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Accuracy of consumer-based activity trackers as measuring tool and coaching device in breast and colorectal cancer survivors.

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ABSTRACT

Purpose

Consumer-based activity trackers are used to measure and promote PA. We studied the accuracy of a wrist- and waist-worn activity tracker in cancer survivors and compared these results to a healthy age-matched control group.

Methods

Twenty-two cancer survivors and 35 healthy subjects wore an activity tracker at the waist and at the wrist combined with a reference activity monitor at the waist (Dynaport Movemonitor). The devices were worn for 14 consecutive days. The mean daily step count from both activity trackers was compared with the reference activity monitor to investigate accuracy and agreement (paired t-test, intraclass correlation, Bland-Altman Plots). To evaluate the accuracy as a coaching tool, day-by-day differences within patients were calculated. The Kendall correlation coefficient was used to test the consistency of ranking daily steps between the activity trackers and the reference activity monitor.

Results

The wrist-worn wearable significantly overestimated the daily step count in the cancer group (mean±SD∆:+1305(2685) steps per day;p=0.033) and in the healthy control group (mean±SD∆:+1598(2927) steps per day;p=0.003). The waist-worn wearable underestimated the step count in both groups, although this was not statistically significant. As a coaching device, moderate (r=0.642-0.670) and strong (r=0.733-0.738) accuracy was found for the wrist- and waist-worn tracker, respectively, for detecting day-by-day variability in both populations.

Conclusion

Our results show that wrist-worn activity trackers significantly overestimate daily step count in both cancer survivors and healthy control subjects. Based on the accuracy, in particular the waist-worn activity tracker could possibly be used as a coaching tool.

Keywords: Accelerometry, physical activity, cancer, case-control study

INTRODUCTION

Cancer is an important health problem worldwide. Nine and a half million people died from the disease in 2018 making cancer the second leading cause of death in Europe.[1] Breast cancer (2.1 million) is by far the most frequent cancer in women followed by colorectal cancer (0.8 million). In men, colorectal cancer is the third (1.0 million) most frequent cancer.[1]

Studies have shown that Physical Activty (PA) has a positive effect on survival after a cancer diagnosis.[2] A recent consensus report concluded that PA should be promoted in cancer survivors to reduce side effects of cancer treatments such as anxiety, depressive symptoms, fatigue, lymphedema, and improve health-related quality of life and physical function in general.[3] In addition, we showed that (self-reported) PA levels remain low in patients one and two years after treatment of colorectal[4] and breast cancer[5].

Given the evidence described above, it is important to promote PA before, during and after cancer treatments. Consumer-based activity trackers have gained popularity for this purpose in both the general and patient populations.[6] Consumer-based activity trackers can be effective in providing individuals with the ability to objectively monitor their PA levels.[7] These monitors can also be integrated in a range of health behavioral change techniques (e.g. feedback on behavior) when combined with smartphone and computer apps.[7-9] Using an activity tracker improves daily step count, energy expenditure, and minutes per day spent in moderate and vigorous PA in cancer survivors[6,10].

Despite the different studies regarding the positive effects of consumer-based activity trackers to promote PA[8,10], only a few studies investigated the accuracy of such devices.[11-13] Most studies were performed in healthy or younger populations (<30 years) with a specific condition, and not in cancer cohorts. Also, the majority of studies used activity trackers in a laboratory setting (e.g. on a treadmill).[11-13] Laboratory-based studies show that the validity and the inter-device reliability for step counts are acceptable for activity trackers.[12] However, in free-living conditions, step detection becomes less accurate or movement patterns deviate from typical human gait patterns.[11-13] Another study indicated that the wearing site of the tracker is an important factor impacting the accuracy of performance.[11] Waist-worn trackers generally outperformed wrist-worn trackers for step accuracy.[11] One of the reasons for the overestimation of steps was that the tracker on the wrist kept counts steps while people perform activities only with their arms.[11]

Given the increasing interest in the use of consumer-based activity trackers to promote PA, the lack of validity studies in the cancer populations, and the lack of research in daily living situations outside the laboratory, the primary aims of this study was to investigate the accuracy of consumer-based activity trackers worn at the wrist and waist for measuring PA in patients after treatment for two common cancers (breast or colorectal cancer) and healthy age-matched controls in a real-life situation. In addition, the potential of consumer-based activity trackers as coaching tools, i.e. the ability to distinguish more and less active days at an individual level, was explored. The secondary aim was to investigate user preferences regarding consumer-based activity trackers.

METHODS

The study was approved by the ethics committee of UZ Leuven (reference number: S-60227). Subjects signed a written consent form prior to participation in accordance with the Declaration of Helsinki. This study is part of a series of studies on the validity of consumer-based activity trackers conducted at the Department of Rehabilitation Sciences of KU Leuven in patients with non-communicable diseases (Parkinson's disease[14], breast and colorectal cancer, Chronic Obstructive Pulmonary Disease[15] and patients with lower limb lymphedema[16]).

Participants, inclusion, and exclusion criteria

First, a group of breast or colorectal cancer survivors was recruited pragmatically from an existing GDPR-compliant database of study volunteers of the oncology research group of the Department of Rehabilitation Sciences of KU Leuven between July 2019 and December 2021. The specific inclusion criteria for the cancer group were a diagnosis of unilateral breast cancer or rectal cancer. Participants needed to be in complete remission and adjuvant treatments (surgery, radiotherapy, and chemotherapy) finished. Adjuvant hormonal therapy and immunotherapy were allowed. The exclusion criteria were as follows: people younger than 40, people with cognitive reading impairment and/or difficulties managing electronic devices, as judged by the investigator. People using a walking aid or with morbid obesity (BMI > 40 kg/m^2) were also excluded, as well as people diagnosed with respiratory disease, neurological conditions, or a diagnosis of lower limb lymphedema. Second, a group of age-matched healthy controls was recruited between July 2019 and August 2021 through advertisement within the network of the research team. The inclusion criteria for the healthy subjects were no or marginal smoking history (< 5 pack years) and no history of cancer. Exclusion criteria were the same as for the cancer group.

Procedure

A prospective observational study was performed. In a first visit the study was explained to the participants and informed consent was signed. Participants performed two times a six-minute walking test with a rest interval of at least 30 minutes. The subjects were encouraged to walk as fast as possible in a straight 50-meter corridor. Encouragement was standardized. The maximal distance walked was used as a measure of functional exercise capacity. Patient characteristics including age and cancer treatment history were collected through patients' self-report. Furthermore, an anthropometric assessment of height and weight was performed, and the patient's smoking history was obtained.

At the end of the first visit, every subject received the reference activity monitor (Dynaport Movemonitor, DAM, McRoberts BV, The Hague, the Netherlands). This monitor was proven to be valid[17-21]. Subjects were instructed to wear the DAM for 14 consecutive days during waking hours, except when bathing or showering. The DAM was worn at the lower part of the back via a belt and did not provide any feedback to subjects. The DAM can measure up to 14 consecutive days without charging.

In parallel, all subjects also wore two consumer-based activity trackers, one worn at the wrist (i.e. Fitbit Alta) and one at the waist, (i.e. Fitbit Zip) (Fitbit, Inc., San Francisco, USA). During the study, battery problems occurred with the Fitbit Alta and Zip so they became unavailable for purchase. Hence the Fitbit Inspire (worn at the waist and wrist) was added after five cancer patients. The Fitbit Inspire was worn at the waist using a Fitbit waist clip. The activity trackers for each participant were chosen based on the availability of the devices within the research group at the time of recruitment.

The waist-worn Fitbit Zip and Fitbit Inspire are consumer-based activity trackers with a clip system, which was attached to the same strap as the DAM at the right waist. At the wrist, the Fitbit Alta and/or Fitbit Inspire were worn as a watch at the side preferred by the subject. All consumer-based activity trackers use the same in-built 3-axis accelerometer and use motion pattern algorithms. They provide direct feedback to the subject on the display of the device. The Fitbit Zip has a 3V coin battery, with an autonomy of 4 to 6 months. The other Fitbit devices have in-built batteries that need charging every 5 to 7 days.

After 14 days of wearing the devices, a second visit was scheduled to return the devices. Subjects were asked to fill out a questionnaire asking about their preferences regarding consumer-based activity trackers. The project-tailored questionnaire captured the experiences of participants, including comfort wearing the trackers, how often they looked at the display of the trackers, if and for how long they would wear the trackers, and the trackers' positive and negative aspects. This questionnaire was used before in our research group in patients with chronic respiratory disease[15].

The outcome of interest for all devices was daily step count. The wearing time was only registered by the DAM. Days with wearing times less than 8 hours based on DAM were excluded and only days (at least two per subject) with data from all three devices were used in the analyses. Daily step counts of the consumer-based activity trackers were extracted from the online Fitbit platform on the second visit. All data were entered in Redcap, a Research Electronic Data Capture System[22].

Statistical analyses

Statistical analyses were performed using IBM SPSS 28.0.0.0 and SAS statistical package (V9.4, SAS Institute, Cary, North Carolina, USA). All data are presented as mean $\pm$ SD, unless specified otherwise. Statistical significance was set at $p<0.05$ for all analyses.

To examine the accuracy of the consumer-based activity trackers as a measurement tool for mean daily step counts, the waist-worn and wrist-worn activity tracker were compared to the DAM using a paired t-test in the cancer group and healthy control group separately. The mean daily step count measured for each device was compared between the healthy controls and the cancer survivors with an unpaired t-test. In addition, the intraclass correlation coefficient (ICC) (two-way mixed with absolute agreement) of the mean daily steps and Bland-Altman plots were used to investigate the agreement of the mean step count per subject and the step count of each day measured by the consumer-based activity tracker compared to the DAM. These analyses on the agreement were also performed for the cancer group and the healthy control group separately.

To evaluate the accuracy of the consumer-based activity trackers as a coaching device for an individual person, first, day-by-day differences to the individual mean step counts were calculated for each device for each participant-day. If more than 10 valid days were available, this analysis was based on 10 randomly selected days. Else, all available valid days were used. The day-by-day data were individually sorted based on the DAM measurement, from most active day to least active day and corresponding days from the waist- and wrist-worn activity tracker were added to the sorted database. Mean day-by-day differences for each day for each device were calculated and graphically presented. Second, the step count data retrieved from the three devices were used to evaluate the consistency of ranking between DAM and waist- and wrist-worn activity trackers. The daily step count of was ranked from most active day to least active day for each device separately. The ranking scores (1-10) of each day for each device were compared. The consistency of these rankings was evaluated by a Kendall correlation. The correlation coefficient was interpreted using the following cut-offs: weak correlation r = 0.30–0.50; moderate correlation r=0.51–0.70; strong correlation r = 0.71–0.90; very strong correlation r>0.90.[23]

In APPENDIX A, a sensitivity analysis can be found to verify the interchangeability of the devices.

Lastly, the user preferences regarding the consumer-based activity trackers are described.

RESULTS

Twenty-two cancer survivors were recruited, of which 12 breast cancer survivors and 10 rectal cancer survivors. In addition, 35 healthy age-matched control subjects were assessed. Both groups had a mean (SD) number of valid measurement days of 12 (2). Mean (SD) wearing time in the cancer group was 837 (87) minutes per day and in the control group 878 (98) minutes per day. In the cancer group, 10 and 12 participants wore the Fitbit Alta and Fitbit Inspire, respectively, at the wrist and 15 and 7 participants wore the Fitbit Zip and Fitbit Inspire, respectively, at the waist. In the control group, 21 and 14 participants wore the Fitbit Alta and Fitbit Inspire, respectively, at the wrist and 19 and 16 participants wore the Fitbit Zip and Fitbit Inspire, respectively, at the waist. The subject characteristics are displayed in Table 1.

Table 1: Characteristics of all participants, expressed as mean ± standard deviation. When missing data, n of available participants for that outcome is given.

	Breast cancer (n=12)	Rectal cancer (n=10)	All cancer survivors (n= 22)	Healthy controls (n= 35)	p-value*
Age (years)	62 ± 7	60 ± 12	61 ± 9	58 (6)	0.215
Gender (% female)	100%	30%	68%	54%	0.405
BMI (kg/m^2)	25.6 ± 3.4	22.4 ± 2.6	24.1 ± 3.4	26.2 (3.9)	0.047
6MWD (m)	540 ± 58	510 ± 53	536 ± 60	625 ± 68	<0.001
Surgery	100%	100%			
Chemotherapy	67%	60%			
Radiotherapy	75%	50%			
Hormone therapy	92%	n/a			
Immunotherapy	25%	n/a			

*P-value based on unpaired t-test or Chi Square for comparison between the healthy control group and total cancer group. BMI = body mass index; 6MWD = 6-minute walking distance; 6MWD was missing in 7 heathy controls.

Accuracy as a measurement tool

In the cancer group, the mean daily step count measured with a wrist-worn activity tracker was significantly higher compared to the DAM (see Table 2) with a mean (SD) difference of +1305 (2685) steps per day or +16%; p=0.033. The mean daily step count measured with a waist-worn activity tracker was not significantly different from the reference activity monitor (DAM) (mean (SD) difference of -515 (1294) steps per day or -6%; p=0.076). In the healthy control group, a similar result was found. The mean daily step count measured with a wrist-worn activity tracker was significantly higher compared to the DAM (see Table 2) with a mean (SD) difference of +1629 (2980) steps per day or +18%; p=0.003. No significant difference was found between the waist-worn activity tracker and the DAM (mean (SD) difference of -576 (2013) steps per day or -5%; p=0.100).

Table 2. Mean (standard deviation) daily step count in the cancer group and healthy control group. P-value compares mean steps measured by the Dynaport Movemonitor (DAM) to respectively the waist-worn and wrist-worn activity tracker, using paired t-test.

	DAM	Waist-worn activity tracker	Wrist-worn activity tracker
CANCER group (n=35) Mean daily step count	8250 (3115)	7735 (3665)	9555 (4193)
p-value compared to DAM		0.076	**0.033**
HEALTHY control group (n=22) Mean daily step count	8749 (3740)	8173 (2964)	10378 (3669)
p-value compared to DAM		0.100	**0.003**

For none of the devices, the daily step count was not significantly different between the cancer population and the healthy controls (waist-worn tracker (mean (SD) ∆ 439 (884) steps per day; p=0.622), a wrist-worn activity tracker (mean (SD) ∆ 823 (1055) steps per day; p=0.438) or the DAM (mean (SD) ∆ 499 (956) steps per day; p=0.604)).

In the cancer population, good to excellent agreement between the waist-worn activity tracker (ICC=0.920; 95% CI (0.811-0.967)) and the DAM was found. Agreement between the wrist-worn activity tracker (ICC=0.701; 95% CI (0.384-0.866)) and the DAM was only moderately strong. In the healthy control group, the agreement was found to be strong for the waist-worn activity tracker (ICC=0.814; 95% CI (0.662-0.902) and moderate for the wrist-worn activity tracker (ICC=0.622; 95% CI (0.311-0.801).

The Bland Altman analysis is presented for cancer and control groups separately in Figure 1. For the waist-worn activity tracker, the plots showed a mean bias of -515 (-2021;3052) steps and -576 (-3370;4522) steps in the cancer and healthy control group, respectively. The mean bias for the wrist-worn activity tracker is larger for both the cancer group (+1305 (-6567;3957)) and the healthy control group (+1629 (-7470;4212)).

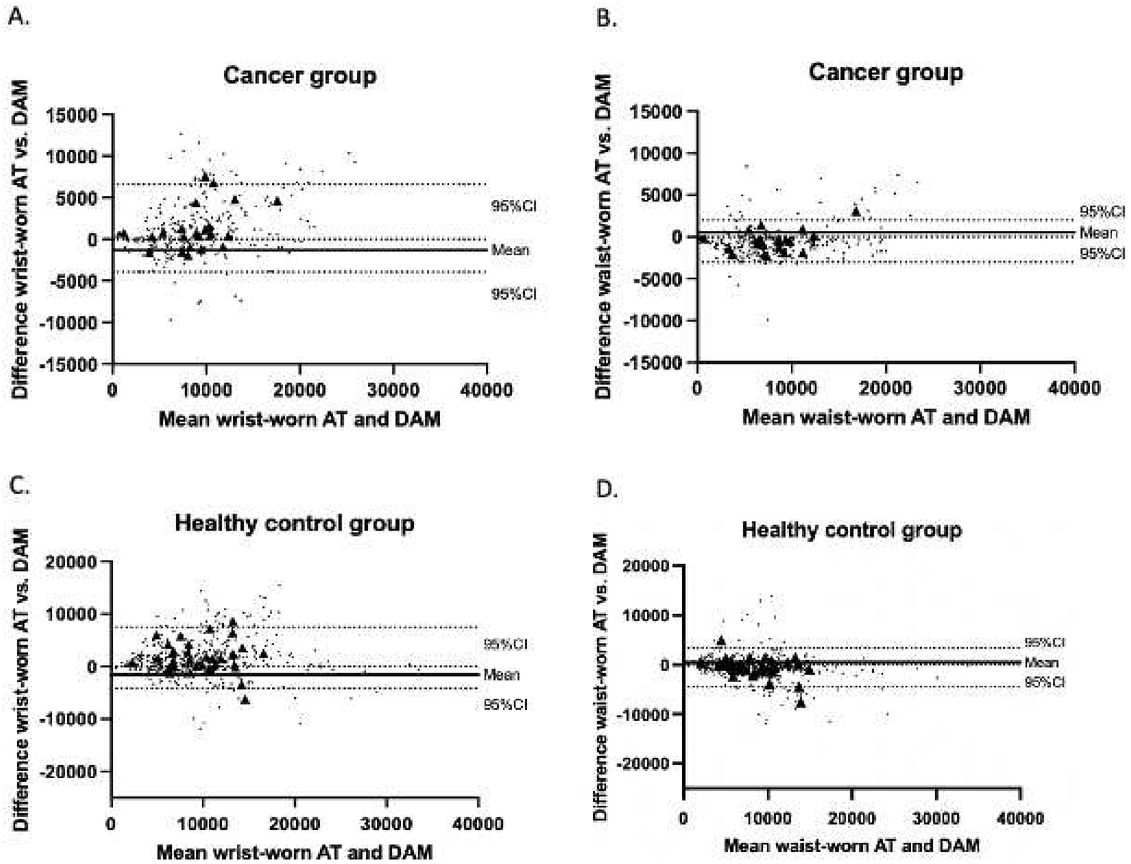

Figure 1. Bland-Altman plots with mean and 95%CI for the waist- and wrist-worn activity trackers compared to DAM. (A,B) Cancer group; (C,D) Healthy control group; Triangle symbols represent the mean individual step count per subject (n=22 for the cancer group and n=35 for the healthy control group); Dots represent the daily step count. Mean and 95%CI are calculated based on the mean daily step count data. AT=Activity Tracker; DAM=Dynaport Movemonitor

Accuracy as a coaching tool

Figure 2 displays the ranked day-by-day variability expressed as mean day-by-day differences measured by the three devices. Visual inspection of the graphs shows that differences in the individual mean step count followed the same pattern for all devices, in both the cancer and healthy control group. This indicates that both consumer-based activity trackers can detect patterns of more and less active days, similar to the DAM. In addition, a moderate and strong Kendall correlation coefficient (as a measure of the consistency of ranking from most active to less active days) was found for the wrist-worn (r=0.642) and waist-worn (r=0.733) activity tracker, respectively, in the cancer population (Figure 3A-B). Likewise, in the healthy control group, a moderate and strong correlation coefficient was found for the wrist-worn (r=0.670) and waist-worn (r=0.738) activity tracker in the healthy control group (Figure 3C-D).

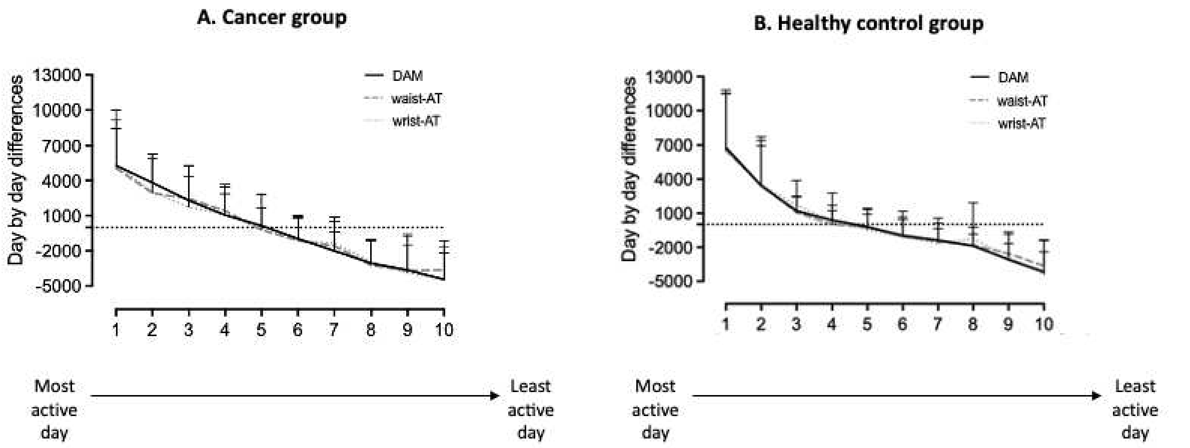

Figure 2. Graphical representation of day-by-day variability in steps per day around the individual mean step count. (A) Cancer group and (B) healthy control group: Mean (SD) day-by-day differences around the mean step count, recorded by the waist-worn activity tracker, wrist-worn activiy tracker. Horizontal line represents the mean step count, positive numbers representing more active days compared to the mean PA measured, negative numbers presenting less active days. Days are ranked from the most active day to the least active day according to DAM. Corresponding data of the waist-worn activy tracker and wrist-worn activity tracker were added. AT=Activity Tracker; DAM=Dynaport Movemonitor

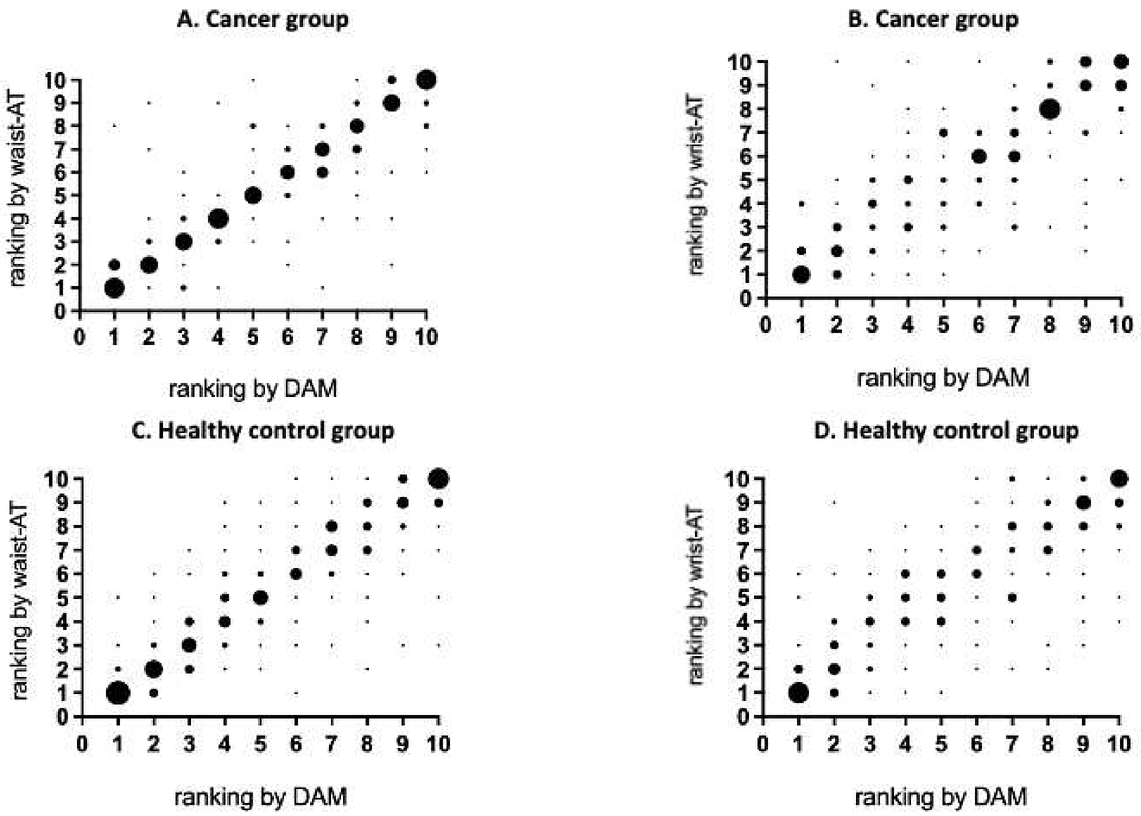

Figure 3. Ranking of daily step count by DAM compared to ranking by activity trackers. DAM compared to wirst-worn activity tracker in the cancer group (panel A) and healthy control group (panel C). DAM compared to waist-worn activity tracker in the cancer group (panel B) and healthy control group (panel D). The larger the dot, the larger number of subjects for the given combination of ranks; r= Kendall correlation for consistency of ranking. AT=Activity Tracker; DAM=Dynaport Movemonitor

User preferences

Regarding user preferences (Table 3) in the cancer group, data from 91% of participants was available. Of them, 68% preferred the wrist-worn activity tracker rather than the waist-worn tracker. Only one person had no preference.

In the healthy control group, data on user preferences could be collected in 86% of the participants. Forty-seven % of the subjects preferred an activity tracker worn at the wrist and 17% chose an activity tracker worn at the waist. Thirteen participants (36%) had no preference.

The majority in both groups found it pleasant to wear the devices. Only a small minority of the participants found the devices unpleasant. In the cancer group, 75% would wear a wrist-worn activity tracker for more than a year, versus 15% for the waist-worn activity tracker. In the healthy control group, only 47% and 17% would wear a wrist- or waist-worn activity tracker for more than one year. Detailed information about the user preferences is given in Table 3.

Table 3. User preference expressed as percentages.

		Healthy control group (n=30)		**Cancer group (n=20)**	
		Waist-worn	**Wrist-worn**	**Waist-worn**	**Wrist-worn**
How pleasant was it to wear the tracker?	*Very pleasant/ pleasant (%)*	47	77	30	75
	Neutral (%)	37	20	65	20
	Not pleasant (%)	17	3	5	5
How often did you look at the step count on the tracker?	*Multiple times a day (%)*	20	77	32	70
	Once a day (%)	30	13	37	15
	Once or twice a week (%)	40	10	21	10
	Never (%)	10	0	10	5
How long would you like to wear the tracker in the future?	*A year (%)*	17	47	15	68
	Months (%)	7	7	20	16
	Weeks / days (%)	33	23	40	0
	Never (%)	43	23	25	16

DISCUSSION

The aim of this study was to investigate the accuracy of consumer-based activity trackers worn at the wrist and waist for measuring daily step count in breast and rectal cancer survivors and healthy age-matched controls. In addition, the ability to identify more or less active days at an individual level was investigated in order to assess the potential of consumer-based activity trackers for PA coaching.

Wrist-worn activity trackers significantly overestimated daily step count in cancer survivors and healthy control subjects by approximately 17%. The waist-worn activity trackers on the contrary slightly underestimated daily step count in both populations (~-5%), but this did not reach statistical significance. As a criterion for accuracy, a study by Tudor-Locke et al. propose that the difference between the daily steps measured by the wearables and the reference monitor (DAM) should not exceed 10% in a daily living setting.[24] In the present study, the wrist-worn wearables were beyond this benchmark for both populations. This questions the accuracy of consumer-based activity trackers as a measurement device. The waist-worn wearables performed within the 10% benchmark in the healthy control and cancer groups. Our results were in line with other studies. An overestimation by wrist-worn activity trackers is commonly observed and can be explained by movements of the arm whilst standing or sitting that are often incorrectly registered as steps[11,12].

The observation of a comparable step count between cancer patients and healthy controls must be interpreted against the background that cancer patients had finished primary cancer treatments, including surgery, radiotherapy, and chemotherapy. In addition, literature indicates that PA levels remain low after cancer treatment compared to pre-surgical levels and healthy controls [5,25]. Also, there may have been selection bias in the sample of this study. On the one hand, the healthy subjects had lower PA levels (mean daily step count) than recommended[26,27]. On the other hand, cancer patients recruited at the University Hospital are generally encouraged to be physically active. Therefore, caution is necessary when generalizing these findings to cancer patients undergoing active treatment since they may be more limited with regards to the amount and speed of walking[28], known to negatively affect the accuracy of waist-worn activity trackers in other chronic health conditions.[15]

As a coaching tool, a strong and moderate consistency of the ranking of days was found for the waist- and wrist-worn activity trackers, respectively. The waist-worn activity appeared slightly more accurate in picking up day-by-day variability. The number of studies using consumer-based activity trackers in different patient populations, including cancer patients, is increasing. Studies using activity trackers to improve adherence and motivation show promising results for improving for example fatigue, mood, anxiety, and depression.[8] In those studies, the use of the activity tracker as a coaching tool is common, often in combination with a smartphone application or with remote coaching by a healthcare provider.[8] The present study supports the use of activity trackers in this way rather than using the wearable as a measurement device of daily steps.

Finally, there was a strong user preference for the wrist-worn activity tracker. Other studies confirm the high feasibility and acceptability of wearing activity trackers in general.[15,29,30] In addition to age, other studies indicated the importance to consider work status, education level, and aesthetics (including display size) when choosing an activity tracker.[29,31] The wrist-worn activity trackers play a role in promoting PA as well. Patient preference and acceptable accuracy as coaching tools provide support for their use in this setting. Providing options to patients seems important.

The strength of this study is the use of specific statistical approaches to test the accuracy of consumer-based activity trackers against a reference activity monitor as well as their ability to reliably detect relative variability over several days. The comparison with a healthy age-matched control group and the testing in real-life conditions provide the external validity to our results. Few limitations should nevertheless be considered when interpreting the results. First, the DAM served as the reference measure, allowing testing in real-life conditions. The DAM has been validated in the elderly and different chronic diseases but not specifically in the cancer population. Second, different Fitbit devices were used due to the sudden unavailability of the devices during the study. Whereas this can be considered a limitation of the study, it reflects the current real-world problem, where technologies keep changing at a fast pace with regularly new devices being released on the market. In a small sample, as sensitivity analysis, we compared the results of the trackers. We observed only marginal differences between the types of wearables when worn at the same location on the body. These difference are likely explained by the way of the devices were worn. We could not control for wearing time as no information on wearing time is available for the trackers individually. Therefore, some caution is necessary when translating our results to other (newer) devices of Fitbit and other brands, although our results are in line with previous studies.[15] Surely wrist and waist-worn trackers give different readings so we recommend sticking to one device. Third, the activity tracker at the wrist was worn by the subjects on the preferred side. Unfortunately, no information is available on whether the activity tracker was worn on the dominant or non-dominant side. As previous research showed larger overestimation at the dominant arm, this might have influenced the present results. Last, selection bias can be present in this study sample given recruitment took place from an existing database for the cancer population and within the network of the researchers for the healthy control group. This may have resulted in an active study population.

CONCLUSION

Wrist-worn consumer-based activity trackers were less accurate than waist-worn devices in measuring daily step counts in a cancer population and in healthy controls. Validity to capture day-to-day variability was excellent to good in waist and wrist-worn activity trackers, respectively. Activity trackers, therefore, have potential as a health-promoting coaching tool for breast and colorectal cancer survivors.

DECLARATIONS

Ethics approval and consent to participate

The study was approved by the local ethics committee of UZ Leuven (reference number: S-60227). The study is reported according to the STROBE guidelines. All participants signed informed consent.

Consent for publication

n/a

Authors' contributions

ADG, TT, HD, IG, ND, AN conceived and desgined the study and analyses;
ADG, AA, TDV collected the data;
ADG, AB, HD performed the analyses;
ADG, AB, HD wrote the paper.
All co-authors reviewed the manuscript.

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Competing interest

The authors have no competing interest to declare.

Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author, ADG.

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