Scand J Med Sci Sports 2012: 22: 259–264
doi: 10.1111/j.1600-0838.2010.01155.x

SCANDINAVIAN JOURNAL OF MEDICINE & SCIENCE IN SPORTS

Concurrent validation of estimated activity energy expenditure using a 3-day diary and accelerometry in adolescents

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Accepted for publication 6 April 2010

Estimates of daily energy expenditure are important to studies of physical activity and energy balance. Objective measures are not always feasible and further research is needed to validate survey instruments and diaries. The study validates estimated activity energy expenditure (AEE) based on a 3-day diary protocol relative to AEE derived from uniaxial accelerometry in adolescents, 265 girls and 227 boys (12.5–16.4 years). Participants completed the diary and wore a GT1M Actigraph accelerometer on the same days. Height and weight were measured. Correlations between protocols were significant ($P < 0.001$) but moderate, $r = 0.65$ in males and $r = 0.69$ in females. The highest correlation occurred among males on Friday, $r = 0.74$ ($P < 0.01$). Controlling for body mass, partial correlations between protocols decreased to 0.44 and 0.35 in males and females, respectively. About 97% of the cases fell within the limits of agreement in a Bland–Altman plot. The criterion of inclusion for the accelerometer excluded 18% of the initial sample. In summary, the 3-day diary was completed without any major problems and provided a reasonably valid alternative for assessing AEE. Concordance between methods was slightly lower for individuals with higher values of AEE.

Quantification of habitual physical activity is relatively complex and it is also generally accepted that no single measurement technique accurately reflects all dimensions of physical activity (Trost, 2001; Welk, 2002; Armstrong & Welsman, 2006). Objective measures of physical activity (heart rate monitors, accelerometers, pedometers) provide reliable and valid information, whereas subjective protocols (questionnaires, diaries) provide less accurate alternatives, but are more suitable for large samples (Janz et al., 1995; Montoye, 1996; Eston et al., 1998; Welk, 2002).

Estimates of daily energy expenditure (DEE) are an important component in studies of physical activity. The 3-day diary protocol of Bouchard et al. (1983) allows an estimate of DEE and of the type, intensity, frequency and duration of specific activities, including sedentary behaviors (Katzmarzyk & Malina, 1998). The 3-day diary has been used with adolescents in Canada (Katzmarzyk et al., 1998, 1999), United States (Katzmarzyk & Malina, 1998), Taiwan (Huang & Malina, 1996, 2002) and Australia (Lee & Trost, 2006).

The initial validation of the 3-day diary (Bouchard et al., 1983) was established using interclass correlations between estimated DEE and body fat and physical working capacity (i.e. predictive validity). Based on 300 subjects of both sexes, 10–50 years of age, there was a significant relationship between mean DEE per unit body mass and physical working capacity expressed per kg of body weight. Estimates of activity energy expenditure (AEE) based on a single day of the diary showed a strong linear relationship with counts derived from Tritrac activity monitors in young adults of both sexes (Wickel et al., 2006).

With advances in technology, accelerometers are increasingly used in physical activity research and allow an estimate of AEE. Accelerometers, however, have limitations, specifically the exclusion of subjects due to non-compliance with wear time. Costs remain prohibitive for some research groups and also others, including practitioners interested in quantifying physical activity and estimating AEE. Further study of the validity of physical activity assessment tools such as the 3-day diary are thus warranted.

The purpose of the present study is to examine the relationship between estimated AEE based on the 3-day diary protocol (Bouchard et al., 1983) and AEE derived from uniaxial accelerometry in adolescents of both sexes. It was hypothesized that the diary protocol is an alternative to accelerometers in the assessment of DEE and provides a valid estimate of AEE, especially if the amount of vigorous physical activity (which often occurs in episodes less than the 15-min periods of the diary) is not the central question of the research.

Methods

Participants

The sample included 265 girls and 227 boys, 12.5–16.4 years of age (14.2 ± 1.0 years), from public schools in the midlands of Portugal. The study was approved by the Scientific Committee of the University of Coimbra and by the Regional Education Office that required the registration of the initiative in the Portuguese Commission for Protection of Personal Data (Process #3132006). Students and their parents provided assent and informed consent, respectively.

Anthropometry

Height (0.1 cm) and weight (0.1 kg) were measured at school in the morning. A portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) and scale (Seca model 770, Hanover, Maryland, USA) were used. Six skinfolds – triceps, biceps, subscapular, suprailiac, abdominal, medial calf – were measured using a Lange caliper (Beta Technology, Santa Cruz, California, USA). Replicate measurements of height and weight were taken on 23 students after 1 week, while replicate measurements of skinfolds were taken on 34 students within the same day. The technical errors of measurement (σ_e) and reliability (R) were calculated (Mueller & Martorell, 1988). Technical errors were as follows: height, 0.34 cm; weight, 0.58 kg; extremity skinfolds, 0.89–1.0 mm; trunk skinfolds, 0.85–1.66 mm. Reliability coefficients were as follows: height, 1.0; weight, 1.0; extremity skinfolds, 0.92–0.96; trunk skinfolds, 0.90–0.94. The technical errors and reliabilities of skinfolds were within the range of reported values for the Quebec Family Study: 1.0–2.1 mm and correlations $\geq$ 0.94 (Bouchard, 1985). The technical errors were also well within the range of reported values for national and local surveys (Malina, 1995).

3-day diary

The 3-day diary protocol (Bouchard et al., 1983) partitions each day into 96 periods of 15 min and requires the subject to record activities over 3 complete days, 2 weekdays and 1 weekend day. Participants were asked to rate the intensity of the primary activity performed in each 15-min period using a numeric code ranging one to nine. Energy expenditure was subsequently estimated from equivalents for each activity: (1) sleeping or resting in bed: 0.26 kcal/kg/15 min; (2) sitting: 0.38 kcal/kg/15 min; (3) light activity standing: 0.57 kcal/kg/15 min); (4) slow walking $\sim$ 4 km/h: 0.69 kcal/kg/15 min; (5) light manual tasks: 0.84 kcal/kg/15 min; (6) leisure and recreational sports: 1.2 kcal/kg/15 min; (7) manual tasks at a moderate pace: 1.4 kcal/kg/15 min; (8) leisure and sport activities of higher intensity – not competitive: 1.5 kcal/kg/15 min; (9) very intensive activities – competitive sports: 2.0 kcal/kg/15 min. The energy equivalents used in the Bouchard protocol were approximate averages established from existing energy cost values that are now included in the Compendium of Physical Activity (Ainsworth et al., 2000). The minimum and maximum values for each intensity category are shown in appendix table 1 of the original paper by Bouchard et al. (1983). DEE was estimated for each day. Intensity categories 1–3 represented sedentary behaviors (<2.8 METs) and categories 6–9 represented moderate-to-vigorous physical activities (4.8–7.8 METs) based on definitions of the categories in the original report (Bouchard et al., 1983).

Twenty-three subjects completed the diary protocol twice separated by 1 week. The technical error and reliability coefficient were 146.3 kcal (0.10 kcal/min) and 0.91, respectively. Intra-individual correlations were 0.93 ($P<0.01$) for weekdays and 0.70 ($P<0.01$) for weekend days. The correlation for weekdays, 0.93, was similar to those in the development of the diary protocol, 0.95 and 0.90 for 2 weekdays, while that for the weekend day was lower, 0.70 compared with 0.86 (Bouchard et al., 1983).

Accelerometry

The GT1M Actigraph accelerometer incorporated a uniaxial motion sensor that was firmly placed at waist level using an elastic belt. The sampling period was set at 1 min as in other studies of adolescents (Mota et al., 2002; Trost et al., 2002; Pate et al., 2003; Riddoch et al., 2004) and adults (Freedson et al., 1998; Schmidt et al., 2003). Although most studies have used an epoch of 60 s, some evidence suggests an underestimation of vigorous and high-intensity activity in youth (Nilsson et al., 2002; Rowlands et al., 2006; Stone et al., 2009). The accelerometer was worn on the same days that the diary protocol was completed (Thursday, Friday, Saturday).

Accelerometer monitors were downloaded following procedures indicated by the manufacturer and imported to a personal computer. Activity data were analyzed and processed using a special program (MAHUffe, http://www.mrc-epid.cam.ac.uk). Data processing and inclusion criteria were those of the European Youth Heart Study (Riddoch et al., 2004; Sardinha et al., 2008). The output also included the total amount of time (min) registered each day. Subjects were excluded if they failed to provide a minimum of 600 min (10 h) of valid data after removing sequences of 20 or more consecutive zero counts. Valid accelerometer records were provided for 403 subjects (82% of the initial sample).

Field procedures

The first visit to the schools occurred on a Wednesday and was used to explain the objectives of the study; to measure height, weight and skinfolds; and to distribute the diary and accelerometers with specific directions for each. A master's level graduate student was assigned to each school and was charged with monitoring the protocol. Participants were contacted at school on Thursdays and Fridays to ensure adequate completion/application of the diary and accelerometer, and/or to address potential problems. The instruments were collected for analysis on the following Tuesday.

Analysis

The analysis was based on the total sample of boys and girls combined, consistent with the analytical approach in the original development of the diary protocol (Bouchard et al., 1983). Descriptive statistics were calculated for chronological

age, height, weight, sum of six skinfolds and measures derived from the diary and accelerometer.

The diary protocol assumes a standard energy equivalent for all activity codes, including code 1 [resting energy expenditure (REE)]. AEE was calculated by subtracting REE from the estimated DEE. Values for each period different from category 1 were summed across the whole day to provide the estimate of the total AEE in the diary. For accelerometry, average counts per minute were converted to AEE using the equation of Trost et al. (1998):

$$-2.23 + 0.0008\,(\text{counts/min}) + 0.08\,[\text{body weight (kg)}]$$

Agreement between estimated EE in activity (kcal/min) based on the diary and accelerometry was examined using the Bland–Altman procedure (Bland & Altman, 1986). Before analysis, tests for normality were conducted on the measures of PA (AEE) provided by accelerometer and the 3-day diary. The tests suggested that both measures were not normally distributed (diary: skewness = 1.79, Kolmogorov–Smirnov value = 0.09, $P<0.001$; accelerometer: skewness = 0.89, Kolmogorov–Smirnov value = 0.06, $P<0.001$). Log transformation (log10) of the variables substantially improved normality for the diary (skewness = 0.40, Kolmogorov–Smirnov value = 0.03; $P = 0.059$), but not for the accelerometer data. As such, only the diary data were transformed. Day-specific Pearson product–moment correlations (one tailed) were calculated between AEE estimated from the diary and accelerometer. Relationships between methods were determined by gender for each day (Thursday, Friday, Saturday) and within different intervals of validly measured time using the accelerometer. Partial correlations between methods controlling for body mass were also calculated. The association between AEE and adiposity was also computed.

Results

Descriptive statistics for age, body size, adiposity and AEE are summarized in Table 1. Estimated AEE differs between protocols: 2.47 ± 0.89 and 2.22 ± 0.75 kcal/min for accelerometry and the diary, respectively. Correlations between AEE (kcal/min) based on accelerometry and the diary by day and all days combined are given in Table 2 for males and females separately. Overall correlations between protocols are significant ($P<0.001$), but moderate and similar in magnitude in males ($r = 0.65$) and females ($r = 0.69$). Correlations for single days range from 0.61 to 0.74 in males and from 0.67 to 0.73 in females. Partial correlations between estimates of AEE based on the diary and accelerometry for the 3 days combined, controlling for body mass, are 0.44 and 0.35 in males and females, respectively. Partial correlations for individual days among males are 0.41, 0.46 and 0.46 for Thursday, Friday and Saturday, respectively; corresponding partial correlations among females are 0.34, 0.35 and 0.39, respectively.

Table 1. Descriptive statistics for the total sample

Variable	Mean	SD
Chronological age	14.18	1.03
Height (years)	161.2	8.5
Weight (kg)	54.3	10.9
Sum of six skinfolds (mm)	75.8	36.5
Accelerometry		
Habitual physical activity (counts/min)	452.6	224.4
Valid activity measured time (min)	857.5	97.5
Estimated activity energy expenditure (kcal/min)	2.47	0.89
Diary		
15-min episodes in category 1 (f)	45.5	11.3
15-min episodes in category 2 (f)	32.7	12.5
15-min episodes in category 3 (f)	3.1	4.1
15-min episodes in category 4 (f)	4.8	4.7
15-min episodes in category 5 (f)	3.1	5.4
15-min episodes in category 6 (f)	2.2	3.8
15-min episodes in category 7 (f)	1.0	2.6
15-min episodes in category 8 (f)	0.8	2.5
15-min episodes in category 9 (f)	2.8	4.2
Estimated activity energy expenditure (kcal/min)	2.22	0.75

f, frequency

Table 2. Correlations between energy expenditure (kcal/min) estimated from accelerometry and the 3-day diary by day and the 3 days combined and partial correlations controlling for body mass for males and females separately

	Bivariate correlation			Partial correlations (controlling for body mass)		
	r	*P*	*N*	*r*	*P*	df
Males ($n = 186$)						
Day 1 – Thursdays	0.62	<0.001	186	0.41	<0.001	183
Day 2 – Fridays	0.74	<0.001	186	0.46	<0.001	183
Day 3 – Saturdays	0.61	<0.001	186	0.46	<0.001	183
All days	0.65	<0.001	558	0.44	<0.001	555
Females ($n = 217$)						
Day 1 – Thursdays	0.67	<0.001	217	0.34	<0.001	214
Day 2 – Fridays	0.68	<0.001	217	0.35	<0.001	214
Day 3 – Saturdays	0.73	<0.001	217	0.39	<0.001	214
All days	0.69	<0.001	651	0.35	<0.001	648
Total ($n = 403$)						
Day 1 – Thursdays	0.65	<0.001	403	0.40	<0.001	400
Day 2 – Fridays	0.71	<0.001	403	0.43	<0.001	400
Day 3 – Saturdays	0.68	<0.001	403	0.45	<0.001	400
All days	0.67	<0.001	1209	0.42	<0.001	1206

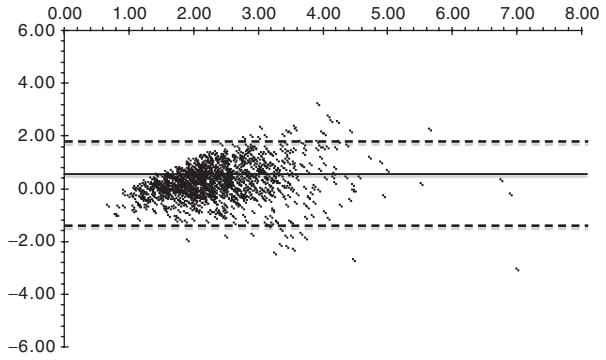

Fig. 1. Bland -Altman plot of differences between estimated activity energy expenditure (AEE) from the two protocols (*Y*: accelerometer–diary, kcal/min) relative to mean estimated AEE based on the two protocols (*X*: mean of AEE, kcal/min). The solid line represents the mean difference and the dashed lines are the upper and lower limits of agreement (1.96 standard deviations).

The Bland–Altman plot of differences between estimated AEE based on the diary and accelerometry relative to mean estimated AEE based on the two protocols (kcal/min) is shown in Fig. 1. About 97% of cases fall within the upper and lower limits of agreement. The mean difference between the methods is 0.25 kcal/min, suggesting that AEE estimated with the diary tends to be lower than the estimate with accelerometry. Compared with the objective measurement, the diary yields higher estimates for 429 days, equal values for 10 days and lower estimates for 770 days.

Discussion

Objective assessment of EE (accelerometry, heart rate counters, etc.) in large epidemiological studies is often limited due to the costs of the instruments, trained personnel to deal with a large sample and the accelerometer-related software. As such, reliable and valid questionnaires and diaries provide reasonable alternatives. Although information about the reliability and validity of the 3-day diary in young people is limited, the protocol has been used in several studies of youth, including the relationship between sociogeographic variables and estimated EE in Taiwanese adolescents (Huang & Malina, 1996), a comparison of the health-related physical fitness of adolescents at the extremes of activity and inactivity (Huang & Malina, 2002), the contribution of organized youth sports to estimated daily EE (Katzmarzyk & Malina, 1998) and relationships among physical activity, fitness and coronary heart disease risk factors in youth from the Québec Family Study (Katzmarzyk et al., 1999). Results of the present study indicated that DEE estimated with the diary was quite reproducible and valid in a large sample of adolescents of both sexes.

Actigraph accelerometers have become one of the more commonly used tools for assessing physical activity in free-living youth, and the equation of Trost et al. (1998) is commonly used to convert Actigraph "counts" to units of moderate-to-vigorous physical activity. The equation was developed on 20 subjects 10–14 years of age during treadmill walking and running at 3, 4 and 6 mph (Trost et al., 1998). Activity counts were strongly correlated with energy expenditure estimated with indirect calorimetry ($r = 0.86$). The equation was then cross-validated on 10 subjects. The predicted mean EE was within 0.01 kcal/min of measured EE, and the correlation between the actual and the predicted EE was 0.93. However, a subsequent study indicated that the equation underestimated EE during walking and overestimated EE during fast running (Trost et al., 2006). However, when expressed as time spent in MVPA, the equation exhibited high classification accuracy. Moderate correlations between EE estimated with Trost and colleagues' equation and indirect calorimetry were reported for sweeping, bowling and basketball, 0.50–0.68, but the correlation for the pooled data was higher, 0.78 (Eisenmann et al., 2004).

The correlation between estimates of AEE (kcal/min) over 3 days based on accelerometry and the diary was 0.65 in males and 0.69 in females (Table 2). Among young adults aged 18–23 years, the correlation for estimated AEE based on the Tritrac and diary protocols was higher, 0.72 (Wickel et al., 2006). The latter study, however, did not consider variation in body mass. In the current sample of Portuguese adolescents, the strength of the association between estimated AEE based on accelerometry and the diary was reduced when variation in body mass was statistically controlled, 0.44 in males and 0.35 in females (Table 2).

A large and significant difference in estimated AEE (576 ± 381 kcal) between the accelerometry and diary protocols was observed in young adults (Wickel et al., 2006). The 3-day diary provided higher estimates of AEE than the Tritrac. In the present study, the diary protocol yielded higher estimates of AEE (kcal/min) for only 36% of the measured days in the Portuguese adolescents, but the mean estimated AEE assessed by the diary was 0.25 kcal/min lower than the mean AEE estimated using accelerometry.

Failure to wear the accelerometer is a potential source of error in estimates of AEE. The literature recommends searching for extended blocks of data with zero counts to identify cases in which a person may have removed the accelerometer (Welk, 2002; Rowlands, 2007). In the current study, the valid

measured time was 858 ± 98 min, which was substantially higher than the sum of minutes spent in diary categories 2–9, 758 ± 170 min. The relationship between the two protocols was also examined within different intervals of valid measured time using accelerometry. Correlations for AEE (kcal/min) were quite similar among tertiles of valid epochs: 0.62 for days with valid measured time between 600 and 826 min, 0.60 for days between 826 and 901 min of valid measured time and 0.63 for days with >901 min of valid measured time.

Energy expenditure is not entirely constant from day to day and many studies have considered variation between week and weekend days. Correlations between protocols for individual days were 0.62, 0.74 and 0.61 for Thursdays, Fridays and Saturdays, respectively, among males. The corresponding correlations for females were 0.67, 0.68 and 0.69, respectively (Table 2). The correlations varied by day among males, but were somewhat higher and stable across the 3 days among females. However, the intraindividual correlation for repeated assessments was lower on Saturdays (0.70) compared with Thursdays or Fridays (0.93). The trend in the Bland–Altman plot showed a tendency for smaller differences between protocols for lower levels of estimated AEE and larger differences between protocols as estimated AEE increased.

The 3-day diary with 288 entries (ninety-six 15-min periods per day over 3 days) with a defined coding system was not as accurate as the 60-s epochs provided by accelerometry. The diary procedure relied on approximation; the energy cost assigned to each categorical value approximated the median energy expended in the dominant activity of each 15-min period. On the other hand, the 60-s epoch of accelerometry data used in the current study tends to underestimate the portion of time spent in activities of vigorous and very vigorous intensity (Welk, 2002; Baquet et al., 2007; Rowlands, 2007; Troiano et al., 2008). These methodological factors probably contribute to the observation that the difference between methods was higher for cases with mean AEE > 2.00 kcal/min.

In summary, the 3-day diary protocol (Bouchard et al., 1983) was used without any major technical problems in 403 subjects comprising a span of 1209 days. The criterion of inclusion for the accelerometer, a minimum of 600 min of valid data, excluded 18% of the sample. Further study of the activity level of excluded subjects is needed. Relationships between estimates of AEE based on the diary and accelerometry protocols indicated that the 3-day diary method was quite reliable and reasonably valid. Thus, the 3-day diary is a valid supplement for assessing DEE and its AEE component in adolescents. The diary appears to be especially useful for studies that consider the amount of time spent in sedentary activities.

Key words: sedentary behavior, physical activity, assessment, Bland–Altman plot.

Acknowledgements

This research was partially supported by *Fundação para a Ciência e a Tecnologia – Ministério da Ciência, Tecnologia e Ensino Superior* (PTDC/DES/110158/2009, SRFH/BD/38988/2007). The authors also acknowledge the support provided by the *Portuguese Ministry of Education*. Thanks are due to Professor Chris Riddoch for supporting the stay of the first author in the University of Bath, UK.

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