

Comparison of Epoch and Uniaxial Versus Triaxial Accelerometers in the Measurement of Physical Activity in Preschool Children: A Validation Study

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The objectives of this study were to explore whether triaxial is more accurate than uniaxial accelerometry and whether shorter sampling periods (epochs) are more accurate than longer epochs. Physical activity data from uniaxial and triaxial (RT3) devices were collected in 1-s epochs from 31 preschool children (15 males, 16 females, 4.4 ± 0.8 yrs) who were videoed while they engaged in 1-hr of free-play. Video data were coded using the Children's Activity Rating Scale (CARS). A significant difference ($p < .001$) in the number of minutes classified as moderate to vigorous physical activity (MVPA) was found between the RT3 and the CARS ($p < .002$) using the cut point of relaxed walk. No significant difference was found between the GT1M and the CARS or between the RT3 and the CARS using the cut point for light jog. Shorter epochs resulted in significantly greater overestimation of MVPA, with the bias increasing from 0.7 mins at 15-s to 3.2 mins at 60-s epochs for the GT1M and 0 mins to 1.7 mins for the RT3. Results suggest that there was no advantage of a triaxial accelerometer over a uniaxial model. Shorter epochs result in significantly higher number of minutes of MVPA with smaller bias relative to direct observation.

Accurate methods of measuring physical activity are important for determining physical activity levels of populations and to gain insights into relationships between physical activity and health (16). Most accelerometry studies in preschool children to date have involved uniaxial accelerometers, but the accuracy of these studies has been called into question because uniaxial accelerometers are unable to detect movements in all three planes of movement (27). It would, theoretically, be preferable to use triaxial accelerometry rather than uniaxial accelerometry. However few studies have carried out formal comparisons of tri versus uniaxial devices

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(17,31). The only study conducted with preschool children was a comparison study of uniaxial with a biaxial accelerometer which found the uniaxial accelerometer to be more accurate (13). Furthermore, older accelerometry studies in preschool children have used 1-min sampling intervals (epochs), which it is argued may not accurately capture short, sporadic bursts of vigorous activity that are typical of young children (10). Although a number of formal comparisons of the effect of epoch on apparent levels of physical activity in children have now been published these have not focused specifically on preschool children (7,8,15). Moreover, conflicting observations have been reported for the few published investigations involving preschool children with Vale et al. (28) reporting a large difference of 17 min of daily MVPA between 5 and 60 s epochs and Reilly et al. (22) reporting a small difference between 15 and 60 s epochs, which they concluded may not be of biological or clinical significance.

The ability to accurately determine the amount of time spent in MVPA is further complicated by the existence of differing cut points used to classify intensity levels and depending on which cut points are used accelerometry can yield very different results (11). There is currently no consensus as to which cut points are most appropriate for preschool children (3).

Therefore, despite the widespread use of accelerometry to measure physical activity, important methodological questions remain unanswered for their use in preschool children (5,22). These include questions regarding whether triaxial accelerometers may be more accurate in capturing levels of physical activity and the appropriate epoch to use. The aims of the current study were therefore to:

1. Compare the accuracy of uniaxial versus triaxial accelerometers with preschool children during 1 hr of free-play, using direct observation as the criterion method.
2. Test the impact of epoch on accuracy of measurement of physical activity using direct observation as the criterion method.

Methods

A convenience sample of thirty one participants (15 males, 16 females, mean age 4.4 ± 0.8 yrs, height 104.8 ± 6.3 cm, weight 17.7 ± 2.5 kg, BMI 16.1 ± 1.1 kg/m²) was recruited from two preschools in Edinburgh, Scotland. Apparently healthy children, between the ages of three and five years, and who were attending Edinburgh City council preschools, were invited to take part. Children with any known physical problems which would affect their mobility were excluded from the study including neurological, respiratory and musculoskeletal problems. Before participation, written informed consent was obtained from parents and the child gave verbal assent to involvement. Ethical approval for the study was granted from the host institution's Research Ethics Committee. Funding for the study was obtained from the Physiotherapy Research Foundation, the charitable trust of the Chartered Society of Physiotherapy.

The Children's Activity Rating Scale (CARS; 19) is a direct observation scale which is a criterion measure of physical activity in preschool children (25). Puhl et al. (19) developed and validated the CARS against indirect calorimetry and heart rate, creating a 5-point scale for use with young children. Levels 1 and 2 represent

stationary activity with level 2 including movement of the limbs or trunk. Levels 3–5 are translocation activities, with level 3 representing slow/easy movement. Levels 4–5 represent moderate to vigorous intensity physical activity (MVPA), equivalent in the original study to at least 3 times the individual's resting energy expenditure. Using these levels of activity, Puhl et al. (19) scored each level of activity observed and lasting longer than 3 s within a 1 min period. Each level of CARS can only be used once within that minute and these scores are then averaged over the 1 min period to give a final score for that minute. In the current study an adapted CARS scale as used by Sirard et al. (25) was used whereby each activity observed and lasting longer than 3 s is scored once within a 15 s observation period. An averaged score is then calculated for each 15 s. The coding of 15 s interval from the CARS was undertaken to allow comparison with the 15 s epoch data collected from the accelerometers.

For the current study, during 1 hr of free-play within the nursery, children's physical activity was videoed and measurement was taken simultaneously from two accelerometers, the GT1M uniaxial model (ActiGraph, LLC, Walton Beach, Florida), and the RT3 triaxial model (Stayhealthy, Inc., Monrovia, CA). ActiGraph monitors have been validated and used extensively in studies with preschool children (18,25). The RT3 is slightly larger (71 × 56 × 28 mm) and heavier (65.2g) and measures acceleration in three orthogonal planes: anterior-posterior, medio-lateral and vertical. The RT3 was set to provide vector magnitude data which combines data from all three axis of motion. The RT3 has been validated for use in children (24,26). The raw data from both accelerometers are filtered and digitalised converting it to "activity counts" over a predefined period (epoch). These activity counts can then be compared against predetermined cut points for intensity levels. In the current study the epoch duration was set at 1 s.

During the testing sessions the children wore the GT1M on an elasticated belt around their waist. The RT3 was clipped to the waistband of the child's trousers or skirt. Accelerometers were positioned over the right hip in the midaxillary line at the level of the iliac crest. Two video cameras were positioned at opposite ends of the play area and were used to record the children's free-play activity during one hour of out-door playtime. Using the video data the children's activity was then continuously 'scored' for each 15 s by a single researcher using the adapted CARS (25). Data from the accelerometers were downloaded to an Excel spreadsheet and the 1-s epochs reintegrated into 15, 30, and 60 s epochs (8). Using a bespoke program the data were processed using predetermined age-specific cut points for MVPA activity intensity level, as validated with preschool children by Sirard et al. (25) for the Actigraph model 7164 (counts for MVPA for 3 yr olds > 615; for 4 yr olds > 812; for 5 yr olds > 3564 for 15 s epochs).

Several other MVPA cut points have been published for the Actigraph for young children, ranging from 368 cpm to 3200 cpm (Table 1) and the data were also processed using these cut points to allow cross comparison. In addition, one study has suggested that the GT1M accelerometry output is 9% lower than the earlier Actigraph model (MTI-7164; 6) and recommends applying a correctional factor when comparing models. More recent studies have concluded that the models can be used interchangeably showing good cross-validation (12,14) and so in the current study the correction factor was not applied to the GT1M data.

Table 1 Cut Points for the RT3 and Actigraph Accelerometers

Authors	Accelerometer model	Calibration method	Criterion measure	Criterion for MVPA intensity	Sample	MVPA, counts per 15s
Vanhelst et al. (30)	RT3	TM walk, run	VO ₂ (portable metabolic unit)	TM walk, run at ³ 3 km·h ⁻¹	n = 60 age range = 10–16 yr	³ 238
Rowlands et al. (24)	RT3	TM walk, run, other activities	VO ₂ (portable metabolic unit)	³ 3 METS	n = 19 mean age = 9.5 ±0.8 yr, Boys only	³ 243
Sun et al. (26)	RT3	Sit, cycle, TM walk, run, FL	VO ₂ (portable metabolic unit)	Walking relaxed Light jog	n = 25 indoor n = 18 outdoor, age range = 12–14 yr	WR ³ 413 LJ ³ 780
Chu et al. (4)	RT3	TM walk, run	VO ₂ (portable metabolic unit)	³ 3 METS	n = 35 age range = 8–12 yr	³ 465
Freedson et al. (10)	Actigraph	TM walk, run.	VO ₂ (portable metabolic unit)	³ 3 METS	n = 80 age range = 6–18 yr	³ yrs ³ 92 ⁴ yrs ³ 111 ⁵ yrs ³ 133
Pate et al. (18)	Actigraph	Rest, TM walk, run, FL	VO ₂ (portable metabolic unit)	TM brisk walking	n = 29 age range = 3–5 yr	³ 420
Evenson et al. (9)	Actigraph	Walk, run, other	VO ₂ (portable metabolic unit)	TM brisk walk, run ³ 3mph, dribble basketball, stair climbing, jumping jacks.	n = 33 age range = 5–9 yr	³ 574
van Cauwenberghie et al. (29)	Actigraph	TM walk, run, FL, walk.	CARS	Brisk walking ³ 4.8 km·h ⁻¹ . CARS score 3.1–4.0	n = 18 mean age = 5.8 ± 0.3 yr	³ 585
Sirard et al. (25)	Actigraph	Sit, play, walk, run	CARS	Fast walk, run ³ 4.3 ± 0.6 km·h ⁻¹	n = 16 age range = 3–5yr	³ yrs ³ 615 ⁴ yrs ³ 812 ⁵ yrs ³ 891
Puyau et al. (20)	Actigraph	Walk, run, FL	VO ₂ (room respiratory calorimetry)	TM walk, run at ³ 3.5mph (6–7 yr olds); 4.5 mph (8–16 yr olds). Moderate and vigorous free play activities	n = 26 age range = 6–16 yr	³ 800

MVPA- moderate to vigorous activity; TM- Treadmill; WR- walking relaxed; LJ- light jog; FL- Free-living; CARS- Children's Physical Activity Rating Scale

While there are several published cut points for the RT3 for older children (Table 1), many have been developed from validation studies which have used 3 METs as the threshold for MVPA. It is recognized that applying adult MET values may not be appropriate as children's resting metabolic rate are higher (23). Sun et al. (26) has validated cut points for several 'moderate' free-living activities including kicking and catching a ball, walking and jogging. Two cut points were selected for the current study: walking relaxed (RT3^{WR}; counts for MVPA > 413 per 15 s epoch) and light jog (RT3^{LJ}; counts for MVPA > 780 per 15 s epoch). Data processing were undertaken to allow cross comparison between minutes of MVPA resulting from the application of the different RT3 cut points.

To calculate the cut points for the shorter epochs, the 60 s cut points were divided by 60 then multiplied to calculate the cut points for 15, 30, and 60 s epochs, as undertaken in earlier studies (22).

Data were imported into SPSS version 17 for analysis. A Pearson's Correlation Coefficient was calculated to explore the relationship between the total counts for each accelerometer. Spearman's Rank correlation was calculated to determine if the different approaches provided a similar relative assessment of physical activity when compared against the CARS score. Using the Friedman's Repeated Measures Anova the difference between the number of minutes of MVPA recorded by each accelerometer model and direct observation at 15 s epochs was explored with post hoc analysis using the Wilcoxon paired *t* test. To reduce type I error a Bonferroni correction was applied so that the significance level was set at $p < .01$.

To assess the accuracy of the different accelerometer epochs and the two accelerometers for absolute measurement of physical activity, comparison was made between the number of minutes of MVPA recorded by the different accelerometers and their relationship with the criterion measure of direct observation using the Bland and Altman approach (2). To identify whether epoch lengths affected data interpretation, a repeated measures analysis of variance was used to analyze data from 1 s epochs reintegrated into 15, 30, and 60 s. Bland and Altman plots were calculated for 15- and 60-s epochs to explore their accuracy in classifying minutes of MVPA against the CARS at 15-s epoch.

Results

During the 1 hr of free-play, mean (*SD*) of total counts per minute (cpm) for the RT3 was 1544 (442) and for the GT1M was 1300 (476). There was a significant positive correlation ($r = .72$ $p < .001$) in the total counts between the RT3 and the GT1M. Spearman's rank correlations between accelerometry counts per minute (cpm) and percentage of time spent in MVPA as recorded by direct observation for the GT1M was $r = .56$ ($p < .01$) and for the RT3 $r = .39$ ($p < .03$).

The mean (*SD*) number of minutes classified as MVPA by CARS was 7.1 (7.0), while the mean MVPA by the GT1M ranged from 6.3 min (6.2) at 15s epoch to 3.8 min (6.0) at 60s epoch. For the RT3^{WR} mean MVPA ranged from 19.3 min (10.3) at 15s epoch to 20.7 min (12.4) at 60s epoch and for RT3^{LJ} mean MVPA ranged from 7.1 (6.9) at 15 s epoch to 5.3 (7.7) at 60s epoch. There was a significant difference in the number of minutes of MVPA between all epoch s ($p < .001$). Table 2 presents a summary of the mean and *SD* of minutes of MVPA at 15s epoch resulting from the application of the different published cut points.

Table 2 Comparison of Minutes of Moderate-to-Vigorous Activity as Classified by Cut-Points.

Authors	Accelerometer Model/ CARS	Minutes of MVPA Mean (SD)
Puhl et al. (19)	CARS	7.1 (7.0)
Vanhelst et al. (30)	RT3	30.3 (13.1)
Rowlands et al. (24)	RT3	29.9 (13)
Sun et al. (26)	RT3- WR	19.3 (10.3)
Sun et al. (26)	RT3- LJ	7.1 (6.9)
Chu et al. (4)	RT3	16.8 (9.8)
Freedson et al. (10)	Actigraph	32.0 (12.4)
Pate et al. (18)	Actigraph	15.8 (9.1)
Evenson et al. (9)	Actigraph	10.6 (7.2)
van Cauwenberghe et al. (29)	Actigraph	10.3 (7.2)
Sirard et al. (25)	Actigraph	6.3 (6.2)
Puyau et al. (20)	Actigraph	5.3 (4.4)

WR- walking relaxed; LJ- light jog; CARS - Children's Activity Routing Scale

Using the Friedman's Repeated Measures Anova there was a significant difference between the number of minutes of MVPA at 15-s epochs for the GT1M, RT3^{WR}, RT3^{LJ} and CARS score ($p < .05$). Post hoc analysis with Bonferroni correction revealed that there was a non significant difference between the number of minutes classified as MVPA using GT1M and the CARS, the GT1M and the RT3^{LJ}, and the RT3^{LJ} and the CARS ($p > .01$). There was however a significant difference between GT1M and RT3^{WR} and between RT3^{WR} and the CARS ($p < .01$).

Bland and Altman plots were undertaken to explore the agreement between number of minutes of MVPA, between the CARS criterion measure at 15-s and the GT1M, the RT3^{LJ}, the RT3^{WR}. Plots of the 15-s and 60-s epochs are presented in Figure 1 together with the 95% limits of agreement. The mean difference between the number of minutes recorded by the GT1M and direct observation (CARS category 4 and 5) was 0.8 min at 15-s epoch and 3.2 min at 60-s epoch. The mean difference for the RT3^{WR} was 12.2 min and 13.6 min, and for the RT3^{LJ} 0 min and 1.7 min for the 15-s and 60-s epochs respectively.

Discussion

The aims of the current study were to: compare the uniaxial and triaxial accelerometers to determine if triaxial accelerometers were more accurate in capturing physical activity levels of preschool children; and to examine the impact of epoch on accuracy of measurement of MVPA in preschool children. The study found no evidence that the triaxial RT3 accelerometer was more accurate than the uniaxial GT1M accelerometer and that shorter epochs were more accurate for absolute amount of MVPA.

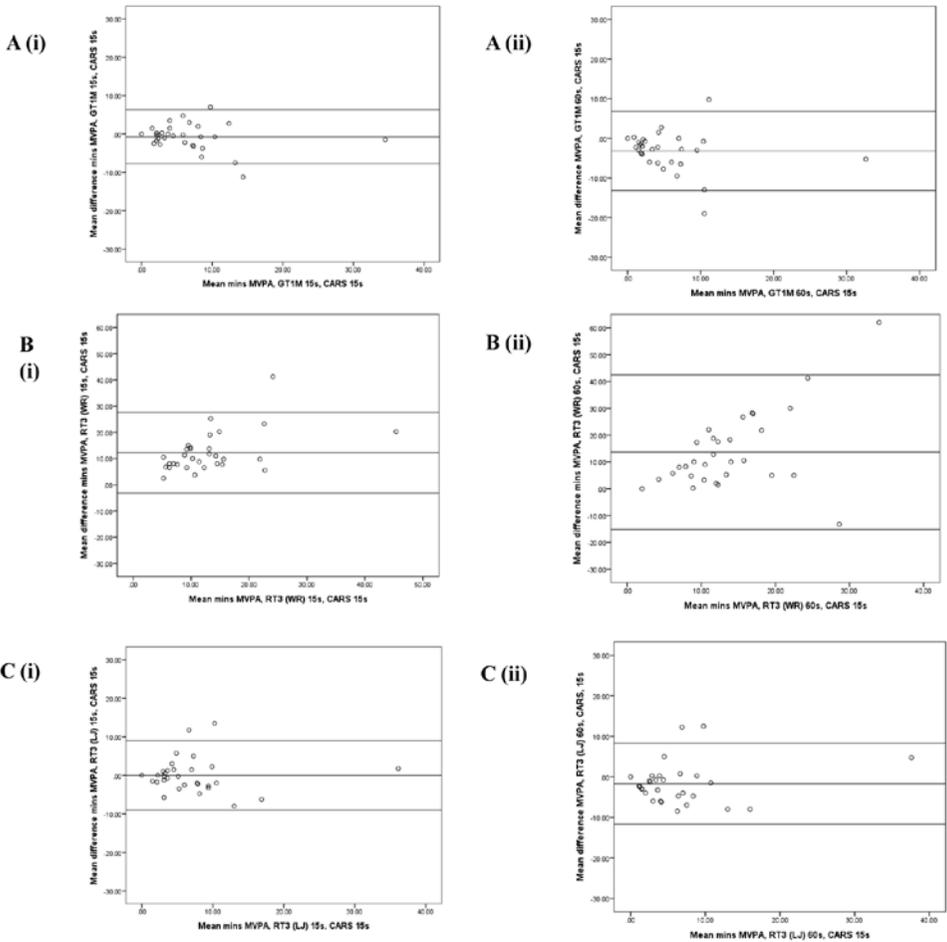


Figure 1 — Bland-Altman plot of the minutes of moderate to vigorous activity (MVPA). A (i) Between CARS and GT1M at 15-s epoch; A(ii) at 60-s epoch. B (i) Between the CARS and RT3^{WR} at 15-s epoch; B (ii) at 60-s epoch. C (i) Between the CARS and RT3^{LJ} at 15-s epoch; C (ii) at 60-s epoch. CARS- Children’s Activity Rating Scale; WR- Walking Relaxed; LJ- Light Jog. The lines indicate the mean difference and the 95% limits of agreement (LOA; $\pm 1.96 SD$).

While there was a significant positive correlation between the accelerometry output between models ($r = .72$), the Spearman’s rank order correlation with percentage of time spent in MVPA as measured by the CARS was significant, but not strong for either accelerometer (GT1M $r = .56$ and RT3 $r = .39$) suggesting possible limitations in the relative assessment of MVPA if raw accelerometer output is used.

The results of this study illustrate the problems which occur as a consequence of applying different cut points to the accelerometry data. The cut points for Actigraph accelerometers range from 368 cpm (10) which would result in 32 min (12.4) of

MVPA in the one hour of free play direct observation as opposed to 3200 cpm (20) which would result in 5.3 min (4.4) of MVPA in the one hour of direct observation. The existence of different cut points has been attributed to their being developed from studies which have used different calibration methods, such as treadmill and free-living protocols, different criterion measures, such as (in)direct calorimetry and direct observation, and the use of 3 METs as the threshold for MVPA in children which may be too low (23). A limitation of this study is that many of the available cut points for the RT3 are based on a threshold of 3 METs, and range from 952 cpm (30) resulting in 30.3 min (13.1) of MVPA to 465 cpm (4) resulting in 16.8 min (9.8) MVPA. As Sun et al. (26) does not provide a definitive cut point for MVPA but lists 'moderate' activities and their respective cut points, a decision was made to select two of these 'moderate' activities. Other 'moderate' cut points were not evaluated and further studies are therefore required to validate appropriate cut points for the RT3 for preschool children.

The RT3^{WR} cut point appeared to overestimate number of minutes of MVPA in preschool children (mean 19.3 min at 15 s epoch) when compared against direct observation (7.1 min at 15 s epochs). The RT3^{LJ} however was more accurate (mean 7.1 at 15 s epoch). This may simply be a reflection of the discrepancy between validation studies as to what is classified as 'moderate' activity. The CARS criterion measure codes slow walking as a 'light' activity (a CARS score of 3; 19). Similarly in the study by van Cauwenberghe (29) they defined 'moderate' activity as being a CARS score of greater than 3.1, which would result in slow walking being classified as a 'moderate' activity, and in the original development of CARS by Puhl et al. (19) this corresponded to an energy expenditure of less than three times individual children's resting metabolic rate. In the current study only those coded as 4 and greater would be classified as 'moderate' activity, for example fast walking. This may go some way to explain why differences between cut points exist.

The findings suggest that there was a significant epoch effect with longer epochs resulting in significantly fewer minutes being classified as MVPA. The difference of 2.5 min of MVPA for the GT1M, 1.7 min for the RT3^{LJ} and 1.45 min for RT3^{WR}, between the 15 and 60 s epochs, when cumulated over a day, could result in a large difference in daily MVPA. The Bland and Altman plots provide a visual illustration of the greater mean differences and the wider limits of agreement present at 60 s epoch for both accelerometers. The epoch effect resulting in a potentially large difference in time spent in MVPA is in agreement with previous studies which have investigated epoch effect in preschool children (28). It is possible that coding the CARS over a 60 s period would also have a 'smoothing' effect on the data but this was not explored in the current study.

The current study made use of the GT1M accelerometer which is a more recent Actigraph accelerometer model than the MTI-7164 from which the Puyau et al. (20) cut points were developed and validated. While similar to the older models from Actigraph, as it measures vertical acceleration, the GT1M differs as it employs a Micro-Electrical Mechanical System (MEMS) system to detect acceleration as opposed to the cantilever beam sensor used in earlier models (12). While some papers have found good cross-validation between this model in a laboratory setting (12,14) other studies state that the GT1M may be underestimating levels of activity suggesting an application of a correction factor (6). Although not presented in the

results of this study, it is noted from post hoc analysis that the application of the 9% correction factor to the GT1M data at 15 s epochs would result in bias (*SD*) of 0.2 min (3.6), slightly less than the 0.7 min presented for the uncorrected data. This could suggest that the correction to GT1M output recommended by Corder et al. (6) might improve the accuracy of GT1M measurement of MVPA, at least in young children.

The present study suggests that the GT1M may have good absolute validity when compared against the CARS criterion measure, with a small bias indicating accuracy particularly for group assessments of MVPA. However, for assessments of individual levels of MVPA the current study is slightly less supportive of absolute accuracy given the large limits of agreement (-7.7–6.3 min) between CARS and GT1M measures at 15-s epoch. The mean minutes of approximately 7 min of MVPA recorded over the 1 hr free-play session in the current study might seem relatively low, but if sustained over the whole day this would lead to accumulation of > 1 hr of MVPA per day, and in fact the levels of MVPA in the current study are higher than those observed in most previous nursery-based studies (21). It should be noted that the usefulness of MVPA has been questioned as a concept for the preschool age-group for example, the recent Australian Government's Department of Health and Ageing guidance on physical activity for early years emphasizes total volume of physical activity and does not recommend amounts of MVPA (1).

Conclusion

In conclusion, the current study suggests that there is no advantage of using a triaxial accelerometer over a uniaxial accelerometer in preschool children, for assessment of either relative or absolute amounts of physical activity. The findings also suggest that shorter accelerometer epochs result in a smaller bias relative to direct observation. Previous studies have shown that choice of epoch can determine the estimated amount of MVPA, but no previous study has determined which epochs are more accurate relative to a criterion method.

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