

Full Length Research Paper

How accurate is triaxial RT3™ (RT3) accelerometer for estimating energy expenditure?

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The participants are instructed to remove the RT3 only for sleeping, bathing and swimming activities but some studies have shown the participants remove the accelerometer for longer times. The activities performed while the accelerometer is not being worn and, or energy that was not recorded during this time has never been estimated. This study aimed to assess compliance in using the accelerometer and quantify the energy expenditure (EE) not recorded by the accelerometer during the time it was not worn in free-living young males in a consecutive 4-day period. Eleven male participants 19 to 23 years of age, 54.7 to 85.5 kg with body mass index of 19.1 to 27.6 kg.m⁻² completed the study. Resting metabolic rate was measured by indirect calorimetry. Daily EE estimation was on average 23.6% higher using the Bouchard Physical Activity Records than the RT3. Accelerometers were worn for 67 to 98% of waking hours but up to 30% of the EE was not recorded due to the device not being worn by participants mainly during intense physical activity. Recording the physical activity when the accelerometer is not being worn would provide a more precise estimative of the EE.

Key words: Energy expenditure, accelerometer, physical activity records, young men.

INTRODUCTION

Habitual physical activity (PA) has been shown to impact significantly on chronic diseases. In order to determine the optimal dose of PA to favourably modify disease risk, the volume of daily PA and energy expenditure (EE) needs to be assessed.

Objective measurement methods such as accelerometers have advantages of not relying on participant's memory. Accelerometers are frequently used to assess EE, pattern

of physical activity and intensity of the activities performed. The RT3™ triaxial accelerometer is a small, lightweight, battery-powered instrument. The sensor is an accelerometer sensitive along three orthogonal axes. The acceleration is measured periodically and stored in memory. The EE estimated from RT3 has been found to be positively correlated with that estimated from Double Labelled Water (DLW) ($r = 0.67$, $p < 0.05$, respectively) and the 95% confidence interval of the mean difference between methods is relatively small (-385 to 145 kcal/day, respectively) (Jacobi et al., 2007) showing small dispersion around the mean. The device is usually clipped to the participant's waist and the participants are instructed to remove the RT3 only for sleeping, bathing and swimming activities. However, some studies have shown the participants remove the accelerometer for longer times. Compliance wearing the accelerometer has never been systematically assessed neither have

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Abbreviations: EE, Energy expenditure; RT3, triaxial RT3™; PA, physical activity; B-PAR, Bouchard Physical Activity Record; BMI, Body mass index; RMR, resting metabolic rate; MET, metabolic equivalent; VM, vector magnitude.

the activities performed while the accelerometer is not being worn and, or the amount of energy that was not recorded during this time. Double Water Labelling (DLW) is the gold standard to assess the EE. However it does not provide any indication of the pattern of activities performed.

The Bouchard Physical Activity Record (B-PAR) (Bouchard et al., 1983) is one of the most commonly used diaries and involves the recording of PA intensity according to type of PA each 15-min throughout the day. Each score is expressed in metabolic equivalent (MET) or as kcal/kg.15 min. The MET is used as an index of the intensity of PA (Schutz et al., 2001), ranging from 1 to 18 (light to vigorous) to represent specific PA which enables comparisons between adults assuming no physical disability or other conditions that would significantly alter their mechanical or metabolic efficiency. The MET provides a convenient option to express the energy needs of a wide range of people in a standardized form (Pannemans et al., 1995).

The aim of this study was to assess compliance in using the accelerometer and quantify the energy expenditure not recorded by the accelerometer during the time it was not worn in free-living young males in a consecutive 4-day period. The hypothesis is that young males will have high compliance in using accelerometer over a period of four days and that similar daily EE will be estimated by B-PAR and RT3 accelerometer during this period.

MATERIALS AND METHODS

Participants

Eleven male Physical Education and Exercise and Sport Science students (19 to 23 years of age) were recruited. Each participant read and signed an approved written consent form in accordance with the Queensland University of Technology Human Research Ethics Committee guidelines.

Anthropometric and physiological measurements

Methods have been previously described in details (Liberato et al., 2008). In brief, anthropometric measures including body weight, height, body composition, and waist and hip circumferences were undertaken. Body mass index (BMI) was calculated as weight (kg) divided by height² (m²). Resting metabolic rate (RMR) was measured by continuous open-circuit indirect calorimetry using a Deltatrac II metabolic cart (Datex-Ohmeda Corp., Helsinki, Finland).

Physical activity measurements

Physical activity was assessed by B-PAR using nine categories of PA for each 15-min period throughout the day during a consecutive 4-day period (two week days, Saturday and Sunday) while wearing the RT3 accelerometer. These categories were explained and illustrated in detail to each participant before they started to record and the participants were allowed to clarify any doubts arising while filling the records and to change the scores if appropriate. The MET

value for each category of PA was established for its corresponding list of activities (Bouchard et al., 1983). The respective scores and specific MET values were summed for all 15-min intervals across a 24-h period and used to calculate daily EE. The EE was calculated by multiplying the MET by RMR.

The RT3™ triaxial accelerometer (Stayhealthy, Inc., Monrovia, CA) is a small (71 × 56 × 28 mm), light weight (65.2 g), battery-powered instrument. The sensor is an accelerometer sensitive along three orthogonal axes (x, y and z), which represent vertical, anteroposterior, and mediolateral motion, respectively. The accelerometers used in the RT3 have a dynamic range of 0.05 to 2.00 g, are sensitive in the range 2 to 10 Hz, and are calibrated at 5.3 Hz (Powell et al., 2003). The acceleration is measured periodically, culminating in the vector magnitude of movement (calculated as $VM = (x^2 + y^2 + z^2)^{0.5}$) and stored in memory. The EE (kcal.min⁻¹) and VM (counts.min⁻¹) outputs from the accelerometer were used in the current study. The outputs were downloaded to a PC, using specific software. The algorithm used by the accelerometer to generate its outputs is unavailable to the researchers. Prior to the commencement of recording, participants' details including age, height, weight and gender were loaded and the RT3 set to record data each minute. The device was clipped to the participant's waist and the participants were instructed to remove the RT3 only for sleeping, bathing and swimming activities. The participants were asked to record the times when the RT3 was removed.

Data analysis

Data from the accelerometer recorded each minute was summed for 15-min periods and compared to data from B-PAR which are recorded in periods of 15-min. For time periods when the participant was awake but not wearing the accelerometer, the RT3 data were considered missing and replaced by mean RT3 data corresponding to each B-PAR score when the participant was wearing the RT3.

For each participant, 15-min periods were classified into three PA levels, according to the Center for Disease Control and Prevention and the American College of Sports Medicine Position Statement (Pate et al., 1995): a) light (EE < 3 METs), moderate (3 METs ≤ EE < 6 METs) and vigorous (EE ≥ 6 METs). For the RT3, VM values corresponding to 3 and 6 METs are 984 and 2340.8 counts, respectively (Rowlands et al., 2004). The B-PAR scores 1 to 4, 5 to 7 and 8 to 9 correspond to light, moderate and vigorous PA, respectively (Bouchard et al., 1983; Dionne et al., 2000).

Statistical analysis

Univariate analysis included means and standard deviations. The agreement between B-PAR and RT3 in relation to daily EE and time engaged in PA was evaluated using scatter plots.

RESULTS

The participants were in average 21.2 ± 1.3 years old, had height of 175 ± 4.8 cm, weight of 72 ± 10.4 kg and BMI of 23.45 ± 2.68 kg/m². Daily EE estimation was on average 23.6% higher using B-PAR than the RT3 and the agreement between both methods ranged from 5 to 48%. Over a 4-day period, the accelerometer was not worn for on average 2.6 h per day during waking time, corresponding to a range of 9 to 918 kcal/day (0 to 30%) not recorded by RT3 according to participants (Table 1).

The RT3 accelerometer was not worn during 63.3% of

Table 1. Body Weight (BW), resting metabolic rate (RMR), daily energy expenditure (EE) and daily time sleeping and wearing RT3 accelerometer over 4 days in 11 young male participants.

| Participant | BW (kg) | RMR (kcal.d ⁻¹) | EE (kcal) | | Time (h) | |
|-----------------|---------|-----------------------------|--------------------|------------------|-----------------------|------------------------------|
| | | | B-PAR ¹ | RT3 ² | Sleeping ³ | Wearing RT3 (%) ⁴ |
| 1 | 76.3 | 1886 | 3436 | 2792 | 9.5 | 14.3 (98) ⁴ |
| 2 | 73.4 | 1843 | 3449 | 3289 | 6.9 | 13.3 (78) |
| 3 | 74 | 1829 | 3676 | 3127 | 7.9 | 13.9 (86) |
| 4 ⁵ | 61.7 | 1670 | 3368 | 2443 | 7.7 | 13.6 (83) |
| 5 | 55.8 | 1814 | 3082 | 2460 | 8.4 | 12.1 (77) |
| 6 | 54.7 | 1714 | 3642 | 2829 | 8.0 | 14.2 (89) |
| 7 | 78.5 | 2074 | 4040 | 3389 | 7.4 | 15.9 (96) |
| 8 ⁵ | 83.7 | 2232 | 4718 | 3583 | 8.0 | 12.4 (78) |
| 9 ⁶ | 85.5 | 1800 | 3707 | 3417 | 7.8 | 10.9 (67) |
| 10 ⁵ | 72.2 | 1901 | 4013 | 3157 | 8.2 | 14.0 (88) |
| 11 | 76.5 | 1771 | 3291 | 2706 | 8.1 | 12.8 (80) |
| Mean | 72.0 | 1867 | 3675 | 2868 | 8.0 | 13.4 (84) |

¹B-PAR, Bouchard Physical Activity Record. ²Estimated from RT3 Accelerometer (when RT3 was not worn, EE was estimated from mean RT3 data corresponding to each B-PAR score for each participant when RT3 was worn). ³Estimated from B-PAR. ⁴Percentage of time wearing RT3 in relation to the waking hours. ⁵Data from 3 days. ⁶Data from 2 days.

Table 2. Time¹ (min.d⁻¹, average over 4 days) spent in light, moderate, and vigorous intensity physical activity estimated by Bouchard physical activity record (B-PAR) and RT3 accelerometer in 11 young male participants.

| Physical activity | B-PAR | RT3 | |
|--------------------------------|---------------|---------------|-------------------------------------|
| | | Recorded | Missed ² |
| Light (< 3 METs ³) | 1281.5 ± 17.6 | 1204.7 ± 30.7 | 130.8 ± 22.8 (4 – 229) ⁴ |
| Moderate (3 ≤ METs < 6) | 110.1 ± 20.9 | 67.0 ± 11.3 | 7.8 ± 3.0 (0 – 30) |
| Vigorous (≥ 6 METs) | 48.4 ± 8.7 | 10.9 ± 4.9 | 18.8 ± 10.4 (0 – 113) |
| Total | 1440 | 1282.6 | 157.4 |

¹Mean ± SE. ² Participants were awake and not wearing the RT3 (Time estimated from B-PAR). ³Metabolic equivalent = EE / RMR. ⁴Minimum - maximum.

time completing vigorous PA (Table 2). All 11 participants estimated longer time engaged in moderate and vigorous PA by B-PAR compared to the time recorded by the RT3. Participants correctly chose B-PAR scores 1 to 4 and 9 for their PA engagement. The B-PAR scores 1 to 4 corresponding to light PA below 3 METs were below the RT3 VM value of 984 counts cut-off. Similarly, the B-PAR scores 9 corresponding to vigorous PA (above 6 METs) were above the RT3 VM value of 2340.8 counts cut-off. However, scores 5-8 did not have good correspondence with the RT3 VM outputs (Figure 1A). Scores 5 to 7 should be between 984 and 2340.8 counts cut-off but they were below 984 counts. Score 8 should be above 2340.8 counts and it was between 984 and 2340.8 counts. For each one of the nine B-PAR scores recorded by participants, the RT3 recorded a large range of VM values (Figure 1B). The agreement between B-PAR scores and RT3 VM outputs was not related to the participants' PA behaviour as there was high variability in the agreement regardless the activity level (data not shown).

DISCUSSION

At the group level, daily EE estimation was 23.6% lower using the RT3 accelerometer than the B-PAR. Lower EE (17.1%) estimated using RT3 accelerometer than that estimated using Double Labelled Water was also observed in a study including 13 overweight adults (Jacobi et al., 2007) and lower estimates of EE by Tritrac accelerometer compared to that estimated by B-PAR was found for 97% of the participants of another study (Wickel et al., 2006).

At the individual level, the difference between B-PAR and RT3 was variable, suggesting that the accuracy of B-PAR for estimating daily EE at the individual level depends on the participant's commitment. A similar finding was observed in a study with overweight women comparing EE estimated by B-PAR with that assessed by Double Labelled Water (Fogelholm et al., 1998). The difference between daily EE estimation by B-PAR and by Double Labelled Water ranged from approximately -8800

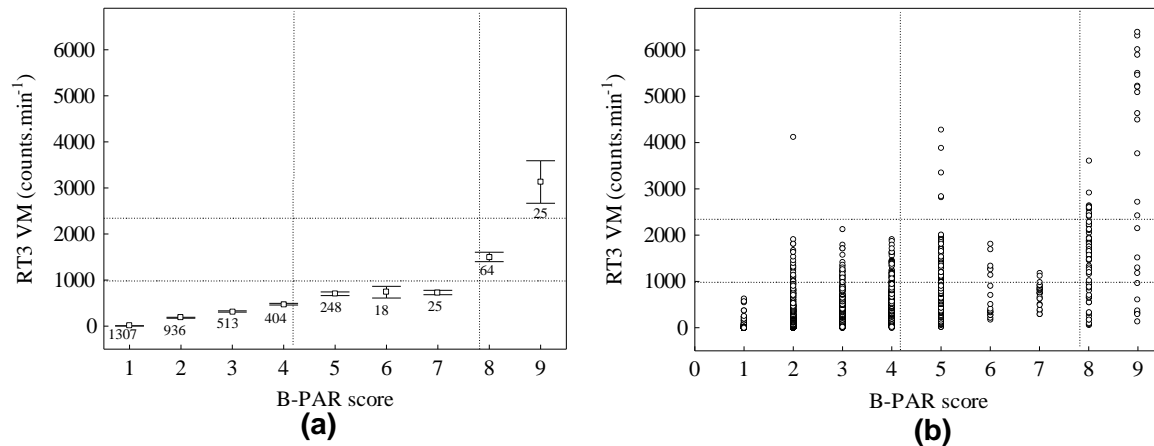


Figure 1. Vector magnitude (VM) from RT3 accelerometer in relation to B-PAR scores. a. Mean \pm standard error. (Below each mean is the number of 15-min period, recorded by 11 participants over 4 days). b. Amplitude of VM values of each score recorded. The dash lines, which represent 3 and 6 METs, are the threshold of light, moderate and vigorous PA level, being the horizontal in relation to VM according to Rowlands et al. (2004) and the vertical in relation to B-PAR.

to 15,000 kcal. Even though the participants were instructed to wear the accelerometer during all time except for sleeping, bathing and swimming activities, the RT3 was worn 84% of the waking hours (13.4 h/day). Similar periods wearing the accelerometer have been found in other studies. Leenders et al. (2001) and Cradock et al. (2004) reported that participants wore accelerometers 13.5 h/day (75 to 85% of waking time) and 12.5 h/day, respectively. A minimum of 9 to 10 h/day wearing the accelerometer has been required in some studies (Schmidt et al., 2003; Cradock et al., 2004).

Up to 918 kcal/day was missed by the RT3 because the participants were not wearing the accelerometer. This value is higher than the range of 100 to 150 kcal.day⁻¹ for missed recorded energy suggested by Leenders et al. (2001).

Most of the time accelerometer was not worn by participants of the current study was found to be while performing vigorous PA. Up to 113 min/day spent in vigorous PA was missed by the RT3. Some participants in the current study reported removing the accelerometer during moderate and vigorous PA due to the fear of damaging the device. A shoe-based activity monitor has been shown to accurately estimate physical activity energy expenditure in 16 adults (Sazonova et al., 2010) and could be an option for estimating energy expenditure in active participants constantly involved in vigorous physical activity.

Good agreement characterized by scores 1 to 4 was observed between B-PAR scores and RT3 VM for physical activities of light and high intensity but not for those of moderate intensity performed by the participants of the current study. Welk et al. (1998) also found an increase in VM with increasing scores but the gradient, as in the current study, was imperfect when the R3D VM

worn by children 10 to 12 years were compared to scores reported by trained research assistants. The low agreement between VM and B-PAR scores for PA of moderate intensity found in the current study may be partly due to PA intensity overestimation. Several sedentary participants overestimated their PA intensity when recording B-PAR and this may be due to their small daily PA intensity spectrum. Other limitations of B-PAR include absence of the activity performed by a participant on the list proposed by Bouchard et al. (1983) and the possibility of different PA performed over 15-min period. However, the participants were allowed to clarify any doubts arising while filling the records and to change the scores if appropriate.

The current study has some limitations. Firstly, the number of participants (11) is small but it does not seem to jeopardize the study because the difference between EE estimated by RT3 and PA records (23%) is higher than the RT3 intra-instrument coefficient of variation (6.6 to 17% depending on the intensity of PA) (Vanhelst et al., 2010). Similar studies (Jacobi et al., 2007) have included similar number of participants. Secondly, the sample of young men, mostly physical education students may have different PA patterns, compliance, awareness and understanding of EE related PA activities from the general population. Therefore, generalizability of the sample to the general population should be done with caution. A third limitation in the current study is the RT3 cut points used for 3 and 6 METs from Rowlands et al. (2004). The cut points were derived from a single sample of 15 men who performed five laboratory-based activities (sitting, kicking, hopscotch, walking and running). Thus, cut-points would be expected to differ from the free-living behaviors assessed in the current study. However, the study conducted by Rowlands et al. (2004) is the only

one that provides a relationship between METs and number of counts (VM) measured by RT3 triaxial accelerometer.

The advantages of the current study include the RMR measurement and the estimation of time and EE not recorded because the participant was not wearing the accelerometer. While other studies have shown that the estimated EE recorded by accelerometer is lower than that estimated by double labelled water (Wickel et al., 2006; Jacobi et al., 2007), this study was able to identify that the missed recorded EE estimated by RT3 was mainly during vigorous activities. Another strength of the current study is that practice guidelines and research recommendations for accelerometer use in physical activity (Ward et al., 2005) were adopted including: (a) triaxial rather than monoaxial accelerometer; (b) trunk location; (c) four days including weekdays and weekends; (d) checking monitor for accurate data output before and after each use; (e) ensured compliance (84% of the time awake wearing accelerometer); and (f) determination of light, moderate and vigorous PA bouts of 15-min periods for each participant.

In summary, this study quantified the EE not recorded by the accelerometer due to participant not wearing the device and identified that most of this energy not recorded was expended performing vigorous PA.

Conclusion

Daily EE estimation was on average 23.6% higher using the B-PAR than the RT3. The accelerometer was worn from 67 to 98% of the waking hours but up to 30% of the EE was not recorded due to the device not being worn by participants, mainly while performing vigorous PA. Recording the PA when the accelerometer is not being worn would provide a more precise estimative of the EE.

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