Title: Comparison of compliance and intervention outcomes between hip- and wrist-worn accelerometers during a randomised crossover trial of an active video game intervention in children

Running Title: Hip & Wrist compliance and intervention outcomes

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Running Head: Hip & wrist compliance & intervention outcomes

Abstract (200 words)

Background: There are several practical issues when considering the use of hip-worn or wrist-worn accelerometers. This study compared compliance and outcomes between hip- and wrist-worn accelerometers worn simultaneously by children during an active video games intervention.

Methods: As part of a larger randomized crossover trial, participants (n=73, age 10-12 years) wore 2 Actical accelerometers simultaneously during waking hours for 7 days, on the hip and wrist. Measurements were repeated at 4 timepoints: 1) at baseline, 2) during traditional video games condition 3) during active video games condition 4) during no video games condition. Compliance and intervention effects were compared between hip and wrist.

Results: There were no statistically significant differences at any timepoint in percentage compliance between hip (77-87%) and wrist (79-89%). Wrist-measured counts (difference of 64.3 counts per minute, 95%CI 4.4, 124.3) and moderate-to-vigorous physical activity (MVPA) (12 min/day, 95% CI 0.3, 23.7) were higher during the no video games condition compared to the traditional video games condition. There were no differences in hip-measured counts per minute or MVPA between conditions or sedentary time for hip or wrist.

Conclusions: There were no differences in compliance between hip- and wrist-worn accelerometers during an intervention trial, however, intervention findings differed between hip and wrist.

Keywords: physical activity, sedentary, children, measurement

Introduction

Practical and accurate measures of physical activity and sedentary time are needed: to obtain reliable estimates of the prevalence of physical activity and sedentary time, to estimate the relationships between activity and health outcomes, and to evaluate changes in response to interventions. Several measures have been widely used including self-report and pedometers, with accelerometers now a common device for objective field measures of physical activity. Traditionally, accelerometers have been worn on the hip for physical activity assessment, close to the body's centre of mass, to maximize correlations with energy expenditure.[1] In contrast, accelerometers are traditionally worn on the wrist for sleep assessment.[2] Several commercial activity monitors (ie Fitbit, Jawbone, iWatch) and research accelerometer devices are increasingly marketed to be primarily (Actigraph Link) or solely (Geneactiv) worn on the wrist. Several studies interested in activity, including the large US surveillance study NHANES, have recently changed their protocol, from hip-worn to wrist-worn accelerometers. There are several proposed reasons for this change including detection of upper limb movement, the ability to more easily obtain 24 hour data which includes sleep measures, as well as increased compliance.[3,4]

While several studies imply and discuss higher compliance as a benefit of wrist placement versus hip placement,[5-7] only two studies have compared compliance between hip-worn and wrist-worn devices in adults and/or children.[3,8] It has been reported that compliance for hip-worn accelerometers for NHANES 2003-2006 was 40-70%, depending on age group, and has increased to 70-80% with a full 24 hour wrist-worn protocol for NHANES 2011-2012.[3] However, this comparison included a large age range of participants, different protocols for hip and wrist, and not the same individuals wearing both hip and wrist accelerometers. In a small feasibility study, 25 children wore Acticals on the hip, Polar Active accelerometers on the wrist, and Sensewear arm bands.[8] The authors found similar compliance for the wrist-worn Polar Actives (98%) and hip-worn Acticals (92%) compared to lower compliance with the Sensewear arm bands (28%). This was primarily a qualitative study and compliance was only assessed by parent report of removal. Thus it is not clear that compliance truly is higher with wrist rather than hip accelerometer placement. Further, studies with children have yet to test wrist-worn accelerometers in a practical intervention trial with multiple assessments.

In addition to compliance, the ability of wrist-worn accelerometers to assess physical activity outcomes in intervention trials is essential for practitioners and researchers considering the selection and placement of accelerometers. To date, the majority of studies using wrist-worn accelerometers have been validation studies conducted in laboratories[6,9,10] or for a short duration of free-living time[7] (including the Actiwatch,[5,7] Actigraph,[6] GENEA,[10] and Actical[9]). Despite differences between hip- and wrist-worn measures, several authors still concluded that wrist-worn accelerometers were sufficiently valid measures of physical activity intensity in children.[5-7] Particularly, wrist-worn accelerometers can be used to make relative comparisons or to rankparticpiants,[5-7] enabling use of wrist-worn accelerometers to measure intervention effects. Yet, no study has examined intervention effects using both hip- and wrist-worn accelerometers.

Importantly, the previous studies comparing hip- and wrist-worn devices have found large variation in the agreement of hip and wrist data between individuals[5,6,9] with potential systematic bias associated with individual characteristics such as activity levels.[5] It is currently unknown what other individual characteristics may contribute to poor correlations between hip- and wrist-worn accelerometers. Identifying characteristics of people with high and low correlations between hip- and wrist-worn accelerometers will assist practitioners and researchers in selecting devices appropriate for specific study populations.

Thus, the purpose of this study was to examine the use of both hip- and wrist-worn Actical accelerometers worn simultaneously during an intervention trial. Compliance and outcome results were compared between the hip- and wrist-worn devices during an active video game condition, traditional sedentary video game condition, and no video game condition. Additionally, characteristics of individuals with high and low minute-by-minute correlations between hip and wrist data were explored.

Methods

Study Design and Participants

This study was part of a larger crossover clinical trial (Australia and New Zealand Clinical Trials Registry (ACTRN 12609000279224)) to test the effectiveness of a home based active video games intervention.[11,12] Participants (n=73, aged 10 to 12 years), were randomly assigned to the order in which they participated in three 8-week conditions at home: active video games, traditional non-active video games, and no electronic games. They were assessed at baseline and at the end of each of the three conditions for a total of 4 assessments. All parents provided informed written consent and the study was approved by the Curtin University Human Research Ethics Committee approval number HR131/2006.

Measures

Participants simultaneously wore two omni-axial Actical (Respironics; Bend, Oregon, USA) accelerometers initialised on the same computer, one on their right hip and the other on their non-dominant wrist. In pilot investigations we found clock drift over several weeks to be very minimal and highly unlikely to result in meaningful changes in accelerometer counts accumulated over 15 second epochs, as used this study. Participants and parents were instructed that children should wear both the devices during waking hours for 7 days and to remove the devices for water activities. Participants were instructed to record when the accelerometer was put on and taken off each day. Data were recorded in 15 second epochs.

Children reported tasks in 30 minute blocks using a modified diary version of the previous-day physical activity recall (PDPAR) for the 7 days while wearing the accelerometers.[13] Tasks were summed into those that would likely be sedentary with wrist movement (included playing a musical instrument, computer for homework, computer for social, computer games, electronic games, handheld games, board games, and crafts) and a separate category for whole body movement sports tasks (included school sport, recess, school/club sport, ball games, playing outside, martial arts, trampolining, athletics/gymnastics, skateboarding/roller skating, jogging, and cycling). Height and weight were measured by research staff and age-specific BMI z-score percentiles were calculated.[14]

Data Processing

There is no consensus for accelerometer processing, thus best practice evidence was used.[1,15,16] Data were screened for counts greater than 20,000, of which none were found. The accelerometer data were processed using a custom designed LabView program. The parent reported daily start-wear and stop-wear times were incomplete and unreliable thus weartimes were identified for each individual assessment by visual inspection of graphed activity of concurrent hipwrist assessments. One-hundred and twenty minutes of consecutive zeros were used to conservatively identify non-weartime, as we have previously found valid periods >90 minutes of non-consecutive weartime for hip accelerometer wear in children (unpublished data). Using a shorter duration of consecutive zeros may bias weartime towards the wrist as shorter durations would be more likely to exclude true sedentary hip worn data. However, 60 minutes of consecutive zeros were also analysed and the compliance findings were confirmed. Two criteria for compliance were evaluated based on previous literature: at least 3 weekdays and 1 weekend day of 10 or more hours,[17] and at least 3 days of at least 8 hours.[18] Compliance was defined as the percentage of participants in the study who had valid accelerometer data according to these two sets of criteria.

Minutes in each intensity level were calculated using validate cutpoints for hip (Evenson) [19] (light >44, moderate >2028, vigorous >2872 counts per minute) and wrist (Schaefer) (light >208, moderate >1552, vigorous >4844 counts per minute).[20] A sensitivity analysis using Colley cutpoints[21] was performed.

Statistical Analysis

To compare compliance between hip and wrist, wear descriptive statistics were calculated for number of valid days worn and mean weartime per day. T-tests were used to compare the percentage compliance and average weartime for hip and wrist at each time point.

To compare intervention outcomes from hip- and wrist-worn Acticals, moderate-to-vigorous physical activity (MVPA) and sedentary time were included as dependent variables in separate models. To be included in the analysis, participants needed to have sufficient/valid data (3 days with at least 8 hours) for at least two of the three conditions (n=63 for hip and n=62 for wrist). To account for the repeated nature of the data (4 timepoints), linear mixed models with individuals as a random factor, adjusted for weartime and order of conditions, were used. The maximum likelihood method estimates missing data based on all available information. Due to slight non-normality in the data, standard errors were bootstrapped with 500 replications. Individual *a priori* contrasts were made between the traditional video game condition and the two other conditions separately.

To explore differences in the hip- and wrist-data and to compare the differences by individual characteristics, the count per minute data files output from Actical software as minute-by-minute .csv files were matched between concurrent hip- and wrist- assessments using date and time codes. Data was aligned and visually checked that high peaks in both hip and wrist counts were aligned (and importantly were not slightly shifted) as high accelerations should be detected simultaneously in both the hip and wrist data. Seven assessments were eliminated due to device malfunctions that resulted in phase shifting that could not be corrected with a time-based realignment. To compare minute-by-minute consistency between hip and wrist for each participant at each time point intraclass correlations were calculated using counts per minute as a continuous variable. To explore the range of agreement between individuals, individuals were stratified into tertiles of agreement based on their mean ICC across the four timepoints. Individual characteristics were then compared between the highest and lowest tertiles of agreement using t-tests and chi-squared tests. These characteristics included the amount of reported wrist-based activities (playing a musical instrument, computer use, etc.) from the task diary, BMI, and overall levels of activity (n=67, includes all participants with valid accelerometer data). No adjustments were made for multiple comparisons and p-values are reported to three decimal places.

All analyses were conducted using Stata/IC 13.0 for Windows (StataCorp LP, College Station TX, USA).

Results

Compliance

The compliance ranged from 88-96% for hip and 89-96% for wrist using the 3 day compliance criteria to 76-87% for hip and 79-98% for wrist at using the four (one weekend) day compliance criteria. At each time point, there was no statistically significant difference between hip and wrist for compliance or weartime (Table 1).

Intervention Outcomes

There were no statistically significant differences in sedentary time between the three conditions (traditional video games, no video games, active video games) for either hip or wrist data. However, when testing *a priori* linear contrasts, during the no video game condition participants had higher counts per minute (mean difference of 64.3 counts per minute (95%CI 4.4, 124.3)) and higher MVPA(12 minutes per day, 95% 0.3, 23.7) than during the traditional video games condition, as seen in Table 2, but no significant differences with hip-worn data. The overall intervention findings were confirmed using the alternative cutpoints, while the absolute minutes in each intensity level differed.

Associations between characteristics of individuals and hip-wrist correlations

The mean ICC comparing minute-by-minute counts between hip and wrist was 0.64 (SD 0.13, 95%CI: 0.39, .82). Individuals in the lowest ICC tertile were older (11.5 years vs 11.0 years), had a higher percentage of females (73.9% vs 36.4%), higher BMI (difference of 2.4 kg/m^2, 95%CI: 1.2, 3.7), higher BMI percentile (11.3%ile, 95%CI: 2.3, 20.2), higher self-reported minutes of wrist activities (215.3 minutes, 95%CI: 118.0, 312.6), higher sedentary minutes from the hip-worn Actical (30.5 minutes per day, 95%CI: 8.3, 52.6), and higher light activity minutes from the wrist (29.8 minutes per day, 95%CI: 11.3, 48.4), as seen in Table 3. Participants in the highest ICC agreement tertile had higher hip counts (168.4 counts per minute, 95%CI: 133.0, 203.8), higher minutes of moderate (5.6 minutes per day, 95%CI: 3.5, 7.7) and vigorous (20.6 minutes per day, 95%CI: 16.8, 24.4) activity from the hip-worn Actical and higher minutes of vigorous activity from the wrist-worn Actical (13.0 minutes per day, 95%CI: 8.2, 17.8).

Discussion

Overall, compliance was comparable for both hip- and wrist-worn accelerometers among children in the current study. Analysis of the hip and wrist data in accordance with current accelerometer data processing practices, resulted in slightly different intervention outcomes and the correlation between the hip and wrist data varied by individual characteristics.

The current study found similar compliance for hip- and wrist-worn accelerometers worn simultaneously by children participating in an intervention. This was in contrast to expectations and the limited previously available evidence. While Freedson and Sirard have reported higher compliance for wrist accelerometers in the NHANES study compared to previous generations of hip-worn data collections,[3] it is important to note that the NHANES protocol had also changed from wake only to 24 hr continuous wear, which may increase compliance.[22] The current study used a simultaneous wear protocol. Compliance may vary when the devices are worn separately and different age populations may have different preferences for placement of the monitors. Further studies are needed to confirm compliance differences among different aged populations and different study protocols.

Whilst the current study is a detailed elaboration of methodological issues, the ability of hip and wrist data to evaluate changes in response to interventions is of particular practical interest. Previously no differences in total day sedentary or MVPA were found using hip-worn accelerometer data from the intervention study referred to in this study[11] The small differences of less than one minute of MVPA per day between conditions from the hip-worn accelerometry are not likely to be meaningful for health. However, the data obtained from the wrist accelerometers suggested a difference of 10 to 12 minutes of MVPA between the traditional video games and the other two conditions, though only the no active video games condition was statistically significant. Being able to detect actual small, differences in MVPA such as 10 to 12 minutes found in the current study, may by important as these small differences have shown to have meaningful health implications,[23] though the exact amount of MVPA needed to achieve health benefits in children is unknown, especially as measured by wrist-worn accelerometers. Importantly, the creation of positive health behaviour habits during childhood that are carried into adulthood may be more meaningful than measurable health risk change in childhood. This finding in only wrist-worn accelerometer data could have been due to measurement characteristics of the device placement or characteristics of the intended physical activity task, i.e. active video games. However, MVPA was higher during both the no electronic game and active video games conditions (though not statistically significant), which would suggest the higher wrist activity was not specific to just wrist movements during active video game play. Therefore the differences between wrist and hip appear to be related to more fundamental differences in the precise construct each measures, wrist movement and hip movement. The relationships between these distinct constructs and health outcomes may therefore be quite different due to differences in energy expenditures.

As there were differences in the hip- and wrist-based outcomes for the overall group, we explored the consistency between hip and wrist minute-by-minute counts. While the overall correlation between hip and wrist counts per minute was moderate, there was large variation between individuals. In the current study, participants with higher consistency between hip- and wrist-worn accelerometers had unique characteristics. Thus, characteristics of the population may be important to consider when selecting accelerometer placement. For example, when measuring a highly active population, wrist-worn accelerometers may be more appropriate but hip-worn devices may be more appropriate to capture differences in a relatively sedentary population. Additionally, participants with higher agreement reported approximately 200 minutes less per week of “wrist” activities. These sedentary activities with wrist movements were likely classified as light or moderate activity by the wrist-worn accelerometer, but sedentary by the hip-worn device.

One limitation of the current study is that only basic methods were used to classify hip and wrist intensities from accelerometer counts from essentially a single axis of movement. However, this is still the most common method of accelerometer data processing and is thus appropriate in this practical example. Advanced methods such as pattern recognition utilizing higher sampling rates in three planes of movement may be useful to better characterise the complexities of accelerometry[24,25] and thus facilitate better intensity agreement. However, pattern recognition may be difficult in free-living conditions due to the large variety of tasks within and across populations. Additionally, as pattern recognition advances, cutpoint methods may still be relevant to make comparisons to the large amount of health and prevalence data collected historically, such as the recent NHANES population norms for minutes based on hip-worn accelerometers.[26] This study applied the same weartime criteria to both hip and wrist (120 minutes consecutive zeros) which has yet to be validated in both hip and wrist. However, 120 is a conservative estimate that would underestimate differences in weartime as it is less likely to inaccurately remove true sedentary time in the hip as non-wear. It may overestimate wrist weartime by not removing non-weartime shorter than 120 minutes, but these shorter bouts of non-wear are less likely to influence overall daily compliance. In the current study, participants were a relatively small and homogenous sample thus findings may not be widely generalizable. The strengths of the current study included identical protocols for hip and wrist wear and assessment at multiple timepoints.

Conclusion

Hip- and wrist-worn accelerometers had similar compliance among children participating in a crossover intervention trial. Using hip- or wrist-worn accelerometers may lead to different conclusions from an intervention. Individuals may have poor correlations between hip- and wrist-worn devices making wrist-worn accelerometers less appropriate for measuring physical activity and sedentary behaviours.

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Table 1: Compliance for hip-worn and wrist-worn accelerometers using two weartime criteria (A and B). Data are mean (SD) or %.

		Time 1	**Time 2**	**Time 3**	**Time 4**
	N in study	75	66	66	66
Criteria A: Valid assessments with at least 3 days of hip & 3 days of wrist (8 hr days)					
Hip	Percent compliant	96	92	88	92
	N hip only	1	0	1	4
	Days Worn	7.3 (1.5)	7.2 (1.9)	7.0 (1.7)	7.4 (1.8)
	Mean weartime (min/day)	801.2 (72.4)	795.3 (79.9)	803.6 (80.6)	805.1 (76.1)
Wrist	Percent Compliant	96	95	91	89
	N wrist only	1	1	3	2
	Days Worn	7.4 (1.8)	7.1 (1.8)	7.3 (1.6)	7.5 (1.6)
	Mean weartime (min/day)	816.2 (72.3)	814.3 (1.8)	816.4 (79.5)	819.8 (78.2)
p-value	*% compliance*	*1.000*	*.859*	*.856*	*.857*
	weartime	*.228*	*.118*	*.399*	*.228*
Criteria B: Valid assessments with at least 3+1 days hip and 3+1 days of wrist (10 hr days)					
Hip	Percent Compliant	87	79	76	77
	N hip only	2	1	1	4
	Days Worn	7.0 (1.6)	7.4 (1.6)	7.1 (1.6)	7.3 (1.7)
	Mean weartime (min/day)	825.8 (59.0)	822.7 (58.8)	833.0 (57.4)	835.7 (58.5)
Wrist	Percent Compliant	89	83	82	79
	N wrist only	4	4	5	5
	Days Worn	7.1 (1.9)	7.2 (1.8)	7.3 (1.4)	7.4 (1.5)
	Mean weartime (min/day)	837.7 (60.0)	837.6 (59.8)	841.7 (61.0)	848.2 (56.4)
p-value	*% compliance*	*.897*	*.799*	*.699*	*.897*
	weartime	*.228*	*.241*	*.296*	*.219*

Table 2: Estimated mean (SE) minutes per day of sedentary and MVPA time in each intervention condition from linear mixed models adjusted for condition order and weartime (Sedentary and MVPA) using compliance criteria of at least 3 days of 8hrs

Outcome		**Traditional Video Games**	**Active Video Games**	**No Video Games**	**Overall p-value**
Counts per minute	*Hip*	373.6 (7.7)	367.8 (8.0)	371.7 (7.6)	.890
	Wrist	906.1 (18.8)	956.9 (17.2)	970.4 (23.4)*	.072
Sedentary (minutes per day)					
	Hip (Evenson)	443.5 (4.6)	449.9 (4.1)	441.2 (4.9)	.382
	Wrist (Schaefer)	237.6 (5.9)	235.9 (5.0)	235.7 (5.5)	.969
MVPA (minutes per day)					
	Hip (Evenson)	39.3 (1.2)	40.0 (1.4)	39.9 (1.4)	.921
	Wrist (Schaefer)	135.8 (3.6)	145.5 (3.5)	147.8 (4.5)*	.083

*Differences in *a priori* contrast from traditional video game condition p<.05

Table 3: Comparison of individual and activity factors between individuals with lower and higher hip- and wrist- worn accelerometer agreement (mean (SD) or %)

	Lowest Tertile of ICC agreement (SE) (n=23)	Highest Tertile of ICC agreement (SE) (n=22)	p-value (t-test or chi-squared)
Mean ICC	.53 (.006)	.75 (.004)	<.001
% female	73.9	36.4	<.001
Age at baseline (years)	11.5 (0.1)	11.0 (0.1)	<.001
BMI (kg/m^2)	20.2 (0.6)	17.7 (0.3)	<.001
BMI percentile	59.3 (3.2)	48.1 (3.2)	.014
Minutes of "Wrist Activities"/week[a]	410.2 (41.5)	194.9 (27.0)	<.001
Minutes of "Sports Activities"/week[a]	600.5 (40.2)	548.4 (54.1)	.442
Hip Counts/day	287.6 (8.8)	456.1 (16.5)	<.001
Wrist Counts/day	874.4 (27.3)	963.0 (27.1)	.024
Hip -minutes/day			
Sedentary	465.2 (8.2)	434.7 (8.2)	.007
Light	304.5 (6.9)	298.5 (6.6)	.540
Moderate	14.4 (0.7)	20.0 (0.8)	<.001
Vigorous	11.8 (0.6)	32.4 (2.0)	<.001
Wrist -minutes/day			
Sedentary	237.7 (74.2)	252.9 (70.2)	.188
Light	421.0 (57.7)	391.1 (60.4)	.002
Moderate	125.0 (46.3)	116.2 (35.5)	.176
Vigorous	11.4 (14.7)	24.4 (15.6)	<.001

[a] the minutes of "wrist" and "sport" activities were self-reported