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Comparison of physical activity assessed using hip- and wrist-worn accelerometers

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Abstract

Objectives—It is unclear how physical activity estimates differ when assessed using hip- versus wrist-worn accelerometers. The objective of this study was to compare physical activity assessed by hip- and wrist-worn accelerometers in free-living older women.

Design—A cross-sectional study collecting data in free-living environment.

Methods—Participants were from the Women's Health Study, in which an ancillary study is objectively measuring physical activity using accelerometers (ActiGraph GT3X+). We analyzed data from 94 women (mean (SD) age=71.9 (6.0) years) who wore a hip-worn and wrist-worn accelerometers simultaneously for 7 days.

Results—Using triaxial data (vector magnitude, VM), total activity volume (counts per day) between the two locations was moderately correlated (Spearman's $r=0.73$). Hip and wrist monitors wear locations identically classified 71% individuals who were at the highest 40% or lowest 40% of their respective distributions. Similar patterns and slightly stronger agreements were observed when examining steps instead of VM counts.

Conclusions—Accelerometer-assessed physical activity using hip- versus wrist-worn devices was moderately correlated in older, free-living women. However, further research needs to be conducted to examine comparisons of specific activities or physical activity intensity levels.

Keywords

exercise; epidemiology; step counts; measurement; objective monitoring

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Introduction

Monitoring physical activity (PA) on a population-wide scale, in addition to conducting observational and experimental studies, has become a key element of public health practice due to the multitude of health benefits associated with PA [1] and the increasing prevalence of physical inactivity [2]. Recently, objective measurement of PA by accelerometers has become increasingly popular in health surveillance systems and epidemiological studies due to decreased costs of the devices [3].

Accelerometers can be worn on a variety of locations on the body, including the hip, wrist (two most common sites), thigh, ankle, and chest. For large studies, placement at only one location is most practical; however, little is known about the impact of wear location on PA estimation. Previous large epidemiological studies have typically used hip-worn accelerometers and validation studies of older generation, uniaxial accelerometers in assessing intensity of PA have been conducted primarily with hip-worn devices [4–6].

Compared to hip-worn devices, wrist-worn accelerometers may be less intrusive, particularly during sleep, and may thus engender higher compliance. While hip-worn devices have typically been used in adult studies, wrist-worn accelerometers have been used in studies of children and adolescents for some time. The National Health and Nutrition Examination Survey (NHANES), which conducts surveillance of PA in the United States population, previously used a uniaxial accelerometer worn on hip to assess PA (2003–2004 and 2005–2006), but has now changed its protocol asking participants to wear a triaxial accelerometer on the wrist instead during recent surveys (2011–2014) among persons aged 6 years [4].

Several studies have previously compared hip- and wrist-worn accelerometers, however these studies are generally performed in a laboratory setting with younger individuals (including adolescents) [7–9] and employ a variety of different accelerometers [10–12]. In one of these studies, Tudor-Locke et al. did investigate a free-living environment as well in younger adults.[7] There are few data available on how hip- and wrist-worn accelerometers compare in free-living environments, particularly among older adults. Thus, the purpose of this study was to compare PA assessed by hip- and wrist-worn triaxial accelerometers among older women in the free-living environment.

Methods

The Women's Health Study (WHS) is a completed, randomized controlled trial of low-dose aspirin and vitamin E in the primary prevention of cardiovascular disease and cancer among 39,876 healthy women aged 45 years in the US, conducted between 1992 and 2004 [13, 14]. At the scheduled end of the trial, women who were willing continued to be followed up in an observational study with yearly health surveys. In 2011, an ancillary study began that assessed PA using hip-worn triaxial accelerometers (ActiGraph GT3X+), asking women to wear this for 7 days. The ActiGraph GT3X+ (ActiGraph, Pensacola, FL) is a small, light-weight, water resistant accelerometer; we set the device to record triaxial accelerations at 30 Hz.

For the present study, in 2013 we randomly selected 146 women, stratified by age (75 aged 60–69 years; 71 aged 70 years and over), who had participated in the ancillary study. In an effort to reduce accelerometer loss and data collection delays, we restricted sampling to those women who had worn and returned an accelerometer within 30 days of being mailed a device and who also returned a PA questionnaire as part of the ancillary study. Of the 133 women who responded to the invitation, 2 women were now unable to walk outside the home without assistance (inclusion criteria) while 15 women declined participation. Of the remaining 116 women who initially agreed to participate in the study, 98 women wore and returned their accelerometers. We excluded 4 women due to insufficient valid wear days or time (see below), leaving a final analysis sample of 94 women. Written consent was obtained from each participant. This study was approved by the Institutional Review Board of Brigham and Women's Hospital (Protocol number: 2010P001914).

For each willing participant, two accelerometers, one to be worn on the hip and one on the wrist, were sent by mail between September and December 2013. Participants were asked to wear the devices simultaneously for 7 consecutive days, 24 hours a day. Participants were asked to start wearing the two accelerometers when they woke up on the day after they received the monitors in the mail. They also were asked to keep a written log, recording the dates and times they woke up and went to bed on the days that they wore the devices. Participants were instructed that they did not need to remove the devices when showering, bathing, or swimming. Women were asked to wear the hip accelerometer, attached to an elastic belt, just above the right hipbone. The wrist accelerometer, attached to a watch strap, was worn on the non-dominant wrist. If women could not use the non-dominant wrist for any reason, they were allowed to wear it on the other wrist and to indicate this information on their daily log. Following 7 days of wear, women were asked to return their devices by mail using an envelope with postage pre-paid.

Upon return of the accelerometers, data were downloaded in 60-second epochs (ActiLife software version 6.11.5 (ActiGraph, Pensacola, FL)). For this analysis, data were restricted to when both the wrist and hip monitors were worn during self-reported waking time according to participant logs. To determine when the accelerometers were worn during self-reported waking time, hip and wrist data were screened using an algorithm developed by Choi et al, modified to include use of triaxial data [15, 16]. Briefly, non-wear time was defined as 90 consecutive minutes of 0 vector magnitude (VM) counts, with allowance for up to 2 minutes of nonzero counts when upstream and downstream windows also contained 30 consecutive minutes of zero counts for detection of artifactual movements. A valid day was defined as at least 10 hours of wear time during self-reported waking time [17, 18].

For both the hip and wrist accelerometers, we extracted the number of steps as well as the VM and axis-specific "counts" per day. Counts are a result of summing post-filtered accelerometer values (raw data at 30Hz) into epoch "chunks." The value of the counts varies based on the frequency and intensity of the raw acceleration and it can exceed the sampling rate in a minute (i.e., $>30 \times 60$). The VM was calculated from the three axes as $(x^2 + y^2 + z^2)^{1/2}$, for both hip and wrist. Step counts were derived from the built-in algorithm of the ActiLife software.

For the hip monitor, we calculated sedentary time and moderate-to-vigorous intensity physical activity (MVPA) using triaxial cutpoints. Sedentary time was defined as the sum of the minutes where the hip accelerometer registered <200 VM counts per minute (cpm) [19]. MVPA was defined as the sum of the minutes where the hip accelerometer registered ≥2,690 VM cpm [20].

As similar cutpoints do not exist for the wrist, we calculated sedentary time and MVPA over a range of arbitrary cutpoints. For sedentary behavior, we used 11 cutpoints ranging from <500 to <10,000 VM cpm. For MVPA, we used 11 cutpoints ranging from 3000 to 15,000 VM cpm. For both the hip and wrist accelerometers, we calculated means and standard deviations (SD) of the estimated PA variables (VM and axis-specific counts per day; number of steps per day; and minutes per day of sedentary behaviour and MVPA). Spearman's rank correlation coefficients were calculated for the number of steps per day as well as the VM and axis-specific counts per day comparing the hip- (using established cutpoints as described above) and wrist-worn (using arbitrary cutpoints) accelerometers.

A classification matrix was constructed by classifying participants into quintiles (arbitrarily chosen to have sufficient numbers) based on the total daily PA distribution (VM counts per day) from the hip and wrist monitors. The overall percent agreement was calculated as the proportion of participants who were in the same quintile for both monitors. This was performed in parallel for the daily step count from each monitor. Classification agreement was evaluated using a weighted Kappa statistic, following the guidelines of Landis and Koch: kappa less than 0.40 indicates "poor" agreement, values between 0.40 and 0.75 indicate "moderate" agreement, and values greater than 0.75 indicate "excellent" agreement [21].

The mean difference in daily sedentary time as assessed using hip and wrist accelerometers was calculated using the established hip cutpoint of <200 cpm [19] over the range of arbitrary defined wrist cutpoints (<500 to <10,000 cpm). A negative mean difference describes an overestimation in sedentary time when using the wrist accelerometer compared to the hip accelerometer. The mean difference in MVPA minutes per day between the hip and wrist accelerometers was calculated using the established hip cutpoint of ≥2690 cpm [20] over the range of arbitrary defined wrist cutpoints (3000 to 15,000 cpm). A negative mean difference describes an overestimation in moderate-to-vigorous intensity activity when using the wrist accelerometer compared to the hip accelerometer. Analyses were carried out using SAS version 9.3.

Results

The mean (SD) age of the 94 women in the present study was 71.9 (6.0) years. The average daily wear time during waking hours was 913.0 (SD=61.1) minutes, approximately 15.2 hours. The mean (SD) and median (25th and 75th percentiles) sedentary time calculated from the hip accelerometer were 513.1 (99.2) and 521.4 (451.6–575.2) minutes per day, respectively. The mean (SD) and median (25th and 75th percentiles) MVPA time calculated from the hip accelerometer were 29.3 (25.6) and 25.1 (10.0–40.9) minutes per day, respectively. Wrist VM counts were far higher than hip VM counts (~4 times higher) (Table

1). The percent differences between axis-specific daily counts were larger for the hip (XY=22.8%; YZ=40.7%; XZ=23.2%) than the wrist (XY=1.9%; YZ=22.4%; XZ=21.0%). The step count was nearly double when assessed by the wrist compared to the hip.

Figure 1 shows a series of scatterplots comparing hip and wrist average daily VM counts and number of steps. The correlation between hip and wrist average counts per day using VM was moderate (Spearman's $r=0.73$, Table 1). Among the three axes of the hip accelerometer, medial-lateral counts had the highest correlation (Spearman's $r=0.79$) with wrist VM. The step count had a correlation of 0.81 between the hip and wrist accelerometers (Table 1).

When categorized into quintiles based on daily VM counts, hip and wrist accelerometers classified participants into the same quintile 46.8% of the time, resulting in a weighted Kappa of 0.56 (Table 2). The range of classification agreement between the two locations was 21.1% to 72.2%, with stronger agreement comparing the extreme ends of the distribution. Those classified into the highest quintile of activity by the hip were not classified in the lowest two quintiles by the wrist. Similar patterns were observed for the lowest hip quintile where no participants were observed in the highest two quintiles for the wrist. Those in the lowest 40% of daily activity (quintiles 1 and 2) by the hip were classified as the lowest 40% according to the wrist 67.6% of the time. Similarly, for higher levels of activity, those classified as the top 40% of daily activity by hip were also top 40% by wrist 73.7% of the time.

The percent agreement and weighted Kappa statistic were slightly higher when comparing hip and wrist step count quintile classification. The overall agreement was 54.3% with a maximum of 77.8% and the weighted Kappa was 0.61 (Table 2). Those individuals identified as in the lowest or highest 40% of daily step counts were similarly classified by the wrist 75.7% and 76.3% of the time.

Figure 2 shows the mean difference in daily sedentary behavior and MVPA when comparing the hip and wrist accelerometers over a range of wrist cutpoints. The wrist cutpoint that minimized the mean difference was <2000 VM cpm for sedentary behavior and between 7500 and 8250 VM cpm for MVPA, respectively.

Discussion

While hip-worn accelerometers have traditionally been used in PA research settings, wrist-worn devices have recently become greater utilized due to expected higher compliance [4, 18]. However, there continues to be debate over how wear location impacts PA assessment [7–9]. This study compared hip-worn and wrist-worn accelerometer PA estimates among older women in a free-living environment.

While there was a large difference in actual counts, the correlation between VM daily counts from hip- and wrist-worn accelerometers was moderate. Perhaps more informative is how validly each monitor classified individuals based on total daily activity. Hip and wrist monitors were able to best classify individuals at the highest and lowest levels of activity. Both wear locations identically classified 71% individuals who were in the highest or lowest

40% of the group according to daily activity. Indeed, individuals in the highest quintile by one monitor were never misclassified in either of the lowest two quintiles by the other monitor. Similar patterns and slightly stronger agreements were observed when examining steps instead of VM counts.

When we examined wrist output, using a range of cutpoints, to the VM hip cutpoints for MVPA [20], we observed that the mean difference between the two wear locations was minimized between wrist VM cutpoints of 7500 and 8250 cpm. For sedentary behavior [19], the mean difference was minimized at a wrist VM cutpoint of <2000 cpm. It should be noted that in the absence of a “gold standard” to properly classify PA intensity, these are not recommended as wrist cutpoints for sedentary behavior or MVPA, but are meant to guide future research.

Independently, wrist and hip monitors have been shown to accurately assess PA and sedentary behaviour. Adult cutpoints for the ActiGraph when worn at the hip have been developed in laboratory settings using metabolic metrics as comparisons [6, 20]. While no established cutpoints for the ActiGraph wrist exist, the GENEa wrist-worn accelerometer has been shown to accurately classify PA intensity and sedentary behaviour in both children and adults [10–12].

Several studies have previously compared hip- and wrist-worn accelerometers, primarily in persons younger than those in the present study [7–9]. Tudor-Locke et al, using the same accelerometer at the NHANES study as well as the present study (ActiGraph) investigated a small sample (N=15, mean age=27 years) in both laboratory and free-living environments. They reported that a wrist accelerometer records fewer steps compared to a hip accelerometer when walking on a treadmill, but more steps than a hip accelerometer when in a free-living environment [7]. A similar pattern was observed in the present study, as the number of daily steps was nearly double using a wrist monitor compared to a hip monitor. The younger individuals in the Tudor-Locke study had a higher daily step count according to the hip monitor compared to WHS (6700 vs 5400), but similar wrist step counts (9300 vs 10,000) [7]. These differences may reflect changes in the biomechanics of walking with age but at the present time it is unclear why step counts are greater at the wrist than at the hip. Trost et al, in a study of children and adolescents, reported that a machine learning algorithm could be used to accurately identify specific activity classes from both hip and wrist monitors [9]. Hildebrand et al, using raw data from accelerometers (ActiGraph and GENEa) in a study of 30 adults (18 to 65 years) and 30 children, concluded that in adults, wrist and hip outputs were comparable for activity detection [8]. Rosenberger et al. compared prediction of sedentary behaviour and MVPA using a triaxial accelerometer (Wockets) on the hip and the wrist in 37 adults (aged 18–74 years) in a laboratory setting against indirect calorimetry, and found that hip accelerometers generally predicted activities more accurately than wrist monitors [22]. In the present study, we limited analyses to count-based and step-based analyses, since other methods for analysing accelerometer data are currently being developed and there is no consensus on standards [8, 23–25]. However, future advanced data processing methods may provide a clear picture of activity detection and identification as well as intensity classification [4].

This study has several strengths. First, this study examined the comparability of hip- and wrist-worn accelerometers in a free-living environment while many previous studies were conducted in laboratory settings. Second, we used an identical triaxial accelerometer to that being used in the NHANES 2011–2014 data collection and some large cohort studies [3, 4]. Finally, participants were recruited from throughout the United States, representing various geographic locations.

However, there also are limitations. As noted above, there was no “gold standard” used in the present study. We are thus unable to test agreements of different intensity levels against a standard. Participants from the WHS were older, primarily white, and of higher socioeconomic status. However, previous analyses of accelerometer data from the WHS participants showed similar levels of PA and sedentary behaviour to a comparably-aged US national sample [3, 26, 27]. Participants of the present study were randomly selected from those who promptly returned their devices in the main ancillary accelerometer study, and thus may be a select group with higher PA levels [26]. This may limit the generalizability of the present findings.

Conclusion

In conclusion, free-living PA assessed using hip- and wrist-worn accelerometers correlate moderately in older women. For women in the top 40% or bottom 40% of the distribution of daily PA, hip and wrist accelerometers agree on classification for about three quarters of the women. Further research is needed to examine the association of wear location and PA estimates for specific activities or intensity levels.

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Figure 1.

Scatterplots of daily vector magnitude counts (A) and daily step counts (B) from hip- and wrist-worn accelerometers, Women's Health Study.

Figure 2.

Mean differences in sedentary behavior and moderate-to-vigorous intensity physical activity between hip and wrist accelerometers across a range of wrist cutpoints, Women's Health Study. Hip sedentary behavior and moderate-to-vigorous intensity physical activity defined as <200 and ≥2690 vector magnitude counts per minute, respectively. The 95% confidence intervals are displayed as error bars. CPM, counts per minute.

Table 1

Descriptive statistics and Spearman's correlations between hip and wrist accelerometer measures (N=94), Women's Health Study

Hip Accelerometer Measures	Wrist Accelerometer Measures				
	X Axis	Y Axis	Z Axis	Vector Magnitude	Steps
Mean (SD)	1124 182 (316 460) counts/d ^a	1103 330 (332 287) counts/d ^a	1422 213 (388 492) counts/d ^a	2190 625 (597 108) counts/d	10 107 (2785) number/d
X Axis	260 646 (100 398) counts/d ^a	0.82	0.74	0.79	0.86
Y Axis	201 130 (84 307) counts/d ^a	0.74	0.60	0.68	0.78
Z Axis	339 414 (144 241) counts/d ^a	0.69	0.59	0.63	0.68
Vector Magnitude	507 542 (189 764) counts/d	0.79	0.67	0.73	0.82
Steps	5378 (2269) number/d	0.70	0.55	0.63	0.81

Note. SD, standard deviation.

^aX, Y, and Z planes of the hip and wrist accelerometer may not represent the same planes on the participant in space. For hip accelerometer: X=medial-lateral, Y=vertical, Z=anterior-posterior. For wrist accelerometer: Y aligns with forearm.

Accelerometer measures used are daily averages during self-reported waking time.

All correlations are statistically significant, $P<0.01$

Table 2
Classification matrices of vector magnitude and step count by hip and wrist accelerometers, Women's Health Study.

Hip Vector Magnitude	Wrist Vector Magnitude					Percent Agreement
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	N
Quintile 1	13	4	1	0	0	18
Quintile 2	4	4	6	3	2	19
Quintile 3	1	6	7	4	1	19
Quintile 4	0	5	4	7	3	19
Quintile 5	0	0	1	5	13	19
N	18	19	19	19	19	94
Percent Agreement	72.2%	21.1%	36.8%	36.8%	68.4%	46.8%

Hip Step Count	Wrist Step Count					Percent Agreement
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	N
Quintile 1	14	3	1	0	0	18
Quintile 2	3	8	4	3	1	19
Quintile 3	0	4	10	2	3	19
Quintile 4	1	4	4	7	3	19
Quintile 5	0	0	0	7	12	19
N	18	19	19	19	19	94
Percent Agreement	77.8%	42.1%	52.6%	36.8%	63.2%	54.3%