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ORIGINAL ARTICLE

Sedentary behavior and physical activity classification using accelerometer cut points in 9—11-year-old children

Classification du comportement sédentaire et des activités physiques en utilisant les points de rupture de l'accéléromètre chez les enfants âgés entre 9 et 11 ans

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KEYWORDS
Energy expenditure;
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Summary
Objectives. — To validate accelerometer counts against oxygen uptake in 9 to 11 years old children performing a number of highly variable physical activities and to determine accelerometer cut-off points for sedentary behavior, light, moderate, and vigorous physical activities.
Equipment and methods. — Eight boys and 6 girls aged 9 to 11 years old (height: 1.40 ± 0.06 m, body mass: 33.5 ± 5.1 kg, BMI: 16.9 ± 2.0 kg/m^2, body fat: 17.0 ± 4.8%, estimated VO_2max: 50.85 ± 4.8 ml.kg^{-1}.min^{-1}) volunteered to participate in this study. They performed eight activities of different intensity namely watching TV, arts-crafts, slow and brisk forward walking, slow backward walking, forward running, aerobics and step-ups while VO_2 and counts were determined using indirect calorimetry and accelerometer, respectively.
Results. — A highly significant correlation was found between accelerometer counts and VO_2 ($r = 0.86$, $P < 0.01$). Significant differences were observed between predicted and measured VO2 for ART, SWB and Aerobic activities ($P = 0.0003$; $P < 0.0001$ and $P = 0.0004$, respectively). Bland and Altman plot revealed no significant bias for all other activities (−0.6 ml.kg^{-1}.min^{-1}, $P = 0.347$) with 95% limits of agreement (LoA) ± 9.7 ml.kg^{-1}.min^{-1}. In addition, watching TV and participating in art activities were classified as sedentary activities (< 61 counts. min^{-1}), slow walking forward was classified as light activity (61—3435 counts. min^{-1}), slow backward walking, brisk walking and aerobics were classified as moderate activities (3436—6100 counts. min^{-1}) and step-ups and running were defined as vigorous activities ($\geq$ 6101 counts. min^{-1}).

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MOTS CLÉS
Dépense énergétique ;
ActiGraph ;
Exercice ;
Enfant ;
Validité

Résumé
Objectifs. — Valider les données d'un accéléromètre par rapport aux valeurs de la consommation d'oxygène chez des enfants âgés entre 9 et 11 ans réalisant des activités physiques d'intensités variables et de déterminer les points de rupture de l'accéléromètre entre les activités dites sédentaires, légères, modérées et vigoureuses.
Matériels et méthodes. — Huit garçons et 6 filles âgés entre 9 et 11 ans (taille : 1,40 ± 0,06 m, masse corporelle : 33,5 ± 5,1 kg, IMC : 16,9 ± 2,0 kg/m^2, masse grasse : 17,0 ± 4,8%, VO_2max estimé : 50,85 ± 4,8 mL.kg^{-1}.min^{-1}) ont participé volontairement à cette étude. Ils ont réalisé 8 activités d'intensités variables : regarder la télévision, participer à des activités artistiques, marche lente et rapide, marche lente vers l'arrière, course avant, aérobic et step-ups durant lesquelles le nombre de coups et la consommation d'oxygène sont déterminés en utilisant respectivement la calorimétrie indirecte et l'accéléromètre.
Résultats. — Une forte corrélation est enregistrée entre le nombre de coups donné par l'accéléromètre et la consommation d'oxygène (r = 0,86, p < 0,01). Des différences significatives ont été observées entre les valeurs mesurées et celles prédites pour les activités artistiques, la marche en arrière et aérobie (respectivement, p = 0,0003 ; p < 0,0001 et p = 0,0004). La figure de Bland et Altman montre des différences non significatives au niveau du biais pour toutes les autres activités (−0.6 mL.kg^{-1}.min^{-1} p = 0,347) avec 95% des limites de concordance (LoA) ±9.7 mL.kg^{-1}.min^{-1}. En plus, regarder la télévision et participer aux activités artistiques sont classés comme comportements sédentaires (< 61 coups.min^{-1}), la marche lente vers l'avant est classée comme activité légère (61—3435 coups.min^{-1}), la marche lente vers l'arrière, la marche rapide et l'aérobic sont classés comme intensité modérée (3436—6100 coups.min^{-1}) et la course avant et le step-ups sont classés comme activités vigoureuses (≥ 6101 coups.min^{-1}).

1. Introduction

The increasing prevalence of accelerometer use has revealed different approaches to converting accelerometer output (counts.min^{-1}) into appropriate biological variables (e.g. energy expenditure) to define the physical activity intensity [1—6]. Studies have calibrated accelerometer counts based on a predictive energy expenditure equation derived from adults [7—9]. However, many factors exist that restrict the use of adult prediction equations with children, such as children's higher resting metabolic rate (RMR) and poorer biomechanical efficiency of movements in performance, compared to adults [7,10—16].

Identification of these important differences between children and adults highlights the necessity of defining physical activity (PA) intensity in children using child specific energy expenditure prediction equations [11]. For this reason, many studies began to consider the physiological differences between the two populations and have calibrated accelerometer counts in a controlled laboratory environment with samples of children using both heart rate (HR) and energy expenditure as an objective measurement criterion [7,10—15,17—19]. Some studies have focused on calibrating walking and running activities at different speeds using the treadmill [7,15,20]. Others have included some structured free-living activities in the calibration process [3,10,14].

In view of the fact that the relationship between accelerometer counts and energy expenditure is dependent on the type of activities performed [21], studies have established different thresholds to define PA intensities in children and adolescents [3,11,14,22,23]. Nevertheless, these thresholds vary significantly. For instance, the light physical activity intensity (LPA) has been defined as any activity count between 100 and 1262 counts.min^{-1} by Freedson et al. [22] using walking and running activities only. Eston et al. [13], Puyau et al. [10] and Treuth et al. [14] have included free-living activities with running and walking activities in their studies and defined the light activity threshold as any count between 500 and 3999 counts.min^{-1}, 800 and 3199 counts.min^{-1} and between 100 and 2999 counts.min^{-1}, respectively. Thus, studies have provided an enormous range of values; between 100 and 3999 counts.min^{-1}, with which to define LPA intensity [7,10,13—15]. In addition, for moderate and vigorous PA intensity thresholds in children, studies varied widely in their results. Moderate intensity ranged between 1263 to 5700 counts.min^{-1}, while the range of 4136 to 10,000 counts.min^{-1} has been used to define vigorous intensity activity [7,10,13,14,22]. The range and overlap between PA intensity thresholds (counts.min^{-1}) highlights the problem of how to correctly distinguish light activity from moderate physical activity intensity levels using accelerometer. Child and adolescent studies also illustrated a wide range of metabolic equivalent of task (MET) values for the different PA intensity levels. According to laboratory studies, Freedson et al. [7] revealed that sedentary, light, moderate and vigorous intensity activity were represented by <1.5, 1.5—3, 3—6, and ≥ 6 METs, respectively. However, using both forwards ambulatory and free-living activities, Eston et al. [13] and Freedson et al. [18] later revised these values and defined sedentary, light, moderate and vigorous intensity activity as equivalent to <3 METs, 3—6, 6—9 and ≥9 METs, respectively.

In practice, as the majority of the studies have validated the accelerometer counts in children and adolescents against calorimetry methods, several existing accelerometer cut-off points and MET scales are available for

Table 1 Daily time plan and intensity of activities protocol.

Day one protocol	5 min resting	10 min Watching TV	2 min resting	10 min Aerobics
Day two protocol	5 min resting	10 min Participating in art\craft	2 min resting	10 min Brisk waking
Day three protocol	5 min resting	10 min Slow walking forwards	2 min resting	10 min Step-up
Day four protocol	5 min resting	10 min Slow walking backwards	2 min resting	10 min Running

determining activity intensity [10,14,24]. However, the differences in age group, number of subjects, range of activities that have been studied, speed of locomotion and the statistical process used to create the thresholds have led to dissimilarity in cut-off point values [11,22,25]. The variations in the PA thresholds confirm the idea that there is no standard approach to define PA intensity in children and adolescents.

Fundamentally, as activity type is the main impact on the accelerometer count thresholds that have been developed [23], it has been documented that studies applying a treadmill-based predictive equation to estimate energy expenditure from accelerometer counts underestimate the energy expenditure of free-living activities [21]. Moreover, when a cross-validity study applied different types of activities rather than just walking and running, a higher level of classification error occurred [26]. Critically, accelerometer prediction equations developed under a controlled setting do not accurately predict energy expenditure in children during walking and running in free-living conditions [27]. Factors that may influence these developed equations include the environmental conditions, ground surface type and differences in pace and mechanical work under both conditions [28].

Physical activity, particularly under free-living conditions, is considered to be one of the most complex behaviours to measure accurately. To our knowledge, there is no study that has validated accelerometer counts against energy expenditure in 9 to 11 years old children in a free-living environment using both ambulatory and non-ambulatory activities. The purpose of the present study was twofold:

- to validate accelerometer counts against oxygen uptake (energy expenditure) in 9 to 11 years old children performing a number of highly variable physical activities typical of those undertaken in free-living conditions;
- to determine cut-off points for sedentary (S), light (L), moderate (M) and vigorous (V) physical activity using accelerometer counts in 9 to 11 years old children.

2. Materials and methods

2.1. Subjects' characteristics

Fourteen children (8 males and 6 females) aged 9 to 11 years old (height: 1.40 ± 0.06 m, body mass: 33.5 ± 5.1 kg, BMI: 16.9 ± 2.0 kg/m^2, body fat: 17.0 ± 4.8%, estimated VO_2max: 50.85 ± 4.8 ml.kg^{-1}.min^{-1}) volunteered to take part in this study. Children and their parents were informed beforehand about the objectives and scope of the project, the procedures, risks, and benefits of the study and gave their written consent. The present study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Institutional research ethics committee of ASSIX University.

2.2. Structured protocol and data collection

All participants completed eight activities of different intensity, each of 10 minute duration, across four different monitoring days (Table 1). These activities included watching TV, arts-crafts, pedestrian locomotion (slow and brisk forward walking, slow backward walking, forward running) and fitness exercises without covering distances (aerobics and step-ups).

2.3. Instrumentation

2.3.1. Indirect calorimetry

Respiratory gas exchange was measured using a portable breath-by-breath gas analysis system (MetaMax® 3B manufactured by Cortex Biophysik, Germany). The gas analysis system provided direct measurement of gas exchange including O_2 and CO_2 concentrations of the expired air and other physiological variables. O_2 uptake and CO_2 output were measured during each breath whilst participants performed different physical activities. The gas analysis system takes a sample of expired air to the O_2 and CO_2 sensors straight from the turbine through the sample line and determines expired O_2 and CO_2 concentration. The system measures volume continuously and simultaneously. Before each testing session started, respired O_2 and CO_2 concentration and respired volume and flow calibrations were performed according to the manufacturer's guidelines. After warming up the unit for 40 minutes, the following four stages of calibration were applied. Firstly, O_2 and CO_2 analysers were calibrated against the room ambient gas alignment. Secondly, O_2 and CO_2 analysers were calibrated with a reference gas of known composition; oxygen 16.93% and carbon dioxide 5.04% using a disposable calibration check gas. Following this step, a calibration of the turbine volume was undertaken using a standard 3000 mL calibration syringe (model 7200 WYANDOTTE, Hans Rudolph Inc. USA). The last step is the one point calibration and is performed immediately before the test starts to check for accurate reading during all measurements, as well as to check the association between the gas flow and gas concentrations. All data collected during the measurement were stored in the internal data logger for later downloading to a PC using Metasoft, version 1.3.

2.3.2. Accelerometry

Participant activity was monitored during eight different activities (as described previously) using a unidirectional accelerometer that measures acceleration in the vertical plane (model ActiGraph GT1 M, ActiGraph LLC, Fort Walton Beach, FL). The ActiGraph is a uniaxial accelerometer that measures body movement in terms of acceleration, which can then be used to estimate physical activity intensity levels over time [28,29]. This instrument has the ability to detect the normal human motion and to reject high frequency motion vibrations encountered while performing the activities [27]. The accelerometer is a compact instrument, which means it does not inhibit the participant during the study. It measures $3.8 \times 3.7 \times 1.8$ cm and weighs just 27 g and detects acceleration in the range of 0.05—2.0 g with a frequency response between 0.25—2.5 Hz and memory storage capacity of 1MB RAM [5]. Each digitised signal is summed according to a user specified time interval (epoch), which is then stored internally at the end of each epoch. The ActiGraph was used according to the manufacturer's instructions for setting the initiation and data downloading. In the present study, the ActiGraph was set to record the movement counts for a 5 second epoch. Activity counts were expressed as the average counts per minute over 10 minutes for each activity.

2.4. Statistical analyses

Oxygen uptake and accelerometer counts for each 10-minute session were checked minute by-minute by using a one way within subjects ANOVA, with a posthoc paired samples *t*-test and Bonferonni adjustment to find out if there were any spurious data. After that a period with stable response of a measured signal during the activities was identified.

Using this analysis it was noted that VO_2 increased up to minute 4 and remained almost stable thereafter until minute 9. Furthermore, VO_2 either increased or decreased during minute 10 because participants tended to give either additional or less effort during the last minute depending on the type of activity. Therefore VO_2 results from minute 4 to 9 of the data for each activity were identified as stable and used in subsequent data analysis.

A one way within subjects ANOVA, with paired samples *t*-test and Bonferonni correction factor were then carried out to determine differences in oxygen uptake ($mL.kg^{-1}.min^{-1}$) and accelerometer ($counts.min^{-1}$) between activities during the stable periods. A linear regression model was then used to characterise the relationship between accelerometer ($counts.min^{-1}$) and VO_2 ($mL.kg^{-1}\cdot min^{-1}$) for only slow and brisk forwards walking and running firstly, and then for all eight activities together.

After checking the normality of the differences between subjects' measured and predicted VO2 (that is residual error) by using the Kolmogorov-Smirnov test, the 95% limit of agreement (LoA) method originally described by Bland and Altman [30] was used to assess the agreement and proportional bias between measured and predicted VO2. To investigate systematic bias, a paired Student's t-test was used to test hypothesis of no difference between the sample mean values for the measured versus the sample mean values for predicted VO2. Since, significant differences were observed between predicted and measured VO2 for ART, SWB and Aerobic activities ($P = 0.0003$; $P < 0.0001$ and $P = 0.0004$, respectively), Bland and Altman plot was presented for all other activities (watching TV, SWF, BW, Step-ups and running). Heteroscedasticity was revealed by calculating a correlation coefficient between the absolute difference and the average of measured and predicted VO_2. As heteroscedasticity was found in the present data, a log transformation and antilog (back transformation) were applied giving values that can be interpreted in relation to the original scale.

Finally, all participants' VO_2 max were predicted from 20 m Shuttle Run Test (20 m RST) with PA intensity levels defined according to the American College of Sports Medicine (ACSM) using oxygen uptake reserve (VO_2.R) as an alternative to the maximal oxygen consumption percentage [31]. Accordingly, a range of the activity counts were then used to define thresholds for children's PA intensity levels. The selected method was adopted from Treuth et al. [14]. The intensity classification method is based on two criteria: firstly, identification of the highest activity intensity and secondly, identification of the lowest activity intensity level. This method attempts to minimise the number of false positives (counts observed for low intensity threshold that go higher than a given threshold) and negatives (counts observed for higher intensity threshold that fall below a given threshold). Significance was set to $P \leq 0.05$ throughout. All analyses were performed using SPSS software (SPSS, version 20. Inc, Chicago, IL, USA) and MedCalc software program.

3. Results

3.1. VO_2 and accelerometer counts from minute 4 to 9 in all activities

VO_2 values and accelerometer data for all activities are displayed in Fig. 1. TV and art activities have the lowest mean VO_2 and accelerometer values were significantly lower than all other activities ($P < 0.001$). Comparison between mean values for TV and art activities demonstrated no significant difference in the mean VO_2 or accelerometer values ($P > 0.05$).

In terms of VO_2, slow walking backwards (SWB) was significantly ($P < 0.001$) higher than slow walking forwards (SWF). However, when comparing SWF and SWB using the mean accelerometer counts it was found that there was no significant difference between activities ($P > 0.05$). Fig. 1a also shows that SWB, brisk walking (BW) and aerobics activities gave similar mean VO_2 values. Mean accelerometer counts for SWB, BW and aerobics (Fig. 1b) were significantly different from one another ($P < 0.001$). In contrast to the VO_2 mean values, accelerometer counts showed that aerobics was performed at a significantly higher intensity than SWB or BW ($P < 0.001$).

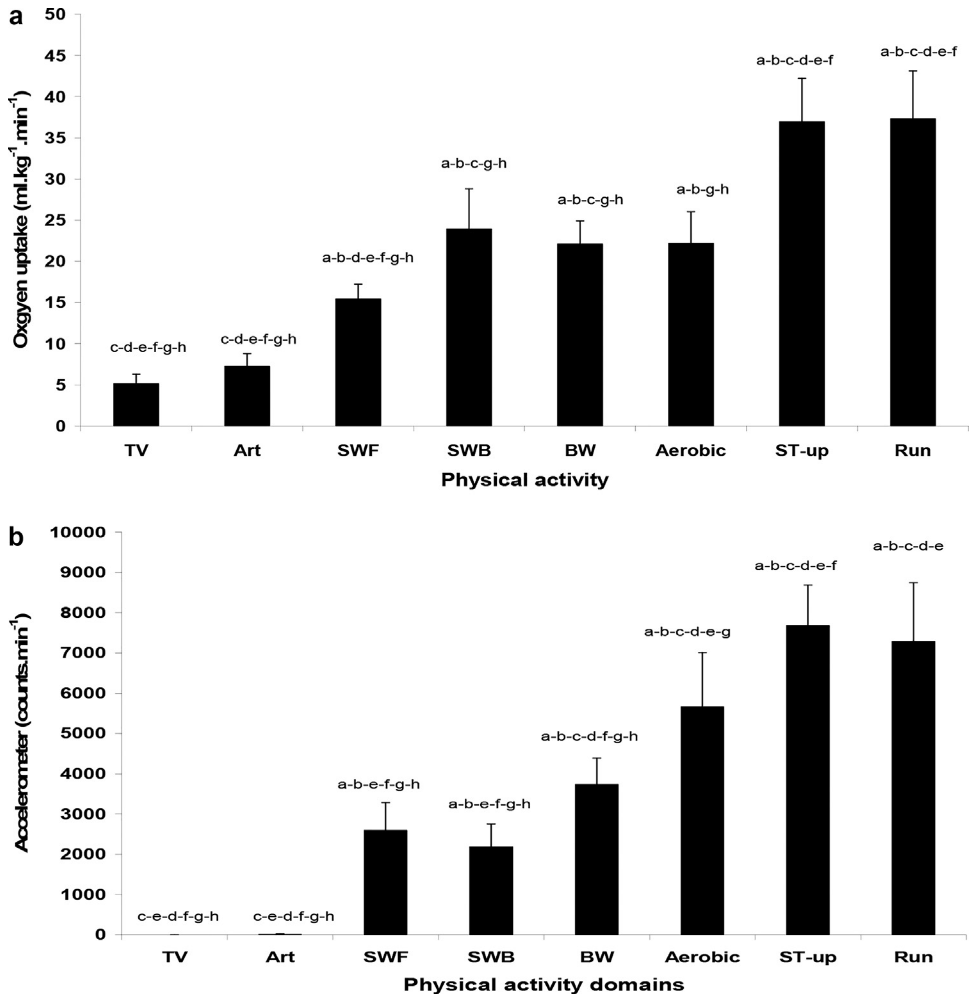

Figure 1 a: Relative VO_2 values in all physical activity domains for minutes 4—9; b: accelerometer counts (counts.min^{-1}) in all physical activity domains for minutes 4—9. a: indicates significantly different from TV;b: indicates significantly different from Art;c: indicates significantly different from SWF;d: indicates significantly different from SWB;e indicates significantly different from BW; f indicates significantly different from Aerobic; g: indicate significantly different from step-up; h: indicates significantly different from running.

Step-ups and running activities showed the greatest mean values for VO_2 and accelerometer counts and both were significantly higher intensities than all other activities ($P < 0.001$). They were not significantly different from each other with respect to the two different methods of measurements ($P > 0.05$).

3.2. VO_2 as a function of accelerometer counts

Relationship between VO_2 values and accelerometer data, for ambulatory activities (slow and brisk forwards walking and running) and for all activities are shown in Fig. 2. When looking at the mean values from all eight activities, a highly significant correlation ($r = 0.86$, $P < 0.01$) was found between accelerometer counts and VO_2. Fig. 2 also illustrates that VO_2 for all pedestrian forward locomotion (slow and brisk forwards walking and running activities) were well explained by accelerometer counts. Including all eight activities demonstrated, however, a risk of underestimation of VO_2 with the more coordinative challenge such as backward walking. Moreover, in all eight activities linear regression tends to overestimate VO_2 values in activities with vertical movements without significant locomotion such as in aerobics.

Giavarina [32] stated that ''correlation studies the relationship between one variable and another, not the differences, and it is not recommended as a method for assessing the comparability between methods''. The Bland and Altman plot analysis is a simple way to assess a bias between the mean differences, and to estimate the limits of agreement, within which 95% of the differences of the second method, compared to the first one, fall. Our results showed that mean bias between predicted and measured VO_2 for Art, SWB and Aerobic activities were statistically significant (−2.0, −22 and 6.1 ml.kg-1.min-1, respectively).

Bland and Altman plot of measured versus predicted VO2 values for watching TV, BWF, BW, Step-ups and running is shown in Fig. 3. The residual errors between scores on the two methods were normally distributed ($P = 0.168$) and the

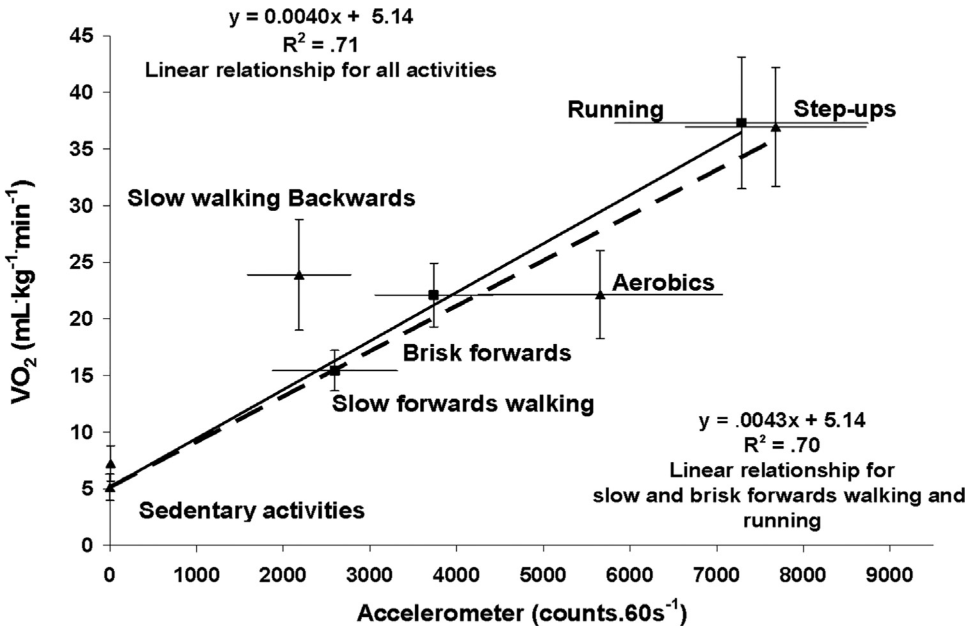

Figure 2 Relationship between VO_2 values and accelerometer data, for slow and brisk forwards walking and running (dark line) and for all activities (dashed line).

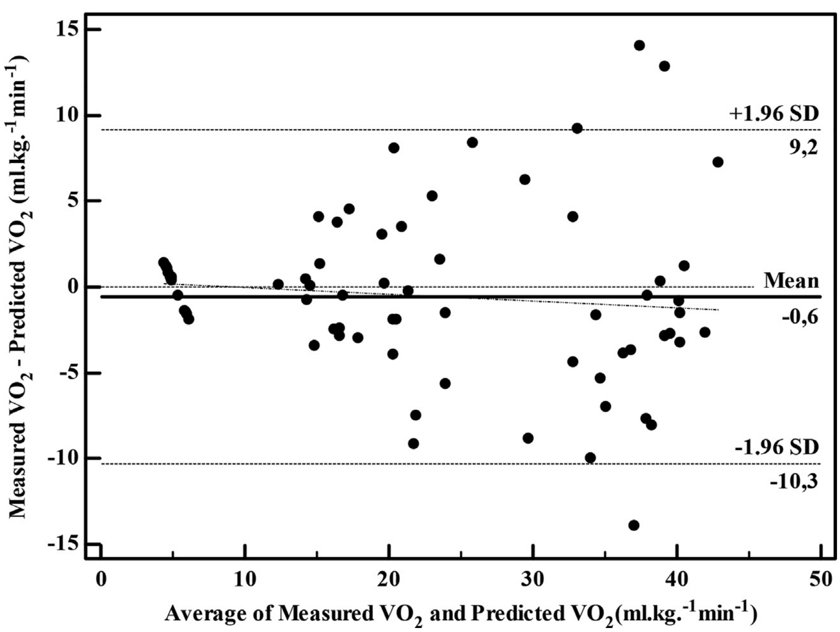

Figure 3 Bland and Altman plot of measured versus predicted VO_2 during watching TV, slow and brisk forwards walking, step-ups and running.

heteroscedasticity coefficients was $r = 0.482$ ($P < 0.0001$). The mean difference (bias) and the 95% limits of agreement was -0.6 ± 9.7 ml.kg-1.min-1. Log transformation of the measured and predicted VO2 reduce the heteroscedasticity to $r = -0.108$ ($P = 0.373$). There is no significant bias between log-transformed mean scores for the two methods ($P = 0.610$). The residual errors between scores on the two methods log transformed data were normally distributed (P =0.915). The mean difference (bias) $\pm$ the 95% limits of agreement was -0.01 ± 0.16. Taking antilog of these values gave a mean bias of 1.010 with an agreement component of $\times \div 1.174$.

3.3. Defining accelerometer cut-off points for PA intensities

Classification of PA intensity threshold [33] was defined according to the participant's level of fitness related to VO_2 max estimated from 20 m SRT as shown in Table 2. According to the participants' average VO_2 max value, four different

Table 2 Summary of PA intensity for sedentary, light, moderate and vigorous levels, calculated from estimated VO_2 max.

Physical activity level	$VO_{2 \cdot R\%}$	VO_2 (mL.kg^{-1}.min^{-1})
Sedentary	< 20	< 13.8
Light	20—39	13.9—22.9
Moderate	40—59	23—32.1
Vigorous	60—84	32.2—43.5

$VO_{2 \cdot R\%}$ indicates the Oxygen uptake reserve.

PA levels were found. Watching TV and participating in art activities were classified as sedentary intensity, SWF was classified as light intensity, SWB, BW and aerobics were classified as moderate intensity and step-ups and running were defined as vigorous intensity.

Table 3 shows summary of the PA intensity threshold counts for sedentary, light, moderate and vigorous levels and the numbers of true cases, false positives and false negatives for the accelerometer threshold. Based on the selected methods of defining the accelerometer threshold in children's PA intensities; TV and Art reported no false positives or false negatives at < 61 counts.min^{-1} as shown in Table 3. However, only 2 false positives were found when classifying activity at light intensity; and no false negatives were reported at the light/moderate threshold. When SWB was included to define the moderate activity intensity, a high number of false negatives were recorded. This is a consequence of the fact that the accelerometer could not detect any significant differences between SWB and SWF. To minimise the number of false negatives at moderate intensity, SWB was excluded from the analysis. A lower number of false positives and false negatives were observed at the threshold range from 3436 to 6100 counts.min-1. Using both step-ups and running activities to define vigorous PA intensity resulted in 4 false negative cases at a threshold of $\geq$ 6101 counts.min^{-1}. However, no false positive was reported at this PA intensity level.

4. Discussion

The purpose of the current study was twofold:

- to validate accelerometer counts against oxygen uptake in 9 to 11 years old children performing a number of highly variable physical activities typical of those undertaken in free-living conditions;
- to determine cut-off points for sedentary (S), light (L), moderate (M) and vigorous (V) physical activity using accelerometer counts in 9 to 11 year old children.

The main finding of the present study was the strong correlation (r = 0.86) and the acceptable 95% limits of agreement between the accelerometer counts and energy expenditure as measured by VO_2, which supports the suggestion that accelerometer-based activity monitoring is a valid and useful assessment of children's PA in general. However, whilst activities such as watching TV, BWF, BW, Step-ups and Running appear to be robustly detected by accelerometry, there are clear limitations concerning the correct detection of activity intensity of all other activity domains like participating to Art-Craft, SWB and aerobic activities. Indeed, the accelerometer used in the present study significantly underestimated the energy expenditure as measured by VO2 of Art-Craft and SWB (−2.0, −9 ml.kg.-1.min-1, respectively), but significantly overestimated the energy cost of Aerobic activity (6.1 ml.kg.-1.min-1).

Accelerometry was not able to discriminate between real light exercise with relatively low vertical movements like SWF and coordinative more complex activities such as SWB, which requires more muscular activity as indicated by the relatively high VO_2. This additional muscular activity appears not to induce sufficient vertical movements of the centre of body mass to be measured by the accelerometer. Reflecting on how the children managed SWB suggests that the additional muscular activity compared to SWF were included to performance. Moreover, many body segments, including the trunk, are being coordinated during the SWB activity; mainly compensatory balance movements of arms and possibly co-contractions of leg and trunk muscles which did not generate sufficiently strong vertical movements of the centre of body mass to register on the accelerometer [33]. Masumoto et al. [34] reported that walking backwards in water resulted in a significantly greater muscle activation compared with walking forwards; for instance in paraspinal muscles, vastus medialis and tibialis anterior muscles. Furthermore, numerous performance differences between modes of locomotion such as forwards and backwards movements have been shown by empirical studies as reviewed in Bates et al. [33]. For example, SWB has less trunk inclination and tends to reduce overall range of motion at the hip joint in terms of greater flexion and lesser extension. Additionally, SWB increases the active functional range of motion at the knee joint. Moreover, the general muscle activity patterns are unique for each direction of walking where the muscle activity of the lower extremities is greater in backwards versus forwards walking. This explains

Table 3 Summary of the PA intensity threshold counts for sedentary, light, moderate and vigorous levels and, the true cases, false positives and false negatives for accelerometer threshold.

PA level	Accelerometer (counts.min^{-1})	Total number of cases	Truecases	False positives	False negatives
Sedentary (SPA)	< 61	28	28	0	0
Light (LPA)	62—3435	14	12	2	0
Moderate (MPA)	3436—6100	28	20	4	4
Vigorous (VPA)	$\geq$ 6101	28	24	0	4

the greater physiological demands resulting in higher energy expenditure by SWB [35]. Unfortunately, using a uniaxial accelerometer placed on the right hip in the current study did not detect the extra motion produced by different body segments that led to this additional energy expenditure. Whether a three-dimensional accelerometer might be able to recognise the potential slow hip movements is as yet unknown. Possibly combinations of different accelerometer positions located at the arms and/or legs are a feasible alternative to address this kind of traditionally undetected activity. On the other hand, the nature of aerobic activity is a combination of movements such as walking without locomotion, jumping, and trunk bending etc., most of which generate vertical hip movements, which may lead to overestimation of energy expenditure via accelerometer counts (Fig. 2). To validate accelerometer counts against oxygen uptake (energy expenditure) across a range of physical activities (watching TV, SWF, BW, Step-ups, Running) a Bland and Altman method was used. No significant bias was observed between the two methods. Bias $\pm$ 95% LoA was given as -0.6 $\pm$ 9.7 ml.kg-1.min-1. This LoA seems to be very large. Since heteroscedasticity was found in the present data, a log transformation and antilog (back transformation) were applied giving values that can be interpreted in relation to the original scale [30]. Log transformed data reduced heteroscedasticity coefficient and gave a mean bias $\pm$ 95% LoA of -0.01 ± 0.16. When antilog of these values was taken, the results could be expressed as the mean bias $\times \div$ 95% of agreement component (0.990 $\times \div$1.174). Consequently, 95% of the ratios for the sample (log-transformed measured values divided by log transformed predicted values) should be contained between the values 1.162 (0.990 $\times$ 1.174) and 0.844 (0.990 $\div$ 1.174). To put these results in a practical context [36], for a subject from the study population presented with measured VO2 of 20 ml.kg-1.min-1, there is a 95% probability that their predicted values from the accelerometer could be as high as 20 $\times$ 1.162 = 23.24 ml.kg-1.min-1, or as low as 20 $\times$ 0.844 = 16.87 ml.kg-1.min-1. We could consider these LoA very acceptable.

The present results do not fully support previous findings [9] that accelerometry is less sensitive at detecting movements that require raising the body in the vertical plane compared with high frequency body mass oscillations such as running.

Most studies have used the average counts of moderate and vigorous physical activity intensities (MVPA) to predict the time spent participating in free-living PA. BW has been previously identified as moderate activity intensity through the health promotion guideline recommendation, which gives participating at a minimum of moderate activity level using BW as an example [36]. Combining both times spent at MVPA intensities would reduce the current study threshold's false cases from 28% and 14%, respectively, down to only 7% for both intensities.

Comparing the accelerometer thresholds defined in the current study with the previously published accelerometer thresholds in children [10,14,22], illustrated that Puyau's accelerometer intensity threshold results in a lower count threshold ($\geq$ 2880 counts.min^{-1}) for moderate intensity compared to the present study. However, this is combined with higher counts for the lower border of vigorous intensity ($\geq$ 7380 counts.min^{-1}). The higher vigorous threshold presented by Puyau et al. [10] could be due to the use of running on a treadmill as well as jogging on a track compared to running at a set speed of 8 km.h^{-1} in the current study. Therefore, the lower limit of moderate intensity might be attributable to the differences in the type of activity being used between the two studies.

The current study provided similar results to Treuth et al. [14] for the threshold of sedentary intensity (< 90 counts.min^{-1}). However, the present study has a higher threshold count for the rest of the intensities. These differences could be interpreted as a result of using different types and numbers of activities at each intensity level (a total of 11 different activities in Treuth et al. [14] compared to 8 in the current study). Freedson et al. [22] defined the threshold for both moderate and vigorous intensities with almost twice the corresponding count numbers and also used higher counts for the lower light intensity threshold with 1260 compared to 62 counts.min^{-1} for the current study. These large threshold differences may reflect the fact that Freedson's study has combined data from both Puyau et al. [10] and Treuth et al. [14] to develop his threshold model.

In the current study, two regression equations (Equation 1: VO_2 = 0.004 x accelerometer counts + 5.14 and 2: VO_2 = 0.0043 x accelerometer counts + 5.14) were developed to predict VO_2 values from accelerometer counts for all activities and slow and brisk forwards walking and running, respectively. Although high correlations were found between the two variables in both equations, when all eight activities were included the linear regression equation demonstrated a high risk of underestimating VO_2 with the more coordinative challenge of backward walking, and of overestimation in activities with a high proportion of elements generating small vertical impulses without significant locomotion, such as aerobics. These results highlight that the nature of the activity is an important factor that should be considered when the intensity of PA in children is estimated based on accelerometer measurements. Based on VO_2, all forms of pedestrian forward locomotion were well described by accelerometer counts, (R^2 = 0.70). Similar results have been reported by previous research on children [6,7]. However, children do not normally only perform forward walking and running activities. When a comparison was made between observed and predicted VO_2 values from the two energy expenditure prediction equations developed in the current study, equation 1 tended to underestimate only SWB activity compared to the ambulatory activities equation, which underestimated and overestimated SWB and aerobics activities respectively. Thus, equation 1 could be used in the 9—11 age-group to assess energy expenditure for two key reasons. Firstly, children's PA particularly under free-living conditions is considered to be highly variable in terms of the activity types they perform and therefore, since this equation included both ambulatory and non-ambulatory activities, it is applicable in this case. Secondly, as the activity type is the main impact on the accelerometer counts threshold developed [23], both equations tend to underestimate SWB activity only, which is not one of the most common activities, yet is one of the types of linking movements between activities, according to the observation study carried out by the main author.

In conclusion, the present study aimed to define accelerometer cut-off points for sedentary, light, moderate and vigorous PA intensities in 9—11 year old participants in free-living activities using indirect calorimetry as the gold standard. The accelerometer used in this study predicted in a very acceptable way oxygen uptake and could be considered as an interesting tool for predicting energy expenditure during physical activities such as watching TV, SWF, BW, Step-Ups and Running.

In the field of physical activity measurements, studies are normally concerned with how much time individual children spend participating at different PA intensity levels that are operationally defined as sedentary, light, moderate and vigorous activity. Therefore, the accelerometer cut-off points that have been defined in this study could be used to assess the quantity of the PA levels in 9-11 years-old children, especially for watching TV, BWF, BW, Step-ups and Running. In addition, using the current study's defined accelerometer cut-off points could add more features to enhance precision in assessing the PA intensities using the same age group. The current study presented accelerometer cut-off points in terms of counts.min^{-1} for 9—11 year-old children. This method has been used throughout the literature, and therefore allows for the assessment of differences between studies. One unique element of this study was the inclusion of the slow walking backwards and Aerobic activity in the accelerometer validation approach in 9—11 year-old children.

Disclosure of interest

The authors declare that they have no competing interest.

References

[1] Fischer C, Yildirim M, Salmon J, Chinapaw MJM. Comparing different accelerometer cut-points for sedentary time in children. Pediatr Exerc Sci 2012;24:220—8.

[2] Kim Y, Hibbing P, Saint-Maurice PF, Ellingson LD, Hennessy E, Wolff-Hughes DL, et al. Surveillance of youth physical activity and sedentary behavior with wrist accelerometry. Am J Prev Med 2017;52(6):872—9.

[3] McGarty AM, Penpraze V, Melville CA. Calibration and cross-validation of the actiGraph wGT3X+ accelerometer for the estimation of physical activity intensity in children with intellectual disabilities. PLoS ONE 2016;11(10):e0164928.

[4] Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. Med Sci Sports Exerc 2008;40(1):181—8.

[5] Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. Med Sci Sports Exerc 2011;43:1360—8.

[6] Trost SG. Objective measurement of physical activity in youth: current issues, future directions. Exerc Sport Sci Rev 2001;29(1):32—6.

[7] Freedson PS, Melanson E, Sirard J. Calibration of the computer science and applications. Inc. accelerometer. Med Sci Sports Exerc 1998;30(5):777—81.

[8] Hendelman D, Miller K, Baggett C, Debold E. Freedson P. Validity of accelerometry for the assessment of moderate intensity physical activity in the field. Med Sci Sports Exerc 2000;32(9):S442—9.

[9] Swartz AN, Strath SJ, Bassett DR, O'brien WL, King GA, Ainsworth BE. Estimation of energy expenditure using CSA accelerometers at hip and wrist sites. Med Sci Sports Exerc 2000;32(9):S450—6.

[10] Puyau MR, Adolph AL, Vohra FA, Butte NF. Validation and calibration of physical activity monitors in children. Obesity 2002;10(3):150—7.

[11] Saint-Maurice PF, Kim Y, Welk GJ, Gaesser GA. Kids are not little adults: what MET threshold captures sedentary behavior in children? Eur J Appl Physiol 2016;116(1):29—38.

[12] Welk GJ, Corbin CB, Dale D. Measurement issues in the assessment of physical activity in children. Res Q Exerc Sport 2000;71(2):59—73.

[13] Eston RG, Rowlands AV, Ingledew DK. Validity of heart rate, pedometry, and accelerometry for predicting the energy cost of children's activities. J Appl Physiol 1998;84(1):362—71.

[14] Treuth MS, Schmitz K, Catellier DJ, McMurray RG, Murray DM, Almeida MJ, et al. Defining accelerometer thresholds for activity intensities in adolescent girls. Med Sci Sports Exerc 2004;36(7):1259—66.

[15] Trost SG, Ward DS, Moorehead SM, Watson PD, Riner W, Burke JR. Validity of the computer science and applications (CSA) activity monitor in children. Med Sci Sports Exerc 1998;30(4):629—33.

[16] Corder K, Ekelund U, Steele RM, Wareham NJ, Brage S. Assessment of physical activity in youth. J Appl Physiol 2008;105(3):977—87.

[17] Nevill AM, Atkinson G. Assessing agreement between measurements recorded on a ratio scale in sports medicine and sports science. Br J Sports Med 1997;31:314—8.

[18] Trost SG. State of the art reviews: measurement of physical activity in children and adolescents. Am J Lifestyle Med 2007;1(4):299—314.

[19] Rowlands AV, Eston RG. The measurement and interpretation of children's physical activity. J Sports Sci Med 2007;6(3):270—6.

[20] Price K, Bird SR, Lythgo N, Raj IS, Wong JYL, Lynch C. Validation of the fitbit one, garmin vivofit and jawbone up activity tracker in estimation of energy expenditure during treadmill walking and running. J Med Eng Technol 2017;3(41):208—15.

[21] Eisenmann JC, Strath SJ, Shadrick D, Rigsby P, Hirsch N, Jacobson L. Validity of uniaxial accelerometry during activities of daily living in children. Eur J Appl Physiol 2004;91(2):259—63.

[22] Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. Med Sci Sports Exerc 2005;37(11):S523—30.

[23] Zitouni D, Guinhouy BC. Fuzzy logic for characterizing the moderate intensity of physical activity in children. J Sci Med Sport 2016;(19):142—8.

[24] Kim Y, Lee JM, Peters BP, Gaesser GA, Welk GJ. Examination of different accelerometer cut-points for assessing sedentary behaviors in children. PLoS ONE 2014;9(4):e90630.

[25] Rowlands A, Ingledew D, Eston R. The effect of type of physical activity measure on the relationship between body fatness and habitual physical activity in children: a meta-analysis. Ann hum biol 2000;27(5):479—97.

[26] Rowlands AV. Accelerometer assessment of physical activity in children: an update. Pediatr Exerc Sci 2007;19(3):252—66.

[27] Trost SG, Way R, Okely AD. Predictive validity of three ActiGraph energy expenditure equations for children. Med Sci Sports Exerc 2006;38(2):380—7.

[28] Chen KY, Bassett Jr DR. The technology of accelerometry-based activity monitors: current and future. Med Sci Sports Exerc 2005;37(11):S490—500.

[29] Troiano RP. A timely meeting: objective measurement of physical activity. Med Sci Sports Exerc 2005;37(11):S487—9.

[30] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;i:307—10.

[31] American College of Sports Medicine. ACSM's Guidelines for exercise testing and prescription (7ed.). Baltimore: MD: Lippincott Williams & Wilkins; 2006.

[32] Giavarina D, Understanding Bland Altman analysis. Biochemia Medica 2015;25(2):141—51.
[33] Bates B, James C, Dufek J. Single-subject analysis. Innovative analysis of human movement. In: Stergiou N, editor. Human Kinetics. 2004. p. 3—28.
[34] Masumoto K, Takasugi S, Hotta N, Fujishima K, Iwamoto Y. A comparison of muscle activity and heart rate response during backward and forward walking on an underwater treadmill. Gait Posture 2007;25(2):222—8.
[35] Grasso R, Bianchi L, Lacquaniti F. Motor patterns for human gait: backward versus forward locomotion. J Neurophysiol 1998;80(4):1868—85.
[36] Nelson ME, Rejeski WJ, Blair SN, Duncan PW, Judge JO, King AC, et al. Physical activity and public health in older adults recommendation from the American College of Sports Medicine and the American Heart Association. Circulation 2007;116:1094—105.