Published in final edited form as:
J Cancer Surviv. 2019 June ; 13(3): 468–476. doi:10.1007/s11764-019-00768-8.

Breast cancer survivors reduce accelerometer-measured sedentary time in an exercise intervention

Lauren S. Weiner[1,2], **Michelle Takemoto**[1], **Suneeta Godbole**[1], **Sandahl H. Nelson**[1,2], **Loki Natarajan**[1,2], **Dorothy D. Sears**[1,2,3,4], **Sheri J. Hartman**[1,2]

[1]Department of Family Medicine and Public Health, University of California, San Diego, La Jolla, San Diego, CA, USA

[2]UC San Diego Moores Cancer Center, University of California, San Diego, La Jolla, San Diego, CA, USA

[3]Department of Medicine, University of California, San Diego, La Jolla, San Diego, CA, USA

[4]College of Health Solutions, Arizona State University, Phoenix, AZ, USA

Abstract

Purpose—Cancer survivors are highly sedentary and have low physical activity. How physical activity interventions impact sedentary behavior remains unclear. This secondary analysis examined changes in sedentary behavior among breast cancer survivors participating in a physical activity intervention that significantly increased moderate-to-vigorous physical activity (MVPA).

Methods—Insufficiently active breast cancer survivors were randomized to a 12-week physical activity intervention (exercise arm) or control arm. The intervention focused solely on increasing MVPA with no content targeting sedentary behavior. Total sedentary behavior, light physical activity (LPA), and MVPA were measured at baseline and 12 weeks (ActiGraph GT3X+ accelerometer). Separate linear mixed-effects models tested intervention effects on sedentary behavior, intervention effects on LPA, the relationship between change in MVPA and change in sedentary behavior, and potential moderators of intervention effects on sedentary behavior.

Results—The exercise arm had significantly greater reductions in sedentary behavior than the control arm (mean − 24.9 min/day (SD = 5.9) vs. − 4.8 min/day (SD = 5.9), $b = -20.1$ (SE = 8.4), $p = 0.02$). Larger increases in MVPA were associated with larger decreases in sedentary behavior ($b = -1.9$ (SE = 0.21), $p < 0.001$). Women farther out from surgery had significantly greater reductions in sedentary behavior than women closer to surgery ($b = -0.91$ (SE = 0.5), $p = 0.07$).

Sheri J. Hartman, sjhartman@ucsd.edu.

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

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

There was no significant group difference in change in LPA from baseline to 12 weeks ($b = 5.64$ (SE = 7.69), $p = 0.48$).

Conclusions—Breast cancer survivors in a physical activity intervention reduced total sedentary time in addition to increasing MVPA.

Implications for Cancer Survivors—Both increasing physical activity and reducing sedentary behavior are needed to promote optimal health in cancer survivors. These results show that MVPA and sedentary behavior could be successfully targeted together, particularly among longer-term cancer survivors.

Clinical trial registration—This study is registered at www.ClinicalTrials.gov ().

Keywords

Sedentary behavior; Sitting; Physical activity; Breast cancer

Introduction

Numbering over 3.5 million, breast cancer survivors represent the largest group of female cancer survivors in the USA [1]. Breast cancer survivors spend approximately two-thirds of waking time (i.e., ~ 9 h per day) in sedentary behaviors [2, 3], which is higher than individuals without cancer [2, 4]. Sedentary behaviors include activities where the predominant posture is sitting, reclining, or lying and energy expenditure is low [5–9]. A growing body of research has linked sedentary behavior among breast cancer survivors with increased risk of cancer recurrence and mortality [10] and poor health outcomes including adiposity [3], greater number of comorbidities [11], worse quality of life [4, 12, 13], and higher fatigue [4]. Sedentary behavior is distinct from inactivity (i.e., not meeting physical activity guidelines of 150 min of moderate-to-vigorous physical activity (MVPA) per week for health or too little exercise), in that an individual who meets the physical activity guidelines can still be highly sedentary [14]. Most studies have found that the negative health impacts of sedentary behavior are independent of exercise [9, 15, 16], though research is mixed [17, 18]. A recent meta-analysis showed that together, low physical activity and high sedentary behavior increased risk of all-cause mortality by 59% (95% CI 1.52, 1.66) and that the increase in mortality risk was not attenuated by guideline levels of physical activity (i.e., 150 min of MVPA weekly) [17]. Further, a recent analysis of accelerometer-measured sedentary time in 739 adults found that MVPA had little, if any, attenuating effect on the associations between sitting time and cardio-metabolic risk biomarkers [19]. Therefore, among breast cancer survivors who generally have low levels of activity and are highly sedentary [2, 3], both increasing physical activity and reducing sedentary behavior may be needed to promote optimal health [20].

Many interventions have targeted increasing MVPA in cancer survivors [21–23], yet few studies have examined how increasing physical activity impacts accelerometer-measured sedentary time in cancer survivors. In a 12-week randomized controlled trial of a peer-led physical activity intervention among 76 breast cancer survivors, the intervention successfully increased physical activity, but there were no significant changes in sedentary time both within the intervention group and between the intervention and control groups [24].

Moreover, in an 8-week randomized controlled trial of a supervised physical activity intervention in 26 breast cancer survivors, Guinan et al. found no significant changes in sedentary behavior from baseline to 8 weeks in the intervention group compared with the control group; however, the intervention did not improve physical activity either [25]. These results suggest that physical activity interventions may not reduce sedentary behavior in breast cancer survivors. Yet the samples were small, and only one of the interventions significantly increased MVPA [26].

There are numerous potential explanations for the lack of an intervention effect on sedentary time in these previous trials. First, these interventions did not explicitly target sedentary behavior. Two meta-analyses have shown that interventions that included sedentary behavior-specific strategies yielded greater reductions in sedentary behavior compared with interventions solely targeting increases in physical activity or interventions that included both physical activity and sedentary behavior components [27, 28]. For example, strategies such as finding time to exercise or scheduling a daily exercise session are unlikely to change sedentary behavior because sedentary behavior is highly habitual [29]; interrupting sedentary behavior may require frequent prompts and environmental cues to help individuals become more conscious of their sitting and form new habits [29–31]. Alternatively, the lack of intervention effect on sedentary behavior in the study by Pinto and colleagues [24] may have been due to a compensatory “rest and recover” process, whereby higher activity leads to fatigue, and therefore sedentary behavior remains unchanged [32, 33] or even increases during non-active periods [34]. The “rest and recover” phenomenon following MVPA has been documented in the intervention literature in non-cancer populations [34] but is understudied among cancer survivors. This process may be particularly relevant for breast cancer survivors, who often experience high levels of fatigue long after treatment has concluded [35]. As the evidence linking sedentary behavior to adverse health consequences in cancer survivors continues to grow, it is important to understand how physical activity interventions impact both physical activity and sedentary behavior.

The primary aim of this secondary analysis was to examine changes in sedentary behavior among breast cancer survivors participating in a physical activity intervention that significantly increased MVPA [36]. In line with the “rest and recover” process, we hypothesized that the exercise arm would have greater increases in sedentary behavior from baseline to 12 weeks compared with the control arm. We also examined intervention effects on light physical activity (LPA). Sedentary behavior and LPA were assessed via an ActiGraph accelerometer at baseline and 12 weeks.

Considering the high prevalence of sedentary behavior, emerging evidence of deleterious associations with health outcomes, and limited evidence to date, further investigation of factors that impact sedentary time in breast cancer survivors is needed [29, 32, 37, 38]. In cross-sectional samples, sedentary time has been related to older age and higher BMI [39]. Therefore, we also explored the association between change in MVPA and change in sedentary behavior and potential moderators (age, BMI, receipt of chemotherapy, and time since surgery) of intervention effects on change in sedentary behavior.

Methods

Participants and design

Participants were enrolled in the Memory & Motion Study, a 12-week randomized controlled trial of a theory- and technology-based physical activity intervention [40]. Data were collected from February 2015 to July 2016. The UC San Diego Institutional Review Board approved all study procedures and all study participants provided written informed consent. Eligible participants were female breast cancer survivors, age 21–85 years old, who were diagnosed less than 5 years prior to study enrollment, had completed chemotherapy and/or radiation treatment, self-reported less than 60 min of MVPA in 10-min bouts per week, and had access to the Internet and a Fitbit-compatible computer, tablet, or phone. Exclusion criteria included any medical condition that could make it potentially unsafe to partake in an unsupervised physical activity intervention (based on the Physical Activity Readiness Questionnaire [41]), other primary or recurrent invasive cancer within the last 10 years, or unable to commit to a 12-week intervention.

A full description of the study protocol has been previously published [40]. In brief, women were recruited through cancer registry lists. Potential participants were phone-screened to determine eligibility. Interested and eligible women were then scheduled for an in-person visit and received an ActiGraph GT3X+ accelerometer to wear for 7 days and bring back to the randomization visit. At the randomization visit, 87 breast cancer survivors were randomized to receive either a 12-week physical activity intervention (exercise arm, $N = 43$) or waitlist wellness contact control condition (control arm, $N = 44$). For the final assessment, participants were mailed an ActiGraph GT3X+ and asked to wear it at the start of week 12 and bring it with them to the final in-person visit. One participant in each arm was lost to follow-up prior to the final visit, leading to a 97.7% retention rate (exercise $n = 42$, control $n = 43$) [36].

Physical activity intervention (exercise arm)

The intervention focused solely on increasing MVPA to meet the study goal of 150 min of MVPA per week and did not contain any content related to decreasing sedentary time. At the beginning of the intervention, participants met face-to-face with a trained interventionist who used motivational interviewing techniques to help each participant set a specific, personalized physical activity goal and an action plan to gradually increase their activity. Participants received a Fitbit One activity tracker and were taught how to use it to self-monitor their physical activity. Two 20-min intervention phone calls at the 2- and 6-week time points focused on reviewing Fitbit data and discussing progress toward the goal. To promote accountability, the interventionist also checked Fitbit data at least once per week and contacted participants between calls to provide encouragement or extra support. Specifically, the interventionist emailed participants who met any of the following criteria: met or exceeded their personal activity goal, reduced activity by more than 20% from previous week, or were 20% or more below their personal activity goal. Participants who reduced their activity or did not meet their personal activity goal were offered an extra intervention phone call. Four of 44 exercise arm participants received an additional call, which focused on providing support or problem-solving as needed. All participants in the exercise arm also received standardized, twice-weekly emails throughout the 12-week intervention with theory-based content and reminders to wear and sync their Fitbit. The emails targeted constructs of social cognitive theory [42] and control theory [43–45] including self-monitoring, how to get social support for being active, how to find places to be active, exercise videos, and tips on how to change outcome expectations and use your thoughts to motivate you to exercise [40].

Waitlist wellness contact control condition (control arm)

The control arm received standardized emails every 3 days on women's health topics (e.g., healthy eating, stress management, and general brain health). The control arm also received intervention materials and a Fitbit after completing the final measures.

Measures

Physical activity and sedentary behavior

The ActiGraph GT3X+, a well-validated research-grade accelerometer [46], was used to assess the frequency, duration, and intensity of sedentary behavior, LPA, and MVPA at baseline and 12 weeks. For 7 days prior to each measurement time point, participants were instructed to wear the ActiGraph on their right hip during all waking hours except while bathing, for at least 12 h per day. Wear time was screened using ActiLife software (ActiGraph, Pensacola, FL) applying guidelines outlined by Choi et al. [47]. Non-wear time was defined as intervals of at least 60 consecutive minutes of zero counts, with allowance for up to 2 min of observations of < 100 counts per minute within the non-wear interval. To be considered valid, days of data collection required at least 600 min (10 h) of wear time. Sufficient wear time was classified as at least 10 h of wear per day for at least 5 days or greater than 50 h across 4 days. All complete and valid data were processed in ActiLife software using the low-frequency extension and aggregated to 60-s epochs. Each minute of wear time was classified according to intensity (counts per minute (cpm)) using Freedson cut points as follows: sedentary (< 100 cpm), LPA (100–1951 cpm), and MVPA (≥ 1952 cpm) [48]. For each valid day, the number of minutes classified as sedentary, LPA, or in MVPA was taken as an estimate of the total time spent in these activities on that day. Daily estimates of minutes spent sedentary, in LPA, or in MVPA were averaged across all valid days per participant at each time point to estimate mean daily minutes in each activity. The number of minutes in each category was divided by wear time to estimate proportions of the day spent in each behavior.

Demographics and cancer treatment variables

Participants self-reported their age and other demographics at the baseline visit. Body mass index (BMI) was calculated from height and weight objectively measured at the baseline and final in-person visits. Surgery date and chemotherapy treatment regimen were collected through medical chart reviews.

Statistical analysis

All analyses were performed using an intent-to-treat principle. That is, missing data were assumed "missing at random" and were accounted for in the mixed-effects models by using a likelihood-based estimation method, which uses all available data and does not omit individuals with partially missing data. Data were analyzed using R [49]. The distribution (mean [SD] and *n* [%]) of participant demographics and breast cancer characteristics was calculated at baseline. Accelerometer-measured sedentary behavior, LPA, and MVPA, assessed at baseline and 12 weeks, were described using mean (SD). Group differences in baseline characteristics were assessed using t tests, chi-squared tests, or 2-tailed Fisher exact tests (when warranted by small cell counts) for categorical variables. Differences in baseline sedentary time, LPA, and MVPA were each assessed using a separate linear mixed-effects regression model of day-level MVPA (or LPA or sedentary time), adjusting for ActiGraph wear time, and using a fixed-effect term for group.

Separate linear mixed-effects regression models were used to examine differences in (1) sedentary behavior and (2) LPA, over time between the exercise and control arms. Each model controlled for ActiGraph wear time and included fixed-effect terms for group (exercise arm vs. control arm), time point (baseline, 12 weeks), and the time-by-group interaction. To account for the correlation between repeated measures of the same individuals over time, each model included a subject-level random intercept. If there were significant between-group differences over time in MVPA (or LPA), the association between change in sedentary time and change in MVPA (or LPA) was explored using a separate linear mixed-effects regression model. This model controlled for ActiGraph wear time and included fixed-effect terms for group (exercise arm vs. control arm), change in MVPA (or LPA), and the interaction between group and change in MVPA (or LPA). To account for the correlation between repeated measures of the same individuals over time, the model included a subject-level random intercept.

Potential moderators of the intervention effect on sedentary behavior (age, BMI, receipt of chemotherapy, and time since surgery) were examined by adding the potential moderator and a 3-way interaction term (time, group, and moderator) to the mixed-effects regression model. The significance of the interaction term was set at the 0.1 level, as is common practice with interaction analyses. For significant moderators, values for the moderator were modeled to yield predicted change in sedentary time at that value.

Results

Demographic and clinical characteristics of the sample, stratified by study arm, are shown in Table 1. There were no significant differences between study arms on baseline characteristics. Overall, the mean age was 57 years (SD = 10.4) and mean BMI was 27 kg/m^2 (SD = 6.3). On average, participants were 30 (SD = 16.7) months post-surgery and over half (53%) received chemotherapy. At the baseline measurement, on average, participants wore the accelerometer for 837.6 (SD = 63.3) minutes per day (~ 14 h per day) and had 7.2 (SD = 1.1) valid days of wear time. They spent 534.3 min per day (SD = 85.2, 63.8% of wear time) in sedentary behaviors, 288.9 min per day (SD = 70.4, 34.5% of wear time) in LPA, and 14.4 min per day (SD = 14.4, 1.7% of wear time) in MVPA.

Changes in sedentary time, LPA, and MVPA from baseline to 12 weeks between the exercise and control arms are presented in Table 2. Participants in the exercise arm had significantly greater reductions in total sedentary time compared with those in the control arm (mean − 24.9 min per day (SD = 5.9) vs −4.8 min per day (SD = 5.9), with a group difference in change scores of $b = -20.1$ (SE = 8.4), $p = 0.02$). Within the exercise arm, there was a significant increase in LPA from baseline to 12 weeks (mean increase 11.4 min per day (SD = 5.6), $p = 0.04$), but no significant group difference in change in LPA from baseline to 12 weeks between the exercise and control arms ($b = 5.64$ (SE = 7.69), $p = 0.48$). As previously published, participants in the exercise arm had significantly greater increases in accelerometer-measured MVPA compared with the control arm (mean increase 14.2 min per day (SD = 13.9) vs. −0.7 min per day (SD = 9.7), $b = 7.24$ (SE = 0.97), $p < 0.001$) [36]. A greater increase in MVPAwas associated with a greater decrease in total sedentary time ($b = -1.9$, (SE = 0.21), $p < 0.001$), whereby each daily 1-min increase in MVPA was associated with a ~ 2-min decrease in sedentary time. The relationship between change in MVPA and change in sedentary time did not differ between the exercise and control arms.

Time since surgery was a significant moderator of the intervention effect on sedentary behavior between baseline and 12 weeks (group × time × time since surgery, $b = -0.91$ (SE = 0.5), $p = 0.07$). On average, exercise arm women farther out from surgery had greater decreases in sedentary time than women closer to surgery, relative to control arm women (Fig. 1). For instance, in the exercise arm, a survivor who was 36 months from surgery decreased her sedentary time on average by 30.4 min between baseline and 12 weeks, while a survivor who was 12 months from surgery decreased her sedentary time by 10.7 min during the same period. In the control arm, someone 36 months out from surgery decreased her sedentary time on average by 4.1 min, while someone 12 months out from surgery decreased her sedentary time by 6.4 min. Age ($b = 0.70$ (SE = 0.83), $p = 0.40$), BMI ($b = -1.6$ (SE = 1.3), $p = 0.22$), and receipt of chemotherapy ($b = -26.4$ (SE = 16.8), $p = 0.12$) were not significant moderators of the intervention effect on sedentary behavior between baseline and 12 weeks.

Discussion

The aim of this secondary analysis was to assess change in sedentary behavior among breast cancer survivors participating in a 12-week theory-based physical activity intervention that increased MVPA in the exercise arm compared with the control arm. Contrary to our hypothesis that the physical activity intervention would increase sedentary behavior, women in the exercise arm reduced their sedentary time by about 25 min per day, which was significantly greater than the ~ 5-min reduction in the control arm. The magnitude of sedentary behavior decrease observed in this study is comparable to a recent meta-analysis of 19 sedentary-specific interventions which found an overall pooled effect of a − 25 min per day decrease in sedentary time favoring the intervention group [50]. There was no intervention effect on LPA. Overall, our results suggest that breast cancer survivors both increased MVPA and reduced sedentary behavior within the framework of a physical activity intervention, and the volume of sedentary behavior change was similar in size to reductions reported in sedentary behavior-specific interventions. Given the important and potentially independent health effects of physical activity and sedentary behavior [9, 15, 16], it is promising that the exercise intervention did not lead to a compensatory increase in sitting but instead decreased sedentary time.

Strengths of this study include the randomized design and use of mixed-effects models to yield unbiased results. However, because this study was conducted in a predominantly white, highly educated sample of women enrolled at an academic medical center, results may not be generalizable to all breast cancer survivors. Further, sedentary behavior was only assessed for 7 days at baseline and 12 weeks; the 7-day measurement snapshots may not be reflective of usual behavior. On average, participants wore the ActiGraph for ~ 14 waking hours per day. Future studies that measure activity across the 24-h day would provide valuable data to explore changes in all daily activities (i.e., MVPA, LPA, sedentary time, and sleep) in the context of an intervention targeting MVPA and to identify optimal amounts of time that should be spent in each of these activities over the course of the day to maximize health [51].

Using accelerometry to measure sedentary time is both a strength and a limitation. Objective measures of sedentary behavior are less prone to recall and response biases than traditional self-report methods [52]. However, the hip-worn accelerometer *x*-axis cut points used to define sedentary behavior in this study cannot distinguish between standing still and seated postures [53, 54]; therefore, standing still may have been misclassified as a sedentary behavior. Because accelerometry also picks up signals that are not actually intensity (e.g., may recognize sitting in a vehicle as movement, rather than sedentary behavior), use of machine learning classifiers to identify a range of sedentary activities may improve our understanding of how physical activity interventions impact sedentary behaviors [55]. While the Freedson cut points are widely used to determine physical activity in cancer survivors [56], they were derived from healthy young adults (mean age 24 years) [48]. Therefore, they may not optimally capture MVPA in older populations including cancer survivors [56]. Future studies should consider applying other accelerometer cut points that have higher sensitivity to a range of moderate intensity activities, such as the Matthews cut points (moderate intensity = 760 cpm) [57]. Finally, the accelerometer does not collect any data about behavioral context. An ideal approach to understanding the influence of a physical activity intervention on sedentary time would include both objective (i.e., accelerometer and/or ActivPAL) and self-report measures of behavior [38].

Our findings differ from other studies in breast cancer survivors that found no impact of a physical activity intervention on sedentary behavior [24, 25]. One potential explanation for this discrepancy is that the women in Memory & Motion intervention, who completed the study at a comprehensive cancer center, may have been differentially motivated to change their health behaviors compared with participants enrolled in a community-based program delivered by peer coaches [26]. Our participants increased their physical activity by an average of 99.4 min per week [36], while women in the study conducted by Pinto and colleagues had smaller increases in accelerometer-measured MVPA (average of 56.9 min per week) [26]. It is possible that large changes in physical activity may be needed to impact sedentary time. These results also contrast with two meta-analyses of studies in non-cancer populations showing that interventions targeting sedentary behavior result in greater reductions in sedentary behavior compared with interventions targeting increases in physical activity or interventions aimed at changing both physical activity and sedentary behavior [27, 28]. However, neither meta-analysis included any studies among cancer survivors. While our intervention contained no specific content targeting sedentary behavior, increases in MVPA were associated with decreases in sedentary time from baseline to 12-weeks in both study arms. This is consistent with research showing that cancer survivors are particularly motivated to change their health behavior [58] and may explain why our results differ from those in non-cancer populations.

Our findings are supported by results recently reported from the ACTIVATE trial [59]. This study used a wearable activity tracker and motivational interviewing sessions to promote both increasing MPVA and reducing sedentary time over 12 weeks. They also found significant intervention effects on both MVPA (ActiGraph GT3X+; mean increase 52 min per week (95% CI 24.4, 79.6) in the intervention arm vs. 11.4 min per week (95% CI − 16.1, 40) in the control arm; $p = 0.04$) and sedentary time (ActivPal; mean reduction − 23.5 min/day (95% CI − 49, − 2) in the intervention arm vs. + 13.1 min/day (95% CI − 11.1, 37.3) in the control arm; $p = 0.01$). These results are generally consistent with our findings and the aforementioned meta-analysis of sedentary-specific interventions which found comparable reductions in sedentary time [50]. As our study focused solely on promoting MVPA, it is not surprising that, on average, our participants increased their physical nearly twice as much as the ACTIVATE participants. Despite our intervention not targeting sedentary behavior, we found similar reductions in total sedentary time. Results of the ACTIVATE trial also provide evidence for the feasibility of successfully targeting and changing both physical activity and sedentary behaviors in breast cancer survivors.

To further improve our understanding of factors that influence sedentary behavior and to inform future intervention development, we examined potential demographic and clinical moderators of the intervention effect on sedentary time. To our knowledge, this is the first study to examine the moderating effect of time since surgery on the impact of a physical activity intervention on sedentary behavior in cancer survivors. The intervention effect on sedentary behavior was moderated by time since surgery, whereby women farther out from surgery had greater decreases in sedentary time than women closer to surgery. Previous research has shown that cancer survivors encounter different barriers throughout survivorship and have low levels of physical activity and high levels of sedentary behavior in the early survivorship period [2]. The present results add to this literature, suggesting that women closer to surgery may need extra support for changing these behaviors. Moreover, the intervention effect on sedentary behavior was not moderated by factors that have previously been associated with greater sedentary time (age and BMI) [11] or receipt of chemotherapy. Additional studies in larger samples are needed to confirm these findings.

In summary, increasing physical activity did not lead to unintended increases in sedentary behavior among breast cancer survivors participating in a 12-week physical activity intervention. Women in the exercise arm of our study both increased their MVPA and decreased their sedentary time. Therefore, MVPA and sedentary behavior may be synergistic behaviors that could be successfully targeted together in behavioral interventions, particularly among cancer survivors farther out from treatment.

Funding

This work was supported by the National Cancer Institute of the National Institutes of Health (K07CA181323).

References

1. Miller KD, Siegel RL, Lin CC, Mariotto AB, Kramer JL, Rowland JH, et al. Cancer treatment and survivorship statistics, 2016. CA Cancer J Clin. 2016;66(4):271–89. [PubMed: 27253694]
2. Sabiston CM, Brunet J, Vallance JK, Meterissian S. Prospective examiniation of objectively-assessed physical activity and sedentary time after breast cancer treatment: sitting on the crest of the teachable moment. Cancer Epidemiol Biomark Prev. 2014;23(7): 1324–30.
3. Lynch BM, Dunstan DW, Healy GN, Winkler E, Eakin E, Owen N. Objectively measured physical activity and sedentary time of breast cancer survivors, and associations with adiposity: findings from NHANES (2003–2006). Cancer Causes Control. 2010;21(2):283–8. [PubMed: 19882359]
4. Phillips SM, Awick EA, Conroy DE, Pellegrini CA, Mailey EL, McAuley E. Objectively measured physical activity and sedentary behavior and quality of life indicators in survivors of breast cancer. Cancer. 2015;121(22):4044–52. [PubMed: 26308157]
5. Gennuso KP, et al. Sedentary behavior, physical activity, and markers of health in older adults. Med Sci Sports Exerc. 2013;45(8):1493–500. [PubMed: 23475142]
6. de Rezende LF. et al. Sedentary behavior and health outcomes among older adults: a systematic review. BMC Public Health; 2014 14: p. 333 [PubMed: 24712381]
7. Gianoudis J, Bailey CA, Daly RM. Associations between sedentary behaviour and body composition, muscle function and sarcopenia in community-dwelling older adults. Osteoporos Int. 2015;26(2): 571–9. [PubMed: 25245026]
8. Mañas A, del Pozo-Cruz B, García-García FJ, Guadalupe-Grau A, Ara I. Role of objectively measured sedentary behaviour in physical performance, frailty and mortality among older adults: a short systematic review. Eur J Sport Sci. 2017;17(7):940–53. [PubMed: 28532299]
9. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. Ann Intern Med. 2015;162(2):123–32. [PubMed: 25599350]
10. Nelson SH, Marinac CR, Patterson RE, Nechuta SJ, Flatt SW, Caan BJ, et al. Impact of very low physical activity, BMI, and comorbidities on mortality among breast cancer survivors. Breast Cancer Res Treat. 2016;155(3):551–7. [PubMed: 26861056]
11. Phillips SM, Lloyd GR, Awick EA, McAuley E. Correlates of objectively measured sedentary behavior in breast cancer survivors. Cancer Causes Control. 2016;27(6):787–95. [PubMed: 27146839]
12. George SM, Alfano CM, Groves J, Karabulut Z, Haman KL, Murphy BA, et al. Objectively measured sedentary time is related to quality of life among cancer survivors. PLoS One. 2014;9(2): e87937. [PubMed: 24505335]
13. Hartman SJ, Marinac CR, Bellettiere J, Godbole S, Natarajan L, Patterson RE, et al. Objectively measured sedentary behavior and quality of life among survivors of early stage breast cancer. Support Care Cancer. 2017;25(8):2495–503. [PubMed: 28326507]
14. Craft LL, Zderic TW, Gapstur SM, VanIterson EH, Thomas DM, Siddique J, et al. Evidence that women meeting physical activity guidelines do not sit less: an observational inclinometry study. Int J Behav Nutr Phys Act. 2012;9(1):122. [PubMed: 23034100]
15. Chomistek AK, Manson JE, Stefanick ML, Lu B, Sands-Lincoln M, Going SB, et al. Relationship of sedentary behavior and physical activity to incident cardiovascular disease: results from the Women's Health Initiative. J Am Coll Cardiol. 2013;61(23): 2346–54. [PubMed: 23583242]
16. Zhou Y, Zhao H, Peng C. Association of sedentary behavior with the risk of breast cancer in women: update meta-analysis of observational studies. Ann Epidemiol. 2015;25(9):687–97. [PubMed: 26099193]
17. Ekelund U, Steene-Johannessen J, Brown WJ, Fagerland MW, Owen N, Powell KE, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. Lancet. 2016;388(10051):1302–10. [PubMed: 27475271]
18. Stamatakis E, Ekelund U, Ding D, Hamer M, Bauman AE, Lee, IM. Is the time right for quantitative public health guidelines on sitting? A narrative review of sedentary behaviour research paradigms and findings. Br J Sports Med. 2018;53(6):377–82. [PubMed: 29891615]

19. Bellettiere J, Winkler EAH, Chastin SFM, Kerr J, Owen N, Dunstan DW, et al. Associations of sitting accumulation patterns with cardio-metabolic risk biomarkers in Australian adults. PLoS One. 2017;12(6):e0180119. [PubMed: 28662164]

20. Lynch BM, Dunstan DW, Vallance JK, Owen N. Don't take cancer sitting down: a new survivorship research agenda. Cancer. 2013;119(11):1928–35. [PubMed: 23504979]

21. Bluethmann SM, Vernon SW, Gabriel KP, Murphy CC, Bartholomew LK. Taking the next step: a systematic review and meta-analysis of physical activity and behavior change interventions in recent post-treatment breast cancer survivors. Breast Cancer Res Treat. 2015;149(2):331–42. [PubMed: 25555831]

22. Lahart IM, Metsios GS, Nevill AM, Carmichael AR. Physical activity for women with breast cancer after adjuvant therapy. Cochrane Database of Systematic Reviews. 2018;(1):CD011292. [PubMed: 29376559]

23. Short CE, James EL, Stacey F, Plotnikoff RC. A qualitative synthesis of trials promoting physical activity behaviour change among post-treatment breast cancer survivors. J Cancer Surviv. 2013;7(4): 570–81. [PubMed: 23888337]

24. Pinto B, Dunsiger S, Stein K. Does a peer-led exercise intervention affect sedentary behavior among breast cancer survivors? Psycho-Oncology. 2017;26(11):1907–13. [PubMed: 27531024]

25. Guinan E, Hussey J, Broderick JM, Lithander FE, O'Donnell D, Kennedy MJ, et al. The effect of aerobic exercise on metabolic and inflammatory markers in breast cancer survivors—a pilot study. Support Care Cancer. 2013;21(7):1983–92. [PubMed: 23430010]

26. Pinto BM, Stein K, Dunsiger S. Peers promoting physical activity among breast cancer survivors: a randomized controlled trial. Health Psychol. 2015;34(5):463–72. [PubMed: 25110844]

27. Prince SA, Saunders TJ, Gresty K, Reid RD. A comparison of the effectiveness of physical activity and sedentary behaviour interventions in reducing sedentary time in adults: a systematic review and meta-analysis of controlled trials. Obes Rev. 2014;15(11):905–19. [PubMed: 25112481]

28. Martin A, Fitzsimons C, Jepson R, Saunders DH, van der Ploeg H, Teixeira PJ, et al. Interventions with potential to reduce sedentary time in adults: systematic review and meta-analysis. Br J Sports Med. 2015;49:1056–63. [PubMed: 25907181]

29. Conroy DE, Maher JP, Elavsky S, Hyde AL, Doerksen SE. Sedentary behavior as a daily process regulated by habits and intentions. Health Psychol. 2013;32(11):1149–57. [PubMed: 23477579]

30. Lally P, van Jaarsveld CHM, Pots HWW, Wardle J. How are habits formed: modelling habit formation in the real world. Eur J Soc Psychol. 2010;40(6):998–1009.

31. Lally P, Wardle J, Gardner B. Experiences of habit formation: a qualitative study. Psychol Health Med. 2011;16(4):484–9. [PubMed: 21749245]

32. Siddique J, de Chavez PJ, Craft LL, Freedson P, Spring B. The effect of changes in physical activity on sedentary behavior: results from a randomized lifestyle intervention trial. Am J Health Promot. 2017;31(4):287–95. [PubMed: 26559710]

33. Rowland TW. The biological basis of physical activity. Med Sci Sports Exerc. 1998;30(3):392–9. [PubMed: 9526885]

34. Kozey-Keadle S, Staudenmayer J, Libertine A, Mavilia M, Lyden K, Braun B, et al. Changes in sedentary time and physical activity in response to an exercise training and/or lifestyle intervention. J Phys Act Health. 2014;11(7):1324–33. [PubMed: 24184493]

35. Reinertsen KV, Cvancarova M, Loge JH, Edvardsen H, Wist E, Fosså SD. Predictors and course of chronic fatigue in long-term breast cancer survivors. J Cancer Surviv. 2010;4(4):405–14. [PubMed: 20862614]

36. Hartman SJ, Nelson SH, Myers E, Natarajan L, Sears DD, Palmer BW, et al. Randomized controlled trial of increasing physical activity on objectively measured and self-reported cognitive functioning among breast cancer survivors: the memory & motion study. Cancer. 2018;124(1): 192–202. [PubMed: 28926676]

37. Gardner B, Smith L, Lorencatto F, Hamer M, Biddle SJH. How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. Health Psychol Rev. 2016;10:89–112. [PubMed: 26315814]

38. Keadle SK, et al. Targeting reductions in sitting time to increase physical activity and improve health. Med Sci Sports Exerc. 2017;49(8):1572–82. [PubMed: 28272267]

39. Sabiston CM, Lacombe J, Faulkner G, Jones J, Trinh L. Profiling sedentary behavior in breast cancer survivors: links with depression symptoms during the early survivorship period. Psychooncology. 2018;27(2):569–75. [PubMed: 28763129]
40. Hartman SJ, Natarajan L, Palmer BW, Parker B, Patterson RE, Sears DD. Impact of increasing physical activity on cognitive functioning in breast cancer survivors: rationale and study design of Memory & Motion. Contemp Clin Trials. 2015;45(Pt B):371–6. [PubMed: 26427563]
41. Thomas S, Reading J, Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Can J Sport Sci. 1992;17(4):338–45. [PubMed: 1330274]
42. Bandura A. Social foundations of thought and action. Englewood Cliffs: Prentice-Hall; 1986.
43. Carver CS, Scheier MF. Control theory: a useful conceptual framework for personality-social, clinical, and health psychology. Psychol Bull. 1982;92(1):111–35. [PubMed: 7134324]
44. Carver CS and Scheier M. On the self-regulation of behavior. Cambridge, UK; New York, NY, USA: Cambridge University Press; 1998; 439 p
45. Michie S, Abraham C, Whittington C, McAteer J, Gupta S. Effective techniques in healthy eating and physical activity interventions: a meta-regression. Health Psychol. 2009;28(6):690–701. [PubMed: 19916637]
46. Kelly LA, et al. Validity of actigraphs uniaxial and triaxial accelerometers for assessment of physical activity in adults in laboratory conditions. BMC Med Phys. 2013;13(1):5. [PubMed: 24279826]
47. Choi L, et al. Validation of accelerometer wear and nonwear time classification algorithm. Med Sci Sports Exerc. 2011;43(2):357–64. [PubMed: 20581716]
48. Freedson PS, Melanson E, Sirard J. Calibration of the computer science and applications: Inc. accelerometer. Med Sci Sports Exerc. 1998;30:777–81. [PubMed: 9588623]
49. R Core Development Team. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2017.
50. Peachey MM, Richardson J, V Tang A, Dal-Bello Haas V, Gravesande J. Environmental, behavioural and multicomponent interventions to reduce adults' sitting time: a systematic review and meta-analysis. Br J Sports Med. 2018:bjsports-2017–098968.
51. Del Pozo-Cruz J, et al. Replacing sedentary time: meta-analysis of objective-assessment studies. Am J Prev Med. 2018;55(3):395–402. [PubMed: 30122216]
52. Atkin AJ, Gorely T, Clemes SA, Yates T, Edwardson C, Brage S, et al. Methods of measurement in epidemiology: sedentary behaviour. Int J Epidemiol. 2012;41(5):1460–71. [PubMed: 23045206]
53. Kerr J, et al. Comparison of accelerometry methods for estimating physical activity. Med Sci Sports Exerc. 2017;49(3):617–24. [PubMed: 27755355]
54. Kerr J, et al. Objective assessment of physical activity: classifiers for public health. Med Sci Sports Exerc. 2016;48(5):951–7. [PubMed: 27089222]
55. Kerr J, et al. Improving hip-worn accelerometer estimates of sitting using machine learning methods. Med Sci Sports Exerc. 2018;50: 1518–24. [PubMed: 29443824]
56. Peddle-Mcintyre CJ, Cavalheri V, Boyle T, Mcveigh JA, Jeffery E, Lynch BM, et al. A review of accelerometer-based activity monitoring in cancer survivorship research. Med Sci Sports Exerc. 2018;50(9):1790–801. [PubMed: 29683922]
57. Matthew CE. Calibration of accelerometer output for adults. Med Sci Sports Exerc. 2005;37(11):S512–22. [PubMed: 16294114]
58. Demark-Wahnefried W, Aziz NM, Rowland JH, Pinto BM. Riding the crest of the teachable moment: promoting long-term health after the diagnosis of cancer. J Clin Oncol. 2005;23(24): 5814–30. [PubMed: 16043830]
59. Lynch BM, Nguyen NH, Moore MM, Reeves MM, Rosenberg DE, Boyle T, et al. A randomized controlled trial of a wearable technology-based intervention for increasing moderate to vigorous physical activity and reducing sedentary behavior in breast cancer survivors: the ACTIVATE trial. Cancer. 2019 10.1002/cncr.32143.

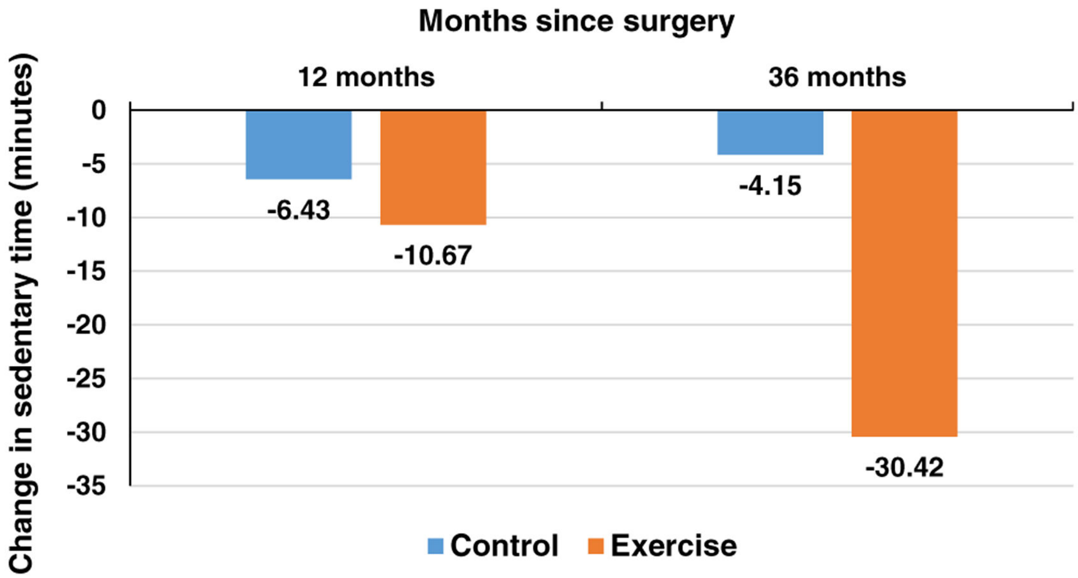

Fig. 1.
Change in sedentary time (minutes per day) between baseline and 12 weeks for someone 12 months vs. 36 months since surgery, by study arm ($N = 87$)

Table 1

Baseline characteristics of breast cancer survivors enrolled in a randomized controlled trial of an exercise intervention, by study arm (*N* = 87)

	Exercise intervention (*n* = 43)	Control (*n* = 44)	*p* value
Demographics			
Age, years, mean (SD)	58.2 (11.4)	56.2 (9.3)	0.35
Education, *n*/%			0.69
Some college or less	14/32.7	11/25	
College graduate	18/41.9	22/50	
Master's degree or higher	11/25.6	11/25	
Ethnicity, *n*/%			0.74
Not Hispanic/Latino	35/81.4	37/84.1	
Hispanic/Latino	8/18.6	7/15.9	
Race, *n*/%			0.62
White	36/83.7	35/79.5	
Non-white	7/16.3	10/22.8	
BMI[a], kg/m^2, mean (SD)	26.7 (6.2)	27.3 (6.4)	0.63
Breast cancer characteristics			
Time since surgery, months, mean (SD)	30.3 (17.4)	30.0 (16.1)	0.997
Cancer stage, n/%			0.79
Stage I	27/62.8	26/59.1	
Stage II	12/27.9	15/34.1	
Stage III	4/9.3	3/6.8	
Received chemotherapy	23/53.5	23/52.3	0.91
Current aromatase inhibitor/tamoxifen	31/72.1	30/68.2	0.69
Accelerometer measured activity			
Valid ActiGraph days, mean (SD)	7.3 (1.4)	7.1 (0.8)	0.25
Total sedentary time, minutes/day, mean (SD)[b]	549.2 (9)	526.6 (9.7)	0.12
Light physical activity, minutes/day, mean (SD)[b]	277.1 (68)	300.4 (71)	0.12
MVPA[c], minutes/day, mean (SD)[b]	13.4 (13)	15.4 (15.7)	0.62

[a] Body mass index

[b] Measured with ActiGraph GT3X+ accelerometer

[c] Moderate-to-vigorous physical activity

Table 2

Change in ActiGraph-measured sedentary behavior and physical activity at baseline and 12 weeks, within and between study arms ($N = 87$)

	Exercise intervention				Control				Difference of change between study arms	
	Baseline	12 weeks	Change	*p* value[a]	Baseline	12 weeks	Change	*p* value[a]	Estimate (SE)	*p* value[b]
Total sedentary time, min/day, mean (SD)	549.2 (9.0)	523.5 (9.8)	−24.90 (5.9)	<0.001	526.6 (9.7)	521.8 (9.7)	−4.8 (5.9)	0.41	−20.1 (8.37)	0.02
Total light physical activity, min/day, mean (SD)	279.7 (9.1)	291.1 (9.1)	11.4 (5.6)	0.04	300 (9)	305.8 (9)	5.8 (5.6)	0.30	5.64 (7.9)	0.48
Total moderate-to-vigorous physical activity, min/day, mean (SD)[c]	13.4 (13)	27.9 (15.1)	14.2 (14)	<0.0001	15.4 (15.7)	14.9 (15.1)	−0.7 (9.8)	0.46	7.24 (0.97)	<0.0001

[a] Test of change over time from mixed-effects model

[b] Group by time interaction from mixed-effects model

[c] Hartman et al. 2018 [36]