



# Reallocating time to physical activity and sleep: associations with quality of life in cancer survivors

Mary C. Hidde<sup>1</sup> · Kate Lyden<sup>2</sup> · Kim Henry<sup>3</sup> · Heather J. Leach<sup>4</sup>

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## Abstract

**Purpose** Quality of life (QOL) is an important psychosocial outcome in cancer survivors (CS). Physical activity (PA), reducing sedentary time (ST), and sleep can help CS improve QOL; however, these behaviors are commonly studied in isolation, despite their interdependence during the 24-h day (i.e., time in one activity cannot increase without time decreasing in another activity). This study examined the effects of reallocating time between moderate to vigorous PA (MVPA), light PA, ST, and sleep on QOL in a mixed sample of CS.

**Methods** A cross-sectional sample of CS ( $N=73$ ) diagnosed with breast (29.7%), colorectal (33.8%), or other (36.5%) cancer. MVPA, light PA, and ST were measured using the activPAL™ accelerometer, and sleep duration using the Actiwatch™ accelerometer. Both were worn for 7 days, 24 h per day. QOL was self-reported using the Functional Assessment of Cancer Therapy-General (FACT-G) questionnaire. Isotemporal substitution models were used to reallocate 30 min between activities. Statistical significance was set at  $p < .05$ .

**Results** Participants accumulated,  $M=24.0 \pm 18.9$  min/day of MVPA,  $291.7 \pm 100.4$  min/day of light PA,  $593.1 \pm 108.3$  min/day of ST, and  $486.6 \pm 57.6$  min/night of sleep. Isotemporal substitution effects for reallocating time between MVPA, light PA, ST, and sleep were not significantly associated with QOL.

**Conclusions** Findings from this study suggest that among CS who are achieving adequate levels of PA and sleep, changes in 30 min of these activities may not impact QOL. Future studies should aim to recruit a larger, more representative sample and explore the role of bouted activity time.

**Keywords** Isotemporal substitution · Sedentary behavior · Sleep · Cancer survivorship · Physical activity · Quality of life

## Introduction

It is estimated that in 2021, nearly 1.9 million new cases of cancer will be diagnosed, resulting in an estimated 608,570 cancer-related deaths [1]. Fortunately, with advances in both earlier detection and cancer treatment(s), the 5-year survival rate for most cancers has increased from 34% in

the mid-1970s to 67% in 2016 [1, 2]. Although treatment efficacy has improved, cancer survivors are often plagued with lingering side effects from systemic therapy, radiation therapy, and surgery. Side effects include depression, anxiety, fatigue, and diminished physical function, which can result in poor QOL [3]. QOL includes physical, functional, emotional, and social well-being and has become a pertinent clinical measure in oncology care due to its known association with morbidity and mortality [4, 5]. Thus, with an increasing number of cancer survivors battling with post-treatment side effects, it is imperative to direct resources to survivorship care strategies that can help cancer survivors improve QOL.

One of the most salient interventions to improve QOL among cancer survivors are those which target lifestyle behaviors, including increasing physical activity (PA), decreasing sedentary time, and getting adequate sleep. Findings from numerous systematic reviews and meta-analyses support the

✉ Mary C. Hidde  
mchidde@mcw.edu

<sup>1</sup> Department of Medicine, Medical College of Wisconsin, Milwaukee, WI, USA

<sup>2</sup> KAL Research and Consulting, LLC, Denver, CO, USA

<sup>3</sup> Department of Psychology, Colorado State University, Fort Collins, CO, USA

<sup>4</sup> Department of Health and Exercise Science, Colorado State University, Fort Collins, CO, USA

important roles increased PA and decreased sedentary time play in improving QOL in cancer survivors. These reviews conclude that QOL improved in cancer survivors who completed PA interventions, as compared to usual care controls, and baseline measurements [3, 6, 7]. In addition to PA and sedentary time, insufficient sleep, a common consequence of cancer treatment, is known to negatively impact QOL in cancer survivors [8, 9].

Current literature examining the effects of PA, sedentary time, and sleep on health outcomes in cancer survivors largely examines these behaviors in isolation (e.g., effect sleep on QOL, *or* effect PA on QOL), disregarding the supposition that increasing time in one activity requires decreasing time in another [10]. For this reason, many scholars have suggested that PA, sedentary time, and sleep should be studied in the context of the 24-h day [10]. By studying these behaviors together, further insights can be delineated regarding the implications of how time is spent on QOL. For example, sleep and MVPA are both considered beneficial behaviors for improving QOL; however, it is unknown if cancer survivors should wake up earlier and/or go to bed later to ensure adequate time spent in MVPA.

Despite growing interest and knowledge regarding 24-h activity patterns, only two studies have examined how reallocating time spent in lifestyle behaviors affects QOL in cancer survivors, with inconsistent findings [11, 12]. One study in colorectal survivors found that substituting sedentary behavior with standing or PA was beneficial for the physical function aspect of HRQoL (van Roekel 2016). The other study, in non-Hodgkin lymphoma survivors, found no effect of reallocating 30 min per day to MVPA on QOL (Vallance 2017) [11, 12]. Furthermore, both studies were conducted in homogenous samples (i.e., single cancer type), and Vallance et al. (2017) utilized a subjective measure of sleep (i.e., self-reported sleep duration); a measure that is known to have only a moderate correlation to objectively measured sleep and systematic bias [11, 13]. In the van Roekel (2016) study, no measures of sleep were utilized, limiting interpretation of time reallocation in the context of the full 24-h day [12].

Therefore, the aims of this study were to build on these previous studies by evaluating the effects of reallocating MVPA, light PA, sedentary time, and sleep on QOL in a mixed sample of cancer survivors using objective measures of all activities in the 24-h day. Based on previous evidence that has demonstrated positive associations between MVPA and QOL [14], we hypothesize that reallocating 30 min/day from light PA, sedentary time, or sleep to MVPA will be associated with higher QOL scores [11, 12].

## Methods

A cross-sectional analysis consisting of a single study visit conducted either in-person or virtually (due to COVID-19 safety protocols). The in-person study visit included informed

consent, demographic and QOL questionnaire completion via Research Electronic Data Capture (REDCap), and fitting of accelerometers [15, 16]. Participants were fitted with the activPAL and Actiwatch-2 accelerometers by research staff. Virtual study visits consisted of a phone call to complete electronic consent followed by demographic and QOL questionnaire completion, both done through REDCap. The accelerometers were delivered and picked up by study staff to the participant's home or shipped with an envelope and label for the participant to return after completing the 7-day wear protocol. Participants were provided written instructions and recorded video for placing the devices, and if necessary (per request of the participant), a virtual visit via Zoom was conducted to properly place the devices.

## Participants

Participants were recruited from 01/20 to 06/21 through local and regional cancer centers, flyers and presentations at community locations and events (e.g., senior center, American Cancer Society Relay for Life), and email and website posting via the University faculty and staff listserv, and the Colorado State University Center for Healthy Aging. Participants were eligible if they were > 18 years at time of their cancer diagnosis and within 60 months of treatment completion (i.e., surgery, chemotherapy, immunotherapy, and/or radiation therapy). All procedures performed were in accordance with the ethical standards of Colorado State University's institutional review board (IRB#19-8914H) and adhere to the tenets of the Declaration of Helsinki.

## Sleep

Sleep duration was measured using an Actiwatch-2, a validated device that utilizes light exposure and accelerations to determine sleep–wake intervals [17, 18]. Sleep duration was defined as minutes spent asleep (minutes between onset of sleep ( $TIB_{start}$ ) and offset of sleep ( $TIB_{end}$ )).  $TIB_{start}$  was determined by 10 consecutive minutes with no activity counts, utilizing the event marker pressed by participants as a guide.  $TIB_{end}$  was determined after 10 consecutive minutes of zero activity counts was disrupted, utilizing the event marker pressed by participants as a guide. Participants wore the device for 7 days, 24 h per day. To be included in analyses, participants must have had a minimum of 4 valid days, including 1 weekend day.

## Physical activity and sedentary time

PA and sedentary time were measured using the activPAL accelerometer (PAL Technologies, Glasgow, Scotland). The

activPAL has been validated to quantify free-living sedentary and ambulatory activities and has been previously used in cancer survivors [19]. The activPAL software quantifies light PA, MVPA, sitting, and lying time based on static and dynamic accelerations [20, 21]. Participants wore the activPAL for 7 consecutive days, 24 h per day. To be included in analyses, participants had to have had a minimum of 4 valid days, including 1 weekend day. Light PA was measured by subtracting “non-wear time” and “primary lying time” from 24 h to create a “waking wear time” variable. This variable was then used to calculate light PA by subtracting MVPA and sedentary time from waking wear time. MVPA was measured using “stepping time, in minutes, with a cadence  $\geq 75$  and duration  $> 1$  min” and “cycling time.” Sedentary time was measured by the time in minutes that participants were sitting or lying down (excluding sleep). All time measurements are in minutes per day.

### Quality of life

QOL was assessed using the Functional Assessment of Cancer Therapy-General (FACT-G). The FACT-G is a validated, self-report measure of QOL [22]. This questionnaire consists of 27 items, including subscales to differentiate changes in physical, social, emotional, and functional well-being. The FACT-G scores range from 0 to 108, with a higher score representing a higher QOL for both total and individual subscales.

### Statistical analysis

Demographics and descriptives of PA, sedentary time, and sleep were summarized using mean  $\pm$  standard deviation or frequencies. To examine the effects of time reallocation between PA, sedentary time, and sleep on QOL, an isotemporal substitution model was used. Isotemporal substitution models were done in three parts: single effects, partition effects, and the isotemporal model. The single effects model estimated the association between BMI and each activity individually. The partition model included QOL as the outcome, and all of the activities of interest (MVPA, light PA, sedentary time, and sleep). The variance inflation factors for each of the exposure variables in the partition model for QOL were less than 4, suggesting absence of problematic multicollinearity (considered problematic at 5). The isotemporal substitution model represented the outcome when the same unit of time in one activity was substituted with another by including total time and all measured activities minus the activity of interest. From the isotemporal model, the regression coefficient was interpreted as the mean effect on the outcome when substitution time from the omitted activity to each of the included activities, holding total activity

constant [23]. All variables were converted to units of 30 min (e.g., 30 min = 1, 60 min = 2). Covariates included in the isotemporal model were age, cancer type, and time since diagnosis. Additionally, clinically meaningful difference, measured by a change in total QOL score of  $> 4$  points, was evaluated as this measure is often utilized by clinicians to guide clinical decision-making [24–27].

## Results

Participant characteristics are presented in Table 1. Briefly, participants were on average  $53 \pm 13$  years old, mostly female (75.7%), and the majority were diagnosed with either breast (29.7%) or colorectal cancer (33.8%). The average total QOL score was  $87.0 \pm 15.3$ . Table 2 outlines average time spent in MVPA, light PA, sedentary time, and sleep.

**Table 1** Demographics

<i>N</i> = 73	Mean $\pm$ standard deviation or frequency (%)
Age	53 $\pm$ 13.0
Sex (% female)	75.7
Race (% white)	93.2
Education (% $\geq$ undergraduate degree)	74.3
Income (% $\geq$ \$50,000/year)	74.3
Body Mass Index (kg/m <sup>2</sup> )	27.0 $\pm$ 5.7
QOL-Total	87.0 $\pm$ 15.3
QOL-Physical	24.6 $\pm$ 3.8
QOL-Functional	20.9 $\pm$ 5.6
QOL-Emotional	19.8 $\pm$ 3.3
QOL-Social	22.5 $\pm$ 5.4
Diagnosis	
Breast	29.7
Colorectal	33.8
Leukemia/lymphoma	9.7
Other	27.0
Stage	
0	5.4
1	25.7
2	31.1
3	20.3
4	9.5
Do not know	8.1
Time since diagnosis (months)	33.9 $\pm$ 26.4
Time since surgery (months) ( <i>n</i> = 66)	31.2 $\pm$ 28.3
Time since chemotherapy (months) ( <i>n</i> = 54)	24.8 $\pm$ 22.8
Time since radiation therapy (months) ( <i>n</i> = 38)	30.5 $\pm$ 17.4
Time since other therapies (months) ( <i>n</i> = 12)	16.3 $\pm$ 13.9

The partition models revealed sedentary time was significantly correlated with light PA (Pearson's  $r = -0.75$ ) and MVPA ( $r = -0.48$ ). All other correlations between the different activities were low (0.09–0.22) and not statistically significant. In the single effects model, there were no statistically significant associations with QOL. When removing sedentary time due to its correlation with light PA and MVPA, no statistically significant associations with QOL were present.

### Reallocating 30 min from sleep

Reallocating 30 min of sleep to light PA ( $-0.64$ , 95% CI  $[-2.69, 1.42]$ ), sedentary time ( $0.10$ , 95% CI  $[-1.93, 2.13]$ ), and MVPA ( $0.42$ , 95% CI  $[-1.94, 10.79]$ ) resulted in no statistically significant associations with QOL (Fig. 1). Additionally, no statistically or clinically significant allocations were observed for any of the QOL subscales (Fig. 2).

### Reallocating 30 min from sedentary time

Reallocating 30 min of sedentary time to sleep ( $-0.10$ , 95% CI  $[-2.13, 1.93]$ ), light PA ( $-0.74$ , 95% CI  $[-1.90, 0.43]$ ), and MVPA ( $4.32$ , 95% CI  $[-1.61, 10.25]$ ) resulted

in no statistically significant associations with QOL (Fig. 1); however, a clinically meaningful increase was observed for reallocating 30 min of sedentary time to MVPA. No statistically significant changes were observed for any of the QOL subscales (Fig. 2).

### Reallocating 30 min from light PA

Reallocating 30 min of light PA to sleep ( $0.64$ , 95% CI  $[-1.42, 2.69]$ ), sedentary time ( $0.74$ , 95% CI  $[-0.43, 1.90]$ ), and MVPA ( $5.06$ , 95% CI  $[-1.29, 11.40]$ ) resulted in no statistically significant associations with QOL (Fig. 1); however, a clinically meaningful increase was observed for reallocating 30 min of light PA to MVPA. Additionally, no statistically significant associations were observed for any of the QOL subscales (Fig. 2).

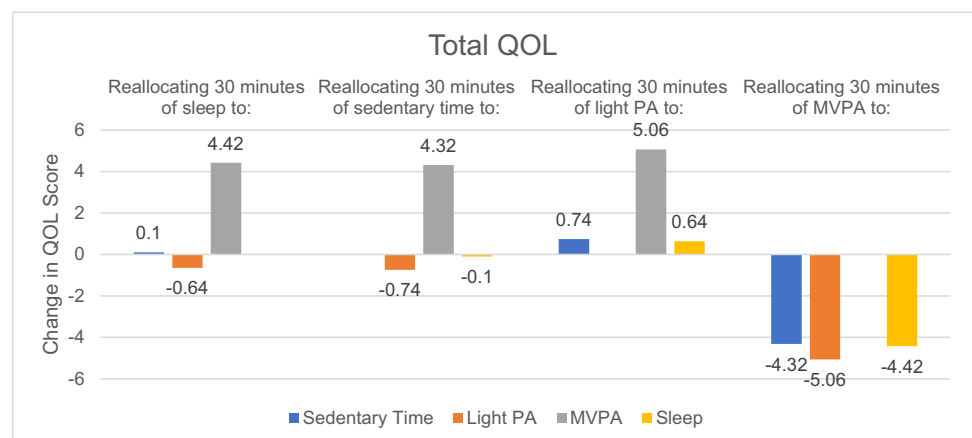
### Reallocating 30 min from MVPA

Reallocating 30 min of MVPA to sleep ( $-4.42$ , 95% CI  $[-10.79, 1.94]$ ), sedentary time ( $-4.32$ , 95% CI  $[-10.25, 1.61]$ ), and light PA ( $-5.06$ , 95% CI  $[-11.40, 1.29]$ ) resulted in no statistically significant associations with QOL (Fig. 1). A clinically meaningful decrease ( $> 4$  points) was observed for all activities when reallocating time from MVPA. No statistically significant associations were observed for any of the QOL subscales (Fig. 2).

**Table 2** Physical activity, sedentary time, and sleep profiles

	Mean $\pm$ standard deviation or %
MVPA (min/day)	24.0 $\pm$ 18.9
Light PA (min/day)	291.7 $\pm$ 100.4
Sedentary time (min/day)	593.1 $\pm$ 108.3
Sleep duration (min/day)	486.6 $\pm$ 57.6
> 30 min/day of MVPA	80.8%
> 7 h/night of sleep	90.4%

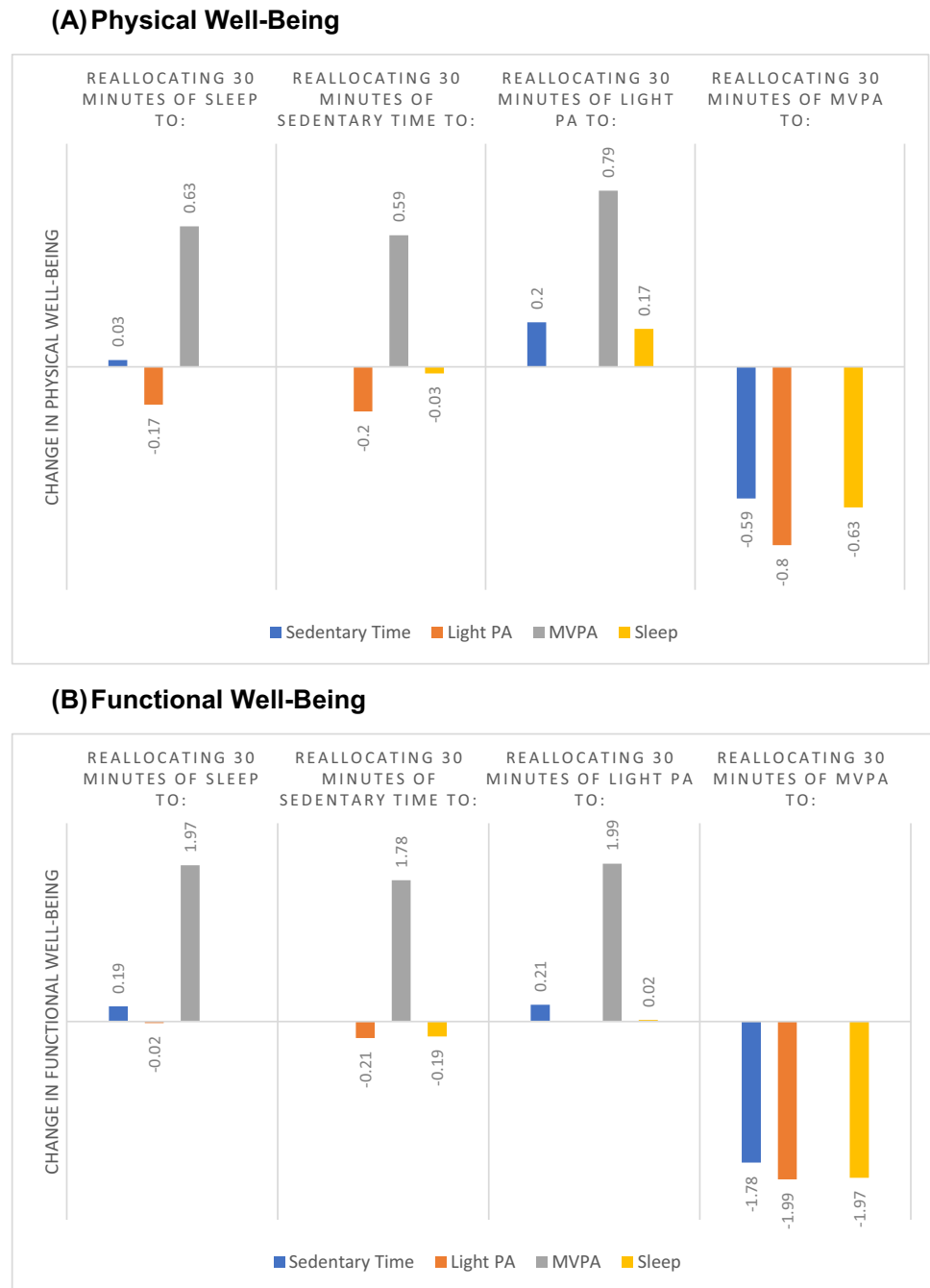
**Fig. 1** Time reallocation for QOL. Associations between sleep, sedentary time, light PA, and MVPA on QOL when reallocating 30 min of one activity of interest to another activity of interest in a mixed sample of cancer survivors. QOL, quality of life; PA, physical activity; MVPA, moderate-vigorous physical activity



## Discussion

The goal of this study was to examine the effects of reallocating time between daily activities (i.e., MVPA, light PA, sedentary time, sleep) on QOL in a between persons comparison of cancer survivors. Results revealed no statistically significant effect of reallocating time on QOL.

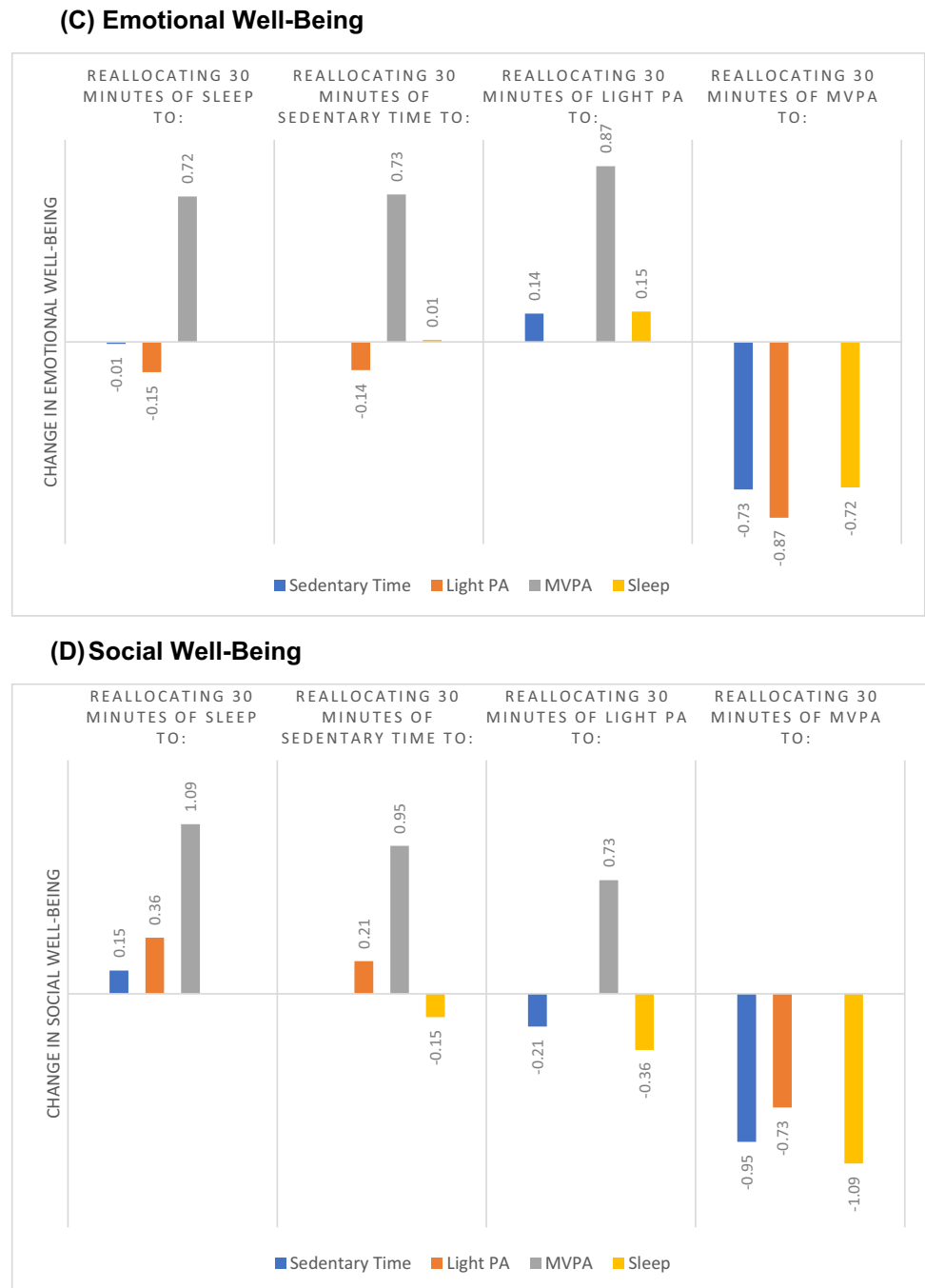
**Fig. 2** Time reallocations for QOL subscales. Associations between sleep, sedentary time, light PA, and MVPA on QOL subscales (**A** physical, **B** functional, **C** emotional, **D** social) when reallocating 30 min of one activity of interest to another activity of interest in a mixed sample of cancer survivors. QOL, quality of life; PA, physical activity; MVPA, moderate-vigorous physical activity



These findings are in alignment with Vallance et al. (2017) but in disagreement with results found by van Roekel et al. (2016) [11, 12]. Vallance et al. had a lack of robust, statistically significant effects of reallocating more time in the day to MVPA or sleep, similar to the current study while van Roekel et al. did result in statistically significant findings from time reallocation. The differences in results between these studies could be attributed to a few things: a ceiling effect, selection bias, and large standard errors. First, Vallance et al. and the current study, could potentially be attributed to a selection

bias, as most participants were meeting recommendations for MVPA ( $\geq 150$  min per week) and sleep (7–9 h/night); resulting in a ceiling effect [28, 29]. Supporting this notion of a ceiling effect is the study by van Roekel et al. (2016), which found, in contrast to the current study, statistically significant effects of reallocating sedentary time to PA on QOL in colorectal cancer survivors [12]. This study included cancer survivors who on average were less active ( $24.0 \pm 18.9$  min/day of MVPA and 10.2 h/day of sedentary time), potentially allowing for the observation of more robust effects on QOL [12].

Fig. 2 (continued)



Ceiling effects on QOL must also be considered as this sample, on average, had higher QOL than previous studies that have examined the effects of time reallocation on QOL [12]. However, QOL in this population still had some room to improve. Although the results in the current study were not statistically significant, reallocating 30 min from sedentary time or light PA to MVPA resulted in higher QOL scores that reached a clinically meaningful threshold (i.e., 4 points) [24], indicating that for cancer survivors already achieving recommended levels of PA and sleep, focusing

on reallocating time in sedentary time and light PA may be important. The lack of statistical significance in the presence of clinical significance may be due to large standard errors (i.e., measurement error, variability), and thus, a sample size that was not adequately powered to detect the relatively (i.e., clinically) large effects.

Strengths of the current study include the use of objective measures of sleep, sedentary time, and PA. To date, no reallocation studies in cancer survivors have utilized objective measures for all activities across the 24-h day, relying

on subjective measures of PA and sleep, which have demonstrated poor reliability and validity, potential for recall bias, and floor effects due to questionnaires failing to capture spontaneous or light activities of daily living (i.e., chores, caregiving) [30, 31]. This study allowed for evaluating activities simultaneously rather than independently, providing more context for the effects on QOL of increasing or decreasing time in specific activities throughout the 24-h day (i.e., in order to increase time in one activity, time in another was decreased).

Limitations of this study include a sample size that did not allow the inclusion of additional activity characteristics (i.e., bouts MVPA and sedentary time, standing time) in statistical models, or the ability to conduct subgroup analyses (e.g., by cancer type or those meeting vs. not meeting activity or sleep guidelines). The cancer survivors in this study were majority female, white, and high income, limiting generalizability. This study included predominantly active cancer survivors obtaining adequate durations of sleep with 80.8% meeting MVPA guidelines and 90.4% meeting sleep guidelines. This sample differs from typical cancer survivor populations found in the literature. However, this population is not immune to long lasting, treatment-related side effects. Despite a high percentage of these survivors meeting sleep duration guidelines, 71.2% of the population required utilization of a sleep aid over the past month and 38.5% reporting “fairly bad” or “very bad” sleep quality, as assessed by the Pittsburgh Sleep Quality Index [32]. Therefore, this sample allows for evaluation of alternative lifestyle behaviors (i.e., sedentary, light PA) ability to improve QOL for survivors meeting PA and/or sleep guidelines who may struggle with total or specific subscales of QOL. Finally, like many studies that employ isotemporal substitution models, a between-persons approach to examining reallocation was taken. This approach assumes that comparing one person to another is a reasonable way to estimate what might happen if time for an individual was actually reallocated from one activity to another.

In summary, this study revealed no effect of reallocating time from sleep, sedentary time, or light PA to MVPA on QOL. Future studies should continue utilizing objectively measured activity and sleep in isotemporal substitution to elucidate the interdependent nature of 24-h activity patterns on cancer survivors, including bouts PA and sedentary time in addition to total PA and sedentary time. Future studies should also evaluate additional measures of sleep health (i.e., sleep quality, latency, and efficiency) as these factors likely contribute to QOL. Furthermore, a within persons approach, collecting objective measures of activity and sleep as well as outcome of interest in individuals at multiple time points, would allow for a more personalized approach to exercise prescription. Results of a within-person model

could be utilized to develop an intervention to determine a causal effect of the pre-determined time reallocation.

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**Author contribution** All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Mary Hidde, Kate Lyden, Kim Henry, and Heather Leach. The first draft of the manuscript was written in full by Mary Hidde, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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**Availability of data, materials, and code (R code)** Raw data and r script were generated at Colorado State University. Derived data and r script supporting the findings of this study are available from the corresponding author (MH) on request.

## Declarations

**Ethics approval** The study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Institutional Review Board at Colorado State University (IRB#19-8914H, Initial Approval: 9/18/2019).

**Consent to participate** Informed consent was obtained from all individual participants included in the study.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

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