Title: Validity of wrist worn accelerometers and comparability between hip and wrist placement sites in estimating physical activity behaviour in preschool children.

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Short title: Validity and comparability of wrist worn accelerometers in preschoolers

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Abstract

Wrist-worn accelerometers can increase compliance with wearing accelerometers, however, several large scale studies continue to use hip- worn accelerometers and it is unclear how comparable data is from the two sites. The study aims were: to investigate agreement between wrist- and hip- worn accelerometers and to determine the validity of Johansson et al cut-points for wrist worn accelerometers in preschool children.

A sample of 32 preschool children (21 boys, 4.2 (0.5) years, BMI 16.6 (1.1)) were videoed wearing GT3X+ accelerometers on their wrist and hip while they engaged in 1 hour of free-play in their nursery. Children's activity were coded using, the Children's Activity Rating Scale (CARS): with CARS, level 1 'sedentary' and levels 2 to 5 were classified as time spent in TPA. Accelerometry data were processed using Johansson *et al* cut-points for the wrist data and Evenson *et al* cut-points for the hip data, into time spent in different intensities of PA. The mean counts per minute (cpm) from the hip and wrist were compared.

There was a strong correlation between the hip and wrist cpm (r=0.81, p<0.01) and total count data (r=0.83 p<0.01), however there was a large systematic bias with wide limits of agreement. Good agreement (mean difference (LOA) 1.1 (-9.9, 12.1) was found between the CARS estimate of TPA (29.5 (10.4) mins) and the wrist estimate, using the Johansson *et al* cut points (28.4 (9.8) mins). There was also a reasonable agreement between the hip estimates with the Evenson *et al* cut-points and Johansson *et al* estimate (mean difference (LOA):6.3 (-8.8, 21.4) mins.

In conclusion, the findings suggest that the Johansson *et al* (2013) cut-points applied to wrist worn accelerometers provides a valid estimate of TPA in preschool children and have reasonable agreement with Evenson *et al* cut-points applied to hip accelerometers.

Introduction

Declining levels of physical activity have been attributed to the dramatic increase in childhood obesity in the UK since the 1980s (Parsons *et al* 1999, Cox *et al* 2012) and while levels of obesity in child and adult populations have plateaued in recent years, it is maintained that resolving the childhood obesity ‘epidemic’ should remain a public health priority (Rokholm *et al* 2010).

The pre-school years (3 to 5 years of age) are argued to be one of the critical periods of childhood during which the long term regulation of energy balance may be programmed (Dietz 2001). This, together with the fact that lifestyle behaviours are thought to track from pre-school to childhood, and subsequently into adulthood (Biddle *et al* 2010, Malina 1996) means that the early years may be a critical time for promoting physical activity and preventing sedentary habits developing (Goldfield *et al* 2012).

Current recommendations for health are for pre-school children to undertake at least 180 minutes (3 hours) of daily physical activity which should include both light and energetic activities, such as running, swimming and skipping and that time spent being sedentary should be minimised (Department of Health, Physical Activity, Health Improvement and Protection 2011, Australian Government, Department of Health and Ageing 2010, Canadian Society of Exercise Physiology 2012, National Association for Sport and Physical Education 2009, National Institute for Health and Clinical Excellence 2009). The focus of these guidelines is for young children to achieve a daily amount of physical activity rather than being concerned with the intensity of that physical activity (Department of Health, Physical Activity, Health Improvement and Protection 2011).

The findings of population based studies, which have described levels and patterns of physical activity and sedentary behaviour in young children, are conflicting and have either reported that preschool children are highly sedentary (Hinkley *et al* 2012, Jackson *et al* 2003) and are not meeting physical activity recommendations (Hinkley *et al* 2012, Alhassan *et al* 2007, Okely *et al* 2009, Taylor *et al* 2009) or that they are meeting physical activity recommendations for health (Heelan and Eisenmann 2006, Janz *et al* 2002, Janz *et al* 2004, Martinez-Gomez *et al* 2009, Metallinos-Katsaras *et al* 2007, Obeid *et al* 2011, Telford *et al* 2005).

These inconsistencies between the findings of studies may be an artefact of the different measurement methods adopted and the variety of different methodological decisions used between studies. It is argued that there is a need for consensus on the methodological decisions which influence accurate quantification of physical activity in young children (Cliff *et al* 2009, Ojiambo *et al* 2011).

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Accelerometers offer an objective means of quantifying physical activity and hip worn accelerometers have been validated for use with preschool children (De Decker *et al* 2013, Adolph *et al* 2012, Pate *et al* 2006, Pfeiffer *et al* 2006, Hislop *et al* 2012). Accelerometers measure acceleration of the body part to which they are attached (de Vries *et al* 2009). It is argued that acceleration of the body is directly proportional to the muscular forces generated, which relates directly to energy expenditure (Freedson and Miller 2000) although their ability to accurately estimate energy expenditure in young children is questionable (de Vries *et al* 2006).

While several models of accelerometer are commercially available, to date the most frequently used accelerometer in studies of children has been Actigraph accelerometers (Actigraph, Fort Walton Beach, FL, USA) (de Vries *et al* 2009, Pate *et al* 2010, Trost *et al* 2011). One of the methodological decisions when using accelerometers is the decision over which position to place the accelerometer during data collection (Cliff *et al* 2009). Until recently, studies involving pre-school children have positioned Actigraph accelerometer over the hip during data collection. The rationale being that this attachment places the accelerometers close to the centre of body mass and aligns the sensitive axis with the vertical plane (Puyau *et al* 2002). However, a recognised limitation of hip worn accelerometers is that they are unable to take into account the increased energy expenditure which occurs with upper limb movements (Janz *et al* 2006) and as a consequence can underestimate activity (Cleland *et al* 2013). Following a review of the evidence, Cliff *et al* (2009) recommended the hip position for the placement of accelerometers during data collection. However, the authors acknowledged that evidence for the optimal position of accelerometers is limited and further investigation is required (Cliff *et al* 2009).

In recent years there has been growing support for positioning accelerometers at this wrist to take account of upper limb movement and in addition, it is argued that the wrist position will help to improve compliance with wearing accelerometers (Routen *et al* 2012). Good compliance with accelerometry wearing is essential in reducing drop-out of participants from large-scale population surveys so that the results are representative of a population’s activity levels (Rowlands *et al* 2014). As a consequence some large scale population based studies such as the NHANES study have moved to using wrist worn accelerometers as opposed to waist worn accelerometers (Rowlands *et al* 2014).

Johansson *et al* (2013) calibrated wrist worn accelerometers in toddlers aged 2-3 years and proposed 'cut-point' thresholds to classify accelerometer data into time spent in different intensities. The authors concluded that wrist worn accelerometers offer a feasible alternative placement site to the hip. However, what this study did not do was to compare accelerometer data collected at the wrist with accelerometer data collected from the hip and it is unclear if data collected at these two different placement sites are comparable. This is important as several on-going, large scale longitudinal accelerometry studies have been using and continue to use, hip worn accelerometers (Basterfield *et al* 2011, Mattocks *et al* 2010). Greater understanding of how accelerometry output compares, between hip and wrist position, is important to be able to make longitudinal comparison of physical activity behaviour using data which has already been collected, for example the International Children's Accelerometry Database, has 44,454 Actigraph data files, from 20 countries of children aged 3-18 years which have been collected using hip worn Actigraph accelerometers (Sherar *et al* 2011).

While other models of accelerometers have been calibrated for the wrist position in older children (Djafarian *et al* 2013) there is limited evidence of how the output compares with that of accelerometers worn at the hip. In one study, Routen *et al* (2012) compared the Actiwatch worn at the wrist against an Actiwatch worn at the hip in 24 children (mean ± SD:11.2±0.5 years). The authors found that accelerometer sites were not comparable with the volume of activity (activity counts) being greater at the wrist compared to the hip and with time spent in light, MVPA, and vigorous being higher with the wrist worn accelerometers. Ekblom *et al* (2012) explored indirect calorimetry as criterion method for energy expenditure in 22 children 8-10 years when comparing Actiwatch (worn on the wrist) against hip worn uniaxial 7164 Actigraph accelerometer and found while there was correlation in 'counts' between accelerometers there was a systematic difference observed such that the output from the accelerometers can not be used interchangeably. Rowlands *et al* (2014) found strong correlations between the wrist worn GENEActiv for average counts per day in a study of 58 children aged 10-12 years recorded over 7 days for time spent in sedentary behaviour and MVPA against waist worn GT3X+ for both vertical (uniaxial) and vector magnitude (triaxial) output. Finally, while Trost *et al* (2014), using pattern recognition approach to analysis of accelerometry data, concluded that the output from the wrist worn GT3X+ accelerometer performed as well as a hip worn accelerometer in 52 children (mean age 13.7 ± 3.1 year), other studies have reported inconsistencies in raw acceleration data between the wrist and hip during structured activities (Hildebrand *et al* 2014).

In summary, there is recent debate about whether wrist worn accelerometers instead of hip worn monitors may improve compliance (Routen *et al* 2012) as well as account for energy expenditure from upper limb movements. While the Actiwatch has been available for a number of years, the Actigraph GT3X+ is now available as a wrist worn monitor. Research is therefore needed to calibrate wrist worn accelerometers such as the GT3X+ and to explore the relationship of data from wrist worn accelerometers with data from Actigraph hip worn accelerometers. Studies which seek to understand how accelerometry output compares are important if there is to be any meaningful longitudinal analysis of physical activity and sedentary behaviour of populations over time.

The aims of this study were:

1) To investigate the relationship between wrist- and hip- worn Actigraph accelerometers output preschool children during free-play
2) To investigate the validity of the Johansson *et al* (2013) cut-points for wrist worn Actigraph accelerometers in preschool children aged 3-5 years.

Method

Data were collected from a convenience sample of 32 children aged 3 to 5 years recruited from pre-schools in Edinburgh (21 boys, 4.2 (0.5) years, height: 105.3 (6.1) cm, weight: 18.4 (2.6) cm, BMI 16.6 (1.1) kg/m^2), 90% of the sample were classified as ‘healthy’ weight and 10% as overweight/obese i.e. BMI at or above 85^{th} centile relative to UK population reference data (Cole 2002).

To recruit participants flyers were distributed to parents at the pre-school inviting their children to take part. Healthy children, aged between 3 to 5 years, were included. Children with any known neurological, respiratory or musculoskeletal problem, which would affect their mobility, were excluded (Hislop *et al* 2012). Prior to taking part, parental written informed consent and the child’s verbal assent to participate was obtained. Ethical approval for the study was granted from the host institution.

Children were video recorded while they engaged in 1 hour of free-play during their usual play-time in the nursery setting. In the nursery, children had access to an outdoor play area where they could play with outdoor toys including carts, scooters and balls. In addition, there was a climbing frame available. In an indoor area children had access to small tables and chairs where they could engage in drawing and crafts. There were books and small toys such as cars and building blocks on the floor, and children also had access to a sand box which was positioned approximately at the child’s waist height, so that the child was in a standing position while playing. During the video recording children could freely choose their activities and move between these. They were therefore able to engage in sedentary and light activities, in sitting and standing, as well as moderate to vigorous activities such as running, skipping, hopping and climbing. Each child wore two $GT3X^+$ accelerometers, one on an elasticated belt around their waist positioning the accelerometer over their hip in the mid-axillary line. A second $GT3X^+$ accelerometer was positioned on the participant's non-dominant wrist. Accelerometers were pre- set to record data in 1s epochs which was reintegrated into 5-s epochs.

The Children's Activity Rating Scale (CARS)(Puhl *et al* 1990) is a direct observation scale which is argued to be the 'gold standard' method of measuring physical activity behaviour in preschool children (Sirard *et al* 2005). Using the video data children's activity were coded using the CARS method adapted from the original study which used 1-minute sampling period to using a 5-s sampling period (Puyau *et al* 2002). This approach involved coding each child's activity on a scale of 1 to 5 depending on level of intensity of the activity and then averaging the score over the 5-s period. Similar to the original study each level of coding was only used once during a 5-s coding period. Researchers were trained in using the coding system using video examples and reliability between coders was assessed at the start and end of the data collection period using randomly selected 10 minute extracts of data. The intra-class correlation coefficient was found to be 0.96.

Table 1 outlines the codes used to classify the observed activities and these were averaged over the 5-second epoch. The intensity of the activity in each epoch was interpreted as outlined in the Johansson *et al* (2013) study whereby level 1, which included any sitting or reclined activities was classified as sedentary behaviour. Level 2, which included standing activities and level 3, which included slow walking, were grouped together and classified being low or light intensity physical activity. Finally, level 4 which included brisk walking, and level 5, which included running, were classified as high intensity physical activity. Similar to earlier studies with preschool children, activities at levels 4-5 were grouped together and classified as being part of MVPA (Hislop *et al*, 2012) and levels 2 to 5 were grouped together as part of 'total physical activity' (TPA).

Table 1: Children's Activity Rating Scale (CARS) 5-point scale to categorize intensity of physical activity.

Level 1:	Stationary/motionless
Level 2:	Stationary/movement of limbs or trunk (very easy)
Level 3:	Translocation (slow/easy)
Level 4:	Translocation (medium speed/moderate)
Level 5:	Translocation (fast or very fast/hard)

Puhl *et al* (1990)

The study took place in the preschools' outdoor and indoor play areas and cameras were set up to capture children as they moved between different areas. If a child was out of screen shot the 5-s epoch was excluded from coding and the corresponding accelerometer period was excluded. The cameras were synchronised with the PC set to internet time and the PC was used to initialise the Accelerometers.

The accelerometry count data were processed using the ActiLife software (ActiGraph, Pensacola, FL) applying cut-points to classify activity into time spent in sedentary behaviour, light intensity, moderate to vigorous (MVPA) intensity and total physical activity (TPA). As this study was interested in total physical activity the Johansson *et al* (2013) cut-points for TPA were applied to the wrist data (> 221 counts per 5 s) and the Evenson *et al* (2008) cut-points were applied to the hip vertical vector data (Y-Axis) to provide estimates of time spent in TPA (TPA^{Ev} > 8 counts per 5 seconds). The Evenson *et al* (2008) are frequently adopted in studies of preschool children and have been calibrated in children aged 5 - 9 years. The total counts from the hip vertical vector output and the vector magnitude (VM) output as well as the wrist vector magnitude output was collected.

Data were imported into SPSS (version 21) for analysis. Normality tests were conducted using the Shapiro-Wilks statistic as the sample was less than 50. All data was found to be normally distributed ($p>0.05$).

Correlational analysis was undertaken to explore the association between the output from the hip and the wrist vector magnitude.

To assess the accuracy of the different accelerometry cut-points as an absolute measure of physical activity, comparison was made between the number of minutes of sedentary behaviour, light intensity, MVPA intensity and TPA as estimated by the different cut-points, applied to accelerometers worn at the wrist and hip and then compared with the estimates as determined by the CARS criterion measure of direct observation. The Bland and Altman approach was used to examine the relationship between the minutes estimated using the cut-points and the estimates using the criterion measure (Dale *et al* 2000).

Results

An average of 36 (11.2) minutes of accelerometer data was recorded and from this a total of 13681, 5-second epochs were coded using the CARS. The mean VM cpm recorded at the wrist were 7222.1 (2224.8) cpm and at the hip were 2245.7 (852.3) cpm. The mean total counts from the accelerometers are presented in table 2.

Table 2: Mean total accelerometry counts

	Mean total counts	**(SD)**
Hip Y-Axis	41042.2	(26018.3)
Wrist VM	262098.0	(115496.7)
Hip VM	82685.8	(434339.0)

VM: Vector Magnitude

The mean VM cpm and the total VM counts from the wrist were significantly different from the mean cpm and the total counts recorded from the hip worn accelerometer ($p<0.5$) and it can be seen that the volume of data is higher when the accelerometer is positioned at the wrist, which is not unexpected given that upper limb movements are likely to increase acceleration output. Despite the significant difference in the VM total count output between the hip and wrist accelerometers these were significantly correlated $r=0.83$, ($p<0.01$) and the mean VM cpm from the wrist and hip were also correlated $r=0.81$, ($p<0.01$). However, as Figure 1 (i) and (ii) illustrate there was a large differences between the wrist and hip total count data and between the cpm data from the hip and the wrist with wide limits of agreement (mean (LOA), total VM counts: 179412.1 (23042.1,335782.1); cpm: 4976.4 (1809.4,8143.4)). It can also be seen in these plots that the discrepancy between sites increases as the physical activity level increases.

Figure 1 (i)

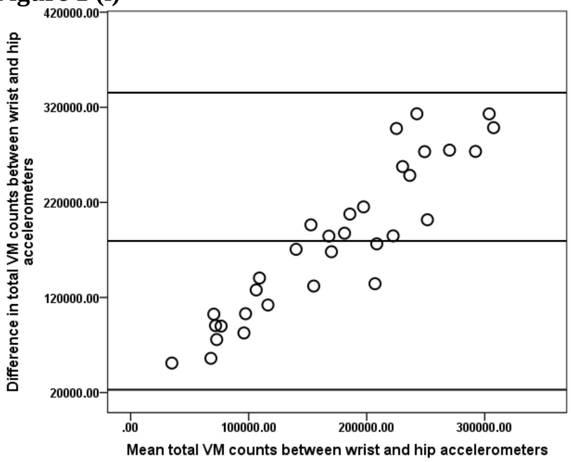

Figure 1 (ii)

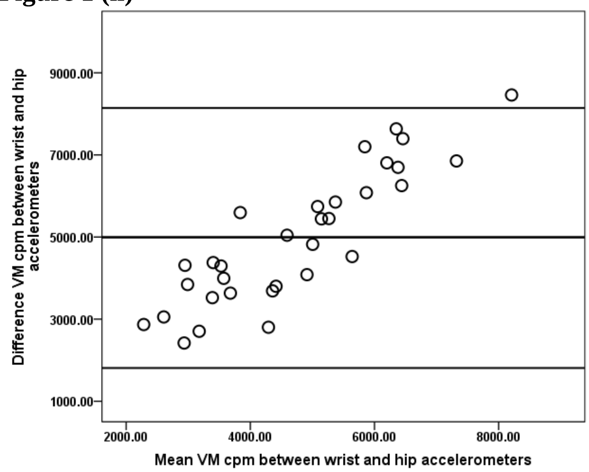

Figure 1: (i) Bland and Altman plot of total vector magnitude (VM) counts between wrist and hip worn accelerometers (ii) Bland and Altman plot of vector magnitude (VM) counts per minute (cpm) between wrist and hip worn accelerometers

Following the application of cut-points, the data on time spent in different intensities and in sedentary behaviour was calculated. The findings are presented in Table 3.

Table 3. Mean minutes (SD) of time spent in different intensities, comparing placement location, cut-points and triaxal and uniaxial output from accelerometers against CARS direct observation scale.

Mean minutes (SD)			
Intensity	CARS	Johansson *et al* (2013) Wrist, triaxial	Evenson *et al* (2008) Hip, unaxial
Sedentary	6.2 (5.8)	7.2 (3.9)	12.2 (7.2)
Light	27.3 (10.6)	16.9 (6.6)	17.2 (6.6)
MVPA	2.2 (2.2)	11.5 (6.3)	6.1 (4.5)
TPA	29.5 (10.4)	28.4 (9.8)	23.3 (9.8)

CARS, Children’s Activity Rating Scale. *MVPA*, moderate to vigorous activity; *TPA*, total physical activity.

It can be seen that there is variability in accelerometry estimates of time spent in the different intensities and in sedentary behaviour. While the wrist estimates of sedentary behaviour were similar to the CARS estimate, the hip position resulted in a greater estimate of time spent in sedentary behaviour.

The accelerometer estimates were greater for time spent in high or MVPA than was observed using the CARS. Data from the wrist worn accelerometer using the Johansson *et al* (2013) cut-points for MVPA is higher than the estimate from the hip worn accelerometer using the Evenson *et al* (2008) cut-point. Figure 2 illustrates the spread of the data plotting accelerometer estimates from the hip and wrist against the CARS for MVPA and for TPA.

Figure 2 (i)

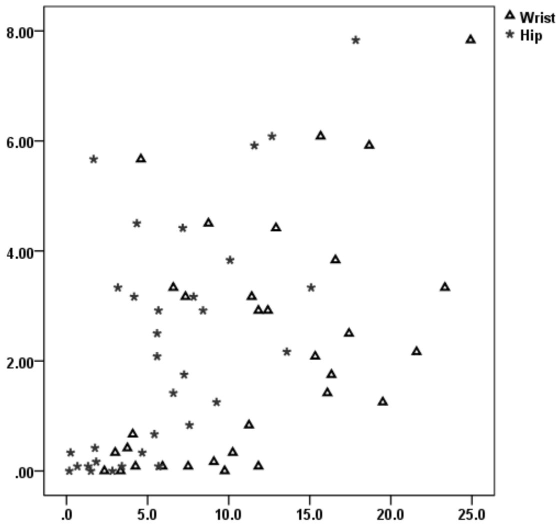

Figure 2 (ii)

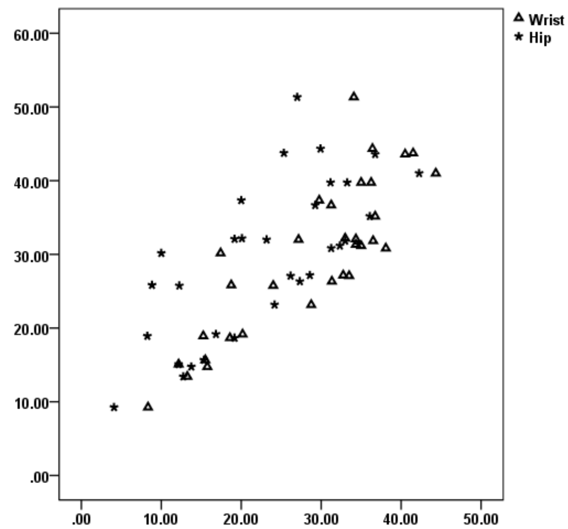

Figure 2: (i) CARS for time spent in MVPA (mins) plotted on y axis, against accelerometer estimates for wrist and hip (x axis). (ii) CARS for time spent in total physical activity (TPA) (mins) plotted on y axis against accelerometer estimate for hip and wrist (x axis).

The majority of the time spent in TPA was categorized as the child engaging in 'light' intensity physical activity. To further examine activities within TPA, the time spent in standing and in locomotion was determined. Standing was all activity coded as CARS level 2 and locomotion was all translocation activities (categorized as ≥ 3, including slow and fast walking). The time spent in these activities was then compared against the accelerometry estimates for the wrist and hip using the Johansson *et al* (2013) Evenson *et al* (2008) cut-points respectively and are presented in table 4.

Table 4 Time spent in standing and in locomotion, compared with accelerometry estimates from the wrist and hip worn accelerometers.

Activity	**Mean minutes (SD)**
Standing activities (CARS 2) (Puhl *et al* 1990)	20.0 (9.3)
Wrist 'low' intensity PA (Johansson *et al* 2013)	16.9 (6.6)
Hip 'light' intensity PA (Evenson *et al* 2008)	17.2 (6.6)
Locomotion activities (CARS ≥3), (Puhl *et al* 1990)	9.5 (5.5)
Wrist 'high' intensity PA (Johansson *et al* 2013)	11.5 (6.3)
Hip 'MVPA', (Evenson *et al* 2008)	6.1 (4.5)

CARS, Children's Activity Rating Scale. *MVPA*, moderate to vigorous activity; *PA*, physical activity.

To explore the agreement between the estimates and the CARS criterion method, mean differences and 95% limits of agreement were calculated between the CARS and the accelerometer estimates and are presented in table 5.

Table 5: Mean difference and 95% limits of agreement (LOA) between wrist and hip estimates and CARS for Total Physical Activity and for MVPA.

	Time (mins)	
	Mean difference	**95% LOA**
TPA CARS - wrist estimate (Johansson *et al* 2013)	1.1	-9.9, 12.1
TPA CARS - hip estimate (Evenson *et al* 2008)	6.3	-8.8, 21.4
MVPA CARS - wrist estimate (Johansson *et al* 2013)	-9.3	-20.0, 1.5
MVPA CARS – hip estimate (Evenson *et al* 2008)	-3.8	-10.7, 3.1
Locomotion CARS – wrist estimate 'high' (Johansson *et al* 2013)	-2.0	-9.4, 5.4
Locomotion CARS – hip estimate 'MVPA' (Evenson *et al* 2008)	3.4	-3.1, 10.0
Standing CARS – wrist estimate 'low' intensity (Johansson *et al* 2013)	3.1	-14.3, 19.9
Standing CARS – hip estimate light intensity (Evenson *et al* 2008)	2.8	-10.3, 16.4

CARS, Children's Activity Rating Scale. *TPA*, total physical activity; MVPA, moderate to vigorous activity, LOA, limits of agreement.

Using a repeated measures ANOVA revealed a significant difference between the cut-point estimates (p<0.01) and post-hoc analysis using a paired t-test revealed significant differences between each of the pairs of cut-point estimates (p<0.01). While a strong and significant correlation was found between the Evenson *et al*(2008) estimate from the hip worn accelerometry output and the Johansson *et al* (2013) estimate from the wrist worn accelerometry output for TPA (r= 0.9 , p<0.01), the mean difference and and limits of agreement were wide. This could suggest a systematic bias with the wrist accelerometer recording higher estimates physical activity in comparison to the hip worn accelerometer when the Johansson *et al* (2013) and the Evenson *et al* (2008) cut-points are used to process accelerometry count data collected from the wrist and hip respectively.

Good agreement was found between the CARS estimate of TPA (29.5 (10.4) mins) and the wrist estimate, using the Johansson *et al* (2013) cut points (28.4 (9.8) mins). In addition, there was good agreement between the CARS estimate for locomotion activities (9.5 (5.5) mins) and 'high' intensity PA as estimated by the wrist worn accelerometer using the Johansson *et al* (2013) cut-points (11.5 (6.3) mins). This findings are presented in Figure 3 (i) and (ii).

Figure 3(i)

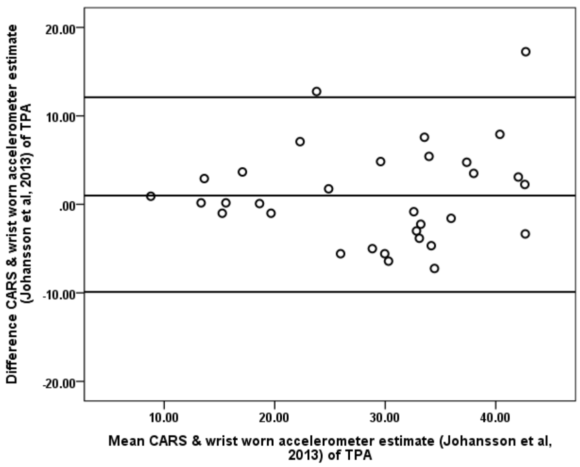

Figure 3(ii)

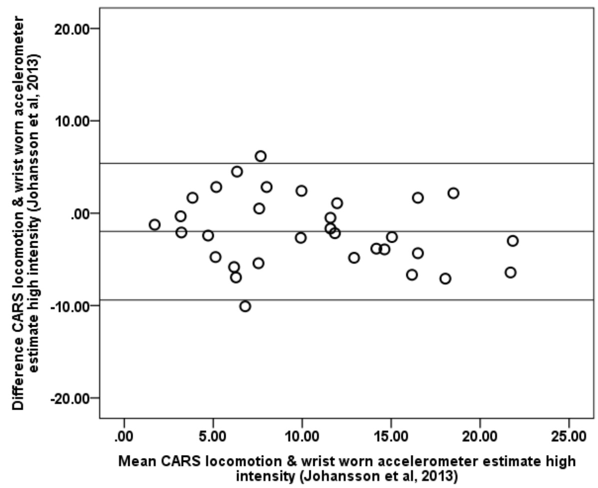

Figure 3:
(i) comparison between the CARS (Puhl *et al* 1990) wrist worn accelerometer estimate using the Johansson *et al* (2013) cut-point for total physical activity
(ii) comparison between the CARS (Puhl *et al* 1990) locomotion and the wrist worn accelerometer estimate for high intensity physical activity using the Johansson *et al* (2013) cut-points.

Discussion

The purpose of this study was to investigate agreement between Actigraph estimates of physical activity intensity and sedentary behaviour from wrist and hip-worn Actigraph accelerometers in preschool children during free-play. In addtion the study set out to investigate the validity of the Johansson et al (2013) cut-points for wrist worn Actigraph accelerometers in preschool children aged 3-5 years. The study found that the total VM count output and the mean VM cpm data collected from the wrist and the hip were significantly correlated ($p<0.01$), however a large and systematic difference, with wide limits of agreement were found between the hip and wrist data. Similar findings have been reported in studies which have involved older children and using other models of accelerometers (Routen *et al* 2012, Rowlands *et al* 2014, Ekblom *et al* 2012). There was good agreement between the CARS and the wrist worn Actigraph estimate of TPA when the Johansson et al (2013) cut-points were applied . There was reasonable group level agreement with the estimates from the hip when Evenson et al (2008) cut-points were used. Notably the agreement at the wrist using the Johannsson et al (2013) and the CARS was better than the hip position estimates when the Evenson et al (2008) cut-points were applied.

One of the outstanding methodological questions regarding accelerometry data processing and interpretation is how to transform the accelerometry count output into a biologically meaningful format (Cliff *et al* 2009). While one approach is to apply count thresholds, there is, however, a lack of consensus over which cut-points should be used (Kim *et al* 2012) and numerous cut-points for Actigraph accelerometers have been developed for children, including pre-school children. The application of different cut-points makes comparison between studies problematic, leading to conflicting conclusions about levels of sedentary behaviour, MVPA and total physical activity (TPA) and without agreement on cut-points it is difficult to ascertain whether children are meeting physical activity guidelines or not (Kim *et al* 2012, Beets *et al* 2011).

It is recognised that cut-points are specific to the sample from which they have been calibrated and these also depend on the protocol from which they have been developed (Mackintosh *et al* 2012). One example is the variability in processing and interpretation of the CARS in calibration studies of accelerometers with preschool children and in particular differences in the classification of sedentary behaviour. In the original CARS scoring system, there is no distinction made between sitting and standing and both these stationary activities, which are level 1 and 2 activities, are classified as being 'sedentary' (Puhl *et al* 1990). However, more recent consensus is that 'true' sedentary behaviour should be defined as sitting or reclining activities where the resting metabolic rate is typically $\leq$ 1.5 METS (Sedentary Behaviour Research Network 2012). Hence a modified CARS approach has been adopted in studies to make the distinction between sitting (level 1) and standing (level 2) activities, where standing is classified as a 'light' intensity and thus part of TPA (Johansson *et al* 2013). Researchers need to be aware that there may be variation in the interpretation of sedentary behaviour used in calibration studies utilising the CARS and this may contribute to differences in cut-point thresholds used to estimate sedentary time and time spent in TPA. Ideally, to compare physical activity estimates using accelerometers worn at the wrist and hip, it would be best to use cut-points developed from the same study (e.g. using the same sample and protocol). At present, this is not available and thus the cut-points applied in the current study are based on different populations and calibration methods. Despite this, the current study adds to our understanding of how estimates of physical activity compare from studies which have used hip and wrist worn accelerometers.

There was no clear agreement seen between time spent in MVPA with the CARS and the wrist worn accelerometry estimate for high intensity PA using the Johansson et al (2013) cut-points (mean difference

(LOA): -9.3, (-20.0, 1.5)). Similarly a difference was found between the time spent in MVPA using the CARS and the hip worn accelerometry estimate with the Evenson *et al* (2008) cut-points (mean difference (LOA): -3.8 (-10.7, 3.1)). However, there was better agreement was found for time spent in translocation or locomotion (including both slow and fast walking) using the CARS and the Johansson *et al* (2013) estimate for high intensity physical activity (mean difference (LOA): -2.0 (-9.4,5.4)). While the interpretation of what constitutes MVPA or high intensity PA needs careful consideration, the wrist worn accelerometer demonstrated good agreement with locomotion activities in this preschool population when the Johansson *et al* (2013) cut-points were applied.

To allow for standardisation in the assessment of physical activity between studies Bassett et al (2015) has argued for the reporting of total volume of activity counts per day (TAC/d). This would provide a more direct measure of physical activity and avoid the issues of applying different cut-point or algorithm to accelerometry data which can result in large apparent difference in physical activity outcomes (Beets *et al* 2011, Bornstein *et al* 2011). The findings of this study suggest that there are wide discrepancies between the volume of count data collected from the wrist and the hip. Given the differences of 184978.1(2114.4,367841.8) counts from 1 hour of data collection, it would be substantially higher over a longer period of data collection. However, these differences are not unexpected and indeed the higher wrist worn may help to capture more accurately total physical activity of preschool children. However, how this count data collected from the wrist relates to uniaxial Actigraph data already collected from the hip warrants further investigation, if trends or patterns in physical activity behaviour is to be explored over time.

There are a number of limitations in this study. The first is that this study was limited to 1 hour of observation of physical activity behaviour of children in a nursing setting. As such further investigation to compare wrist and hip accelerometry over a longer period of time, in day to day living, is important in gaining greater understanding of the relationship between monitor output. Secondly the CARS as a criterion measure has been questioned (Adolph *et al* 2012, Oliver *et al* 2007). Adolph *et al.* (2012) argues that while direct observation is critical for identification of type of activity; this method lacks precision in quantifying intensity levels and thus energy expenditure. Moreover, Oliver *et al.* (2007) argues that direct observation should be considered as a subjective method, as it relies on the observer to observe, interpret and code children's physical activity behaviour. Despite this, given the problems with interpreting energy expenditure in young children, observational methods offer a behavioural approach to calibration as an alternative. In addition, this approach is argued to be valuable in studies of young children, particularly if there is an interest in ‘type’ or ‘patterns’ of physical activity (Freedson *et al* 2005).

Another limitation of the study is that the data were collected in 1-s epochs and then re-integrated into 5-s epochs, in addition cut-points values which were validated for 60-s epochs (Puyau *et al* 2002) or for 15-s epochs (Evenson *et al* 2008) were divided into 5-s epochs and whether this creates errors in the data processing has been raised as a concern (Kim *et al* 2013).

With the availability of raw accelerometry data it has been argued that rather than reporting the ‘count’ output which, varies between the models of accelerometer and trying to convert this to a biologically meaningful format, future accelerometers should provide data in standardised units such as gravitational constant (G, m·s-2) or time-integrated units (m·s-1). This would allow for greater ease of comparison between accelerometry output between models. The use of raw accelerometry data instead of activity counts had been proposed for incorporation within a consensus statement at the 2009 ‘Objective Measurement of Physical Activity: Best Practice and Future Directions’ conference (John and Freedson 2012). One possible concern with using raw acceleration data is how to manage the raw acceleration data and convert this into a meaningful format for the ‘end user’ be it researcher or policy-maker. Advances have, however, been made in accelerometer data processing with the development of more sophisticated approaches to data modelling analysis (Bonomi *et al* 2009, Pober *et al* 2006, Staudenmayer *et al* 2009, Zhang *et al* 2003). This area warrants further investigation in studies of pre-school children to determine if this will offer an accurate means of classifying physical activity behaviour.

Although it is agreed that accelerometer placement has an effect on the measurement of bodily acceleration, there is still some debate over the ideal location of the sensor for particular applications (Cleland *et al* 2013). A strength this study, is that it is one of the few studies to explore the relationship between output from hip and wrist worn Actigraph accelerometers and to date the first exploring this in the preschool population. Greater understanding of this relationship is important for longitudinal comparison of physical behaviour over time. Finally, valid cut-points for wrist worn Actigraph accelerometers had not been previously established in this population.

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In conclusion, the findings of this study suggest that while the output from wrist and hip Actigraph accelerometers were significantly correlated but that there was large bias between the VM count data and the VM cpm data collected from the two placement sites. There was systematic bias with differences accentuated with the wrist higher total VM count and VM cpm data. There is reasonable agreement between the wrist and the hip estimates of TPA when Johansson et al (2013) is applied to the VM data collected at the wrist and the Evenson et al (2008) cut-points are applied to the uniaxial data at the hip. However, this warrants further investigation over a longer duration.

Finally, good agreement was found between the Johansson et al (2013) and a modified version of the CARS, where only sitting activities are classified as sedentary and standing activities were classified as part of 'TPA'. This suggests good validity for Johansson et al (2013) cut-points for wrist worn Actigraph accelerometers in preschool children aged 3-5 years at a group level.

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