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Research article

Energy expenditure and habitual physical activities in adolescent sprint athletes

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Abstract
This study aimed to assess total energy expenditure (TEE) and specific habitual physical activities in adolescent sprint athletes. Two methods used to estimate TEE, an activity diary (AD) and SenseWear armband (SWA), were compared. Sixteen athletes (6 girls, 10 boys, mean age 16.5 ± 1.6 yr) simultaneously wore a SWA and completed an AD and food diary during one week. Basal energy expenditure as given by the SWA when taken off was corrected for the appropriate MET value using the AD. TEE as estimated by the AD and SWA was comparable (3196 ± 590 kcal and 3012 ± 518 kcal, $p = 0.113$) without day-to-day variations in TEE and energy expended in activities of high intensity. Daily energy intake (2569 ± 508 kcal) did not match TEE according to both the AD and SWA (respectively $p < 0.001$ and $p = 0.007$). Athletes were in a supine position for a longer time on weekend days than on week days and slept longer on Sundays. Athletes reported a longer time of high-intensive physical activities in the AD than registered by the SWA on 4 out of 7 days. In addition to specific sprint activities on 3 to 7 days per week, 11 out of 16 athletes actively commuted to school where they participated in sports once or twice per week. The AD and the SWA are comparable in the estimation of TEE, which appears realistic and sustainable. The SWA offers an appropriate and objective method in the assessment of TEE, sleeping and resting in adolescent athletes on the condition that detailed information is given for the times the armband is not worn. The AD offers activity specific information but relies on the motivation, compliance and subjectivity of the individual, especially considering high-intensive intermittent training.

Key words: Indirect calorimetry, armband, exercise, sleep.

Introduction

For optimal athletic performance, recovery and body composition, athletes need to synchronize diet and physical activities. Sprinters are strength athletes who need to achieve a high power to weight ratio by maximizing muscle mass and maintaining low body fat (Tipton et al., 2007). In order to properly harmonize an athlete's dietary intake and training program, assessing the energy balance and physical activity status of the athlete is required (American College of Sports Medicine, 2009; Burke, 2001; Thompson, 1998). Specific sprint training is characterized by short bursts of high intensity with in between active or passive recovery periods of low intensity. Whereas the physiological and metabolic aspects of intermittent exercise and multiple sprint work have been well described (Glaister, 2005), so far no data exist on total energy expenditure (TEE) and activity patterns in adolescent sprint athletes. Monitoring should be done in the athlete's normal environment, enabling maintenance of habitual dietary intake and activity participation. Therefore, the methods used to determine dietary intake and activity patterns should preferably be as accurate as possible and at the same time be easy in use with a minimal burden on the athlete.

An activity diary (AD) is considered to be an accurate subjective technique. Despite the high participant burden, adolescents are able to complete the AD. Seliger et al. (1974) used a 24-hour AD in 12 year old boys and found increasing heart rates for each of the 7 intensity categories the boys used to evaluate their activity. Bratteby et al. (1997) found a mean difference of only 1.2% in TEE as estimated by an AD compared to the doubly labeled water method in 15 year old adolescents. However, based on the high participant burden, the accuracy of adolescent AD reports should be viewed with caution as stated in a review by Sirard and Pate (2001). Though self-report methods can be a principal source of information, other approaches or the use of combined measures may be needed to better characterize children's and adolescent's activity levels. Reporting the results with different instruments provides a more complete description of activity levels and permits triangulation of outcomes (Welk et al., 2000).

The SenseWear Armband (SWA) combines five different sensors into one device attached as an armband around the upper arm. The SWA has been shown to give reliable estimates of TEE in healthy free living adults (Johannsen et al., 2010; King et al., 2004; Sint-Onge et al., 2007). Johannsen et al. (2010) found a significant agreement between the SWA and doubly labeled water estimates of TEE with an intra class correlation of 0.8. The SWA accurately estimated energy expenditure during intermittent sub-maximal treadmill exercise in children varying in age and body size (Andreacci et al., 2006). Fruin and Rankin (2004) found the SWA to provide valid and reliable estimates of energy expenditure at rest and on an ergometer as compared to indirect calorimetry. One of the features of the SWA is its ability to distinguish sleeping from being awake in a supine position which has shown its usefulness in sleep research (Andre and Teller, 2005; Miwa et al., 2007). On the other hand, the SWA does not provide information on the type and context of all other activities. Moreover, several studies have shown

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the SWA to underestimate the energy cost of most activities and this underestimation increases with increasing exercise intensity in both children (Arvidsson et al., 2007; 2009) and adults (Drenowatz and Eisenmann, 2010; Jakicic et al., 2004; Johannsen et al., 2010). A ceiling effect around an intensity of 10 METs was reported by Drenowatz and Eisenmann (2010). Still, the SWA remains highly feasible to use, especially in free-living children and adolescents (Arvidsson et al., 2009).

It was the aim of this study to assess TEE and the specific habitual physical activities in talented adolescent sprint athletes using a combination of an AD and the SWA. Secondly, it was our aim to compare the estimations from the AD and the SWA.

Methods

Athletes simultaneously recorded their activities in an AD, wore the SWA, and completed a food diary during 7 consecutive days.

Subjects

Based on the Flemish Athletics League rankings of all sprint disciplines (60 m indoor to 400 m outdoor), 16 top 5-ranked athletes between 13.8 and 19.0 years old (6 girls and 10 boys, aged 16.5 ± 1.6 yrs; Mean ± SD) were selected and invited for participation. As this study was part of a larger 3 year follow-up study on sprint start performance, physical development and nutrition in adolescent Belgian sprint athletes, the randomly selected participants for this subsample were already familiarized with completing the AD and food diary. The recording was done during a week of normal training in the preparation phase before the outdoor (spring 2008, n = 10) and indoor (autumn 2008, n = 6) competition season. All athletes were competing in one or more sprint disciplines from 60 m indoor to 400 m outdoor including hurdles, for a minimum of 5 years. Before data collection, the university's ethical committee approved the study protocol. Participating athletes and their parents received detailed information about the study and gave written informed consent.

Energy expenditure and physical activities

Basal energy expenditure (BEE) was calculated with the Institute of Medicine equation (2005). A physical activity diary (AD) (Vermorel, 2004) was completed, using a 7-level intensity scale in order to calculate TEE and physical activity level (PAL = TEE/BEE). For each intensity scale, example-activities were given. The 6th and 7th intensity scales consist of activities corresponding with 6 to 9 metabolic equivalents (METs) and more than 9 METs respectively (Ainsworth et al., 2000). Special attention was given to the detailed description and context of activities reported in the 6th and 7th intensity scale.

The SenseWear Pro3 Armband (SWA) (BodyMedia Inc., Pittsburgh, PA) was worn on the back of the right upper arm. The SWA is a multiple-sensor device collecting different parameters: skin temperature, near-body temperature, heat flux, galvanic skin response, body position and movements of the upper arm. The skin temperature sensor and near-body temperature sensor (a vent on the side of the armband) consist of sensitive thermistors in contact to the skin relying on changes in resistance with changing temperature. The heat flux sensor uses the difference between skin temperature and near-body temperature to assess heat loss. The galvanic skin response sensor measures the conductivity of the skin between two electrodes in contact to the skin. The conductivity of the skin varies according to physical and emotional stimuli. Registration of upper arm movements and body position is provided by a biaxial accelerometer. Energy expenditure was calculated at 1-min intervals, using Innerview Sensewear Professional Software, including data from all sensors, together with gender, age, body height, and weight. Time spent sleeping, spent awake in supine position and time when energy expenditure was higher than 6 METs were analyzed.

According to the SWA guidelines, athletes were instructed to take off the armband only when showering, bathing, swimming, or in case of hinder (i.e. during competition or social events). In such cases, the SWA stops measuring and automatically takes the calculated BEE for energy expenditure during the off-body period. Activities done when the SWA was not worn were described in detail by the participants in the AD. This information was used in the analysis to correct the 1 MET off-body energy expenditure as taken by the SWA, with the corresponding MET of the reported activity using the values as proposed by Ainsworth et al. (2000).

According the model of Pate et al. (1995), activities reported in the 6th and 7th activity scale of the AD and MET values above 6 METs as recorded by the SWA were defined as high intensity activities.

Energy intake

Total energy intake (TEI) was estimated based on the completion of a 7-day food diary. The athletes were clearly instructed to maintain their normal eating pattern and to report all foods as accurately as possible considering preparation, composition and portion size. For the latter they were asked to weigh the items, using their personal scale. When not feasible, household measures were given to make an estimate of the portion size. Within 1 week after completion the diary was handed over at the investigator who checked the diaries and asked additional information when necessary. Diaries were analyzed by one and the same investigator using BINS 3.0 software based on the Belgian food data bank.

Anthropometric measurements

Within 1 week after completing, the diaries and wearing the SWA, athletes came to the laboratory of human biometry and biomechanics. Standing body height was measured to the nearest 0.1 cm using a wall-mounted stadiometer. Body weight was measured with the TANITA-TBF 410, accurate up to 100 g. As a control, athletes weighed themselves at home in the morning at the beginning and after ending the 7-day recording period.

Statistical analysis

Statistical analysis was performed with SPSS 17.0. The Kolmogorov-Smirnov test was used to test for normal distribution of the data. To compare TEE according the AD and the corrected SWA, and to compare TEI with

Table 1. **TEE, activity-specific energy expenditure and time spent in different physical activities according the AD and SWA. Data are means (SD).**

	AD	SWA	p value
TEE (kcal·day^{-1})	3196 (590)	3012 (518)	.113
Sleep + supine position(min·day^{-1})	546 (37)	520 (35)	.053
Sleep (min·day^{-1})	/	407 (52)	
High intensity exercise (min·day^{-1})	94 (40)	45 (34)	.002
High-intensity exercise (kcal·day^{-1})	649 (393)	530 (341)	.068

TEE: Total energy expenditure; /: no data available

TEE as estimated by the AD and SWA, a paired t-test was applied. Day-to-day variability in energy expenditure, energy intake or times spent in specific activity categories (sleeping, supine position, high intensity activities) was tested with an ANOVA followed by a paired t-test with Bonferroni correction. Pearson correlations and, in case of non-parametric data, Spearman correlations were calculated between TEE and TEI as estimated by the AD and SWA as well as between times spent in specific activity categories according the AD and SWA. The standard error of the estimate (SEE) and the 95% confidence intervals (CI) were presented (Hopkins, 2004). The significance level was set at $p < 0.05$.

Results

The self-measured body weight at the beginning and end of the recording week did not significantly change (63.7 ± 5.2 kg versus 63.9 ± 5.2 kg respectively, p = 0.09).

Besides taking a shower or a bath (13.4 ± 5.5 min·day^{-1} in all athletes), reasons for taking off the SWA were swimming (40 ± 9 min, mean of 3 athletes), hinder during training or competition (186 ± 83 min, mean of 5 athletes) and hinder on social events (250 ± 168 min, mean of 3 athletes). The correction made for these activities resulted in a mean additional 112 ± 118 kcal·day^{-1} (range 4 to 306 kcal·day^{-1}).

Without correcting the SWA for activities done when the armband was not worn the SWA gave a significant lower estimate of TEE (p = 0.019). Table 1 shows that TEE was not different (p = 0.113) according the AD and the SWA when taking into account the activities done when the armband was not worn. The calculated PAL was 1.83 ± 0.17 (range 1.51 to 2.20) and 1.74 ± 0.25 (range 1.36 to 2.14) for the AD and SWA respectively (p = 0.169)

Mean TEI of 2569 ± 508 kcal was lower than TEE according both the AD and the SWA after correcting the latter for the periods that the armband was not worn ($p < 0.001$ and p = 0.007, respectively).

Without correcting for those periods the SWA was not worn, a day-to-day variability in energy expenditure could be observed. The day-to-day variability disappeared after correcting for these periods (p = 0.20). Neither the AD (p = 0.91) nor the food diary (p = 0.202) revealed a day-to-day variability in energy expenditure or energy intake, respectively.

Mean time spent in supine position was not different according the AD and SWA (Table 1). Figure 1 shows the time spent in a supine position for all days of the week as reported in the AD and as registered by the SWA which made the distinction between sleeping and being awake. According to both the AD and SWA, athletes were in a supine position for a longer time on Sunday than on all other days of the week (range $p < 0.001$ to p = 0.006), except for Saturday (p = 0.146). The SWA

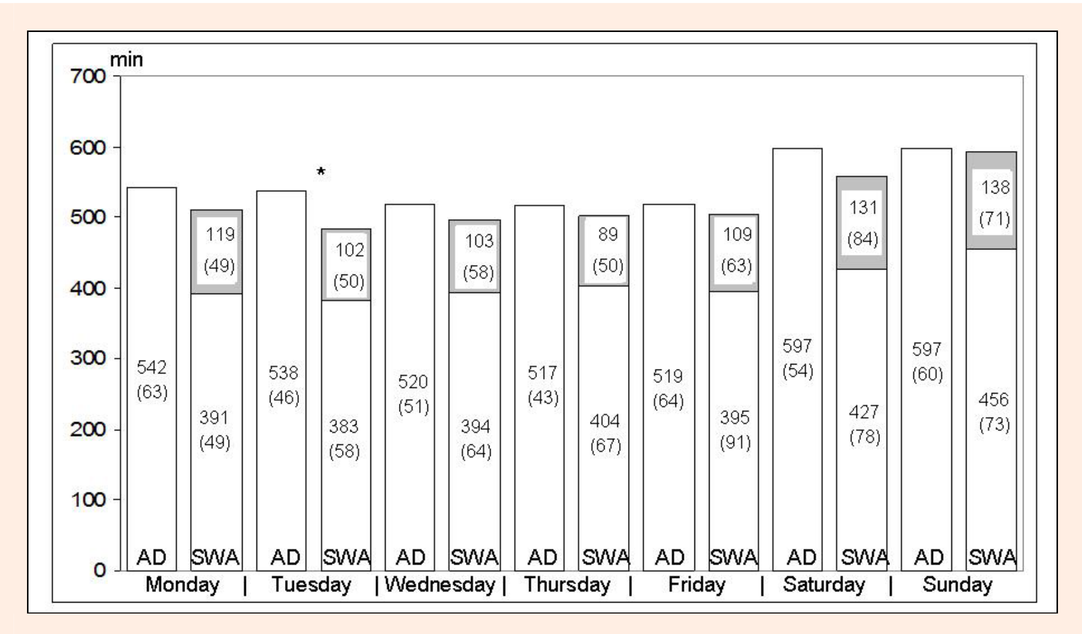

Figure 1. **Time spent in supine position according the activity diary (AD) and the Sensewear armband (SWA) with SWA discriminating between sleep (white) and awake (grey). Data are means (SD).** * Significant difference in time spent in supine position between the AD and SWA at $p < 0.05$.

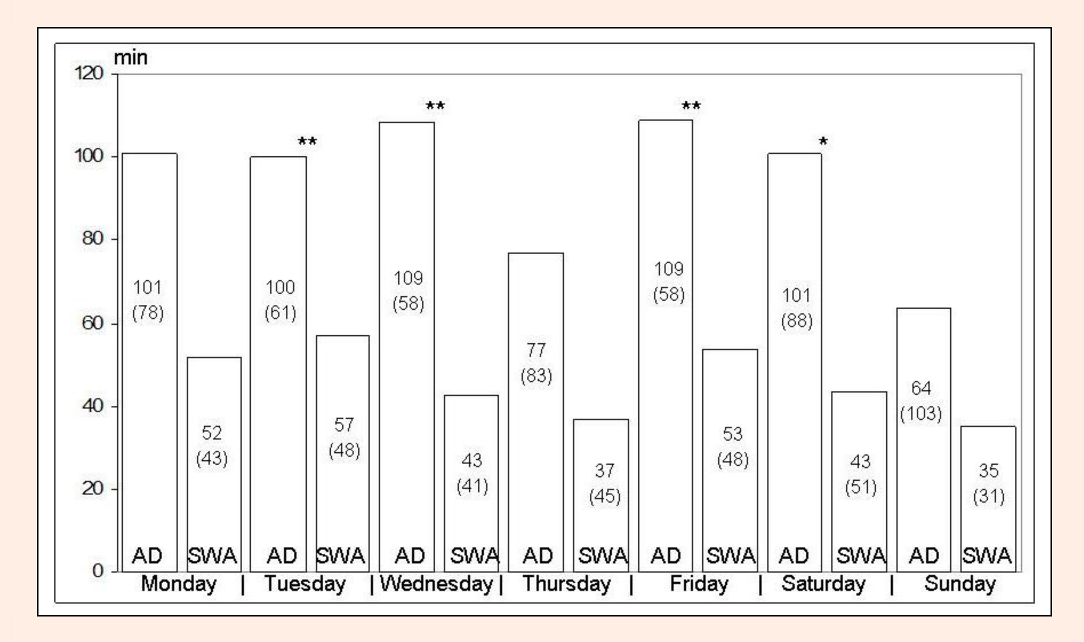

Figure 2. Time spent in physical activities of high intensity according the activity diary (AD) and the Sensewear armband (SWA). Data are means (SD). *, ** Significant difference between the AD and SWA at $p < 0.05$ and $p < 0.01$ respectively.

registered significantly longer sleep times on Sunday as compared to Monday (p = 0.001) and Tuesday (p < 0.001), and a non significant difference in sleep time between Sunday and Wednesday (p = 0.009), Thursday (p = 0.027), Friday (p = 0.019) and Saturday (p = 0.207). Comparing the AD and the SWA regarding time in supine position on the different days of the week, the AD gave higher values than the SWA on Tuesday only (538 ± 46 min versus 485 ± 56 min, p = 0.027).

Athletes reported in the AD to spend on average significantly more time doing physical activities of high intensity than was registered by the SWA (p = 0.002). Mean daily energy expended in physical activities of high intensity was not significantly different between the calculations from both methods (Table 1). Figure 2 and Figure 3 respectively present time spent and energy expended in physical activities of high intensity for all days of the week. The AD and SWA gave different values for time spent in physical activities of high intensity for Tuesday (p = 0.002), Wednesday (p = 0.001), Friday (p = 0.001) and Saturday (p = 0.025). On Wednesday only, energy expended in physical activities of high intensity was significantly (p = 0.014) higher according the AD as compared to the SWA. Neither the AD nor the SWA revealed day-to-day variations in time spent or energy expended in physical activities of high intensity (respectively p = 0.941 and p = 0.673).

TEI correlated significantly with TEE estimated by

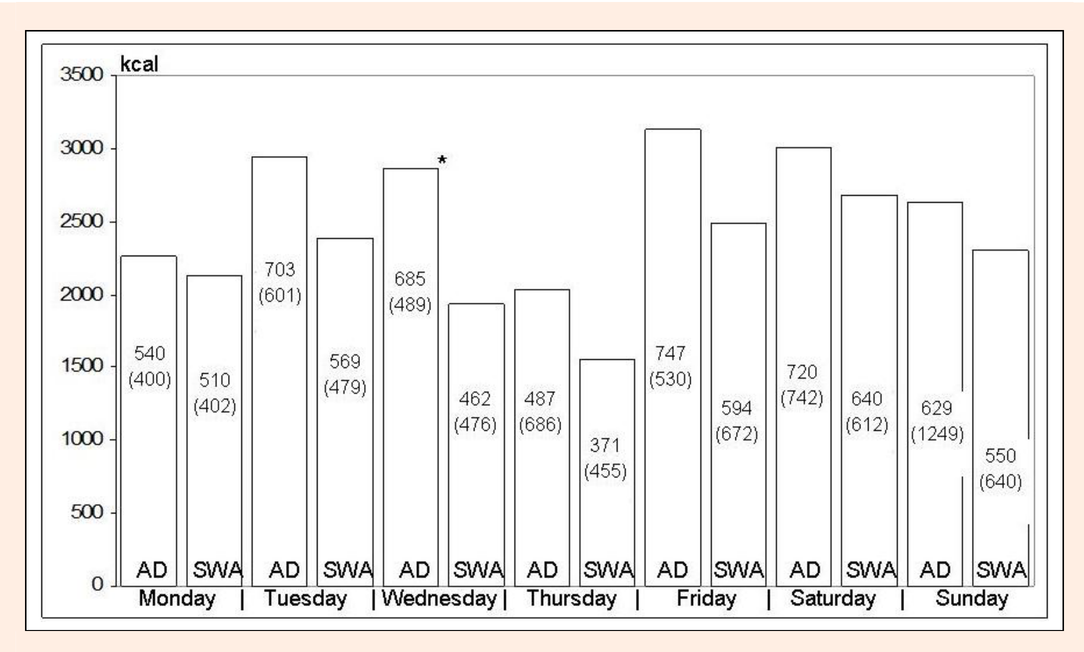

Figure 3. Energy expenditure in physical activities of high intensity according the activity diary (AD) and the Sensewear armband (SWA). Data are means (SD). * Significant difference between the AD and SWA at $p < 0.05$.

the AD ($r = 0.67$, $p = 0.007$, SEE = 381, 95% CI = -355, 1969) but not with the estimation of the SWA ($r = 0.45$, $p = 0.122$, SEE = 474, 95% CI = -504, 3010). The correlation between TEE estimated by the AD and SWA was significant ($r = 0.79$, $p = 0.002$, SEE = 383, 95% CI = -1018, 2020). Time spent sleeping and lying down did not correlate significantly between the 2 instruments ($r = 0.51$, $p = 0.093$, SEE = 33, 95% CI = -151, 610). Time spent in physical activity of high intensity did not correlate significantly between the AD and SWA ($r = 0.31$, $p = 0.309$, SEE = 40, 95% CI = 36, 120). A significant correlation was found between energy expended in activities of high intensity between the AD and SWA ($r = 0.85$, $p < 0.001$, SEE = 214, 95% CI = -134, 391).

Specific athletic training (all athletes) and resistance training (6 athletes) was done 3 to 7 times per week. Cycling for transport to school was done by 11 athletes. Gym classes in school and other extra sports activities were done by 8 and 7 athletes respectively but only at a frequency of 1 or 2 times per week. In 5 out of 8 athletes the gym class was on a training day.

Discussion

Knowledge of an athlete's TEE and energy expenditure during physical activities is a requisite to properly plan dietary intake according to the specific needs and goals of the individual (American College of Sports Medicine, 2009; Burke, 2001; Thompson, 1998). In this special group of talented adolescent sprint athletes, we simultaneously assessed TEE and TEI in combination with detailed information on participation in habitual physical activities which offers new insights in the energy and physical activity status that need to be taken into consideration when programming training and dietary intake. The reader should keep in mind that no gold standard measures of TEE were carried out, in this study two indirect methods were used and compared. Based on its objectivity and conducted validation studies (Arvidsson et al., 2007; 2009; Dorminy et al., 2008; Jakicic et al., 2004; Johannsen et al., 2010), we consider the TEE as estimated by the SWA after correction for periods not wearing the armband as more acceptable when compared to the AD. Correction of energy expenditure for periods that the SWA was not worn is necessary to obtain representative results as indicated by an additional energy expenditure up to 306 $kcal.day^{-1}$ and the significant difference between the SWA and the AD for TEE estimation without this correction. Although it has been shown that the SWA underestimates the energy cost of most activities, a daily TEE of 3012 ± 518 kcal appears to be a reasonable estimation in these adolescent sprint athletes. This assumption is supported by the comparable TEE as estimated by the AD, which did not give a significantly higher estimation. Moreover, the correlation between the TEE estimations from the AD and SWA was very high. The negative energy balance observed according both the AD and SWA, together with the constant body weight during the week of recording, indicates that these athletes most probably underreported their dietary intake which resulted in an underestimation of TEI. This corroborates with earlier research revealing that most self-reports of food intake substantially underestimate TEI in athletes, due to underreporting or undereating during the period of record keeping (Burke, 2001). Still, a possible overestimation of TEE by both the AD and the SWA can not be excluded. A validation study by Dorminy et al. (2008) compared the SWA with indirect room calorimetry in African American children and found the SWA to overestimate TEE by 22% during a 24 hour period with a peak up to 43% during the resting period following 30 minutes of running. This is in contrast with our suggested underestimation. This discrepancy may be explained by the younger subjects studied by Dorminy et al. (2008), carrying out physical activity at low intensity only.

Despite a non-significant correlation between the AD and SWA concerning time spent in sleeping and being in supine position, both methods were in reasonable agreement in estimating mean times spent in a supine position. They both revealed that these athletes stayed longer in bed on Sundays as compared to other days of the week, but that this did not result in a lower energy expenditure on Sundays. In fact, besides time spent sleeping and awake in supine position, no day-to-day variability was observed in TEI, TEE or times spent and energy expended in activities of an intensity higher than 6 METs. These athletes reported spending significantly more time in activities of high intensity than was registered by the SWA. This might be due to the underestimation of energy expenditure in high intensity physical activities by the SWA (Arvidsson et al., 2007; 2009; Drenowatz and Eisenmann, 2010; Jakicic et al., 2004; Johannsen et al., 2010). Another possible explanation could be the intermittent nature of sprint specific training, which makes it difficult for the athlete to attribute such activities to a certain intensity level. However, the estimated energy expenditure of all activities with an intensity above 6 METs was comparable between the AD and the SWA on 6 out of 7 days of the week. Moreover, the AD and SWA showed a very high correlation for the estimated energy expended in high intensity activities. The different values in time spent and the comparable values for energy expended in high intensity physical activities according the 2 methods is somewhat contradictive, however, can be explained by a lower sensitivity of the AD compared to the SWA (2 highest intensity scales with a fixed activity level versus unlimited registration). In other words, the SWA detected intensities from 6 METs and higher resulting in a mean activity level higher than those of the 6th and 7th intensity scale of the AD.

The PAL of these athletes was below the upper limit of 2.2 – 2.5 as suggested by Westerterp (2001) and can be considered to be sustainable, which is also reflected by the normal height and weight for age of these athletes and the constant body weight during the week of recording. A comparable PAL was found in adolescent speed skaters ranging between 1.58 and 2.63, assessed by doubly labeled water (Ekelund et al., 2002).

Besides competition events, sprint and resistance training, it is important to implement sufficient rest to allow recovery and avoid overtraining and burnout (Brenner, 2007). The SWA detected that these athletes slept on average between 6 and 7 hours per night. This is low considering the 9 to 10 hours of sleep per night adolescents require (Mercer et al., 1998) and the importance of a good night rest in athletes (Carskadon, 2005). However, our findings agree with the study of Mercer et al. (1998) showing a sleep time between 6.5 and 8.5 hours during school nights and an increasing gap in sleep time between school nights and weekend nights. Brand et al. (2010) showed that high exercise levels favor sleep quality in adolescents, which might explain a shorter sleep time needed in these sprint athletes. The objective representation of sleep time by the SWA offers useful extra information for coaches when monitoring athletes. Daily living activities can contribute significantly to TEE but appear difficult to define and quantify (Donnely et al., 2009). Besides on-track and resistance training, defined as sprint specific activities, these athletes commuted in an active way to school and participated in gym classes at school. Five athletes had to combine sport at school with training in one day. In talented athletes, cooperation between the school and athletics coaches can be useful in better programming these athletes' physical activities, training and competition. The high standard deviations observed in times spent and energy expended in high intensity activities can be explained by an inter-individual difference in training frequency and planning training bouts on different days of the week. Therefore, assessment of habitual physical activities requires an individual approach.

Conclusion

We can conclude that the SWA is an appropriate and objective device in the assessment of TEE, sleeping and resting in adolescent athletes provided that detailed information is given for the times the armband was taken off enabling correction of energy expenditure for these moments. When more specific information is desired about their activities or when examining a large sample of athletes at the same time, the AD is a suitable alternative which can supply reliable results. The use of an AD demands clear instructions and highly motivated athletes to ensure compliance.

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Key points

- The activity diary and Sensewear armband provide comparable estimates of TEE in adolescent sprint athletes.
- A high inter-individual variation was observed in time spent in high-intensity physical activities, advocating an individual based assessment when coaching athletes.
- The activity diary is useful when detailed information on specific physical activities is desired. The Sensewear armband offers objective information on sleeping, resting, and physical activity duration.
- Wearing the Sensewear combined with reporting on activities when the Sensewear is not worn and when doing specific activities of interest results in more complete information.

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