated with poor cognitive executive function in cancer survivors with moderate to severe sympoms of chemotherapy-induced peripheral neuropathy (CIPN) [16]. They also found decreased gait stability in those with no or mild CIPN compared to cancer survivors with no chemotherapy exposure. An increase in gait variability has been shown to be an indicator of fall risk in other clinical populations such as older adults and adults with Parkinson's disease [17–19]. Further, older adults with a history of falls have been shown to walk with increased temporal variability [20]. Stride, swing, double support time, and stride length variability have also been shown to predict future falls [21,22]. In a sample of 512 female cancer survivors, 47% of the women reported symptoms of CIPN and among these symptomatic women, 57% reported a fall within the previous year [23]. Interestingly, 43% of the asymptomatic female cancer survivors also reported experiencing a fall within the past year [23]. Although the risk of falls is increased with the presence and severity of CIPN [23], these results demonstrate that falls risk is not limited to symptomatic cancer survivors alone.

Recently, backward walking has also been shown to be a useful assessment to estimate fall risk in older adults and clinical populations [22–25]. In particular, absolute and variability parameters during backward walking have been shown to be more sensitive and impaired in older adults compared to younger and middle-aged adults [24,25]. Further, age was more closely associated with backward walking performance compared to forward walking [24,25]. Children with cerebral palsy and individuals with Parkinson's disease have also been shown to have greater asymmetry and variability during backward walking [26,27]. Given the strength deficits, decreased physical activity, impaired postural instability and decreased functional balance in BCS, it is plausible that BCS may show altered gait characteristics compared to individuals without a diagnosis of cancer; however, such information is currently unknown, which supports the need to do further research [28].

Therefore, the purpose of the current study was to examine the differences between BCS and individuals without a prior cancer diagnosis in terms of 1) spatio-temporal gait parameters, 2) variability of spatio-temporal gait parameters and 3) muscular strength. We hypothesized that BCS will show altered gait and gait variability, and reduced strength compared to individuals without a prior cancer diagnosis.

2. Methods

2.1. Participants

Seventeen female postmenopausal BCS (stages 0-III; mean age 58.5 (8.5) years; mean BMI 26.4 (5.1)) and 17 age-matched women without a prior cancer diagnosis (control group; age: 59.1 (5.6) years; BMI 25.3 (3.8) kg/m^2) participated in this study. For age-matching, participants in the control group were specifically recruited within 1 year of each BCS in our study. Participants were recruited from the community via e-mails, word of mouth, and social media posts. Breast cancer survivors were included if they had completed all primary treatment (surgery, chemotherapy and radiation) at least 2 months prior to beginning the study. Women currently on hormone suppressant therapy were included in the present study. Male BCS and women diagnosed with stage IV breast cancer or who had active cancer were excluded from the study. Women receiving endocrine or neuroactive drugs, with a history of uncontrolled hypo or hyperthyroidism, uncontrolled hypertension, uncontrolled diabetes, heart disease, kidney disease, and those with physical limitation that would prevent participation in exercise testing were excluded. None of the participants used assistive devices or walking aids. All participants had physician consent prior to participation and read and signed an informed consent form approved by the University's Institutional Review Board.

2.2. Instrumentation

All the data were collected using a 16' X 4' Zeno walkway (ProtoKinetics LLC, Havertown, PA). The Zeno walkway uses pressure sensors underneath a linoleum surface to measure spatio-temporal parameters of gait. The concurrent validity for Zeno for measuring spatio-temporal gait parameters has been established [29]. Data were collected at 128 Hz.

2.3. Protocol

2.3.1. Gait assessment

Participants walked barefoot under three conditions: 1) at a self-selected comfortable pace in forward direction (FWD), 2) at a self-selected comfortable pace in backward direction (BKWD), and 3) at a self-selected fast pace in forward direction (FASTFWD). The order of the conditions was not randomized as pilot data in our laboratory indicated that the fast condition influenced the subsequent conditions. However sufficient rest time of at least a minute was given between the conditions. After one practice trial, participants performed five continuous walking trials under each condition. To ensure safety, during BKWD condition, participants were given a verbal signal of "On" and "Off" when they were about to step on or step off of the walkway, respectively. A 1-m lead-up and follow-through distance was given to ensure steady-state gait was recorded. One of the investigators walked close to each participant during the FWD and FASTFWD conditions and slightly behind during the BKWD condition without influencing the pace yet ensuring participant safety.

2.3.2. Strength assessment

Upper and lower body muscular strength were assessed via one-repetition maximums (1-RM) measured on the chest press and leg press machines (Precor®, Woodinville, WA). Handgrip strength was measured via a handgrip dynamometer (Creative Health Products Inc, Ann Arbor, MI). Three measurements were taken on each arm and the highest measurement from the right and left arms were added together for the total handgrip score.

2.4. Data analyses

Gait data were analyzed using the PKMAS software (ProtoKinetics LLC, Havertown, PA). For BKWD condition trials, the first and last step on the walkway of each of the five trials were not included in the analyses because of the verbal instructions provided. Data from right and left legs were averaged as they were not significantly different. The average of 5 trials from each participant was used for statistical analyses. Within-subject mean, standard deviation and coefficient of variation (CV) were computed for commonly used spatio-temporal gait parameters. CV was defined as the % ratio of standard deviation and mean [30]. Given the exploratory nature of the study, the following variables were included: gait speed, step length, step width, stance time, swing time, single support time, and double support time.

2.5. Statistical analyses

Normality was confirmed using the Shapiro-Wilk test. A 2-way mixed ANOVA was conducted using group as the between-subjects factor and condition as the within-subjects factor. If significant condition main effects were found, Bonferroni post hoc tests were performed to check for significance between conditions. An independent samples *t*-

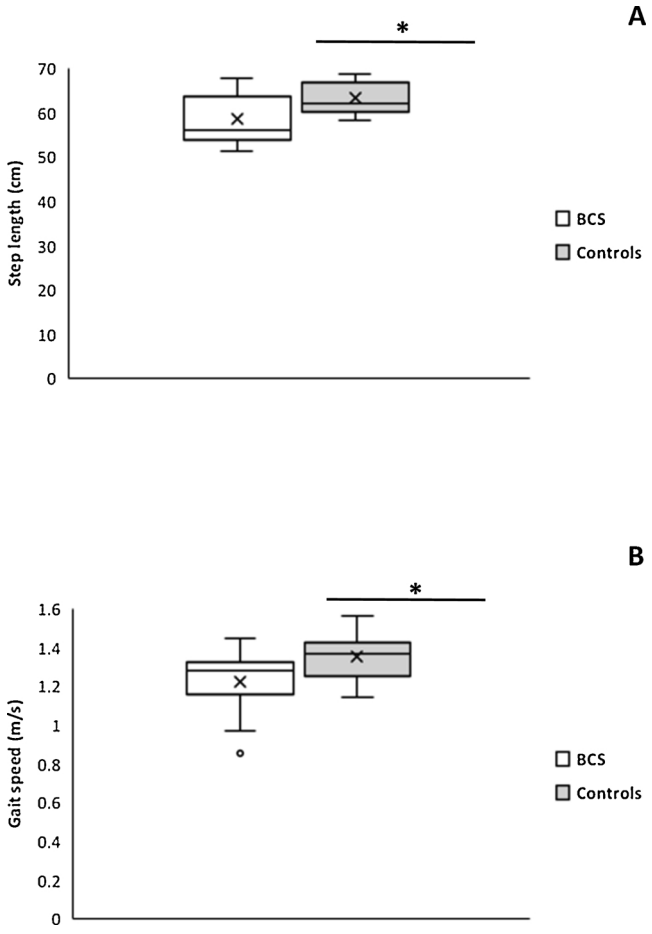

Fig. 1. Box and whisker plot of A) Step length and B) Gait Speed; BCS – Breast Cancer Survivors; Values shown are averaged across all the conditions; * Significant group main effect ($P < 0.05$).

test was conducted to compare strength data. All statistical tests were conducted using SPSS 22 (IBM, Corp., Armonk, NY). An alpha-value of 0.05 was used for all statistical analyses.

3. Results

3.1. Absolute estimates of spatio-temporal gait parameters (Table 1)

No significant interaction was observed. Significant group main effects indicated that when averaged across all the conditions, BCS had 7% shorter step length ($P = 0.019$; Fig. 1A) and 8% slower gait speed ($P = 0.048$; Fig. 1B) compared to the control group. Significant condition main effects were observed for all the variables ($P < 0.001$ for all). Averaged across all the groups, participants had slower gait speed ($P < 0.001$), shorter step length ($P < 0.001$), greater step width ($P < 0.001$), and greater double support time ($P = 0.019$) while walking in the BKWD condition compared to the FWD condition. Compared to the FASTFWD condition, participants had slower gait speed ($P < 0.001$), shorter step length ($P < 0.001$), greater stance time ($P < 0.001$), greater swing time ($P = 0.001$), greater single support time ($P < 0.001$), greater double support time ($P < 0.001$) while walking in the BKWD and FWD conditions. Compared to the FASTFWD condition, participants also had greater step width ($P < 0.001$) in the BKWD condition. No other measures were significantly different.

3.2. Variability estimates of spatio-temporal gait parameters (Table 2)

A significant interaction was observed for stance time variability ($P = 0.035$). BCS had greater stance time variability during FWD and FASTFWD conditions, but lesser variability during BKWD condition (Fig. 2). A significant group main effect indicated that BCS had 38% greater step length variability ($P = 0.043$; Fig. 3A), 50% greater gait speed variability ($P = 0.028$; Fig. 3B), and 28.5% greater single support time variability ($P = 0.004$; Fig. 3C) compared to the control group. Significant condition main effects were found for all the variables except for swing time variability (all $P \leq 0.013$). Compared to the FWD condition, participants had greater gait speed variability ($P < 0.001$), step length variability ($P < 0.001$), lesser step width variability ($P = 0.005$), greater stance time variability ($P = 0.001$), greater single support time variability ($P < 0.001$), and greater double support time variability ($P < 0.001$) while walking in the BKWD condition. Compared to the FASTFWD condition, participants had greater gait speed variability ($P = 0.001$), step length variability ($P < 0.001$), stance time variability ($P = 0.036$), and single support time variability ($P < 0.001$) along with lesser step width variability ($P = 0.002$) while walking in the BKWD condition. Compared to the FASTFWD condition, participants had lesser double support time variability ($P = 0.049$) while walking in the FWD condition. No other measures were significantly different.

3.3. Strength (Table 3)

Upper body strength, measured via the chest press, was 26% lower in BCS compared to controls ($P = 0.036$). However, there were no significant differences between groups in handgrip ($P = 0.098$) and leg press ($P = 0.719$) strength measures.

4. Discussion

The purpose of the current study was to examine the differences between BCS and individuals without a prior cancer diagnosis (control group) in terms of 1) spatio-temporal gait parameters, 2) variability of spatio-temporal gait parameters, and 3) muscular strength. Results from the current study support our hypothesis that BCS showed altered gait and gait variability compared to individuals without a prior cancer diagnosis. The calculated effect sizes for group differences were moderate (0.3 to 0.5) to large (> 0.5).

Breast cancer survivors walked slower and took shorter steps compared to the control group while walking both forwards and backwards. This could be indicative of a more cautious gait strategy. Gait speed is often considered to be a functional vital sign and an indicator of fall risk in different populations [31–33]. Gait speed measured in the current study differed from those reported by Winters-Stone et al. (2011) in both the FWD (0.3 m/s) and FASTFWD (0.45 m/s) conditions completed during the 4 m walk test [15]. Even though the mean age was similar in both studies, other possible factors such as lower BMI (26.4 vs. 28.3 kg/m^2), greater time since diagnosis (76.4 vs. 20.9 months), the number of participants diagnosed with stage I (63% vs. 29%) and stage II (13% vs. 39%) could have contributed to these differences. While Winters-Stone et al. (2011) used the GAITRite system to measure gait speed, which was different than the Zeno Walkway that was used in this current study, the difference in instruments may not have contributed to the differences seen in gait speed values as Zeno and GAITRite have been shown to have excellent concurrent validity for measuring gait speed [29]. Lack of information on the number of trials performed and the inclusion of acceleration and deceleration phases to measure steady-state gait speed may have also contributed to the difference in gait speed seen in both studies. Since fall history information was not obtained in the current study, it is not clear how fall history may have influenced the gait speed differences observed in both studies. Hence it needs to be determined how fall history will affect gait speed in FWD and BKWD directions among BCS. To our knowledge, the minimum detectable change (MDC) for BCS has not been established. For a 4-m walk test, which is equivalent to the gait assessment done in the current

Table 1
Mean (SD) (minimum-maximum) of absolute estimates of spatio-temporal gait parameters.

DV	BCS			Controls			p-values		
	Forward Comfortable	Forward Fast	Backward Comfortable	Forward Comfortable	Forward Fast	Backward Comfortable	GME	CME	INT
Gait speed (m/s) *#	1.16 (0.14) (0.86–1.35)	1.66 (0.26) (1.21–2.19)	0.87 (0.13) (0.50–1.12)	1.28 (0.17) (1.06–1.52)	1.74 (0.31) (1.41–2.10)	1.00 (0.15) (0.84–1.19)	0.048	< 0.001	0.887
Step length (cm) *#	60.60 (4.65) (50.67–68.15)	69.78 (6.15) (58.74–82.24)	45.66 (6.15) (33.44–57.98)	65.45 (5.54) (59.96–71.48)	73.20 (7.32) (67.56–79.03)	51.20 (7.32) (43.72–57.95)	0.019	< 0.001	0.529
Step width (cm) #	8.13 (2.12) (4.65–12.54)	8.32 (3.16) (3.90–20.67)	17.74 (3.29) (12.04–24.00)	7.65 (2.52) (4.28–10.12)	7.42 (3.76) (4.40–10.92)	16.73 (9.69) (7.13–26.77)	0.993	< 0.001	0.655
Stance time (s) #	0.67 (0.06) (0.54–0.79)	0.51 (0.06) (0.41–0.64)	0.68 (0.09) (0.52–0.87)	0.64 (0.07) (0.58–0.72)	0.51 (0.07) (0.42–0.62)	0.65 (0.11) (0.55–0.81)	0.350	< 0.001	0.533
Swing time (s) #	0.40 (0.03) (0.34–0.46)	0.35 (0.04) (0.30–0.48)	0.40 (0.07) (0.27–0.54)	0.40 (0.03) (0.37–0.44)	0.35 (0.05) (0.31–0.42)	0.40 (0.08) (0.33–0.48)	0.811	< 0.001	0.996
Single support time (s) #	0.40 (0.03) (0.34–0.45)	0.34 (0.03) (0.30–0.40)	0.39 (0.06) (0.27–0.54)	0.40 (0.03) (0.37–0.44)	0.35 (0.04) (0.31–0.42)	0.39 (0.07) (0.33–0.46)	0.790	< 0.001	0.917
Double support time (s) #	0.26 (0.04) (0.19–0.37)	0.16 (0.04) (0.08–0.22)	0.29 (0.05) (0.21–0.42)	0.23 (0.05) (0.20–0.28)	0.16 (0.04) (0.10–0.20)	0.25 (0.06) (0.20–0.35)	0.096	< 0.001	0.313

DV – Dependent variable; BCS – Breast Cancer Survivors group; GME – Group Main Effect; CME – Condition Main Effect; INT – Interaction; * Significant group main effect ($P < 0.05$); # Significant condition main effect ($P < 0.05$).

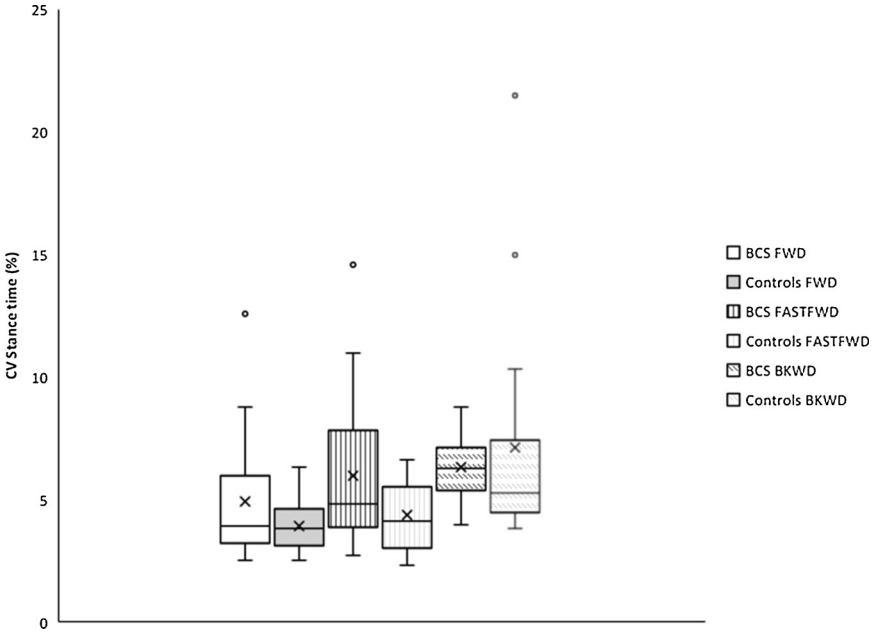

Fig. 2. Box and whisker plot of stance time variability measured using coefficient of variation showing significant interaction across the three conditions and two groups ($P < 0.05$); BCS – Breast Cancer Survivors; FWD – Forward comfortable condition; FASTFWD – Fast forward condition; BKWD – Backward comfortable condition; From left to right the boxes represent data from BCS FWD, Controls FWD, BCS FASTFWD, Controls FASTFWD, BCS BKWD and Controls BKWD respectively; boxes with no background pattern represent data from FWD; boxes with background pattern of dots represent data from FASTFWD; boxes with background pattern of stripes represent data from BKWD.

study, the MDC for gait speed during FWD condition has been established for older adults as 0.11 to 0.14 m/s [32,34] and for individuals with COPD as 0.11 m/s [35]. The MDC for gait speed during FASTFWD condition has been established as 0.14 m/s for older adults [34]. To our knowledge, the MDC for gait speed during the BKWD condition has not been established for any population. In the current study, the mean difference in walking speed between BCS and control groups during the FWD condition was 0.12 m/s and for the FASTFWD condition was 0.13 m/s – both of which are within the aforementioned range for other populations. This could indicate that the changes observed during the FWD and FASTFWD conditions are above the threshold of measurement error and can be considered real.

Breast cancer survivors had greater stance time variability during the FWD and FASTFWD conditions, but lesser variability during the BKWD condition compared to the control group. It is possible that the BCS focused on controlling spatial parameters like step or stride length during forward walking, but during backward walking they focused on controlling a temporal parameter such as stance time to perform the task. Hence there may have been greater variability of stance time during forward, but lesser variability during backward walking compared to controls. In fact, previous researchers have shown that increased stance time variability was an independent predictor of future mobility and disability in older adults [18,36]. Brach and colleagues have also associated stance time variability with impairments in the central nervous system compared to the peripheral nervous system in older adults [17]. An increase in gait variability has also been shown to be an indicator of fall risk in other clinical populations such as older adults and those with Parkinson's disease [17–19]. Older adults with a history of falls have been shown to walk with increased temporal variability [20]. Stride, swing, double support time, and stride length variability have also been shown to predict future falls [21,22]. It remains to be seen if that is the case for BCS as well. Backward walking is also a less familiar task than forward walking and so it is plausible that BCS may devote greater cognitive resources to walking backwards and hence showed lesser stance time variability during backward walking. Recently, Monfort et al. (2019) reported that gait stability was reduced when cancer survivors walked forward on a treadmill while performing a concurrent dual task compared to walking alone, thus showing that increased cognitive demand could increase gait variability in cancer survivors [16].

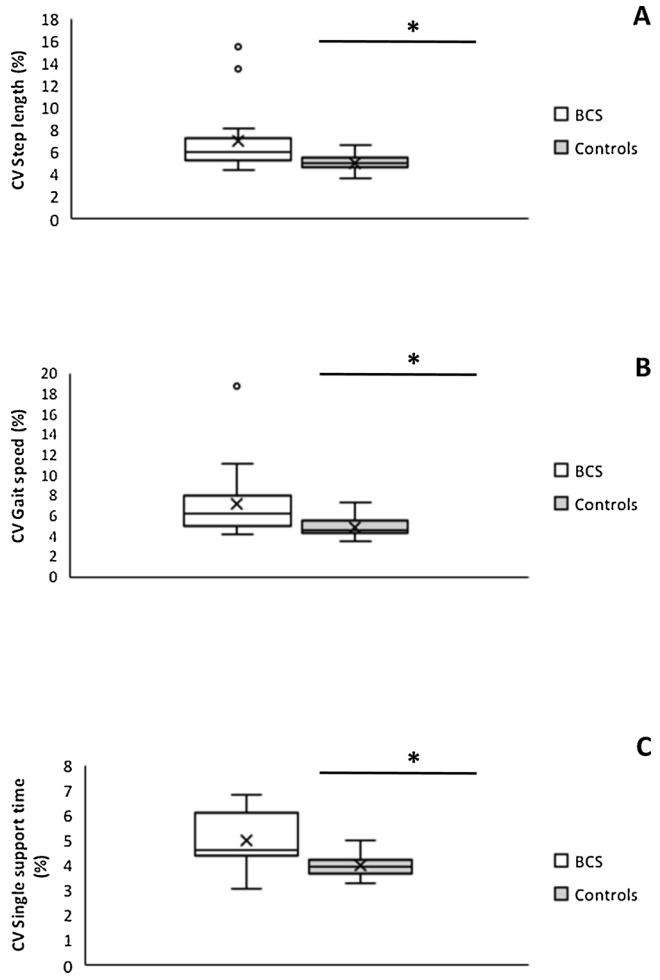

Fig. 3. Box and whisker plot of A) Step length Variability, B) Gait Speed Variability and C) Single Support Time Variability measured using coefficient of variation; BCS – Breast Cancer Survivors; Values shown are averaged across all the conditions; * Significant group main effect ($P < 0.05$).

Several factors could have contributed to altered gait in BCS. For instance, Monfort et al., (2017) showed that taxane-based chemotherapy affected gait in early-stage BCS [37]. Other parameters that could have played a role are greater lower extremity fatigue index [38] and overall increased levels of fatigue that lead to the reduction in physical activity [39] in BCS, all of which could affect gait. A recent study in frail older adults showed that gait variability was related to muscle quality and power output [40]. Though previous studies have shown lower body strength in BCS [8,38], in the current study, BCS showed weaker upper body strength, but similar lower body and handgrip strength compared to controls. Despite the lack of differences, our findings of reduced upper body strength in BCS is in agreement with previous findings [8,41]. In a similar cross-sectional study, it was reported that BCS were 17% weaker than non-cancer controls as measured via 1-RM chest press. However, the BCS in that study also had significantly less lower body strength, in contrast to the findings of the present study. This may be due to the type of 1-RM lower body strength test used in that study compared to the present study (leg extension vs. leg press).

Recently, backward walking has also been shown to be a useful assessment to estimate fall risk in older adults and clinical populations including individuals with Parkinson's disease and children with cerebral palsy [24–27]. To our knowledge, the current study is the first to assess backward walking in BCS. Results observed in the current study were similar to those observed in the previous studies in other populations that used backward walking. Previous studies reported that older adults walk with significantly lesser stride length, wider step width, slower gait and greater gait variability compared to younger and middle-aged adults [24,25]. Moreover, Fritz et al. (2013) reported that older adults with a history of falls had significantly lesser stride length, wider step width, slower gait and greater gait variability compared to older adults with no fall history [24]. These studies also reported that individuals walked slower and with smaller step length while walking backwards compared to walking forwards. Similar results were also observed for individuals with Parkinson's disease [42] and individuals with Huntington's disease [43]. Fritz et al., (2013) mentioned a cut-off

Table 3
Mean (SD) of muscular strength measures between BCS and Controls.

Dependent variable	BCS	Controls	p-value
Handgrip Dynamometer (kg)	53.79 (9.50)	58.58 (7.01)	0.098
1-RM Chest Press (kg) *	33.47 (9.89)	42.09 (13.14)	0.036
1-RM Leg Press (kg)	56.29 (21.88)	54.04 (14.49)	0.719

BCS – Breast Cancer Survivors group; 1-RM = one repetition maximum.
* Significant difference between the groups ($P < 0.05$).

Table 2
Mean (SD) (minimum-maximum) of variability estimates of spatio-temporal gait parameters.

DV	BCS			Controls			p-values		
	Forward Comfortable	Forward Fast	Backward Comfortable	Forward Comfortable	Forward Fast	Backward Comfortable	GME	CME	INT
CV Gait speed (%) *#	5.99 (3.69) (2.89–21.92)	6.40 (3.63) (2.39–22.97)	9.21 (2.76) (6.40–15.65)	3.48 (4.40) (2.12–5.58)	3.78 (4.32) (2.18–6.36)	7.11 (3.28) (4.22–15.53)	0.028	< 0.001	0.911
CV Step length (%) *#	4.89 (3.08) (2.42–19.38)	5.91 (4.73) (2.62–28.94)	10.16 (2.77) (6.95–16.05)	3.28 (3.66) (2.17–4.45)	3.20 (5.63) (1.44–4.38)	8.71 (3.29) (5.50–13.35)	0.043	< 0.001	0.745
CV Step width (%) #	38.19 (21.26) (14.94–120.94)	36.42 (31.99) (7.89–144.43)	17.87 (5.69) (10.86–29.27)	22.98 (25.30) (13.61–42.08)	31.13 (38.07) (13.73–135.88)	23.14 (10.77) (8.76–47.66)	0.356	0.001	0.326
CV Stance time (%) # &	4.94 (2.08) (2.53–12.59)	5.98 (2.53) (2.73–14.57)	6.32 (3.55) (3.99–8.77)	3.70 (2.47) (2.54–5.09)	3.99 (3.01) (2.34–5.67)	7.83 (4.23) (3.88–21.47)	0.410	0.001	0.035
CV Swing time (%)	7.74 (11.68) (2.26–66.10)	12.64 (13.63) (2.13–56.33)	14.68 (17.90) (2.91–83.37)	3.27 (13.90) (2.17–5.07)	3.12 (16.22) (2.22–4.30)	9.72 (21.31) (3.99–27.60)	0.131	0.120	0.691
CV SST (%) *#	4.11 (1.55) (2.31–9.55)	3.80 (0.93) (2.13–6.43)	7.09 (1.95) (2.91–11.15)	3.27 (1.85) (2.17–5.07)	3.12 (1.10) (2.22–4.30)	5.27 (2.33) (3.56–8.33)	0.004	< 0.001	0.315
CV DST (%) #	6.67 (1.74) (4.28–12.58)	11.08 (7.82) (1.58–43.26)	10.02 (3.16) (4.71–15.71)	5.80 (2.07) (4.69–7.31)	9.09 (9.30) (3.73–15.74)	9.65 (3.76) (4.71–17.92)	0.382	0.013	0.799

DV – Dependent variable; CV- Coefficient of variation; BCS – Breast Cancer Survivors group; SST - Single support time; DST – Double support time; GME – Group Main Effect; CME – Condition Main Effect; INT – Interaction; * Significant group main effect ($P < 0.05$); # Significant condition main effect ($P < 0.05$); & Significant interaction ($P < 0.05$).

score of 0.6 m/s to identify olders adults with a fall history [24]. In the current study, the mean gait speed of the BCS group was greater than this cut-off value and only 1 BCS walked slower than 0.6 m/s during the BKWD condition. Compared to forward walking, backward walking poses a greater challenge to the postural control system as individuals are forced to rely more on their proprioceptive and vestibular inputs to help supplement the limited visual cues. This could be particularly challenging for those with proprioception difficulties such as individuals with Parkinson's disease or BCS who have CIPN. Differences between forward and backward walking have also been attributed to different cortical areas of activation while walking as well as different motor patterns and biomechanical constraints such as joint moments and powers [44–48]. Moreover, higher incidences of falling backwards and postural instability in the posterior direction have been noted in populations such as Parkinson's disease [42,49,50]. Whether this is true for individuals with BCS needs to be determined. Moreover, usability of backward walking as an assessment of dynamic balance in BCS needs to be established, especially given the lack of additional differences between the groups during backward walking compared to forward walking.

Results of the current study should be noted along with its limitations. First, the current study does not differentiate between different treatment types and stages of cancer, both of which could influence gait and postural control in BCS. Future studies with larger sample sizes within each category of stage of cancer and/or treatment type are needed to examine how these affect gait characteristics within BCS. Second, all testing was done during barefoot walking which may not be representative of the ecological conditions of daily living among BCS;however, this was done to standardize the gait measurement across all the participants. Also, given that backwards walking is a novel task, there may have been some learning effects within the five trials even though a practice trial was given for all the participants. The current study also found only a single significant interaction (for stance time variability). Given the number of statistical comparisons, it is possible that this significant interaction was due to chance as well; however, given the findings of the current study and previous studies that have used stance time variability, it is suggested that future studies include this measure of variability. Future studies also need to include fall history, history of physical activity, current physical activity, peripherial neuropathy, comorbidities, orthopedic issues like arthritis, and pain as potential co-variates in interpreting results reported in the current study. In the current study, all the trials were performed under single task conditions. Given the growing literature on cognitive dysfunction among BCS, effects of using dual-task paradigms during gait assessments used in the current study also need to be examined [16].

5. Conclusion

Compared to age-matched women without a prior cancer diagnosis, BCS walked slower, took shorter steps and showed altered gait variability while walking both forwards and backwards. Compared to controls, BCS also demonstrated lower upper body strength, but similar lower body and handgrip strength. Whether these alterations are related to an increased fall risk within BCS needs to be determined.

Declaration of Competing Interest

None.

Acknowledgements

The authors would like to thank Ms. Emily Harrison for her help with data collection and processing and Elon Undergraduate Research Program for funding the study.

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