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ORIGINAL ARTICLE

Depression, happiness, and satisfaction with life in women newly diagnosed with breast cancer: Associations with device-measured physical activity and sedentary time

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Abstract

Background: Few studies have examined depression after a cancer diagnosis and before initiating adjuvant or neoadjuvant systemic treatments. In this study, we present baseline data on device-measured physical activity, sedentary behaviour, depression, happiness, and satisfaction with life in newly diagnosed breast cancer survivors.

Purpose: To examine associations of accelerometer-assessed physical activity and sedentary time with depression symptoms and prevalence, happiness, and satisfaction with life.

Methods: Shortly after diagnosis, 1425 participants completed depression, happiness, and satisfaction with life measures and wore an ActiGraph® device on their hip to measure physical activity and the activPAL™ inclinometer on their thigh for 7 days to measure sedentary time (sitting/lying) and steps (1384 completed both device measures). ActiGraph® data were analysed using a hybrid machine learning method (R Sojourn package, Soj3x), and activPAL™ data using activPAL™ algorithms (PAL Software version 8). We used linear and logistic regression to examine associations of physical activity and sedentary time with depression symptom severity (0–27) and depression prevalence, happiness (0–100), and satisfaction with life (0–35). For the logistic regression analysis, we compared participants with none-minimal depression (n = 895) to participants with some depression (that is, mild, moderate, moderately-severe, or severe depression [n = 530]).

Results: Participants reported a mean depression symptom severity score of 4.3 (SD = 4.1), a satisfaction with life score of 25.7 (SD = 7.2), and a happiness score of 70 (SD = 21.8). Higher moderate-to-vigorous physical activity (MVPA) was associated with reduced depression symptom severity scores (β = −0.51, 95% CI: −0.87

to −0.14, $p = 0.007$). A 1 hour increase in MVPA was associated with a reduced odds of at least mild or worse depression by 24% (Odds Ratio [OR] = 0.76, 95% CI: 0.62–0.94, $p = 0.012$). Higher daily step counts were associated with lower depression symptom severity scores ($\beta = -0.16$, 95% CI: −0.24 to −0.10, $p < 0.001$). Perceptions of happiness was associated with higher MVPA ($\beta = 2.17$, 95% CI: 0.17–4.17, $p = 0.033$). Sedentary time was not associated with depression severity, but higher sedentary time was associated with lower perceptions of happiness ($\beta = -0.80$, 95% CI: −1.48 to −0.11, $p = 0.023$).

Conclusions: Higher physical activity was associated with fewer depression symptom severity scores and reduced odds of mild or worse depression in women newly diagnosed with breast cancer. Higher physical activity and daily step counts were also associated with stronger perceptions of happiness and satisfaction with life, respectively. Sedentary time was not associated with depression symptom severity or odds of having depression, but was associated with stronger perceptions of happiness.

KEYWORDS
accelerometers, breast cancer, depression, happiness, physical activity, psycho-oncology, satisfaction with life, sedentary behaviour

1 | BACKGROUND

Depression is a leading cause of disability, and women diagnosed with breast cancer are at a higher risk of mental illness when compared to the general population.[1] One recent meta-analysis of 72 studies found ~32% of women with breast cancer experience symptoms of depression compared to ~6% in the general population.[2] After a breast cancer diagnosis, women may have negative thoughts about shortened survival, recurrence, metastasis, and other more immediate symptoms, including disturbed body image, sexual dysfunction, cancer-related fatigue, nausea and vomiting, and other side effects of treatment(s).[3] Some breast cancer treatments are associated with a higher risk of depression. For example, a recent systematic review and meta regression found a higher risk of depression after total mastectomy than breast reconstruction.[4] Depression may often decrease quality of life,[5] increase breast cancer treatment costs,[6] and impact return to work.[7] Research has even suggested that depression may be associated with increased mortality among breast cancer survivors.[8]

In the general population, physical activity is an important lifestyle behaviour in preventing and treating depression.[9] Population-based studies comparing inactive and active individuals have found that depression risk is significantly reduced in more active and less sedentary individuals.[10] Hypothesised antidepressant mechanisms include changes in neuroplasticity, inflammation, oxidative stress, self-esteem, social support, and self-efficacy.[11] Recent systematic reviews and meta-analyses of exercise interventions after a breast cancer diagnosis have found small but statistically significant improvements in depression symptoms.[12] More recent research has studied the role of sedentary behaviour in the cancer context, but one recent meta-analysis reported no associations between post-diagnosis sedentary time and depression.[13] Most studies included in these reviews are limited by small sample sizes and self-reported physical activity and sedentary behaviour measures. More studies are now using accelerometers to monitor cancer populations' physical activity and sedentary behaviour.[14] Accelerometry provides precise, detailed, and reliable measurement across the movement continuum (e.g., light, moderate, vigorous-intensity, sedentary time) and allows the analysis of activity accumulation patterns (e.g., physical activity bouts, specific activity durations). Device-based measurement (compared to self-report) of the activity patterns of women with breast cancer may provide a better understanding of how these exposures are related to patient reported outcomes.

Few studies have examined depression after a cancer diagnosis and before initiating adjuvant or neoadjuvant systemic treatments. This phase is characterised by a series of medical consultations to make often difficult treatment decisions based on the results of recent procedures (e.g., biopsies, imaging). Women often report psychosocial distress, including anxiety and fear regarding upcoming treatments.[15] We previously reported the associations of physical and sedentary time with QoL and fatigue.[16] In this study, we present data on physical activity, sedentary behaviour, depression, and affect outcomes of happiness and satisfaction with life, in newly diagnosed breast cancer survivors.

The primary objective of this study was to examine associations of accelerometer-assessed daily steps, light, and moderate-to-vigorous intensity physical activity (MVPA) with the severity of depressive symptoms and the prevalence of at least mild depression. Secondary objectives were to (a) examine associations of sedentary time with depression symptom severity and depression prevalence

and (b) examine associations of physical activity and sedentary time with perceptions of happiness and satisfaction with life. We hypothesised that higher physical activity (i.e., daily steps, light, and MVPA) and lower sedentary time would be (a) associated with reduced depression symptom severity and depression prevalence and (b) associated with higher perceptions of happiness and satisfaction with life.

2 | METHODS

2.1 | Study design and participant recruitment

We are currently conducting the Alberta Moving Beyond Breast Cancer (AMBER) Study, a dual site prospective cohort study designed to measure the role of physical activity, sedentary behaviour, and health-related fitness on breast cancer outcomes.[17,18] Women who were newly diagnosed with breast cancer ($N = 1528$) and consented to the AMBER Study completed comprehensive assessments including detailed health and lifestyle questionnaires (regarding lifestyle, physical activity, and diet), one to 2 days of in-person fitness testing including muscular strength and endurance tests as well as aerobic fitness, a blood sample, screening for lymphoedema, a body composition measurement using dual x-ray absorptiometry scan, and monitoring physical activity and sedentary behaviour for 1 week using two accelerometers. Data are collected at three time points: baseline (one to 2 months following breast surgery) and at intervals of one and 3 years. At the 5-year follow up time point, only the questionnaires are completed. Recruitment and baseline, 1- and 3-year data collection is now complete. Data processing of 1- and 3-year data will be completed in mid-2023 and data collection for the Year 5 questionnaires will be completed in mid-2024. Follow up for all cancer outcomes will be on-going until 2027–2028.

We recruited participants between July 2012 and July 2019. Newly diagnosed breast cancer patients living in Edmonton or Calgary (Alberta, Canada) were eligible if they had histologically confirmed stage I (≥T1c) to stage IIIc breast cancer, were 18–80 years old, and were able to complete questionnaires in English. The two study sites had slightly different recruitment approaches. In Edmonton, eligible participants were identified through the Cross Cancer Institute's New Patient Breast Cancer clinics and approached by their treating oncologist on their first visit. Those who expressed interest in AMBER were then further screened for eligibility. In Calgary, we identified potential participants through the Alberta Cancer Research Biobank, who approached all breast cancer patients at the time of diagnosis, requested a blood sample for the biobank, and obtained their agreement to be contacted for research studies. These women were contacted for the AMBER cohort study once their clinical and pathology results were available to confirm eligibility. In both centres, AMBER recruiters explained the study to the patient. They provided potential participants with a letter and information brochure and telephone followed up with eligible participants to confirm their interest in the study. Informed consent was obtained from all individual participants included in the study. We obtained ethics approval through the Health Research Ethics Board of Alberta: Cancer Committee (HREBA.CC-17-0576), and each participant completed a signed consent form.

2.2 | Timing of assessments and measurements

Participants completed baseline assessments before neoadjuvant therapy or within 90 days of surgery and before adjuvant therapy. Participants were allowed into the cohort if they had completed up to two cycles of chemotherapy or 10 fractions of radiation therapy. In a subset of women who received neoadjuvant treatment, the goal was to complete baseline assessments before initiating adjuvant chemotherapy but always before the third cycle.

The *Baseline Health Questionnaire* included participants' sociodemographic characteristics such as age, marital status, ethnicity, education, income, and employment. The questionnaire also assessed participants' menstrual, reproductive and medical history, exogenous hormone and medication (e.g., antidepressant) use history, family history of cancer, lifetime smoking and alcohol use histories, and comorbidities.

Clinical information about the patient's cancer diagnosis was extracted from medical charts by a trained study staff member. Data extracted included the date of diagnosis, tumour stage, grade, histology, surgery type, and treatment(s) received.

Depression was assessed using the Patient Health Questionnaire-9 (PHQ-9), which has good criterion, construct, and external.[19] Participants were asked, 'During the last 2 weeks, how often have you been bothered by any of the following problems?', for each of the nine DSM-IV criteria, which included such items as 'Feeling tyred or having little energy' and 'Feeling down, depressed, or hopeless'. Response options ranged from 0 to 3 and included 'not at all', several days', 'more than half the days', and 'nearly every day'. The nine items were summed to provide a depression symptom severity score ranging from 0 to 27. Higher scores are indicative of stronger depression symptom severity. The PHQ-9 also functions as a screening tool for different levels of depression including none-minimal (0–4), mild (5–9), moderate (10–14), moderately severe (15–19), and severe (20–27).[19] The PHQ-9 has high sensitivity and specificity and is the most commonly used depression screening tool in primary and general settings.[20]

Satisfaction with life was assessed using Diener's Satisfaction With Life Scale (SWL)[21] The SWLS is a short 5-item scale designed to measure global cognitive judgements of satisfaction with one's life. Participants indicate how much they agree or disagree with each item on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). Scores range from 0 to 35. SWLS items are summed, and the sum score is divided by 5. Higher SWLS scores reflect a higher sense of satisfaction with life. *Happiness* was measured using the Happiness Measure (HM)[22] The HM assesses an affective component of subjective well-being and indicates a person's perceived happiness. Participants are asked to rate how happy they

have felt over the past 7 days on a scale of 1 (extremely unhappy) to 10 (extremely happy). The HM contains a second question asking for the percentage of time spent happy, unhappy, and neutral over the past 7 days. The scale score and percentage estimates are used to determine the overall happiness score out of 100 (scale score * 10 + % happy)/2. Higher HM scores reflect stronger and more frequent feelings of happiness.

Physical activity was assessed using the waist-worn ActiGraph® GT3X+ (ActiGraph®, LLC, Pensacola, FL). The ActiGraph® is a small, lightweight device that records acceleration using a tri-axial accelerometer. Participants wore the monitor on their right hip attached by an elastic belt during all waking hours for seven consecutive days. Light, moderate, and vigorous-intensity physical activity time was estimated using a hybrid machine learning technique that combined a decision tree and an artificial neural network (R Sojourn package version 1.1.0, Soj3x).[23] We used the Soj3x prediction method because it incorporates a broad range of 30 common daily activities in the neural network to predict activity behaviours and their intensity levels. This approach avoids the use of cut-point based methods typically calibrated only to two types of behaviours (walking, running) that can substantially underestimate MVPA.[24] This method has also been cross-validated in free-living studies using direct observation[23] and doubly labelled water.[25]

Sedentary time and daily *steps* were measured using the activPAL™ device (PAL Technologies, Glasgow, Scotland). Participants were instructed to adhere the activPAL™ device to the front-midline portion of the thigh with stretch tape that was provided. Participants enrolling in the study from 2013 to 2017 wore the activPAL™ during waking hours only for 7 days. However, after 2017, participants were instructed to wear the device continuously (i.e., 24 h per day) for 7 days. Sedentary time (sitting/lying) and steps were calculated using activPAL™ algorithms (PAL Software version 8). We used the VANE algorithm from the PAL software suite. Previous work has suggested the activPAL™ yields more accurate step counts compared to the ActiGraph®.[26]

2.3 | Statistical analysis

Descriptive statistics were used to examine the demographic, clinical, and behavioural characteristics of the sample. Analyses included preliminary evaluations of the relevant data, including checks for sparsity, distributions, and missingness. We handled missing data on covariates via multivariate imputations through chained equations, which includes all correlated covariates in regression models to avoid reducing the sample size.[27,28] We used linear regression to determine associations between the accelerometer variables and depression symptom severity, happiness, and satisfaction with life. To examine associations between the accelerometer variables and depression screener levels, we created two groups of participants based on their depression screener scores. We compared those reporting *none-minimal depression* (n = 895) to those reporting *mild*, *moderate*, *moderate-severe*, and *severe depression* (n = 530). We ran a second model comparing participants with *none-minimal* or *mild depression* (n = 1276) to those reporting *moderate*, *moderate-severe*, and *severe depression* (n = 152). Binary logistic regression was used to examine associations between accelerometer variables and depression prevalence.

All models were adjusted for relevant covariates considered to be potential confounders. Sociodemographic and clinical variables were screened independently and retained as covariates in our adjusted models if they had a statistically significant correlation with the dependent variable. Covariates in the depression models included age, comorbidity, body mass index, employment, income, smoking, receiving chemotherapy, and antidepressant use. Happiness models included age, ethnicity, comorbidity, family history of breast cancer, and antidepressant use. Satisfaction with life models included age, comorbidity, cancer stage, body mass index, ethnicity, education, employment, marital status, income, smoking, and antidepressant use. MVPA, light intensity physical activity, and sedentary time were analysed in one hour units, and steps per day were analysed in 1000 steps/day units to provide more meaningful (and interpretable) unstandardised beta weights. Linear regression results are reported as unstandardised beta weights (β). Logistic regression results are reported as odds ratios (OR). An $\alpha = 0.05$ was used as a threshold for determining statistical significance. All models were generated using SPSS (version 28) (IBM, Chicago, IL).

3 | RESULTS

The flow of participants through the study has been presented in detail elsewhere.[18] To summarise, we screened 14,680 newly diagnosed breast cancer patients for eligibility, and 11,007 were ineligible. Of the 1528 recruited into the cohort study, 1425 had complete ActiGraph® and/or activPAL™ data (1383 completed both device measures), and complete depression and psychosocial health data. Of these, 1409 participants (92.2%) had complete ActiGraph® and depression, happiness, and satisfaction with life data while 1396 participants (91.3%) had complete activPAL™, depression, happiness, and satisfaction with life data. We collected depression, happiness, satisfaction with life, and accelerometer assessments 55 and 50 days after surgery (median), respectively. Of the sample, 108 (7.6%) participants received neoadjuvant treatment. For participants scheduled to receive chemotherapy, 20% started treatment before their baseline accelerometer assessment. For those scheduled to receive radiation, 6.6% started radiation before their baseline accelerometer assessment.

Full descriptive information for study variables has been published previously.[16] The mean age of this sample was 55.5 years of age (SD = 10.7), most were Caucasian (88%) and had an average body mass index (BMI) of 27.5 (SD = 5.6) (Table 1). Overall, 62.6% of the sample had either overweight or obesity. Most participants were diagnosed with stage II or III (55%) breast cancer, and 40.8% had a mastectomy. Average resting heart rate was 72.2 (SD = 10.1) beats per minute and VO_2max was 26 (SD = 6.1) ml/kg/minute. Of the

TABLE 1 Demographic and clinical characteristics of the Alberta Moving Beyond Breast Cancer (AMBER) cohort participants at baseline, 2012–2019, $N = 1425$.

Characteristic	*N*	%	Mean ± SD
Age at diagnosis			55.5 ± 10.7
Body mass index (kg/m^2)			27.5 ± 5.6
Normal weight	533	37.4	
Overweight or obese	892	62.6	
Waist circumference (cm)			92.8 ± 13.4
% body fat			43.1 ± 7.2
Resting heart rate			72.2 ± 10.1
Maximal cardiopulmonary fitness (VO2 max [ml/kg/minute])			26 ± 6.1
Number of first degree relative breast cancer family history			0.3 ± 0.6
Stage			
I	641	45	
II	659	46.2	
III	125	8.8	
Mastectomy			
Yes	582	40.8	
No	843	59.2	
Chemotherapy			
Yes	822	57.7	
No	603	42.3	
Comorbidity score (0–8)			0.9 ± 1.0
Smoking			
Never smoker	821	57.6	
Past smoker	513	36	
Occasional smoker	11	0.8	
Current smoker	80	5.6	
Antidepressant use (within past 12 months)			
Yes	208	13.6	
No	1320	86.4	

Note: Data are presented as the mean (standard deviation) for continuous variables and frequency (percentage) for categorical variables.
Abbreviation: SD, standard deviation.

sample, 208 (13.6%) participants reported anti-depressant use within the previous 12 months of study enrolment.

The average number of valid days of wear time was similar for ActiGraph® (5.5 days, 14 h per day) and the activPAL^{TM} (5.9 days, 14.2 h per day) (Table 2). The AMBER study participants had an average of 1.02 h per day (SD = 0.57) of MVPA, and 4.4 h per day (SD = 1.2) of light intensity physical activity. For MVPA accumulated in at least 10-min bouts, participants averaged 0.3 h (SD = 033) per day (i.e., 18 min per day). Participants averaged 7384 (SD = 3114) steps per day. Participants on average reported a low mean depression symptom severity score of 4.3 (SD = 4.1), a high satisfaction with life score of 25.7 (SD = 7.2), and a high happiness score of 70 (SD = 21.8). Over half of the sample reported none to minimal depression (62.6%) while 40 participants reported moderately severe and severe depression (2.8%). Higher depression symptom severity scores were associated with lower perceptions of happiness ($r = -0.59$, $p < 0.001$) and satisfaction with life ($r = -0.42$, $p < 0.001$) scores.

3.1 | Depression symptom severity

All associations between accelerometer variables and depression, happiness, and satisfaction with life are found in Table 3.

TABLE 2 Descriptive statistics for device-measured physical activity, sedentary time, depression, happiness, and satisfaction with life in Alberta Moving Beyond Breast Cancer (AMBER) cohort study participants, 2012–2019, *N* = 1425.

Variable	Mean (SD)	Median	IQR
Physical activity			
ActiGraph® valid days[a]	5.5 (1.4)		
ActiGraph® weartime (hours/day)	14 (1.3)		
Light-intensity physical activity (hours/day)	4.4 (1.2)	4.3	1.6
Moderate-intensity physical activity (hours/day)	0.86 (0.48)	0.78	0.57
Vigorous-intensity physical activity (hours/day)	0.16 (0.19)	0.1	0.19
MVPA			
Hours per day	1.02 (0.57)	0.92	0.71
Hours per day accumulated in 10-min bouts	0.3 (0.33)	0.19	0.40
Sedentary time			
activPAL™ valid days[b]	5.9 (1.5)		
activPAL™ weartime	14.2 (1.2)		
Daily steps	7384 (3114)	6983	3974
Sedentary hours/day	8.9 (1.7)	9.0	2.2
Depression and psychosocial health			
Depression symptom severity	4.3 (4.1)	3.0	5.0
Happiness	64 (21.7)	64	30.0
Satisfaction with life	25.7 (7.2)	28	10.0
Depression category	***N***	**%**	
None-minimal	895	62.8	
Mild	381	26.7	
Moderate	109	7.6	
Moderately severe	28	2.0	
Severe	12	0.8	

Note: Data are presented as the mean (SD: standard deviation), median, and interquartile range (IQR).
Abbreviation: MVPA, moderate and vigorous intensity physical activity.
[a]*N* = 1409 (ActiGraph®).
[b]*N* = 1396 (activPAL™).

Higher MVPA was associated with reduced depression symptom severity scores (β = −0.51, 95% CI: −0.87 to −0.14, p = 0.007). Higher MVPA in 10-min bouts (β = −0.65, 95% CI: −1.3 to −0.02, p = 0.045) and light intensity physical activity (β = −0.30, 95% CI: −0.48 to −0.12, p = 0.001) were also associated with reduced depression symptom severity scores. Higher daily step counts were associated with lower depression symptom severity scores (β = −0.16, 95% CI: −0.24 to −0.10, $p < 0.001$). Sedentary time was not associated with depression symptom severity (β = 0.05, 95% CI: −0.08–0.18, p = 0.437).

While we adjusted for antidepressants as a possible confounder in our models we also explored the role of antidepressants as a possible effect modifier of the associations between MVPA, sedentary time, and depression severity scores. We created interaction terms to determine if the strength of the associations between physical activity and sedentary time and depression varied in women who do/did not take antidepressants (i.e., MVPA by antidepressant use; sedentary time by antidepressant use). We found a statistically significant interaction for MVPA by antidepressant use and PHQ-9 severity scores (p = 0.009). This interaction indicated that the association between higher MVPA minutes and lower PHQ-9 severity score appeared to be stronger among participants taking antidepressant medication. There was no statistically significant interaction for sedentary time by antidepressant use and PHQ-9 severity scores (p = 0.163).

3.2 | Prevalence of at least mild depression

A 1 hour increase in MVPA was associated with a reduced odds of at least mild or worse depression by 24% (Odds Ratio [OR] = 0.76, 95%

TABLE 3 Adjusted associations of physical activity and sedentary time with depression symptom severity, happiness, and satisfaction with life in the Alberta Moving Beyond Breast Cancer (AMBER) cohort study, $N = 1425$.

Activity/sedentary time	Depression symptom severity β (95% CI)	Happiness β (95% CI)	SWL β (95% CI)
MVPA	−0.51 (−0.87, −0.14)**	2.17 (0.17, 4.17)*	0.38 (−0.26, 1.03)
MVPA 10-min bouts	−0.66 (−1.30, −0.02)*	2.5 (−0.96, 5.87)	0.92 (−0.20, 2.04)
Light intensity activity	−0.30 (−0.48, −0.12)**	0.54 (−0.38, 1.45)	0.07 (−0.25, 0.39)
Steps per day[a]	−0.16 (−0.24, −0.09)**	0.50 (0.13, 0.87)**	0.17 (0.04, 0.29)*
Sedentary time	0.05 (−0.08, 0.18)	−0.80 (−1.48, −0.11)*	−0.11 (−0.33, 0.11)

Note: *Depression symptom severity models* adjusted for age, resting heart rate, comorbidity score, BMI, employment, income, smoking, chemotherapy, and anti-depressant use. *Happiness models* adjusted for age, ethnicity, comorbidity, family history of breast cancer, and anti-depressant use. *Satisfaction with life models* adjusted for age, comorbidity score, BMI, ethnicity, education, employment, marital status, income, smoking, and anti-depressant use. Activity models ($N = 1409$); Sedentary time models ($N = 1396$).

Abbreviations: B, unstandardised regression coefficient; CI, confidence interval; MVPA, moderate-to-vigorous physical activity.

[a]Steps per day were analysed in 1000 steps/day units to provide more meaningful (and interpretable) beta weights.

*$p \leq 0.05$, **$p \leq 0.01$.

CI: 0.62–0.94, $p = 0.012$). A one hour increase in MVPA accumulated in 10-min bouts was associated with a reduced odds of at least mild or worse depression by 34% (OR = 0.69, 95% CI: 0.45–0.96, $p = 0.03$). For every 1000 step increase, the odds of having at least mild or worse depression was reduced by almost 10% (OR = 0.91, 95% CI: 0.87–0.95, $p < 0.001$). For every 1 hour increase in light intensity physical activity, the odds of having at least mild or worse depression was reduced by 12% (OR = 0.88, 95% CI: 0.80–0.98, $p = 0.016$). Sedentary time was not significantly associated with depression (OR = 1.01, 95% CI: 0.94–1.08, $p = 0.773$). We also compared those with none-minimal and mild depression to those with at least moderate depression and found no associations between MVPA and depression (OR = 0.87, 95% CI: 0.62–1.24, $p = 0.447$). Associations with other behaviours (i.e., steps, sedentary time, light) remained unchanged.

3.3 | Happiness and satisfaction with life

Higher MVPA was associated with higher happiness scores ($\beta = 2.17$, 95% CI: 0.17–4.17, $p = 0.033$). More steps per day was also associated with higher happiness scores ($\beta = 0.50$, 95% CI: 0.13–0.87, $p = 0.008$). Higher sedentary time was associated with lower happiness scores ($\beta = -0.80$, 95% CI: −1.49 to −0.11, $p = 0.023$). Steps per day was associated with a stronger perceptions of life satisfaction ($\beta = 0.17$, 95% CI: 0.04–0.29, $p = 0.009$).

4 | DISCUSSION

The primary objective of this study was to examine associations of accelerometer-assessed steps, light, and moderate-to-vigorous intensity physical activity (MVPA) with depressive symptoms and the prevalence of at least mild symptoms of depression. We partially confirmed our hypothesis that physical activity (i.e., MVPA, steps, and light intensity activity) was associated with reduced depression symptom severity. MVPA was associated with significantly reduced odds of having at least mild or worse depression, and higher perceptions of happiness. Each additional 1000 steps were associated with a 10% reduced odds of having at least mild or worse depression. Average daily steps were also significantly associated with higher satisfaction with life. Sedentary time was not associated with depression or satisfaction with life. However, higher sedentary time was significantly associated with lower perceptions of feeling happy. Study strengths include using accelerometers (i.e., Actigraph® and activPAL™ devices) to measure physical activity and sedentary time (i.e., sitting), using a validated and reliable depression screening tool, the large sample size, and the novel timepoint of data collection (i.e., post-diagnosis and pre-treatment).

Our data suggested that a one hour-increase in MVPA was significantly associated with a reduced odds of mild or worse depression by 24%. MVPA accumulated in bouts of at least 10 min was significantly associated with a 34% reduced odds of at least mild or worse depression. Physical activity and depression risk in the general population has been studied extensively. Our odd ratios corroborate those published in a recent meta-analysis of over 190,000 participants.[9] In their analysis, Pearce et al. reported a dose-response effect in the risk reduction for depression across three physical activity levels. Those accumulating 2.5 h per week of at least moderate-intensity activity had a 25% lower risk of depression. Those achieving 5 hours per week reduced their risk of depression by 28%. All studies reported in this meta-analysis used self-reported measures of physical activity. Our study is the first in the cancer context to examine physical activity and depression using device-based activity measures. A recent sample of 88,522 adults (not included in the Pearce review) using the PHQ-9 and self-reported physical activity reported that active individuals had 29% lower odds of depression.[29] To our knowledge, no prospective cohort studies of newly diagnosed breast cancer survivors or longer term survivors have evaluated associations between physical activity and depression risk.

There were small, yet significant associations between MVPA and depression symptom severity scores. For every 1 hour increase in MVPA, symptom severity scores decreased by approximately 0.5 points. We did find antidepressant use moderated this association as there was a significant interaction between MVPA and antidepressant use. There was a significant association between higher MVPA and lower PHQ-9 severity scores among participants not taking antidepressant medication. However, this interaction indicated that the association between higher MVPA minutes and lower PHQ-9 severity score appeared to be stronger among participants taking antidepressant medication. A previous systematic review of 13 interventions concluded there was a strong effectiveness of combining exercise/physical activity with antidepressants with nine out of 13 studies showing significantly reduced depression scores in favour of combined interventions.[30] A more recent network meta-analysis of 21 trials among individuals with non-severe depression comparatively assessed the effectiveness of exercise, antidepressants, and combined treatments. All treatments were beneficial, but combined treatments were not superior to the individual treatments.[31] While our study was cross-sectional, there were overall significant associations between higher MVPA and lower depression symptoms, but associations were stronger among those taking antidepressant medication.

We found that the number of steps taken per day was associated with a significantly reduced odds of at least mild or worse depression. Each additional 1000 steps were associated with an almost 10% reduced odds of at least mild or worse depression. Our data suggest that women newly diagnosed with breast cancer may reduce their odds of having at least mild or worse depression by more than 30% by adding 3000 steps to their daily routine. It is estimated that 3000 steps is the equivalent of 30 min of walking.[32] Walking is one of the most widely studied physical activity behaviours and has consistently been linked to reduced depression symptoms. However, few studies have examined walking activity and its associations with depression prevalence. The most recent synthesis of evidence on the topic was a scoping review of walking and depression that reported three prospective studies of walking, all of which found a protective effect.[33] The most rigorous of these studies found a 10% reduced risk of depression with time spent walking (i.e., 40 min/day) at an average or brisk pace.[34]

Our study found that a one-hour increase of MVPA per day was associated with an additional two points on the Happiness Measure. We also found a higher number of steps per day was associated with significantly higher satisfaction with life. Our study also found that every additional hour of sedentary time was associated with a reduction of one point on the Happiness Measure. There is no conclusive evidence in the breast cancer literature to suggest that physical activity leads to more time spent feeling happy. Only two randomised controlled trials including a total of 126 post treatment breast cancer survivors have reported happiness outcomes using the Happiness Measure.[12] One of these studies reported the percentage of time spent happy in the exercise group increased by 17.3% compared with 0.8% in the control group, which translated into an additional 19 h of happiness per week.[35] The most recent review among breast cancer survivors reported on four studies and suggested there is no conclusive evidence for the role of physical activity in improving satisfaction with life.[12] This study is the first to report on the associations between device-measured activity and sedentary time and perceptions of subjective well-being (including happiness and satisfaction with life) in a large prospective cohort of women newly diagnosed with breast cancer.

Sedentary time was not associated with depression symptom severity or odds of having at least mild or worse depression. This result is consistent with previously published studies in the cancer context. A recent meta-analysis of sedentary behaviour in the breast cancer context reported mostly null associations with depression symptom severity across eight cross-sectional and prospective studies, all categorised as *very low quality evidence*. Most closely related to our study, Sabiston and colleagues used accelerometers to determine associations with depression symptoms in a sample of 187 breast cancer survivors who were, on average, 10 months post-diagnosis.[36] Survivors in a high sedentary cluster reported significantly higher depression symptom scores compared to those in a low sedentary cluster. In the general population, sedentary time has been linked to depression and some of these studies have used accelerometers to measure activity and sedentary time exposures.[37] In a population-based prospective cohort, Vallance and colleagues[10] found higher sedentary time (measured by accelerometer) was significantly associated with a higher prevalence of depression (determined by the PHQ-9) but only in overweight and obese individuals. No interactions with BMI were observed in our data.

The study of sedentary time in the breast cancer context is a new and emerging field, and research into the influence of sedentary time on patient reported outcomes including depression among cancer survivors has yielded mixed results. Breast cancer survivors spend the majority of their waking hours in sedentary pursuits (i.e., ~9 h per day in the AMBER study)[13] and future research should continue to explore the role of sedentary behaviour in influencing depression and other psychosocial health outcomes. Future research should continue to examine device-based physical activity and sedentary time across the breast cancer trajectory and their associations with other depression and psychosocial health. Future research should also examine the intensity (i.e., cadence) at which women with breast cancer walk and determine if greater depression and psychosocial health benefits may be gained with faster walking. Future studies should continue to target depression (both prospective cohorts and intervention studies) and implement precise and accurate measurement approaches, including accelerometers. The AMBER study's prospective design will allow us to examine changes in activity, sedentary time, and depression symptom severity and risk in the years after diagnosis and treatment (i.e., one, three, and 5 years).

5 | STUDY LIMITATIONS

The main limitation of this study is the cross-sectional design which limits the ability to determine causation. While physical activity is associated with reduced odds of depression, it may still be possible

that depression may be causing reduced physical activity patterns. The second limitation of this paper is the lack of contextual information with respect to where physical and sedentary time were occurring given the use of accelerometers. In the context of depression, the physical activity location and context (e.g., physical activity/walking outside and/or with others) plays a significant role in the associations between activity and depression[38] with specific types of activity (e.g., outdoor walking/running, cycling, and group-based) having additional benefits in reducing the odds of depression.[29] While overall sedentary time was not associated with depression in our sample, specific contexts, including watching too much TV and sitting during transport, may be associated with depression symptoms and risk, and future research should examine these questions.

6 | CLINICAL IMPLICATIONS

The timeframe between a breast cancer diagnosis and the start of adjuvant treatment is a period when psychosocial distress may be pronounced. Our results indicate physical activity, and in particular, walking may be beneficial for newly diagnosed women with breast cancer awaiting the start of treatment. These results may also be used to inform clinical trials and policies about incorporating physical activity, walking, and reducing sedentary time as adjuvant therapy for newly diagnosed women with breast cancer starting treatment.

7 | CONCLUSION

We observed statistically significant associations between physical activity and depression in our sample of newly diagnosed breast cancer survivors starting treatment. MVPA was significantly associated with happiness, and steps was significantly associated with satisfaction with life. Given the strong associations between daily steps and depression, our data suggest that increasing walking may reduce the odds of having at least mild depression. Future research should continue to examine device-based physical activity and sedentary time across the breast cancer trajectory and their associations with other depression and psychosocial health. Future research should also examine the intensity (i.e., cadence) at which women with breast cancer walk and determine if greater depression and psychosocial health benefits may be gained with faster walking. Future studies should continue to target depression (both prospective cohorts and intervention studies) and implement precise and accurate measurement approaches, including accelerometers.

AUTHOR CONTRIBUTIONS

Jeff K. Vallance: Conceptualisation and study design; Data analysis and interpretation; Manuscript writing (original draft). **Christine M. Friedenreich:** Conceptualisation and study design; Funding; Data collection; Manuscript editing. **Qinggang Wang**: Data processing; analysis; and interpretation; Manuscript editing. **Charles E. Matthews:** Conceptualisation; Data collection; processing; and interpretation; Manuscript editing. **Lin Yang**: Data interpretation; Manuscript editing. **Margaret L. McNeely:** Conceptualisation and study design; Data collection; Manuscript editing. **S. Nicole Culos-Reed**: Conceptualisation and study design; Manuscript editing. **Gordon J. Bell:** Conceptualisation and study design; Manuscript editing. **Jessica McNeil:** Manuscript editing. **Leanne Dickau**: Project administration; Data collection; Manuscript editing. **Kerry S. Courneya:** Conceptualisation and study design; Funding; Data collection; Manuscript editing. All authors approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

All authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Research data are currently not shared.

ETHICS STATEMENT

All authors declare no conflicts of interest. Informed consent was obtained from all individual participants included in the study. We obtained ethics approval through the Health Research Ethics Board of Alberta: Cancer Committee (HREBA.CC-17-0576), and each participant completed a signed consent form.

OPEN SCIENCE POLICY AND TRANSPARENCY STATEMENTS

This study was not formally registered. The analysis plan was not formally pre-registered. De-identified data from this study are not available in a public archive. There is no analytic code associated with this study. Materials used to conduct the study are not publicly available.

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