Discrepancies in accelerometer-measured physical activity in children due to cut-point non-equivalence and placement site.

Running title: Accelerometer cut-points and placement site

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Abstract

This study examined dissonance in physical activity (PA) between two youth-specific hip-derived cut-points for the Actiwatch (AW), and compared PA between hip and wrist placements using site-specific cut-points. Twenty- four children aged 11.2 ± 0.5 years wore AW on the right hip and non-dominant wrist during a typical school day. Minutes of sedentary behaviour (SB) and vigorous activity (VPA) were greater using Puyau et al. (2002) cut-points, but light (LPA), moderate (MPA), and moderate-to vigorous (MVPA) were lower when derived using Puyau et al. (2004) cut-points ($p<0.01$). Total hip activity counts were lower than wrist. Minutes of SB were greater at the hip. Minutes of LPA, VPA and MVPA were lower at the hip ($p<0.01$). MPA was greater at the hip, but differed only when applying the Puyau et al. 2004 cut-points ($p<0.01$). In conclusion, data comparisons between two hip derived AW cut-points and between hip and wrist data are inappropriate. Future researchers using the AW at the hip should present data reduced using both published cut-points. As hip and wrist data differ, the wrist placement is preferable as it will likely increase children's compliance to monitoring protocols due to reduced obtrusiveness compared to the hip.

Keywords: Body Site, Motion Sensor, Intensity Thresholds, Participant Compliance, Actiwatch.

Introduction

Accelerometers are widely used to objectively measure the frequency, intensity and duration of physical activity in children (Trost, 2007). Accelerometer validity is examined by correlating activity counts against energy expenditure or direct observation (Sirard et al., 2005; Mattocks et al., 2007). To give biological meaning to the raw accelerometer output, end-users typically value calibrate accelerometers by creating regression equations to describe the relationship between proprietary activity counts and energy expenditure (Freedson, Pober & Janz, 2005). Cut-points to discriminate between intensity categories have been established using these regression equations (Mattocks et al., 2007), as well as receiver operating characteristic curves (ROC) and decision boundary methods (Jago, Zakeri, Baranowski, & Watson, 2007).

The Actiwatch accelerometer has been validated against direct observation (Finn & Specker, 2000) and energy expenditure (Puyau, Adolph, Vohra & Butte, 2002; Puyau, Adolph, Vohra, Zakeri & Butte, 2004; Ekblom, Nyberg, Ekblom Bak, Ekelund, & Marcus, In Press) in children. To date three sets of youth-specific Actiwatch cut-points have been published (Puyau et al., 2002; Puyau et al., 2004; Ekblom et al., In Press). It is well acknowledged that the existence of multiple cut-points for an accelerometer device hinders comparison between studies (Guinhouya et al., 2006; Cliff & Okely, 2007; Guinhouya, Lemdani, Vihelm, Durocher, & Hubert, 2009; Guinhouya, Hubert & Zitouni, 2011; Trost, Loprinzi, Moore & Pfeiffer, 2011). Numerous studies have reported differences in activity estimates using multiple cut-points (Guinhouya et al., 2006; Cliff & Okely, 2007; Guinhouya et al., 2009; Bornstein et al., 2011; Trost et al., 2011), this has been termed *'cut-point non-equivalence'* (Bornsetin et al., 2011). Currently no studies have examined the extent of non-equivalence between the two hip developed cut-points for the Actiwatch (Puyau et al., 2002; Puyau et al., 2004).

Whilst the Actiwatch is intended to be used as a wrist-worn device, it has been value calibrated at right hip (Puyau et al., 2002; Puyau et al., 2004), lower right leg (Puyau et al., 2002) and non-dominant wrist (Ekblom et al., In Press) placement sites. Potential placement differences in accelerometer output have been examined between the hip and lower back in children (Nilsson, Ekelund, Yngve, & Sjostrom, 2002) and adults (Yngve, Nilsson, Sjostrom & Ekelund, 2003). In adults, Kumahara, Tanaka & Schutz. (2004) reported greater accelerometer output (Lifecorder) at the waist compared to wrist during treadmill walking, but greater wrist derived estimates during mixed static/dynamic lifestyle activities. Similarly, Esliger et al. (2011) observed comparable wrist and hip derived acceleration output during ambulatory activities but not lifestyle activities, when calibrating the GENEA accelerometer in adults. Currently no studies have explicitly examined differences in accelerometer output between wrist and hip placement sites when using site specific cut-points, both in adults or children.

Therefore the purpose of this study was two-fold: 1) to examine the degree of dissonance in physical activity between two published youth-specific cut-points for the Actiwatch, and 2) to compare physical activity estimates derived from hip and wrist placement sites using placement specific cut-points in children.

Participants

Twenty four Year 6 children (boys: n = 15; height: 141.9 ± 8.1 cm; weight: 37.8 ± 9.5 kg; BMI: 18.6 ± 3.3 kg.m^2; girls n = 9; height: 141.6 ± 6.5 cm; weight: 36.9 ± 7.6 kg; BMI: 18.4 ± 3.5 kg.m^2) aged 11.2 ± 0.5 years were recruited from three primary schools in the West Midlands region of England. The experimental protocol received institutional ethics committee approval and written parental consent and child assent was obtained.

Instrumentation

Actiwatch 4 Accelerometer (AW)

The AW4 is a small (37 x 29 x 10 mm) wrist-worn accelerometer which weighs 16 g. It constitutes of a rectangular piezoelectric bimorph plate and seismic mass. It is omnidirectional but is most sensitive in the vertical direction. This technology detects the peak amplitude of movement acceleration and generates a transient voltage signal proportional to the rate of acceleration (Cambridge Neurotechnology, 2007). The raw digital voltage strings are converted to activity counts using an integration algorithm, with the peak count being selected for each individual second. Peak activity counts are integrated (and recorded) during a user-specified time interval (epoch), which ranges from 2 seconds to 15 minutes. The device has a sampling frequency of 32 Hz and collects motions in the frequency range of 0.5-7.0 Hz (Chen & Bassett, 2005; Cambridge Neurotechnology, 2008).

Procedure

All data were collected within the hours of 0930-1500 on a typical school day. Participants wore single AW4 units (Cambridge Neurotechnology Ltd., Cambridge, UK) on the right hip and on the non-dominant wrist as per the placement sites in the original calibration studies, between ~0930 to ~1430. The AW4 were set to record at 10 second epochs. Height to the nearest 0.1 cm was measured using a freestanding portable stadiometer (Seca 214, Seca ltd, Leicester, UK), and weight to the nearest 0.1 kg was measured using electronic weighing scales (HD 352, Tanita Corporation, Tokyo, Japan). Body mass index ($kg.m^2$) was calculated by dividing mean weight in kg by the square of mean height in metres.

Data Treatment and Statistical Analyses

Data were first imported into Microsoft Excel and the recorded condition start and end times were identified. The first and last 30 minutes of each unit's data was deleted as AW fitting and removal times were staggered across participants, leaving raw data for a four hour period (1000-1400). Accelerometer counts derived from the right hip placement were converted into minutes of sedentary behaviour (SB), light (LPA), moderate (MPA), vigorous (VPA) and moderate-to-vigorous (MVPA) intensity activity using the cut-points of Puyau et al. (2002) and using the cut-points of Puyau et al. (2004). All variables derived using the Puyau et al. (2002) cut-points were marked with A e.g. $MVPA^{A}$, and all variables derived using the Puyau et al. (2004) cut-points were marked with B e.g. $MVPA^{B}$. Accelerometer counts derived from the non-dominant wrist placement were converted into minutes of SB, LPA, MPA, VPA and MVPA using the cut-points of Ekblom et al. (In Press), and marked with W e.g $MVPA^{W}$. The hip derived cut-points were published as 60 second thresholds (Puyau et al., 2002; Puyau et al., 2004); these were divided by 6 to create cut-points for 10 second data. The wrist cut-points (Ekblom et al., In Press) were published as 15 second thresholds and were divided by 15 and then multiplied by 10 to create cut-points for 10 second data. Original 'as published' and epoch adjusted cut-points are displayed in Table 2.

The data were then imported into SPSS for Windows Version 19.0 (SPSS Inc., Chicago, IL) for further analysis. Normality of all outcome variables was assessed using the Shapiro-Wilks test; no variables violated the normality assumption. A repeated measures ANOVA, with Bonferroni corrected pairwise comparisons, was used to determine differences in SB^{A}, SB^{B} & SB^{W}, LPA^{A}, LPA^{B} & LPA^{W}, MPA^{A}, MPA^{B} & MPA^{W}, VPA^{A}, VPA^{B} & VPA^{W} and $MVPA^{A}$, $MVPA^{B}$ & $MVPA^{W}$. A paired samples t-test was used to determine differences in total activity counts between the hip and wrist. Agreement between data derived using both hip cut-points was calculated as described by Bland and Altman (1986). The alpha level was set at $p<0.05$ for all tests.

Results

Descriptive characteristics for participants are displayed in Table 1. The cut-points used to derive activity intensity estimates are displayed in Table 2. Descriptive data for all activity intensity variables are displayed in Table 3.

The assumption of sphericity was violated for all outcomes ($p<0.05$). Greenhouse-Geisser corrected values are reported hereafter. There were main effects for SB ($F(1.2,28.0)=159.3$, $p<0.01$), LPA ($F(1.3,30.0)=36.5, p<0.01$), MPA ($F(1.1,25.2)=30.5, p<0.01$),VPA ($F(1.0,23.5)=128.8, p<0.01$), and MVPA ($F(1.1,25.3)=46.0, p<0.01$). Results of the pairwise comparisons are presented below.

Intensity cut-point comparison

From Figure 1, minutes of SB^A were greater than SB^B (Mean diff: 18.9 ± 6.0 mins.4hrs^{-1}, 95% CI: 15.8 to 22.1 mins.4hrs^{-1}, $p<0.01$), minutes of LPA^A were less than minutes of LPA^B (Mean diff: -8.9 ± 8.2 mins.4hrs^{-1}, 95% CI: -13.3 to -4.6 mins.4hrs^{-1}, $p<0.01$), minutes of MPA^A were less than MPA^B (Mean diff: -12.7 ± 4.5 mins.4hrs^{-1}, 95% CI: -15.0 to -10.3 mins.4hrs^{-1}, $p<0.01$), minutes of VPA^A were greater than VPA^B (Mean diff: 2.7 ± 1.4 mins.4hrs^{-1}, 95% CI: 1.9 to 3.4 mins.4hrs^{-1}, $p<0.01$) and minutes of $MVPA^A$ were less than $MVPA^B$ (Mean diff: -10.0 ± 3.6 mins.4hrs^{-1}, 95% CI: -11.9 to -8.1 mins.4hrs^{-1}, $p<0.01$).

The mean bias and 95% limits of agreement are displayed in Table 4. The Bland-Altman plot for MVPA is displayed in Figure 2. Mean bias was large for minutes of SB, LPA, MPA and MVPA. Inter-individual variation in bias was large for all variables, reflected by the wide limits of agreement.

Placement site comparison

Total activity counts at the hip were lower than counts registered at the wrist (Mean diff: -99230.4 ± 33458.0 cts.4hrs^{-1}, 95% CI: -113358.5 to -85102.4, t=-14.5, p<0.01).

Minutes of SB^{A} (Mean diff: 48.7 ± 15.6 mins.4hrs^{-1}, 95% CI: 40.5 to 57.0 mins.4hrs^{-1}, p<0.01) and SB^{B} (Mean diff: 29.8 ± 16.3 mins.4hrs^{-1}, 95% CI: 21.2 to 38.4 mins.4hrs^{-1}, p<0.01) were greater than SB^{W}. Minutes of LPA^{A} (Mean diff: -26.3 ± 16.9 mins.4hrs^{-1}, 95% CI: -35.3 to -17.4 mins.4hrs^{-1}, p<0.01) and LPA^{B} (Mean diff: -17.4 ± 18.8 mins.4hrs^{-1}, 95% CI: -27.3 to -7.5 mins.4hrs^{-1}, p<0.01) were lower than LPA^{W}. Minutes of MPA^{A} and MPA^{W} did not differ (Mean diff: 3.8 ± 11.3 mins.4hrs^{-1}, 95% CI: -2.2 to 9.8 mins.4hrs^{-1}, p=0.34) but MPA^{B} was greater than MPA^{W} (Mean diff: 16.5 ± 14.3 mins.4hrs^{-1}, 95% CI: 9.0 to 24.0 mins.4hrs^{-1}, p<0.01). Minutes of VPA^{A} (Mean diff: -26.2 ± 11.8 mins.4hrs^{-1}, 95% CI: -32.4 to -20.0 mins.4hrs^{-1}, p<0.01) and VPA^{B} (Mean diff: -28.9 ± 12.0 mins.4hrs^{-1}, 95% CI: -35.2 to -22.6 mins.4hrs^{-1}, p<0.01) were lower than VPA^{W}. Minutes of $MVPA^{A}$ (Mean diff: -22.4 ± 13.7 mins.4hrs^{-1}, 95% CI: -29.6 to -15.2 mins.4hrs^{-1}, p<0.01) and $MVPA^{B}$ (Mean diff: -12.4 ± 14.0, 95% CI: -19.8 to -5.0 mins.4hrs^{-1}, p<0.01) were lower than $MVPA^{W}$.

Discussion

The first aim of this study was to determine if any differences existed in physical activity estimates calculated from the two hip-derived published Actiwatch intensity cut-points. This is the first study to examine this measurement issue. Data from the present study showed that minutes spent sedentary and in VPA were greater when calculated using the Puyau et al. (2002) cut-points compared to the Puyau et al. (2004) cut-points. This results from the greater range in SB threshold (0-99 vs. 0-49 cts.min^{-1}), and lower VPA threshold (≥2200 vs. ≥2500 cts.min^{-1}) for the Puyau et al. (2002) cut-points. Conversely, minutes of LPA, MPA and MVPA were lower when derived using the Puyau et al. (2002) cut-points compared to the Puyau et al. (2004) cut-points. This results from the lower LPA threshold (50-699 vs. 100-899 cts.min^{-1}), and lower and greater ranging threshold for at least MPA (700-2499 vs. 900-2199 cts.min^{-1}) for the Puyau et al. (2004) cut-points.

The dependence of accelerometer data upon cut-points chosen has been well acknowledged in published literature (Cliff & Okely, 2007; Guinhouya et al., 2009; Bornstein et al., 2011; Trost et al., 2011). The difference in threshold values derived using the same accelerometer device on the same placement site can be attributed to a number of factors. Intensity cut-points are dependent upon the type of calibration activity used, age and maturational stage, gender, fitness level, leg length, and body composition of the sample (Freedson et al., 2005; Welk, 2005; Stone, Esliger & Tremblay, 2007) all of which can contribute to inter-individual variation in the relationship between activity counts and energy expenditure. Indeed Ekelund, Aman, & Westerterp (2003) found Actigraph counts ranged from ~400 to 2600 counts per minute for children walking at 4 km.h^{-1}.

The cut-points derived by Puyau et al. (2002) were established in a sample of 26 boys and girls aged 6-16 years, whereas Puyau et al. (2004) used 32 boys and girls aged 7-18 years. The calibration activities used to define intensity categories differed. For example to define

MPA Puyau et al. (2002) used Tae Bo exercises, playtime activities and treadmill walking (3.5-4 mph), whilst Puyau et al. (2004) used aerobics, ball toss games and treadmill walking (3.5-4 mph). Finally Puyau et al. (2002) derived cut-points by solving a linear regression equation for the corresponding PAEE, whilst Puyau et al. (2004) examined the sensitivity and specificity of various regression predicted cut-points using ROC analysis. Thus differences in sample demographics, calibration activities and analytical techniques will have contributed to the different intensity cut-point thresholds shown in Table 2.

The Bland-Altman analysis (Table 4) revealed poor agreement between hip cut-points for all intensity variables, bar vigorous intensity, which showed acceptable agreement. The 95% limits were large for SB, LPA, MPA and MVPA suggesting that the mean bias between the two cut-points could vary considerably between individuals. For example if 60 minutes of MVPA were calculated using the Puyau et al. (2004) cut-points, the corresponding Puyau et al. (2002) value could be anywhere between 36 to 64 minutes. Therefore not only is the bias statistically significant, but it is biologically meaningful as the minimal increase in MVPA required to lower odds of obesity in children is approximately 15 minutes (Ness et al., 2007). Further, a child classified as 'physically active' i.e. ≥ 60 mins MVPA per day (O' Donavon et al., 2010) by Puyau et al. (2004) cut-points has a high likelihood of being classified as 'inactive' (<60 mins MVPA per day) if reduced using the Puyau et al. (2002) cut-points, according to these 95% limits of agreement.

Recently, efforts have been made to equate cut-points in other accelerometer models using regression equations (Guinhouya et al., 2009; Bornstein et al., 2011). Guinhouya et al. (2009) modelled the bias in MVPA between cut-points at 100 cts.min^{-1} increments, with the increment as the predictor (x) and mean bias as the predictive variable (y), however this was focused on hypothetical Actigraph cut-points (3000-3900 cts.min^{-1}), not published cut-points. Bornstein et al. (2011) offered a more direct conversion to predict MVPA estimates between five commonly used Actigraph thresholds. No such studies have been attempted using the Actiwatch cut-points. Therefore due to the discrepancy highlighted by the present results it would be useful for future researchers using Actiwatch cut-points to present data using both sets of thresholds as recommended by Guinhouya et al. (2011). Further, there is an ongoing need for future Actiwatch calibration studies to be conducted in larger samples, using standardised protocols to ensure greater equivalence between intensity cut-points.

The second aim of this study was to determine if activity estimates from the hip were comparable to wrist data when using placement specific cut-points. Data was compared between the wrist and hip using the Ekblom et al. (In Press) and both Puyau cut-points respectively. Results showed that activity volume (total counts) and minutes of LPA, VPA and MVPA were greater at the wrist than at the hip for both Puyau cut-points. Interestingly SB was greater at the hip, likely as a result of the wrist placed device registering counts when seated (as a consequence of fidgeting or writing) during class time which would be expected to register lower counts at the hip (Kumuhara et al., 2004). Thus more LPA was registered at the wrist than the hip. This is reflected by the lower variability in activity counts observed between epochs (CVhip= 180% vs. CVwrist= 118%) at both wrist sites compared to hip sites i.e. less transitions from low to high counts and vice versa.

Whilst VPA was lower at the hip, the mean bias for MPA was small (3.8 ± 11.3 mins.4hrs^{-1}) between the hip and wrist when applying the Puyau et al. (2002) cut-points. The 95% confidence intervals (-2.2 to 9.8 mins.4hrs^{-1}) however suggest that this bias in MPA could be biologically meaningful for some individuals. Conversely, the bias was much greater (16.5 ± 14.3 mins.4hrs^{-1}) when applying the Puyau et al. (2004) cut-points. This differential bias reflects the difference in hip cut-points to define MPA. From Table 2, the Puyau et al. (2002) cut-points to define MPA (900-2199 cts.min^{-1}) are more closely aligned with the Ekblom et al. (In Press) cut-points (adjusted to 60 sec = 1048-1623 cts.min^{-1}), than the Puyau et al. (2004) cut-points (700-2499 cts.min^{-1}).

The difference in AW output between the hip and wrist is contributed to by numerous factors. Firstly, there is likely a greater acceleration signal at the wrist during sedentary behaviour (i.e. sitting/reclining; SBRN, In Press), mixed static/dynamic movements (e.g. playing catch), and the short bursts of intermittent high intensity activity (e.g. jumping, bounding and sprinting) which typify children's physical activity behaviour (Baquet, Stratton, Van Praagh & Berthoin, 2007). This assertion is supported in part by previous observations that the acceleration signal is stronger at upper limb sites compared to trunk placements during both sedentary activities and mixed static/dynamic lifestyle activities in adults (Kumuhara et al., 2004; Esliger et al., 2011). Further, there is the issue of sensor orientation, as accelerometer output is partly dependent upon the orientation of the piezoelectric sensor(s) (Welk, 2005). That is, the device should be aligned to the axis of movement it is designed to be most sensitive in (Esliger, 2011). The AW is an omnidirectional device, which although affected by motion in all planes, is most sensitive to vertical movement. When placed at the wrist in the present study the piezoelectric sensor was oriented in the vertical plane (most sensitive axis), however when placed at the hip, the sensor was aligned in the anterior-posterior plane, possibly resulting in an attenuated acceleration signal. Finally, the dissimilarity in placement-specific cut-points used to reduce data would have contributed to some of the placement differences, as shown by the differential hip-to-wrist bias observed when applying the two hip cut-points.

The choice of which placement site to use should be dictated by the magnitude of association between counts and physical activity energy expenditure (PAEE). Theoretically as the trunk accounts for the greatest mass of all body segments in motion during dynamic activities, hip derived counts should logically explain the greatest amount of variance in PAEE (Westerterp, 1999). However, Ekblom et al. (In Press) found a strong relationship between non-dominant wrist counts and PAEE using the AW4 (r^2= 0.72), similarly Esliger et al. (2011) reported high correlation coefficients between raw acceleration (GENEA accelerometer) and $V0_2$ for the left (r=0.86) and right wrist (r=0.83) placement in adults. These data suggest that wrist placed accelerometers are a valid alternative to hip placed units. The wrist placement is preferable as it is inherently less obtrusive than the waist; indeed placement at the wrist may enhance participant compliance and allow longer monitoring periods to be used (Esliger et al., 2011; Ekblom et al., In Press).

The short monitoring period (4 hours) is a limitation of this study. However as this period included classroom time (capturing sedentary behaviour and light activity) and recess time (capturing moderate and vigorous activity), and data were registered in each intensity category (see Table 3), it is unlikely relative difference results from a longer monitoring period would differ. The sample used in this study is relatively small and homogenous, yet this is the first data to highlight the identified measurement issues using the Actiwatch, and is similar in sample size to other accelerometer measurement issue studies e.g. Nilsson et al., 2002; Puyau et al. 2002. Future investigations into cut-point non-equivalence and placement site differences should therefore use larger and more heterogeneous samples. Further, the validity of epoch-adjusted cut-points is unknown, however their use is supported in previous published accelerometer work (McClain, Abraham, Brusseau, & Tudor-Locke, 2008; Edwardson & Gorely, 2010).

In addition both Puyau et al. cut-points were derived using the AW16, an earlier generation of the AW range. There are no hardware differences (i.e. raw sampling rate, dynamic range, frequency range etc.) between the AW4 and AW16 other than memory size however

(Personal communication Cambridge Neurotechnology Ltd), thus the cut-points are deemed applicable for both devices. The strengths of this study are that all findings are resultant from AW4 units that have been tested for intra-and-inter-instrument reliability in a mechanical laboratory setting, displaying both CV_{intra} and CV_{inter} of ~5% (Routen, Upton, Edwards & Peters, In Press). The attachment of AW4 units were randomised and thus differences seen in physical activity data between the hip and wrist placements can be attributed to kinematic, cut-point, and sensor orientation differences and not to artificial error intrinsic to the AW4 units themselves. In addition a short epoch (10 secs) was used to capture the data, which ensured that any acute differences between placement sites were not masked by time smoothing which could occur using a conventional 1 minute epoch.

Conclusion

In conclusion, comparisons in activity estimates between the two hip derived cut-points in the AW (Puyau et al., 2002; Puyau et al., 2004), and between hip and wrist derived data are difficult, and would be inappropriate/invalid. If using the hip placement future researchers using the AW should present data reduced using both published intensity cut-points. Ideally a larger sample value calibration using standardised activities would be conducted to create universal cut-points for this device. As hip and wrist data are not comparable, if measures of PAEE are not required, the wrist placement is preferable as it will likely increase children's compliance to extended monitoring periods as it is inherently less obtrusive than a hip placed device.

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Tables

Table 1. Descriptive characteristics of children (Mean ± SD)

	Boys (N=15)		**Girls (N=9)**		**Total (N=24)**	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age (years)	11.2	0.5	11.2	0.5	11.2	0.5
Height (cm)	141.9	8.1	141.6	6.5	141.8	7.4
Weight (kg)	37.8	9.5	36.9	7.6	37.5	8.7
BMI (kg.m^2)	18.6	3.3	18.4	3.5	18.5	3.3

Table 2. Epoch adjusted and original unadjusted published Actiwatch intensity cut-points

Cut-Points	**Duration**	**Sedentary**	**Light**	**Moderate**	**Vigorous**
Puyau et al. (2002)†	60 sec	0-99	100-899	900- 2199	≥2200
	10sec**	0-16	17-149	150-366	≥367
Puyau et al. (2004)†	60 sec	0-49	50-699	700-2499	≥2500
	10 sec**	0-7	8-116	117-416	≥417
Ekblom et al. (In Press)*	15 sec	0-79	80-261	262-405	≥406
	10 sec**	0-52	53-174	175-270	≥271

†Derived using right hip placement.*Derived using non-dominant wrist placement.
**Epoch adjusted.

Table 3. Physical activity intensity variables ($mins.4hrs^{-1}$) by cut-point and placement site (Mean ± SD)

Cut-Point	Placement	Sedentary	Light	Moderate	Vigorous	MVPA
Puyau et al. (2002)	Right Hip	132.6 ± 27.1*†	62.4 ± 15.8*†	33.2 ± 13.8*	11.8 ± 7.7*†	45.0 ± 19.4*†
Puyau et al. (2004)	Right Hip	113.7 ± 26.1$^{*\#}$	71.3 ± 16.8$^{*\#}$	45.8 ± 17.7$^{*\#}$	9.1 ± 6.6$^{*\#}$	55.0 ± 21.8$^{*\#}$
Ekblom et al. (In Press)	Non-Dominant Wrist	83.9 ± 22.2$^{†\#}$	88.7 ± 10.3$^{†\#}$	29.4 ± 8.2$^{\#}$	38.0 ± 14.3$^{†\#}$	67.4 ± 18.1$^{†\#}$

*Difference between Puyau et al. (2002) & Puyau et al. (2004). †Difference between Puyau et al. (2002) and Ekblom et al. (In Press). #Difference between Puyau et al. (2004) and Ekblom et al. (In Press). All p<0.01.

Table 4. Limits of agreement

Variable ($Mins.4hrs^{-1}$)*	Mean of two cut-points	Bias	95% Limits of agreement
Sedentary	123.1	18.9	7.1 to 30.7
Light	66.9	-8.9	-25.0 to 7.2
Moderate	39.5	-12.7	-21.4 to -3.9
Vigorous	10.5	2.7	0.0 to 5.5
MVPA	50.0	-10.0	-17.0 to -3.0

*A negative bias indicates that the Puyau et al. (2002) estimate was lower than Puyau et al. (2004).

Figures

Figure 1. Comparison of intensity minutes (Mean ± SD) between AW hip-derived cut-points (*p<0.01)

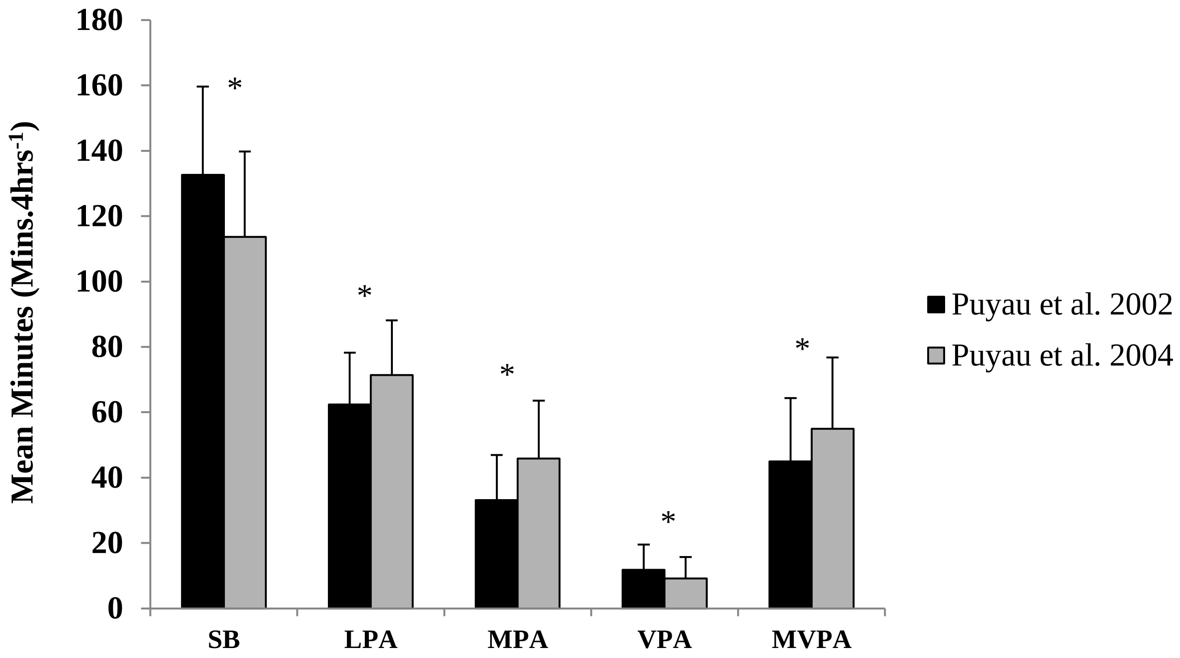

Figure 2. Bland-Altman plot showing mean difference (-10.0 ± 3.6 mins.4hrs^{-1}) and 95% limits of agreement (-17.0, -3.0 mins.4hrs^{-1}) between minutes of MVPA derived from Puyau et al. 2002 cut-points (MVPA^{A}) and Puyau et al. 2004 cut-points (MVPA^{B})