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The Effects of Wearable Health Technology on Cancer Survivors' Physical Activity, Sedentary Behavior, and Weight: A Meta-Analysis

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Wearable health technology (WHT) has been suggested as a health intervention in preventing or reducing health risk factors in clinical populations. Cancer survivors exhibit risk factors prior to cancer diagnosis and acquire comorbidities as a result of their treatment. These conditions may increase likelihood of cancer recurrence and reduce quality of life by inhibiting survivors' physiological function and predisposing them to other maladies. Several studies have suggested WHTs as an intervention in mitigating these risks. However, there lacks a comprehensive review of the current evidence to determine the efficacy of WHT interventions. Thus, a literature search of WHT studies within cancer survivors was conducted and a meta-analysis was performed on the four most commonly reported health outcomes, namely weight, step count, moderate-to-vigorous physical activity (MVPA) and sedentary time. A meta-analysis was performed to determine if positive or negative effects between WHT and these outcomes exist and what the effect sizes were. Twelve papers met inclusion criteria. Of the ten studies that measured MVPA, a moderate positive effect was found between WHT interventions and weekly MVPA. Five studies measured average daily step count and from this, a weak positive effect was found between WHT interventions and step count increase. Five studies measured sedentary time and revealed a weakly positive correlation between WHT use and increased sedentary time, though this data was unreliable. Lastly, three studies measured weight and revealed a weak negative effect between WHT use and weight, however, this was also limited due to the small sample. Thus, this review validates the use of WHT to improve MVPA and possibly step count in cancer survivors while it appears WHTs have a lesser impact on weight and potentially an opposite effect on sedentary time.

The Effects of Wearable Health Technology on Cancer Survivors' Physical Activity, Sedentary Behavior, and Weight: A Meta-Analysis

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Abstract

Wearable health technology (WHT) has been suggested as a health intervention in preventing or reducing health risk factors in clinical populations. Cancer survivors exhibit risk factors prior to cancer diagnosis and acquire comorbidities as a result of their treatment. These conditions may increase likelihood of cancer recurrence and reduce quality of life by inhibiting survivors' physiological function and predisposing them to other maladies. Several studies have suggested WHTs as an intervention in mitigating these risks. However, there lacks a comprehensive review of the current evidence to determine the efficacy of WHT interventions. Thus, a literature search of WHT studies within cancer survivors was conducted and a meta-analysis was performed on the four most commonly reported health outcomes, namely weight, step count, moderate-to-vigorous physical activity (MVPA) and sedentary time. A meta-analysis was performed to determine if positive or negative effects between WHT and these outcomes exist and what the effect sizes were. Twelve papers met inclusion criteria. Of the ten studies that measured MVPA, a moderate positive effect was found between WHT interventions and weekly MVPA. Five studies measured average daily step count and from this, a weak positive effect was found between WHT interventions and step count increase. Five studies measured sedentary time and revealed a weakly positive correlation between WHT use and increased sedentary time, though this data was unreliable. Lastly, three studies measured weight and revealed a weak negative effect between WHT use and weight, however, this was also limited due to the small sample. Thus, this review validates the use of WHT to improve MVPA and possibly step count in cancer survivors while it appears WHTs have a lesser impact on weight and potentially an opposite effect on sedentary time.

Key words: cancer diagnosis, health wearables, moderate-to-vigorous physical activity, obesity, weight management

Introduction

Obesity, hypertension, hyperlipidemia, sedentary activity, and lack of moderate to vigorous physical activity (MVPA) have all been established as risk factors increasing the likelihood of cancer development (Coughlin et al., 2020; Maxwell-Smith et al., 2018). Biomarkers associated with these risk factors include a body mass index (BMI) greater than 30%, elevated resting heart rate, and decreased metabolic exertion (Coughlin et al., 2020). Unfortunately, the nature of modern cancer treatment methods further exacerbates these health risks; treatments often cause severe physical debilitations in patients including reduced physical function, elevated body fat, and impaired health-related quality of life (HRQOL) indicators such as cognitive function (Hartman et al., 2018; Lynch et al., 2019; Ndjavera et al., 2020; Schwartz et al., 2017). The adverse effects of cancer treatments contribute to risk of developing concerning comorbidities such as cardiovascular disease and new or returning cancer development (Beg et al., 2017; Brickwood et al., 2019; Maxwell-Smith et al., 2018).

Cancer patients and survivors often exhibit a combination of these risk factors and comorbidities, which can compromise their health and increase the likelihood for cerebrovascular accidents or cardiac events. A sample of endometrial cancer survivors revealed that roughly three-fourths of these individuals were obese (Fisher et al., 2016). Further, another study of colorectal cancer survivors found that 83% of these individuals were insufficiently active per the health.gov weekly physical activity recommendations (Grimmett et al., 2011). Cancer survivors' cancer history, in addition to possible coincidence of diabetes, obesity, hypertension, hyperlipidemia, or sedentary activity put cancer survivors in a high-risk category for stroke and the American Stroke Association identifies almost all of these comorbidities as being malleable to improvement with lifestyle changes (American Stroke Association, 2018). Promisingly, interventions targeting some of these lifestyle-related risk factors do show to be effective in reducing comorbid diseases and cancer risks (Chea Tham et al., 2018; Ndjavera et al., 2020). For example, increased physical activity has been effective in alleviating treatment-related ailments including fatigue, weakness, physical deterioration, cardiovascular decline, and overall survival rates (Coughlin et al., 2020; Schwartz et al., 2017). According to Schwartz et al., improvements in exercise for cancer survivors during and following cancer treatment may yield a reduction in cancer recurrence and mortality by 30% to 60% (Schwartz et al., 2017).

Several intervention methods have been proposed to improve physical activity, weight management, diet, and other risk factors in cancer survivors. Interventions like personal coaching or guided exercises are effective based upon existing data (Brickwood et al., 2019; Gell et al., 2020; Hardcastle et al., 2019; Maxwell-Smith et al., 2018), there has been a trend toward technology-based interventions for their ease-of-use and greater accessibility. Technology-based interventions have included exercise videos, virtual coaching, informational emails, social media support groups, smart scales, and wearable health technology (WHT) like heart rate monitors or step trackers (Dong, Yi, Gao, Gao, Huang, Chao, & Ding, 2019; Dong, Yi, Ding, Gao, McDonough, Yi, & Qia, 2020; McDonough, Helgeson, Liu, & Gao, 2021; McDonough, Su, & Gao, 2021; Pope, Barr-Anderson, Lewis, Pereira, & Gao, Z., 2019; Pope & Gao, 2020). From a public health perspective, it is imperative that interventions are effective and have high user adherence, however, it is also important that they are affordable and accessible to the populations targeted for implementation. Thus, research focus has shifted away from costly in-person training or coaching that demonstrate lower user adherence towards more affordable tech-based options they are more suited for large-scale implementation.

Wearable health technologies are commonly used already in the general population and are becoming a popular intervention studied for their impact on physiological measures of health. Wrist-worn WHT began as step trackers and have now broadened in capacity to include a plethora of functions. Many wrist-worn WHT are now triaxial accelerometers that are capable of measuring steps taken, distance traveled, sedentary, light, moderate, and vigorous physical activities, metabolic exertion, heart rate, and even sleep quality, among other things (Coughlin et al., 2020; Rastogi et al., 2020; Schaffer et al., 2019; Seiler et al., 2017; Strath & Rowley, 2018; Winkels et al., 2017). A broad cost range of consumer WHT watches have been assessed and validated in their ability to accurately perform these functions; WHT options under fifty dollars were found to be as accurate as more expensive options, while the costlier selection benefitted from a more friendly user-interface and a greater number of functions. Recent studies have explored whether WHT watches have been effective in improving physical activity, weight loss, and other risk factors as compared to previous intervention methods.

Preliminary data indicates that cancer survivors widely prefer WHT watches to other methods due to their functionality, accessibility, and ability to encourage change in activity-related behaviors (Coughlin et al., 2020; Gresham et al., 2018; Ha et al., 2021; Schaffer et al., 2019; Seiler et al., 2017). Further, wrist-worn WHT has demonstrated an ability to increase user awareness of personal activity levels relative to physical activity recommendations and goals (Schwartz et al.,

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2017), and the capacity to motivate behavioral changes (Coughlin et al., 2020) through push-notifications and activity prompts. The expansive field of WHT research has shown promise in the ability to use WHT watches as an intervention method in both cancer survivors and other clinical populations; however, the findings in this field need to be evaluated for trends and significance in effects.

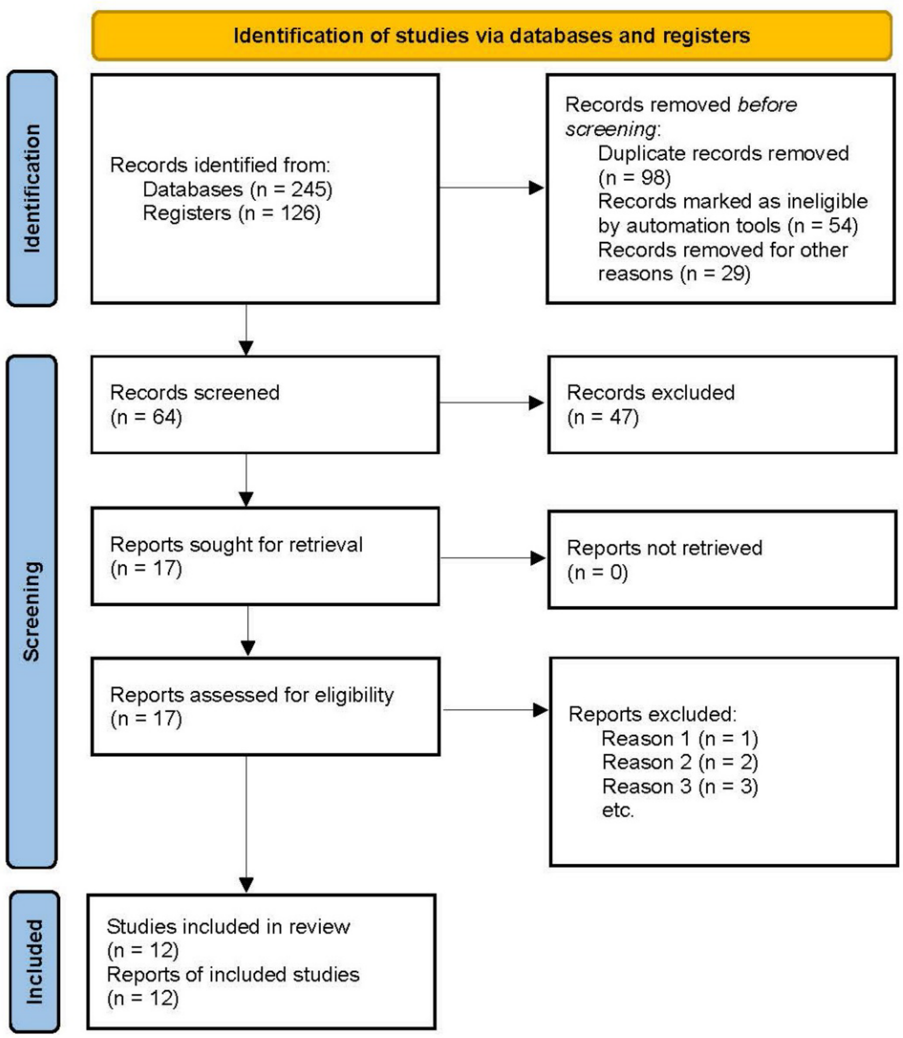
In health-related studies, WHTs have been used as both isolated and combined interventions methods to improve physical, cognitive, and psychological health outcomes, with physical outcomes being by far the most widely researched (Hartman et al., 2018; Maxwell-Smith et al., 2018). While physical effects have been broadly studied, this has caused a lack of consistency in the variables measured and in experimental design. The outcomes measured have included weight, BMI, blood pressure, metabolic exertion, physical activity levels, heart rate variability, and HRQOL indicators (Coughlin et al., 2020; Hardcastle et al., 2019; Kokts-Porietis et al., 2019; Maxwell-Smith et al., 2018; Vallance et al., 2020; Valle et al., 2017). Some experimental designs have implemented WHTs as stand-alone interventions, while others have combined WHT use with virtual coaching, smart scales, or social media interventions. Data collection has varied from days to weeks at a time and some studies rely on user reporting of data, while some studies collect direct-source data from the health trackers. Individual studies have yielded promising results but the range of data types that have resulted from these differing variable measurements has made comparisons across study results difficult. Although there exist systematic literature reviews in this field, there lacks a meta-analysis that has categorized and compared the overarching conclusions of these results (Ha et al., 2021; Schaffer et al., 2019). A meta-analysis examining the effects of wrist-worn WHTs on each variables type would provide the empirical evidence needed to elucidate whether WHT interventions are efficacious.

The body of research related to physical health outcomes in cancer survivors and the use of WHT has become very large in the past decade and especially the last few years. This research is moving in many directions and forward progress first requires a review of the current evidence and an exploration of future directions. The literature reviews that do exist of WHT are dated and often report qualitative trends or focus on a single variable (Ha et al., 2021; Schaffer et al., 2019). A recent literature review of the effects of WHTs among breast, prostate, and colorectal cancer survivors identifies some of the most up-to-date trends in this field, including evidence of preliminary efficacy for WHT to promote physical activity among this population. However, this review also identified several limitations to modern research, including small sample sizes, variation in study design, and points out the need for further research to evaluate whether WHT effectively promotes healthier lifestyle among cancer survivors (Coughlin et al., 2020). Beyond the aforementioned limitations, the conclusions of a literature review are also limited to qualitative findings and the identification of data trends and lacks a more rigorous, quantitative assessment of these trends. Statistical analyses such as meta-analyses can attempt to control for inconsistencies between studies and provide direct comparison of their data despite differences in study design. A meta-analysis will provide an assessment of positive or negative effects that may exist between WHT and physical health outcomes in cancer survivors and further, will provide quantification to this effect size. This can more broadly assess the trends that have been qualitatively identified in WHT research and identify stronger empirical evidence surrounding the efficacy of WHT in improving cancer survivors' health (Ndjavera et al., 2020). Further, a meta-analysis may aid in providing quantitative guidelines for future research and potentially in preventative health treatments by medical professionals.

To accomplish this, a broad literature search was conducted to find all of the existing wrist-worn WHT studies in cancer survivors. PRIMA guidelines were followed to collect studies and organize the relevant study information and findings. The results from these studies will be extracted and the data from common variable types, like step count or sit time, will be grouped for comparison (Ha et al., 2021; Kelley-Quon, 2018). The data were also converted into a common format to allow for direct data comparison within the group, for example all step counts will be converted to steps per hour.

Figure 1

Flow diagram of literature selection process for meta-analysis.



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

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The Cochrane handbook will be used as a guide to perform data analysis (Altman et al., 2020), which will be used to provide further insight into the significance of recent findings (Su, McDonough, Chu, Quan, & Gao, 2020). This method of analysis hopes to provide a comparison of similar results, though the variables measured may differ (Hartman et al., 2018). This will ultimately provide an overview of the current knowledge of WHT in cancer populations and will guide future research in establishing effective intervention methods in both cancer survivors and other clinical populations.

This paper hopes to achieve three key advancements for the field of cancer survivor WHT research. Firstly, the paper aims to provide a succinct overview of the field of WHT both broadly and as it relates to cancer survivors. Secondly, to provide a comprehensive review and discussion of the common goals, methods, and findings within the field to identify new gaps in knowledge to be explored and routes of progress for future exploration. Lastly, the paper hopes to provide a quantitative comparison of the physical health outcome measurements from recent literature and assess the across-study results for statistical significance.

Methods

Literature Search

PRISMA-P guidelines were used to conduct a literature search. Studies considered for inclusion were found electronically using the University of Minnesota library access to the following databases: NCBI, PubMed, Embase, Web of Science, Medline, Academic Search Complete, and Elsevier. These databases were searched using MESH search terms relevant to the target studies including: cancer survivor, heath wearable technology, health wearables, accelerometer, physical activity tracker, wrist-worn, wearable activity tracker, physical activity sensing device, fitness tracker, sport tracker, smart watch. Abstracts were briefed and relevant studies were downloaded in full-access form. These methods yielded 64 studies to be assessed for inclusion. The flowchart to filter articles systematically is shown in Figure 1.

Inclusion Criteria

After an initial literature search was conducted, as above, all papers were assessed and only papers meeting the following inclusion criteria were included in the meta-analysis: (1) published in English language before April of 2021, (2) randomized-controlled trial, (3) utilized wrist-worn WHT as primary intervention, (4) conducted study within adult population of cancer survivors who had cancer treatments prior to participate in the studies, (5) aimed to utilize WHT as intervention for quantifiable physical health outcome (i.e. step-count, heart rate, etc.). These criteria were required to ensure comparisons between the results of each study were meaningful. Of the 64 studies assessed, 12 were found to meet inclusion criteria.

Data Extraction and Sorting

The papers included in this meta-analysis were first read in full and pertinent qualitative information was extracted from each study, including duration of intervention, technology used, physical outcomes measured, sample demographic information, cancer type, and general study design. This information was sorted into an information matrix and considered as factors of variance between studies, a potential source of error. Quantitative information was extracted from each study, chiefly the mean baseline and endpoint measurements of each physical outcome with level of variance (standard deviation, standard error, or confidence interval). For each outcome measured, all study results were converted into a common unit. For weight, kilograms were used; for step count, steps per day were used; for MVPA and sedentary time, minutes per day were used. All levels of variance were converted into standard deviations.

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Table 1

Assessment of potential bias risk in individual studies.

Article	1	2	3	4	5	6	7	8	9	Total
(Cadmus-Bertram et al., 2015)	+	+	-	+	+	+	-	-	-	5
(Chan et al., 2020)	+	+	-	+	+	+	+	-	+	7 ^
(Devine et al., 2020)	+	+	-	+	+	-	+	+	+	7 ^
(Ferrante et al., 2020)	+	+	-	+	+	+	+	+	+	8 ^
(Kenfield et al., 2019)	+	+	-	+	+	+	+	+	-	7 ^
(Lynch et al., 2019)	+	+	-	+	+	+	+	-	-	5
(Maxwell-Smith et al., 2018)	+	+	-	+	+	+	+	-	-	6 ^
(McNeil et al., 2019)	+	+	-	+	+	+	+	+	+	8 ^
(Pope et al., 2018)	+	+	-	+	+	-	-	-	-	4
(Singh et al., 2020)	+	+	-	+	+	+	-	+	-	6 ^
(Valle et al., 2017)	+	+	-	+	+	+	+	-	+	7 ^
(Van Blarigan et al., 2019)	+	+	-	+	+	-	+	-	-	5

Note. Item numbers indicate the following quality: 1 = randomization of subjects, 2 = presence of a control arm, 3 = health wearable tracker technology was used as isolated intervention method, 4 = outcome variables were measured before and after intervention, 5 = baseline measurement was taken of key outcome variables, 6 = study retention was described and at least 70%, 7 = intervention adherence was described and at least 70%, 8 = power analysis was conducted to determine appropriate sample size , 9 = participants were followed up with for a minimum of 3 months post-intervention. Scores indicate: “+” = presence of attribute, “-” = absence of attribute. A “^” denotes a paper at or above the median score of 6 for bias-prevention methods.

Data Items

Physical outcome measures identified within the 64 articles considered included measurements of step count, moderate to vigorous physical activity, sedentary behavior, metabolic exertion, weight change, body mass index, skeletal muscle mass, VO_2 maximum, and heart rate. Step count, sedentary behavior, MVPA, and weight were identified as the four most commonly measured outcomes variables and were selected for focus in this meta-analysis.

Meta-Analysis

The four most commonly reported health outcomes, including weight, step count, moderate-to-vigorous physical activity and sedentary time, were chosen for evaluation by meta-analysis. Differences between group means of the baseline versus endpoint data were selected as the summary statistic, as all data sets were continuous. It was assumed that each study within an outcome category estimated the same intervention effect, namely an improvement in the outcome value, thus a fixed-effect meta-analysis was performed (Altman et al., 2020). The Hedge's g statistic was calculated using mean differences and pooled standard deviations calculated in Excel per the Hedge's and Colleagues methodology (Heckert, 2018). From this, an effect size and direction were calculated along with confidence intervals, variance, weight, and overall summary effect size. The direction of the effect, positive or negative, was used to determine if intervention effects significantly increased or decreased outcome measurements. A forest plot was generated to visually estimate the effect size and direction, as well as a 95% confidence interval for each outcome using Excel software (Quintana, 2015).

Results

Study Selection

Of the 64 studies discovered in the initial screening for this meta-analysis, 12 were chosen for inclusion based upon strict inclusion criteria. As in Figure 1, the assessment of study inclusion found that 47 studies did not meet one or more aspects of the defined inclusion criteria, eliminating them from consideration. Of the remaining 17 studies, five were eliminated from inclusion based upon inability to obtain applicable quantitative data and thus were unable to be considered.

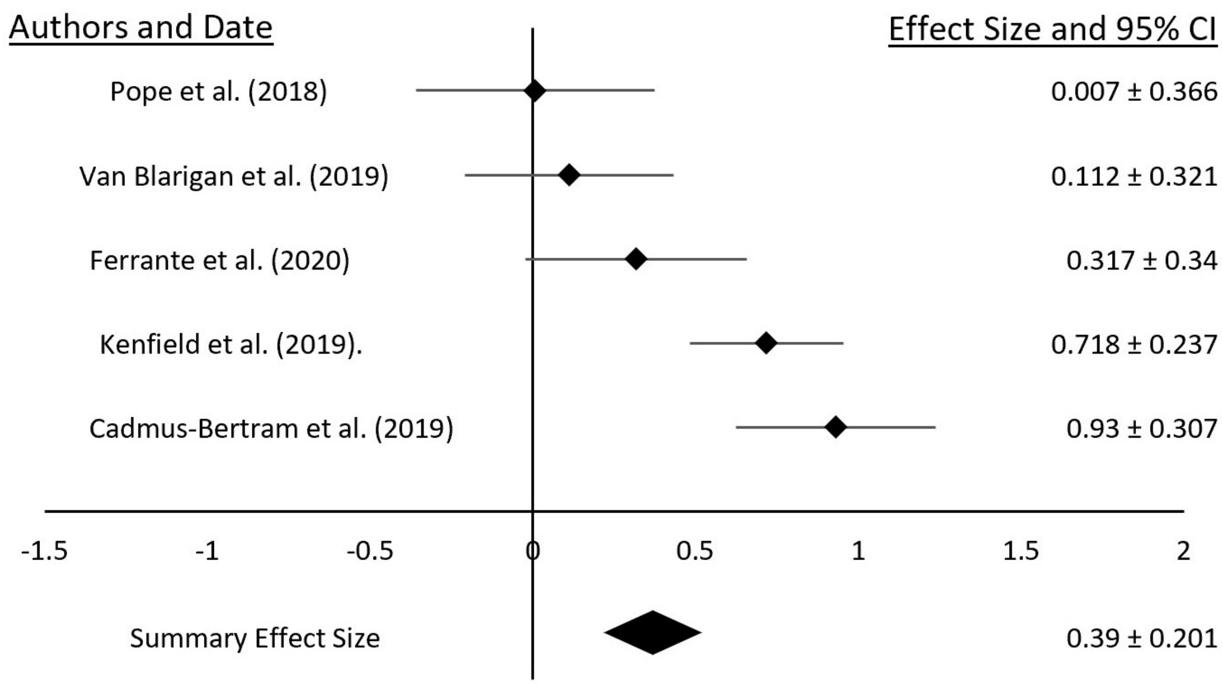
Risk of Bias Assessment

A risk of bias assessment within and between studies was performed, as in Table 1, based upon nine criteria of common practice in randomized-controlled trials, as adapted from previous studies (Pope et al., 2017; Zeng et al., 2017). With this, eight of the twelve included studies were found to have strong risk of bias controls within their studies (Chan et al., 2020; Devine et al., 2020; Ferrante et al., 2020; Kenfield et al., 2019; Maxwell-Smith et al., 2018; McNeil et al., 2019; Singh et al., 2020; Valle et al., 2017). Four of the twelve included studies had weaker bias control, missing four or more of the preferred bias-control techniques within the study design (Van Blarigan et al., 2019; Cadmus-Bertram et al., 2015; Lynch et al., 2019; Pope et al., 2018).

Step Count Result

Step count was chosen as a common physical outcome measurement to evaluate cancer survivors' health improvements with wearable health technologies, as demonstrated in Figure 2. Step count was measured in five studies and most commonly was measured as the number of steps per day (Van Blarigan et al., 2019; Cadmus-Bertram et al., 2015; Ferrante et al., 2020; Kenfield et al., 2019; Pope et al., 2018). All five studies reported changes in standard mean difference as a direct step count measurement from the baseline. All five studies demonstrated an increase in daily step count in the experimental arm. Two control groups also exhibited increased in daily step count (Van Blarigan et al., 2019; Pope et al., 2018). As seen in Figure 2, three studies demonstrated a small positive effect size of less than 0.35 (Van Blarigan et al., 2019; Ferrante et al., 2020; Pope et al., 2018), while one study (Kenfield et al., 2019) had a medium positive effect size between 0.5 and 0.8 and one study (Cadmus-Bertram et al., 2015) had a large effect size greater than 0.8. This resulted in a summary effect size for all step count studies of 0.39, which is a weak, positive overall effect.

Figure 2
Average increase (+) or decrease (-) in mean step count of experimental arm as compared to control arm over course of intervention.



Note. Step count measured in steps per day. Effect sizes reported are Hedge's g statistics with 95% confidence intervals, shown by smaller rhombi on forest plot with confidence interval whiskers. Summary statistic is overall effect size shown by large rhombus beneath graph.

Moderate to Vigorous Physical Activity Results

Of the four physical health outcomes considered, moderate to vigorous physical activity time was the most popularly reported results as demonstrated in Figure 3. Only two of the twelve studies included did not report MVPA (Ferrante et al., 2020; Schwartz et al., 2017). This variable was most commonly reported as minutes per week, though minutes per day was also popular. Nine of the studies measuring MVPA reported increases in MVPA time in their exercise arms (Van Blarigan et al., 2019; Cadmus-Bertram et al., 2015; Chan et al., 2020; Kenfield et al., 2019; Lynch et al., 2019; Maxwell-Smith et al., 2018; McNeil et al., 2019; Pope et al., 2018). Two of the studies measuring MVPA reported decreases in MVPA time in the exercise arm (Devine et al., 2020; Singh et al., 2020) and in three studies, the control group experienced more positive changes on MVPA than the experimental group (Chan et al., 2020; Devine et al., 2020; Pope et al., 2018), thus these three studies exhibited negative effect values, as seen in Figure 3. Of note, McNeil et al. reported multiple experimental arms, therefore two groups are included: the group labeled "low" with moderate baseline MVPA measurement and the group labeled "high" with a baseline MVPA greater than 150 minutes per week. Chan et al. also reported two experimental groups, both of which are included on Figure 3. Of the remaining eight studies reporting MVPA, one study (McNeil et al., 2019) demonstrated a moderate positive effect size between 0.5 and 0.8 when measured from the lower baseline group. The other seven studies yielded strong positive effect sizes greater than 0.8. The summary effect size for all MVPA studies was 0.77, indicating an overall moderate, positive effect size.

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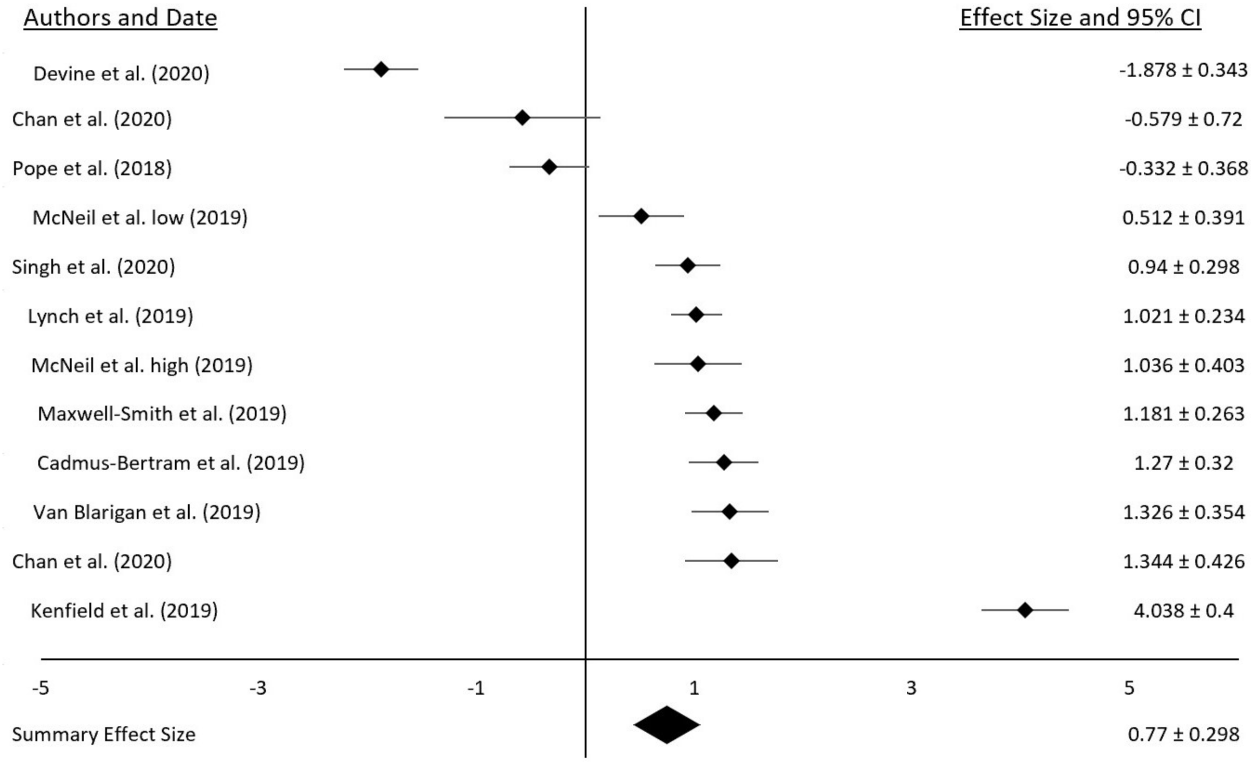
Figure 3

Average increase (+) or decrease (-) in mean MVPA of experimental arm as compared to control arm over course of intervention.

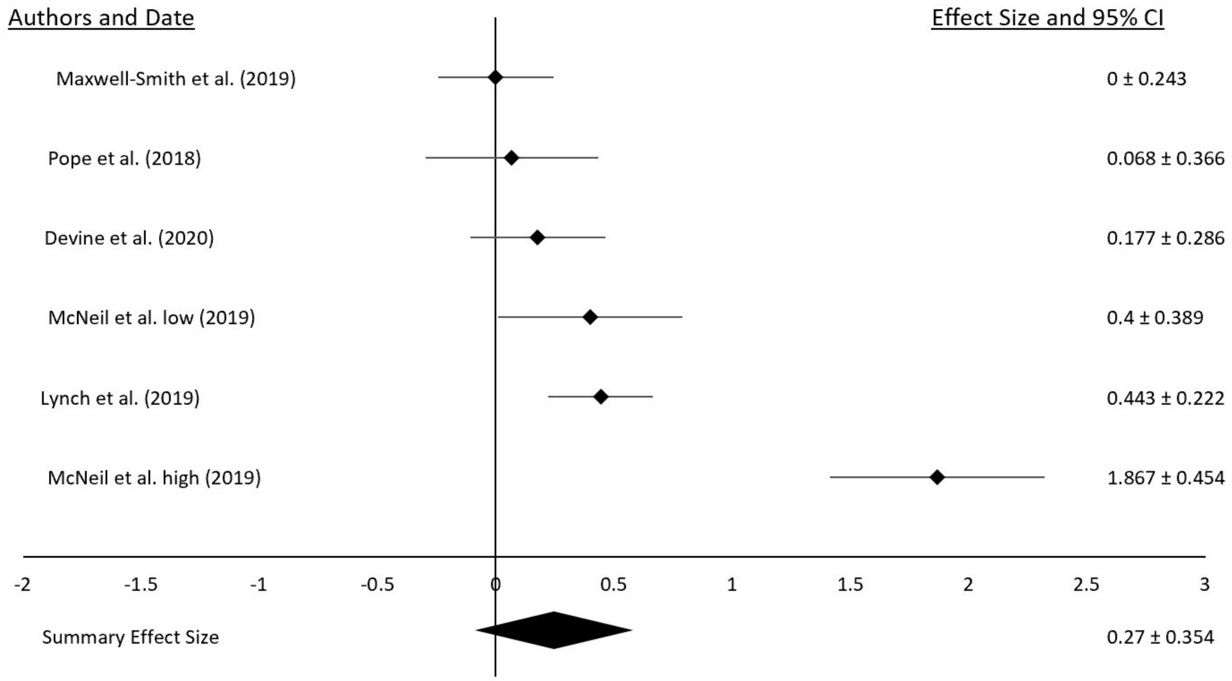


Note. MVPA measured in minutes per week. Effect sizes reported are Hedge's g statistics with 95% confidence intervals, shown by smaller rhombi on forest plot with confidence interval whiskers. Summary statistic is overall effect size shown by large rhombus beneath graph.

Sedentary Behavior Results

Figure 4 shows changes in cancer survivors' sedentary behavior secondary to WHT interventions. Only five studies measured sedentary behavior changes (Devine et al., 2020; Lynch et al., 2019; Maxwell-Smith et al., 2018; McNeil et al., 2019; Pope et al., 2018). Again, McNeil et al. reported multiple experimental groups thus a "low" and "high" group are both included in this forest plot. Only one study reported an increase in sedentary behavior (McNeil et al., 2019) and these results were not statistically significant. Four of the reported measures had weak positive effect sizes below 0.4, including the "low" McNeil group (Devine et al., 2020; Maxwell-Smith et al., 2018; McNeil et al., 2019; Pope et al., 2018). One study exhibited a moderate positive effect (Lynch et al., 2019) and the McNeil et al. "high" baseline measurement group exhibited a strong positive effect size. The overall summary effect size is positive but weak. It is notable that the 95% confidence interval does extend slightly into the negative effect measurement.

Figure 4
Average increase (+) or decrease (-) in mean sedentary time of experimental arm as compared to control arm over course of intervention.



Note. Sedentary activity measured in minutes per day. Effect sizes reported are Hedge's g statistics with 95% confidence intervals, shown by smaller rhombi on forest plot with confidence interval whiskers. Summary statistic is overall effect size shown by large rhombus beneath graph.

Weight Results

Weight was the least common of the included outcome measures as shown in Figure 5, with three studies reporting weight as a primary or secondary finding (Ferrante et al., 2020; Pope et al., 2018; Valle et al., 2017). Valle et al. was the only study to report a negative effect size, corresponding to weight loss in the experimental group, and this effect was weak at less than 0.4. Ferrante et al. and Pope et al. both reported weak positive effects, corresponding to weight gain in these experimental groups. The overall summary effect was weak and negative at -0.18 and it is notable that the confidence interval for this summary effect does extend into the positive effect range.

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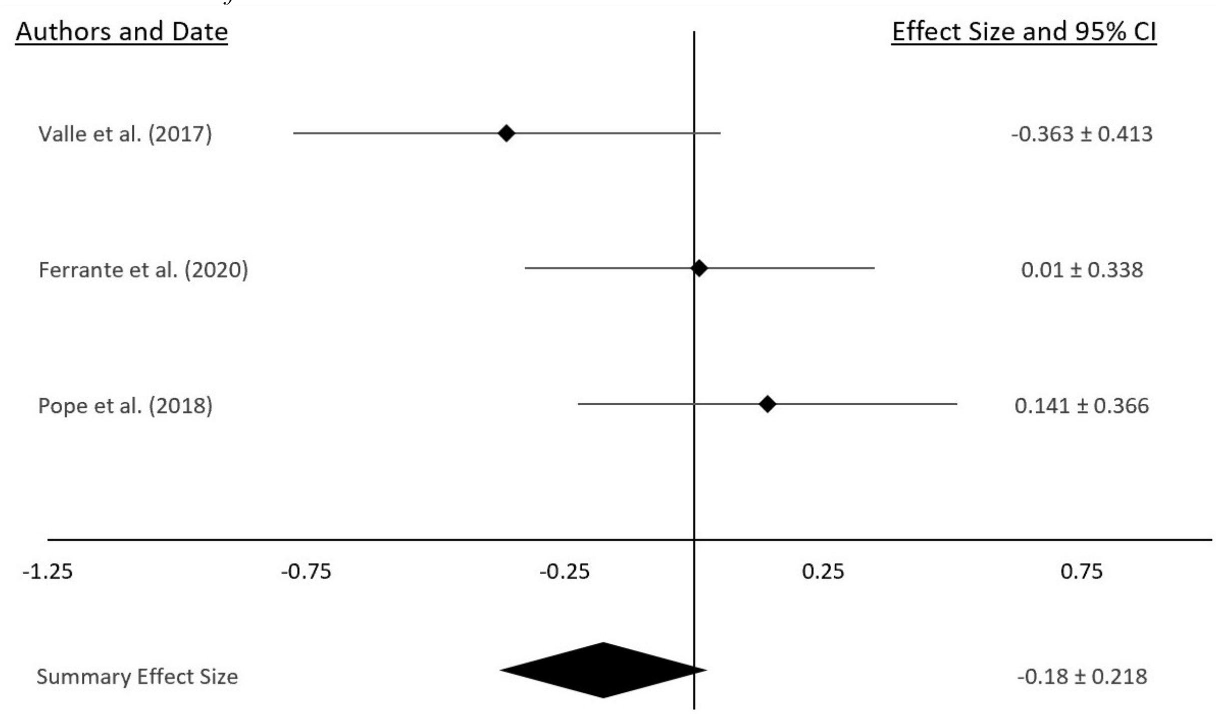
Figure 5

Average increase (+) or decrease (-) in mean weight of experimental arm as compared to control arm over course of intervention.



Note. Weight measured in kilograms. Effect sizes reported are Hedge's g statistics with 95% confidence intervals, shown by smaller rhombi on forest plot with confidence interval whiskers. Summary statistic is overall effect size shown by large rhombus beneath graph.

Discussion

Study Characteristics

This meta-analysis was performed with the primary goal of determining the efficacy of wearable health technology as an intervention to improve physical health outcomes in cancer survivors. The most commonly measured outcome variables, and those included in this comparison, were step count, weight, sedentary behavior, and moderate to vigorous physical activity. While it was found that there are roughly 64 studies within this field of research, only 12 studies met inclusion criteria for this meta-analysis. A great majority of studies originally considered for this review were eliminated due to the lack of a randomized-controlled trial (RCT) design. This provides a very clear area of need for improvement in this field of research, as RCT design is considered an important standard in interventional experimental research and is imperative to reducing risk of bias within studies. A handful of studies were also excluded for reasons related to their data reporting that prevented the ability to perform the necessary calculations. Further, all but three of the included studies (Kenfield et al., 2019; Lynch et al., 2019; Maxwell-Smith et al., 2018) had sample sizes which has less than 50 participants. While this was not considered an inclusion criterion, this should also be considered in future studies. Having an adequate sample size is also pertinent to reducing risk of bias and for altogether strengthening the conclusions that can be drawn from the resultant data.

Outcome Findings

All of the five studies evaluating step count did demonstrate improvement in daily step count with WHT ranging from some weak effect sizes to strong effect sizes. The summary effect size is ultimately positive, suggesting WHT may be efficacious in increasing step count in cancer survivors. However, the magnitude of the effect size at less than 0.40 suggests a weak relationship between the two variables. Three studies did report confidence intervals that extended into the negative effect region (Van Blarigan et al., 2019; Ferrante et al., 2020; Pope et al., 2018). This raises some question regarding the reliability of the summary statistic and this meta-analysis would benefit from having a greater number of studies to compare. Additionally, there is question of how useful step count actually is in measuring changes in physical health behaviors.

The most commonly measured physical health outcome was MVPA, with 10 of 12 studies reporting this as an outcome measurement. The vast majority of studies reported positive effect sizes, supporting the idea that WHT may effectively help to increase MVPA. Notably, only two of 12 groups reported confidence intervals that crossed the midline and both of these studies demonstrated negative effect sizes (Chan et al., 2020; Pope et al., 2018). The reliability of these two effects is decreased with respect to their inconclusive confidence intervals. Further, it should be noted that these two studies, as well as a few others, had shockingly low sample sizes. For example, the two experimental groups reported from Chan et al. included only 14 and three participants, respectively. Pope et al. had a total of 30 participants, as did McNeil et al. This also complicated the reliability of the summary statistics and will be further discussed in regards to the risk of bias assessment.

While sedentary behavior was much less frequently measured, with only five of 12 studies reporting this outcome, all of these studies did reflex positive effect sizes and an overall positive summary statistic. Four of the reported group effects were weakly positive (Devine et al., 2020; Maxwell-Smith et al., 2018; McNeil et al., 2019; Pope et al., 2018) with three of them also have broad confidence intervals that extended into the negative effect region. There was only one moderately strong positive effect size measured (Lynch et al., 2019) and one very strong positive effect size from the second McNeil et al. group. The overall summary statistic is weakly positive and also has a broad confidence interval that cannot rule out the possibility of an overall negative effect. This may seem to suggest that sedentary time actually increased related to WHT, the opposite of the desired effect. However, many of these five studies having small sample sizes and inconclusive confidence intervals, thus the validity of the positive summary effect is unreliable and the results of this meta-analysis are more likely inconclusive. Future research should consider evaluating this measure to increase the sample size and number of studies included in determining intervention efficacy and to further validate that WHT are feasible for sedentary behavior reduction. Future studies should also consider the importance of measuring and reporting sedentary behavior in the cancer survivor population, as both cancer and sedentary time are both highly concerning risk factors for stroke or transient ischemic attack which can both result in brain injury or death. Further, these risk factors have shown to have a compounding effect in raising risk (American Stroke Association, 2018). Because cancer survivors are already a risk with a history of cancer and are unable to eliminate this risk factor, improving sedentary time could be a very important change to reduce risk of future health complications.

The fourth outcome considered in this meta-analysis was weight. Only three studies (Ferrante et al., 2020; Pope et al., 2018; Valle et al., 2017) reported weight as a measured physical health outcome. Further, each of the individual effect sizes and the summary effect all have broad confidence intervals that cannot definitively rule out the opposite effect. The magnitude of all of

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the effect sizes and the summary effect size are considered weak and this, combined with the small number of studies available, make the reliability of this summary statistic very poor. In addition, there is debate about the usefulness in measuring weight changes surrounding WHT interventions. While overweight and obesity are concerning comorbidities and risk factors for dangerous health conditions (American Stroke Association, 2018; Coughlin et al., 2020; Fawcett et al., 2020), a change in this outcome variable is often complex. Further complicating weight modification is that the effects of initial cancer treatment and recovery very often do cause patients to undergo some amount of weight gain and this weight is often retained after the conclusion of treatment. One study (Valle et al., 2017) reported a very slight increase in weight throughout the intervention while another (Ferrante et al., 2020) with non-significant findings reported a weight reduction with a confidence interval larger than the mean difference. Overall, the small number of studies that reported this outcome measure makes it difficult to draw any conclusions about effect size. The field of WHT research would likely benefit from a greater number of studies measuring weight changes in participants throughout intervention duration, however, it should be considered that this is a complex physical outcome measure to modify and changes in weight can stem from many lifestyle factors outside of WHT interventions.

Eight of the 12 studies included were found to score well on the risk of bias assessment tool, indicating that many of the studies had measures in place to reduce error. This does generally help to strengthen the findings within this thesis. Four studies scored relatively low on the bias assessment, suggesting that the findings from these studies are less reliable (Van Blarigan et al., 2019; Cadmus-Bertram et al., 2015; Lynch et al., 2019; Pope et al., 2018). This is especially impactful for the consideration of step count, sedentary activity, and weight, as anywhere from 33% to 60% of the data used to evaluate these categories is sourced from these likely biased papers.

The greatest limitations of WHT research include the small participant sample sizes in individual studies and the scarce number of papers that meet basic RCT criteria for comparison. Several of the original 64 studies assessed for inclusion were unable to achieve a RCT design due to the small sample sizes of individuals recruited. Further, a handful of studies were not included as their data-reporting methods differed greatly from what is most standard in WHT research. With fewer than 20% of papers found in a literature search meeting important criterion for effective WHT research, this meta-analysis is limited in its significance and implications. Randomization and control arms are necessary in reducing risk of bias and should be considered a standard in WHT research. Further, only five papers in this review conducted a power analysis to determine effective sample size. Because many of the included studies are limited by their sample sizes, this should be of greater priority in future research.

Altogether, the studies presented in this meta-analysis most strongly suggest that WHT can result in an overall increase in daily step count and weekly MVPA; however, these findings should be further assessed with a greater number of studies reporting this outcome. As for weight loss and sedentary activity reduction, some studies demonstrate promising changes in these measures but there are not enough significant findings to confirm a direct correlation between WHT and improvement in outcome measures. In fact, this review may suggest WHT correlates with an increase in sedentary activity. With the results of this paper suggesting WHT may improve step count and MVPA, the next important step is to determine the clinical significance of these findings. As aforementioned, the crucial link between physical health outcomes and the health and well-being of cancer survivors is apparent (Beg et al., 2017; Coughlin et al., 2020). These physical health outcomes contribute to the overall risk of cancer recurrence, comorbidity, and mortality. Therefore, it would beneficial to evaluate whether the improvements in steps and MVPA observed in this data translate to improved secondary health outcomes and a clinical reduction in cancer recurrence, comorbidities, and mortality. If WHTs can be demonstrated to have clinically significant improvements in health and risk reduction, this technology may serve as an effective health intervention in preventative medicine.

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