The Effect of Accelerometer Epoch on Physical Activity Output Measures

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Accelerometers are used to assess the total activity and time spent at varying intensities of activity. The time-sampling interval (epoch) used in most field studies is 60 s, as use of epochs lower than this result in limited recording time. The short-burst nature of children's activity can lead to inaccuracies when using long epochs. The purpose of this study was to evaluate the influence of accelerometer epoch on activity measures. Twenty-five 7–11-year-old children (height = 133.1 ± 7.1 cm, body mass = 32.0 ± 6.8 kg) wore two RT3 accelerometers for 6 h. Activity was recorded at 60-s and 1-s epochs. Output measures were total activity and minutes spent in light (⩽3 metabolic equivalents, METs), moderate (3–6 METs), vigorous (6–9 METs), hard (9–12 METs), and very hard (⩾12 METs) intensity activities. Relative to the 1-s epoch, the 60-s epoch overestimated the time in moderate activity (60-s epoch = 40.0 ± 17.1 min, 1-s epoch = 30.6 ± 6.7 min) and vigorous activity (60-s epoch = 11.6 ± 0.9 min, 1-s epoch = 8.4 ± 0.4 min), but underestimated the time in very hard activity (60-s epoch = 3.7 ± 0.9 min, 1-s epoch = 12.4 ± 1.0 min). Total activity and time recorded in light and hard activity did not differ by epoch setting. In conclusion, a 1-s epoch is recommended when assessing ⩾vigorous activity. This is particularly important when assessing the relationship between bone health and activity as bone mass is increased by short periods of intense activity.

Keywords: children, moderate intensity, RT3, triaxial, vigorous intensity

Introduction

Without an accurate measure of physical activity, it is difficult to quantify relationships with health (Boreham & Riddoch 2001). In addition, it is not possible to assess whether a population meets the national guidelines for physical activity unless the tool chosen to quantify physical activity is valid.

Accelerometers measure the accelerations of movement. A time-sampling mechanism allows the capture of intensity, frequency, and duration information. The three dimensions of assessment offered by triaxial accelerometry (X = vertical, Y = anterioposterior, and Z = mediolateral) are potentially important when assessing children's physical activity, due to the greater variety of movements undertaken by the children relative to adults. Eston et al. (1998) showed that a triaxial accelerometer (TriTrac-R3D; Professional Products, a division of Reining International, Madison, WI, USA)

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was a more accurate predictor of oxygen uptake in children, across a variety of activities, than a uniaxial accelerometer. The TriTrac has been successfully validated against energy expenditure measured by indirect calorimetry in the laboratory ($r = 0.86$; Eston et al. 1998); however, a limitation associated with the TriTrac-R3D is its bulky nature (120×65×22 mm, 168 g). The RT3 accelerometer is much smaller (71×56×28 mm, 65.2 g) than the TriTrac-R3D, and was introduced as a more researcher- and user-friendly device, and has been successfully validated against the criterion of oxygen uptake in both children and adults in our own laboratory (Rowlands et al. 2004b).

Accelerometers are often set at a sampling interval (epoch) of 60 s (Ainsworth et al. 2000; Cooper et al. 2000; Levin et al. 1999), which summarizes all registered counts during this period maximizing the memory capacity. However, children's activity patterns are spontaneous and intermittent in their nature (Rowlands et al. 1997). Bailey et al. (1995) reported that children engaged in very short bursts of intense physical activity interspersed with varying intervals of low and moderate intensity. The median duration of high-intensity activities was found to be only 3 s with 95% lasting <15 s. Nilsson et al. (2002) showed the use of longer epochs did not capture the high-intensity activity accurately. Short bursts of very hard activity coupled with light activity may not accumulate enough counts to pass the threshold for the very hard intensity bracket and hence be resigned to a lower intensity bracket. The number of minutes recorded in high-intensity activities decreased as the epoch setting increased from 5 to 60 s. At epoch settings of 5, 10, and 20 s; 11.7, 7.9, and 3.8 min, respectively, were recorded in very high-intensity activities (≥9 metabolic equivalents, METs) compared to only 1.3 min at the 60-s epoch. Therefore, the choice of epoch appears to be very important when assessing activity intensity. The RT3 has epoch settings of 1 s or 60 s only and recording time is very limited with the 1-s epoch (up to 9 h, compared to up to 21 days with the 60-s epoch), therefore, it is important to assess the extent of any misclassification of activity intensity when selecting the 60-s epoch.

Short periods of intense activity are particularly important for bone health. High intensities of strain to the musculoskeletal system appear to be more important than the volume of activity to bone development (Turner & Robling 2003; Parker 1998). Therefore, underestimation of time spent in high-intensity activities might mask the relationship between physical activity and bone health.

The purpose of this study was to investigate the effect of epoch selection (60 s and 1 s) of the RT3 accelerometer on recorded habitual physical activity (total and minutes spent at varying intensities) in children.

Methods

Participants

A total of 25 children, aged 7–11 years, were recruited from a local primary school in North Wales. Of these, 15 were boys and 10 were girls. Written informed consent was obtained from all parents and verbal consent from all children. Each participant was visited at school after assembly (9:30 am), where all procedures were explained. Height was measured to the nearest 0.1 cm using a free-standing Seca stadiometer (Seca AG, Reinach, Switzerland) and body mass was measured to the nearest 0.1 kg using Seca scales.

Instrumentation

The RT3 (Stayhealthy, Inc., Monvovia, CA, USA) is a small (71×56×28 mm), lightweight (65.2 g), battery-powered instrument used as an experimental tool for measuring physical activity. It is worn clipped to the waistband as an "accessory" during waking hours. Depending on its mode of operation, it can record data for up to 21 days, which is then downloaded to a PC for display and statistical processing. The sensor in the RT3 is an accelerometer which measures acceleration periodically; it is then converted to a digital representation and processed to obtain an "activity count" that is stored in memory. The exact relationship of the activity count to the acceleration (measured in ms^{-2} or g, where $1\ g = 9.81\ ms^{-2}$) is not clear.

The RT3 has four modes of operation: mode 1 samples and stores activity counts on three individual orthogonal axes at 1-s epochs for up to 3 h; mode 2 samples and stores vector magnitude (a measure combining all three axes of motion) activity counts at

1-s epochs for up to 9 h; mode 3 samples and stores accumulated activity counts on individual axes over 60-s epochs for up to 7 days; and mode 4 samples and stores accumulated vector magnitude activity counts over 60-s epochs for up to 21 days. The latter two modes store less detail about activity but are more economical in their use of memory, allowing longer duration experiments to be performed. Epoch duration of 1 min is generally used in the field. The vector magnitudes (a culmination of the three vectors) at 60-s and 1-s epochs were used.

Physical activity assessment

From a possible nine RT3 accelerometers, each child wore two randomly selected accelerometers for up to 6 h. The accelerometers were strapped to a belt worn by the child. The accelerometers were taped together and positioned over the right hip; one monitor was programmed to record at 60-s epoch and the other at 1-s epoch. The accelerometers were initialized and downloaded via a computer interface and had no external controls that could be manipulated. Output measures for each monitor were total activity counts, minutes spent in very hard-, hard-, vigorous-, moderate-, and low-intensity activities. The definition and cut-off point used for each activity intensity are shown in Table 1.

Statistical analysis

Descriptive statistics were calculated for all variables. Independent *t* tests were used to examine gender differences. A series of six one-way repeated-measures analyses of variance (ANOVAs) were performed to examine differences between monitors (60-s and 1-s epochs) in time spent at the various activity intensities (light, moderate, vigorous, hard, very hard, ⩾moderate, ⩾vigorous). Pearson's correlation coefficient was used to examine the relationship between total physical activity (1-s epoch) and bias between the time recorded at the various intensities of activity by both monitors, one set at 1-s epoch and the other at 60-s epoch. Alpha was set at 0.05. This was adjusted to 0.01 for the series of one-way ANOVAs to account for the increased risk of type 1 error due to multiple tests.

To assess the extent to which the total physical activity and the time recorded at each intensity agreed between the 60-s and 1-s epochs, levels of agreement were calculated as described by Bland and Altman (1986). The consensus of opinion suggests that this is the most appropriate technique for the assessment of measurement agreement (Nevill & Atkinson 1997). The average bias and 95% confidence interval for the bias were calculated for total physical activity, and time recorded in light, moderate, vigorous, hard, very hard, ⩾moderate, and ⩾vigorous activity. Systematic bias was shown by a positive correlation between bias and the average of the time recorded by both monitors for all measures except total physical activity and time recorded in very hard intensity activity. This systematic bias affects the accuracy of the limits of agreement. Log transformation of the data, as recommended by Bland and Altman (1986), did not solve this problem. Therefore the calculated limits of agreement for these measures will have a tendency to be too far apart (Bland & Altman 1986).

Table 1. The relation of activity intensity to accelerometer counts and METs

Activity intensity	Activity counts*		MET value*
	60-s Epoch	1-s Epoch	
Low	0–970	0–16	0–2.9
Moderate	970–2333	17–39	3–5.9
Vigorous	2333–3200	40–54	6–8.9
Hard	3201–4100	55–69	9–11.9
Very hard	4101+	70+	12+

* Activity counts and METs taken from Rowlands et al. (2004b).

Results

Descriptive data are shown in Table 2. There were no significant differences between the boys and the girls on any of the variables. There were no significant differences between monitors for minutes in light-intensity activity ($F_{1,24} = 2.7$, $p = 0.11$), minutes in hard intensity activity ($F_{1,24} = 0.9$, $p = 0.35$) or minutes in ⩾moderate-intensity activity ($F_{1,24} = 2.5$, $p = 0.13$). However, the monitor with a 60-s epoch recorded a significantly greater number of minutes in moderate activity ($F_{1,24} = 11.6$, $p < 0.01$) and vigorous activity ($F_{1,24} = 20.7$, $p < 0.01$), and fewer minutes

Table 2. Descriptive data

Variable (mean ± SD)	Boys ($n = 15$)	Girls ($n = 10$)	Total ($n = 25$)
Age (years)	8.8 ± 1.1	8.5 ± 0.9	8.7 ± 1.0
Height (cm)	133.6 ± 6.9	132.4 ± 8.1	133.1 ± 7.3
Weight (kg)	32.9 ± 8.0	30.6 ± 4.3	32.0 ± 6.8
60-s epoch	228,044.6 ± 49,964.1	183,809.9 ± 60,908.5	210,350.7 ± 57,763.4
1-s epoch	246,495.5 ± 50,496.5	219,421.7 ± 61,484.7	235,666.0 ± 55,572.7

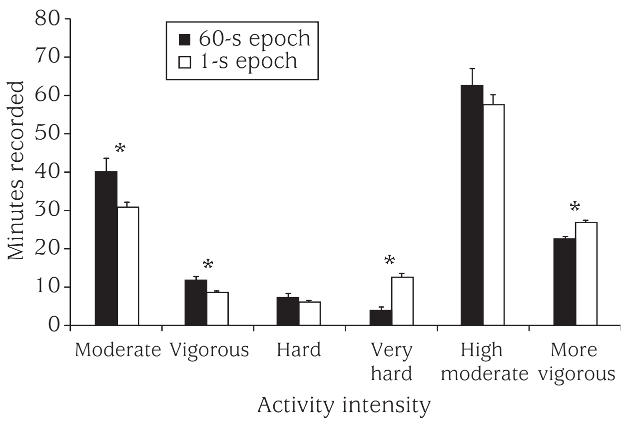

Fig. Number of minutes recorded at each activity intensity by the 1-s and 60-s epochs. *Number of minutes recorded by the 1-s epoch monitor significantly different from number of minutes recorded by the 60-s epoch monitor.

in very hard activity ($F_{1,24} = 63.5$, $p < 0.01$) and ≥vigorous activity ($F_{1,24} = 7.9$, $p < 0.01$), relative to the monitor with a 1-s epoch (Figure).

Total physical activity (1-s epoch) correlated significantly ($r = -0.71$, $p < 0.001$) with the difference in time recorded at a very hard intensity by the 1-s and 60-s epoch monitors. The negative correlation indicates that the degree of underestimation by the 60-s epoch increased as total physical activity increased. No other significant correlations between total physical activity and bias were evident.

The mean bias and 95% limits of agreement are shown in Table 3. Mean bias was low for total and light-intensity activity, though, increased with intensity. Individual differences were substantial, reflected by the large limits of agreement. The estimates of limits of agreement may be on the liberal side for all measures except total physical activity and very hard physical activity due to the systematic bias in the difference between monitors.

Discussion

When assessing physical activity in the field using accelerometry, a 60-s epoch is generally selected due to memory limitations when shorter epochs are selected. However, the accuracy of assessment of high-intensity activity when using a 60-s epoch has been questioned (Trost et al. 2005; Nilsson et al. 2002). This study aimed to determine whether output measures of physical activity were affected by the duration of the epoch of the RT3.

Minutes spent in moderate activity (3–5.9 METs) were overestimated by the 60-s epoch, presumably due to vigorous minutes being misclassified as moderate. However, no significant differences were found in the number of minutes recorded during light (<3 METs) and ≥moderate (≥3 METs) intensity activity, when using the 60-s and the 1-s epoch setting. Similarly, Nilsson et al. (2002) found no significant difference between the number of minutes recorded at ≥moderate-intensity activity (≤6 METs) by a 5-s epoch compared to a 60-s epoch, when using the CSA accelerometer (Computer Science Applications, Shalimar, FL, USA). This suggests that activities expending no more than 6 METs are usually maintained for over 60 s. Therefore, a 60-s epoch setting is adequate to capture these periods of movement.

Vigorous-intensity activity (6–8.9 METs) was overestimated, whereas very hard intensity activity (>12 METs) and ≥vigorous intensity were underestimated, by the 60-s epoch relative to the 1-s epoch setting. However, no significant difference was recorded between the epoch settings during hard (9–11.9 METs) activities. In contrast, Nilsson et al. (2002) reported an underestimation in the time recorded at high (6–9 METs, equivalent to our vigorous intensity) and very high (>9 METs, equivalent to our hard and very hard intensity activity combined) by a 60-s epoch setting relative

Table 3. Limits of agreement

60-s and 1-s Epoch*	Mean of the two monitors	Bias	95% Limits of agreement
Total physical activity	223,008.3	−25,315.2	92,614.7
Light†	279.9	−5.3	31.6
Moderate†	35.3	9.4	27.0
Vigorous†	10.0	3.3	7.1
Hard†	6.5	1.0	10.2
Very hard	8.0	−8.6	10.6
⩾moderate†	59.9	5.0	31.4
⩾vigorous†	24.5	−4.4	15.4

* A negative bias indicates an underestimation by the 60-s epoch monitor relative to the 1-s epoch monitor.
† Bias significantly correlated with mean of the two monitors ($p < 0.05$), therefore limits of agreement may be inflated.

to a 5-s epoch setting. No differentiation was made with activities exceeding 12 METs. However, when the number of minutes were combined in the present study to form the corresponding >9-METs category, the 60-s epoch setting similarly underestimated the time relative to the 1-s epoch ($p < 0.001$).

Children show sporadic activity patterns engaging in very short bursts of intense activity, typically lasting <15 s (Bailey et al. 1995); a 60-s epoch is unlikely to capture these short episodes. To be classified as very hard intensity activity when using an epoch setting of 60 s a count of >4101 must be accumulated during the 60 s. This may be due to prolonged very hard intense activity (>12 METs) lasting for over 60 s or very intense bouts of activity (>12 METs) coupled with lower intensity motion. If the very hard intensity activities are not maintained or the bouts are not intense enough to accumulate >4101 counts, they will be resigned to a lower category activity intensity. If the child participates only in sporadic hard or very hard intensity activity it is likely to go undetected (Nilsson et al. 2002). This may also explain the overestimation during vigorous-intensity activity. Activity classified as very hard by the 1-s epoch monitor may have been too short to be recorded as very hard or even hard by the 60-s epoch monitor and hence may be classified as vigorous. This would lead to the overestimation of vigorous activity and the underestimation of very hard activity.

Despite the lack of significant differences between time recorded at most intensities, levels of agreement analysis revealed wide individual variation for all but light-intensity activity. For example, if the 1-s epoch monitor recorded 30 min moderate activity, the 95% limits for the 60-s epoch monitor indicate that it could read between 12 and 66 min; 10 min vigorous activity could read between 6 and 20 min; 10 min hard activity could read between 1 and 21 min; 10 min very hard activity could read between 0 and 12.6 min; 60 min ⩾moderate activity could read between 34 and 96 min; 30 min ⩾vigorous activity could read between 10 and 41 min. The increase in relative size of the 95% limits of agreement with intensity indicates that choice of epoch setting is important for the assessment of all activity above light intensity. While some of these differences will be accounted for by inter-unit variation (Powell & Rowlands 2004; Powell et al. 2003), the differences between time recorded by the two epoch settings is actually lower than that reported by Nilsson et al. (2002), where the same monitor was used to assess all epochs simultaneously so that inter-instrument variation was not a factor.

As the total physical activity increased, the likelihood of the underestimation of very hard activity when using a 60-s epoch also increased. With sedentary groups, or if activity intensity need only be classified as time spent in ⩾moderate-intensity activity, a 60-s epoch setting may be adequate to obtain a full picture of activity. However, particularly in active populations or where vigorous and hard activity need to be assessed, it is recommended that the 1-s epoch setting is used to maximize the accuracy of measurement of activity intensity. Problems may be encountered when assessing habitual physical activity (minimum 4 days assessment, Trost et al. 2000); at a 1-s epoch setting the memory capacity of the RT3 accelerometer is limited to 9 h of monitoring with the vector magnitude, and only 3 h when using all three vectors. This does not allow an adequate measurement period, therefore it necessitates the download of activity data on a twice daily basis, compared to the 60-s epoch setting which allows up to 21 days of measurement (7 days if all three vectors are used and 21 days if only the vector magnitude is used). However, the latest version of the uniaxial actigraph (GT1M Actigraph, Fort Walton Beach, FL, USA) is capable of storing data in 1-s epochs for 5 days.

The RT3 has been shown to be a valid tool for the assessment of physical activity in children and adults (Rowlands et al. 2004b). However, inter-unit variability has been shown to exist (Powell & Rowlands 2004; Powell et al. 2003) and, therefore, all monitors were electronically tested before inclusion in this study (Powell et al. 2003). Outliers (activity counts greater than two standard deviations above or below the mean) were not included. The cut-off points used in the present study were developed across a range of laboratory activities including treadmill walking/running, passing a football, playing computer games and playing hopscotch (Rowlands et al. 2004b). Research has indicated that the relationship between accelerometer counts and metabolic demand differs depending on the type of activity and whether activity is assessed in the laboratory or the field, therefore, the relationship between METs and accelerometer counts cannot be considered consistent between or within individuals (Nichols et al. 2000). Individual calibration of the accelerometer counts/METs relationship has been recommended to reduce error due to inter-individual differences in the biomechanical efficiency of movement (Ekelund et al. 2003), although this does not impact on misclassification due to the relationship between metabolic demand and activity counts being dependent on activity type. However, as pointed out by Nilsson et al. (2002) the actual value of the cut-off points is not important for the assessment of the epoch effect. The demonstration of the importance of short epochs for the capture of high-intensity activity is the important factor.

To our knowledge this is the first study to assess the time-sampling effects of the RT3 accelerometer in the field. Epoch selection should be carefully considered when wishing to obtain a measure of vigorous-intensity physical activity and greater. While a 60-s epoch allows longer data collection periods, it is likely that time spent in high-intensity activity will be underestimated. This is particularly important when assessing the relationship between physical activity and bone health as high intensities of strain appear to be more beneficial to bone development than to volume of activity (Rowlands et al. 2004a; Turner & Robling 2003; Parker 1998). Underestimation of vigorous activity could hinder the understanding of relationships between physical activity and health, and the setting of appropriate public physical activity targets. This would be detrimental as advising higher levels of activity than necessary may decrease adherence to guidelines, and advising lower levels of activity than necessary may not lead to the anticipated health benefits. An increased memory capacity of the RT3 accelerometer would aid researchers wishing to quantify time spent at varying physical activity intensities.

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