REVIEW ARTICLE

Sports Med 2001; 31 (6): 439-454
0112-1642/01/0006-0439/$22.00/0

Physical Activity Assessment in Children and Adolescents

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Contents

Abstract

Chronic disease risk factors, including a sedentary lifestyle, may be present even in young children, suggesting that early prevention programmes may be critical to reducing the rates of chronic disease. Accurate assessment of physical activity in children is necessary to identify current levels of activity and to assess the effectiveness of intervention programmes designed to increase physical activity. This article summarises the strengths and limitations of the methods used to evaluate physical activity in children and adolescents. MEDLINE searches and journal article citations were used to locate 59 articles that validated physical activity measurement methods in children and adolescents. Only those methods that were validated against a more stringent measure were included in the review.

Based on the definition of physical activity as any bodily movement resulting in energy expenditure (EE), direct observation of the individual's movement should be used as the gold standard for physical activity research. The doubly labelled water technique and indirect calorimetry can also be considered criterion measures for physical activity research, because they measure EE, a physiologic consequence closely associated with physical activity. Devices such as heart rate monitors, pedometers and accelerometers have become increasingly popular as measurement tools for physical activity. These devices reduce the subjectivity inherent in survey methods and can be used with large groups of individuals. Heart rate monitoring is sufficiently valid to use in creating broad physical activity categories (e.g. highly active, somewhat active, sedentary) but lacks the specificity needed to estimate physical activity in individuals. Laboratory and field validations of pedometers and accelerometers yield relatively high correlations using oxygen consumption (r = 0.62 to 0.93) or direct observation (r = 0.80 to 0.97) as criterion measures, although, they may not be able to capture all physical activity.

Physical activity has traditionally been measured with surveys and recall instruments. These techniques must be used cautiously in a paediatric population that has difficulty recalling such information. Still, some studies have reported 73.4% to 86.3% agreement between these instruments and direct observation. Future investigations of physical activity instruments should validate the novel instrument against a higher standard. Additional studies are needed to investigate the possibility of improving the accuracy of measurement by combining 2 or more techniques. The accurate measurement of physical activity is critical for determining current levels of physical activity, monitoring compliance with physical activity guidelines, understanding the dose-response relationship between physical activity and health and determining the effectiveness of intervention programmes designed to improve physical activity.

Physical activity is defined as 'any bodily movement produced by skeletal muscle that results in energy expenditure'.[1] It is now well established that an inverse relationship exists between physical activity and risk for developing several chronic diseases, including obesity, coronary heart disease (CHD), diabetes and colon cancer.[2-4] Since obesity and the risk factors for CHD and diabetes can be present even in young children,[5-7] it is important that primary prevention programmes involving physical activity begin early in life. To assess levels of physical activity and determine the effectiveness of physical activity intervention programmes, accurate measures of physical activity are required.[8,9] Measurement techniques used for research and programme evaluation purposes must be valid, reliable, practical and nonreactive.[8,10]

This article will review the strengths, limitations and validity of the subjective and objective techniques that have been developed to assess physical activity in children and adolescents. MEDLINE searches were used to identify studies of physical activity measurement in children and adolescents; keywords included physical activity, children, youth, adolescent and energy expenditure (EE). Other sources were identified by journal article citations. Only studies that reported the validity of the instrument were included in the review. Reliability of the instrument is also presented if that information was provided along with the validation data.

1. Criterion Standards

This review considered 3 types of measures of physical activity in children and adolescents: primary measures, secondary measures and subjective measures. Figure 1 represents the 3 levels of physical activity measures used for this review. For the purpose of this review, direct observation, doubly labelled water (DLW) and indirect calorimetry are considered the primary standards for assessment of physical activity in children and adolescents. DLW is well recognised as a criterion measure for field evaluations of EE. This technique assesses total caloric expenditure by estimating carbon dioxide production using isotope dilution during a minimum of 3 days. EE is a physiologic consequence of physical activity and is directly linked to health and disease prevention. Thus, DLW and indirect calorimetry can be used as criterion measures for physical activity assessment. However, it should be noted that EE and physical activity are distinct constructs, which may limit attempts to validate physical activity measures against EE. Cardiorespiratory fitness measured by indirect calorimetry during progressive exercise tests has been used to indirectly validate physical activity surveys. This association, however, is weak or unclear in children and adolescents.[11,12] Therefore, studies using this indirect validation were not included in this review.

Direct observation is a more practical and comprehensive criterion measure for physical activity research. Based on the above definition of physical activity, direct observation of movement seems to be the most appropriate standard for physical activity assessment. Subsequent sections will explore the strengths and limitations of these techniques in more detail.

Heart rate monitors, pedometers and accelerometers will be considered secondary measures because they provide an objective assessment of physical activity. Validating one of these measures against another secondary measure provides little insight to the instruments' true validity. For this reason only the results from studies that validated a secondary method against a primary measure are included in this review. These secondary measures may be used, however, as criterion standards to validate subjective measures of physical activity behaviour (see fig. 1).

Surveys and other subjective techniques used as criterion measures carry the least compelling validation results and should not be used in this capacity. Therefore, only those subjective measures that were validated against a more stringent standard are included in this review.

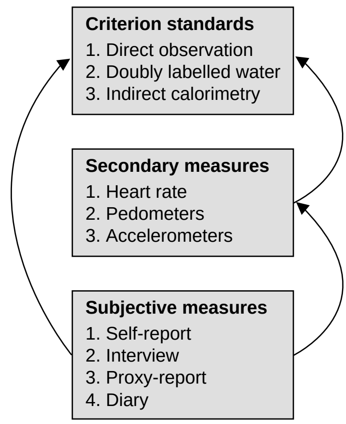

Fig. 1. Validation Schema. Arrows indicate acceptable criterion standards for the validation of tertiary and secondary level methods.

1.1 Direct Observation

Direct observation is the most practical and appropriate criterion measure of physical activity and patterns of activity. Seven observational systems are reviewed in table I. While 2 of these systems are specific for observation during physical education classes,[16,18,19] the others can be used in a variety of settings.[13-15,17,20] Evidence supporting the use of these instruments is available from studies comparing direct observation scores with heart rate or oxygen consumption. Correlations range from r = 0.61 to 0.91[15,16,20] and heart rate or oxygen consumption were significantly different among the observed physical activity intensity levels.[13,14,18] All 7 observational techniques attained satisfactory inter-observer agreement (84% to 99%) among simultaneous observations of the same child.[13-17,19,20]

The total observation time required to attain acceptable day-to-day stability is not clear for most observational instruments. Drawbacks of direct observation include the relatively high experimenter burden and the potential reactivity of the study participant. Puhl et al.[13] found that only 16.6% of the 5- to 6-year-olds observed in their study reacted to the observers. The ability of observational techniques to capture short term patterns and sudden changes in physical activity is crucial for the study of young children. McKenzie[21] suggests using a previously tested instrument rather than creating new techniques so that results from future studies will be comparable to earlier research.

Table I. Validation of direct observation techniques used to assess young people's physical activity

Instrument	Technique	Participants	Reliability	Criterion measure	Validity	Reference
Children's activity rating scale (CARS)	1 minute partial time sampling with 5 categories during various conditions	12 boys, 13 girls; 5-6y	84 ± 10% agreement between observers; n = 192, 3-4y	$\dot{V}O_2$, HR	$\dot{V}O_2$ and HR differed between treadmill speeds designed to represent the 5 categories of exercise intensity ($p < 0.05$)	13
Modified fargo activity timesampling survey (FATS)	3 second continuous time sampling with 30 categories during free-living[a] conditions	2 boys, 2 girls; 7-10y	91% agreement between observers; n = 15, 6-10y	$\dot{V}O_2$	Categories separated by intensity as measured by $\dot{V}O_2$	14
Activity patterns and energy expenditure (APEE)	15 second momentary time sampling with 5 categories during freeplay	19 girls; 5-8y	86-99% agreement between observers	HR	r = 0.72-0.91	15
Children's physical activity form (CPAF)	1 minute partial time sampling with 4 categories during PE	18 boys, 18 girls; 8-10y	96-98% agreement between observers	HR	r = 0.61-0.72	16
Behaviours of eating and activity for children's health evaluation system (BEACHES)	1 minute momentary time sampling with 5 categories during various conditions	19; 4-9y	94-99% agreement among observers; Kappa = 0.71-1.0; n = 17 boys, 25 girls; 4-8y	HR	HR increased for each of the 5 categories	17
System for observing fitness instruction time (SOFIT)	10 second momentary time sampling with 5 categories during PE class	173; Grades 1-8	N/A	HR	HR increased for each of the 5 categories except lying versus sitting categories	18
System for observing fitness instruction time (SOFIT)	10 second momentary time sampling with 5 categories during PE class	88; Grades 3-5	88.3% agreement among observers	lesson context (fitness)	r = -0.65 w/ standing; r = 0.49 w/ walking; r = 0.36 w/ very active; r = 0.69 w/ MVPA	19
Fargo activity timesampling survey (FATS)	10 second momentary time sampling with 8 categories during various conditions	7 boys, 7 girls; 2-4y	91-98% agreement among observers	LSI®	r = 0.78-0.90	20

a normal daily life.

HR = heart rate; **LSI®** = large scale integrated physical activity monitor; **MVPA** = moderate to vigorous physical activity; **n** = sample size; **PE** = physical education; **r** = Pearson product-moment correlation coefficient; **$\dot{V}O_2$** = oxygen consumption; **y** = age of participants (years).

1.2 Doubly Labelled Water

With this method, a dose of a radio-labelled isotope ($^2H_2 18O$) is administered orally and the oxygen atoms in expired CO_2 equilibrate with the oxygen atoms in the body water. Over the next 5 to 14 days, ^2H is eliminated as water, while ^{18}O will be eliminated as water and CO_2. The difference between the elimination rates is proportional to CO_2 production (i.e. EE).[22] The DLW method has been validated against whole room calorimetry in adults[22-24] and with periodic respiratory gas exchange in infants.[25] Similar research with children was not found, probably because of the difficulty in obtaining consent from children and their parents for multiple days of calorimeter confinement. One study was identified that associated the DLW technique with several biological markers in thirty 4- to 6-year-old children.[26] Total energy expenditure (TEE) was positively associated with fat-free mass ($r = 0.86$), body mass ($r = 0.83$), body surface area ($r = 0.82$), height ($r = 0.74$) and fat mass ($r = 0.65$). Activity energy expenditure (AEE) [AEE = total – resting EE] was significantly correlated with the same variables ($r = 0.56$ to 0.74).[26]

The DLW technique has several advantages for evaluating EE. It can be easily used easily in free-living (normal daily life) participants, has low reactivity and is accurate to within 3 to 4% of calorimeter values in adults.[24] Unfortunately, DLW also has several major limitations.[24] First, the isotopes are difficult to obtain, very expensive and not suitable for large studies. Second, accurate dietary records must be obtained during the measurement period for EE calculations. Lastly, measurements must be taken over at least a 3-day period[23] and only TEE can be obtained. Therefore, daily or hourly patterns of EE cannot be investigated. While TEE is critical, it may be equally important to evaluate other parameters associated with physical activity such as the duration, intensity and frequency of moderate-to-vigorous physical activity (MVPA), vigorous physical activity (VPA), or sedentary behaviour.

1.3 Indirect Calorimetry

Open-circuit indirect calorimetry measures EE from O_2 consumption and CO_2 production. Indirect calorimetry during rest and exercise is used extensively and considered an accurate and valid measure of short term EE.

However, using indirect calorimetry to measure physical activity is difficult because of the non-portable gas analysis equipment required. Therefore, this method is impractical for validating a survey that measures ‘usual’ or weekly physical activity. Indirect calorimetry has been used, however, to validate heart rate monitors, pedometers and accelerometers in laboratory settings.[27-32] Manufacturers are now introducing portable, lightweight metabolic systems that should improve the estimates of EE during physical activities under more natural settings. Despite this advance, the equipment is still too cumbersome to use under long term free-living conditions, especially in young children.

2. Objective Techniques

Several objective techniques, such as heart rate monitors, pedometers and accelerometers, are now widely available for the measurement of physical activity.[33] This review includes only the results from these secondary measures which have been validated against a primary standard. The strengths and limitations of each technique are also considered.

2.1 Heart Rate Monitors

Heart rate monitoring as a means of estimating EE or physical activity has been used in both young people and adults and relies on the linear relationship between heart rate and oxygen consumption ($\dot{V}O_2$). But this relationship is not as robust at the low end of the physical activity spectrum. During sedentary or light intensity activities, an individual’s heart rate can be affected by factors other than body movement.[34] Psychological and environmental stress, as well as caffeine and some medications can significantly affect heart rate.[28] The FLEX HR method has been employed to limit these ef-

Table II. Validation of heart rate monitoring used to assess young people's physical activity

Instrument	Variables	Participants	Criterion measure	Validity	Reference
Heart rate monitor	1 day TEE	9 boys, 10 girls; mean age = 8.5y	TEE from 1-day whole-room calorimeter; 2-week TEE_{DLW}	TEE_{HR} 10.4% > TEEcalorimeter; TEE_{HR} 12.3% > TEE_{DLW}	28
Sport tester PE3000 heart rate monitor®	2-3 day TEE	23 boys, 21 girls; 7, 9, 12 and 15y	2-week TEE_{DLW}	95% CI for bias, –0.56-0.01 Mj/d	34
Polar sport tester ™ ®	2-3 day TEE	obese: 4 boys, 2 girls; nonobese: 3 boys, 4 girls; mean age = 9y	1-week TEE_{DLW}	95% CI for bias; obese: 0.04-0.92 Mj/d; nonobese: –0.59-0.63 Mj/d	35
Sport tester heart rate monitor®	2-3 day TEE	5 boys, 4 girls; 8-13y[a]	2-week TEE_{DLW}	Spearman r = 0.88; relative bias = –0.07 Mj/d; estimate of error = 1.09 Mj/d	36
Heart rate monitor	24 hour TEE	10 boys, 9 girls; mean age = 10.5y	24-hour whole room calorimetry	95% CI for bias, –0.15-1.21 Mj/d; TEE_{HR} > TEEcalorimeter; 7.6 ± 20.6%	27

a TEE was assessed in children who had reduced physical activity i.e. spastic cerebral palsy.

CI = confidence interval; **DLW** = doubly labelled water; **HR** = heart rate; **r** = Pearson product-moment correlation coefficient; **TEE** = total energy expenditure.

fects in young people[27,28,34-36] and adults.[37,38] Livingstone et al.[34] describe the FLEX HR as an individually-determined heart rate, measured in conjunction with $\dot{V}O_2$, that can be used to distinguish between resting and AEE. Resting metabolic rate is substituted for periods when the heart rate falls below the FLEX HR.

The FLEX HR technique was validated in the studies summarised in table II using the DLW technique or whole room calorimetry as the criterion measure. While the FLEX HR method assessed TEE at the group level even in children with cerebral palsy,[36] this was not the case for calculating individual TEE. Bitar et al.[27] note that improvements in estimating individual TEE may be obtained by not only increasing the number of replicate heart rate and $\dot{V}O_2$ calibration measures but by also including typical activities performed by children during these procedures. Also, Maffeis et al.[35] found that $TEE_{FLEX\ HR}$ was equivalent to TEE_{DLW} for non-obese children but significantly overestimated TEE in obese children. These differences may be due to higher resting and submaximal heart rates and also prolonged post-exercise heart rate elevations of the obese children in this study. The small sample size, however, limits the interpretation of these results.

Several studies have used absolute heart rate values to distinguish between activity intensities.[39-43] This method is based on using a percentage of the maximum heart rate[44] and the recommendation by Simons-Morton et al.[45] that an intensity of ≥140 beats per minute approximates MVPA. This may be a useful method for large epidemiological studies when individual heart rate/$\dot{V}O_2$ curves are not available. Allor and Pivarnik[46] recently tested this method using 6th grade girls. Their findings indicate that heart rates of 140 and 160 beats per minute were attained at approximately 46±8% and 63±9% of $\dot{V}O_{2max}$, which would correspond to approximately 5.7 and 7.7 metabolic equivalents (MET; a measure of energy expenditure equivalent to 1.5 kcal /kg/h in adults. Resting energy expenditure is considered 1 MET). Because of the limited age range of the individuals in this study and the imprecise nature of this method, it should only be used to classify groups of individuals rather than to estimate individual EE or physical activity levels.

Using heart rate monitors for the assessment of physical activity and EE allows for the assessment of patterns of activity as well as TEE. It is unobtrusive, requires minimal participant and experimenter burden and is cost effective for use in small to moderate size studies. Drawbacks of the FLEX HR method include the need to calibrate individual heart rate/$\dot{V}O_2$ relationships to avoid contamination from psychological and environmental stressors. Although there are several limitations to heart rate monitoring, the results indicate that this method is a valid means of estimating EE and physical activity patterns in groups of free-living, nonobese young people.

2.2 Motion Sensors

Consistent with the definition that physical activity is bodily movement producing EE, motion sensors detect that body movement and provide an estimate of physical activity. Advancements in technology have increased the sophistication and accuracy of these instruments. Results validating these motion sensors are presented separately for pedometers, the Caltrac® accelerometer (Hemokinetics, Inc., Madison, WI) and other accelerometers in the following sections.

2.2.1 Pedometers

Pedometers are relatively simple electronic devices used to estimate mileage walked or the number of steps taken over a period of time. Studies using adult participants wearing recent pedometer models have shown favourable validity and reliability.[47-49] Four pedometer validation studies were identified that used children[29,30,50,51] and the results are summarised in table III. Kilanowski et al.[51] observed a strong association (r = 0.80 to 0.97) between a Digiwalker DW-200 pedometer and the Children's Activity Rating Scale (CARS) direct observation system.[13] Correlations between pedometer step counts and $\dot{V}O_2$ during treadmill locomotion ranged from r = 0.62 to 0.93.[29,30]

These findings indicate that several newer pedometers may be suited for population-based assessments of physical activity. They are relatively inexpensive, re-useable, objective and nonreactive. Pedometers detect only total counts or steps over the observational period and cannot assess the intensity or pattern of activities performed. Participants could be instructed to record the number displayed on the pedometer at regular intervals to better capture patterns of activity, but this practice would decrease objectivity by relying on accurate transcription.

2.2.2 Accelerometers

Accelerometers are more sophisticated electronic devices that measure accelerations produced by body movement. In contrast to the spring mechanisms of pedometers, accelerometers use piezoelectric transducers and microprocessors that convert recorded accelerations to a quantifiable digital signal referred to as 'counts'. Westerterp[52] recently reviewed laboratory validations of various accelerometers using indirect calorimetry in adult participants; pearson correlations ranged from r = 0.25 to 0.91. This large variability is due to the use of different monitors, their placement (e.g. hip, low back, or ankle) and the specific activities performed during the measurement protocols.

The Caltrac® monitor was one of the first commercially available accelerometers and has been

Table III. Validation of pedometers used to assess young people's physical activity

Pedometer	Variables	Participants	Criterion measure	Validity	Reference
Yamax Digiwalker DW-200®	Mean counts.min-1	10, 7-10y	CARS DO[13] TriTrac®	r = 0.80-0.97 r = 0.50-0.99	51
Yamax Digiwalker DW-200®	Total counts from hip Total counts from ankle Total counts from wrist	15 boys, 15 girls; 8-11y	HR, $\dot{V}O_2$	r = 0.62-0.92 r = 0.59-0.91 r = 0.17-0.87	29
Yamax Digiwalker DW-200®	Total counts from hip Total counts from ankle Total counts from wrist	21 Chinese boys; 8-10y	$\dot{V}O_2$	r = 0.77-0.93 r = 0.68-0.92 r = –0.45-0.82	30
Pedometer	Number of steps	11, 4-6y	DO (unspecified)	r = 0.93	50

CARS = Children's activity rating scale; **DO** = direct observation; **HR** = heart rate; **r** = Pearson product-moment correlation coefficient; **Tritrac®** = tri-axial accelerometer; $\dot{V}O_2$ = oxygen consumption; **y** = age of participants (years).

Table IV. Validation of the Caltrac® accelerometer used to assess young people's physical activity

Variables	Participants	Reliability	Criterion measure	Validity	Reference
Total counts.h free-play^{-1}	18 boys, 12 girls; 2-6y	N/A	FATS DO[20]	r = 0.39	53
Total counts.h^{-1}, total counts.day^{-1}	17 boys, 13 girls; 2-4y	N/A	FATS DO[20]	Spearman r = 0.54	54
kcal.h^{-1}	11 boys, 9 girls; 29 to 40 mo	N/A	FATS DO[20]	Total: r = 0.25-0.62; indoor: r = 0.47-0.56; outdoor; r = 0.16-0.48	55
Total counts.h free-play^{-1}	29 boys, 22 girls; 2-5y	N/A	CARS DO[13]	r = 0.86	56
24-h; counts, TEE, SEE, WEE	40 girls; 10-16y	N/A	24h; TEE, SEE and WEE via whole room calorimeter	r = 0.80 w/ TEE; r = 0.84 w/ SEE; r = 0.85 w/ WEE; Caltrac® underestimates EE by 6.8% to 30.4%	57
3-day counts, calculated AEE[58]	22 boys, 14 girls; mean age = 8.3y	N/A	14-day AEE_{DLW}	r = –0.09 w/ counts; calculated AEE > AEE_{DLW} ($p < 0.01$)	59
Calculated EE	10 boys, 10 girls; mean age = 15.2y	N/A	EE_{video}	$EE_{video} < EE_{Caltrac}$; ($p < 0.05$); r = 0.95 w/ video	60
Counts at 3 treadmill speeds	9 boys, 6 girls; 8-13y	Left hip *vs* right hip; r = 0.89	$\dot{V}O_2$	r = 0.82	31
Mean counts.min^{-1}.activity^{-1} (using normal and 'cycling' modes)	16 boys, 15 girls; 10-16y	7-13 day test-retest; cycling: R = 0.73-0.74; treadmill: R = 0.76-0.80	$\dot{V}O_2$	r = 0.66 w/ cycling; r = 0.93 w/ treadmill	32

AEE = activity energy expenditure; **Caltrac®** = uniaxial accelerometer; **CARS** = Children's activity rating scale; **DLW** = doubly labelled water; **DO** = direct observation; **EE** = energy expenditure; **FATS** = Fargo activity timesampling survey; **r** = Pearson product-moment correlation coefficient; **R** = intraclass correlation coefficient; **SEE** = sedentary energy expenditure; **TEE** = total energy expenditure; $\dot{V}O_2$ = oxygen consumption; **WEE** = waking energy expenditure.

the most frequently studied. It is a single (vertical) plane accelerometer that either provides 'count' values or can estimate EE if biodata (height, bodyweight, age, gender) are supplied. The Caltrac® monitor is small and unobtrusive (14 × 8 × 4cm, 400g) making it an attractive method for collecting physical activity data. Nine studies that met the inclusion criteria were identified and are summarised in table IV.[31,32,53-57,59,60] These studies are presented in order of the strength of the criterion measure. Research has found positive but variable associations between the Caltrac® accelerometer and direct observation methods (r = 0.16 to 0.86)[53-56] or whole room calorimetry (r = 0.80 to 0.85).[57] The wide variation in correlations against direct observation are most likely because of the young age of the participants in several studies (2-6 years) and the type of activity monitored. Because the Caltrac® is a single plane accelerometer, it is limited in its ability to detect the wide variety of movements engaged in by these young participants. Lower correlations were also observed when the activity took place outdoors compared with controlled laboratory conditions. Johnson et al.[59] used a previously developed regression equation[31] to calculate 3-day AEE from Caltrac® counts. Based on low correlations with 14-day AEE_{DLW}, they concluded that the Caltrac® accelerometer was not a useful predictor of AEE. This equation, however, was developed in a laboratory setting and applied to a free-living situation in this study. It may be more appropriate to use just the accelerometer counts rather than attempt to convert counts to units of EE.

Validation studies with newer accelerometers primarily involve the CSA® (Computer Science and Applications, Inc., Shalimar, FL) or the Tritrac-

R3D® (Professional Products, Reining International, Madison, WI) accelerometers. While the CSA® is a single plane accelerometer, the Tritrac-R3D® is 3-dimensional and may provide a more accurate assessment of physical activity. Eight studies that used these and other accelerometers with childen and adolescents are presented in table V.[29,30,32,53,61-64] The studies are listed by the type of accelerometer and the strength of the criterion measure. Fairweather et al.[61] reported a relatively high correlation between direct observation[16] and the CSA® accelerometer during a preschool exercise class (r = 0.87). Welk et al.[63] also reported promising results (r = 0.70 to 0.77) for the TriTrac-R3D® accelerometer validated against the CARS direct observation system.[13] Using whole room calorimetry as a criterion measure of EE, Treuth et al.[64] assessed the validity of simultaneously measuring heart rate and leg accelerometry to estimate EE. Combining the methods resulted in valid estimates of EE (percentage error; -2.9 to 5.1%, kJ/d) for both groups and individual children.

Accelerometers provide an objective, nonreactive and re-useable tool for assessing physical activity. Nevertheless, they have a limited ability to assess cycling, locomotion on a gradient or other activities with limited torso movement. Also, converting accelerometer counts to units of EE may provide inaccurate estimates because of the additional measurement error. The Caltrac® device is a first generation accelerometer and is limited by possible participant tampering because of the easy accessibility to its controls, and by its inability to detect daily or hourly patterns of activity without participant involvement. The CSA®, Tritrac-R3D® and other accelerometers are promising devices that detect both the patterns of physical activity and total activity, using internal memory with no exterior controls. The benefit of the 2 extra dimensions of measurement in the Tritrac-R3D® compared

Table V. Validation of other accelerometers used to assess young people's physical activity

Monitors	Variables	Participants	Reliability	Criterion measure	Validity	Reference
LSI®	Counts.h free-play^{-1}	18 boys, 12 girls; 2-6y	N/A	FATS DO[20]	r = 0.38	53
CSA®	Counts.period^{-1}	11, mean age = 4.0y	Left hip *vs* right hip counts different ($p < 0.05$)	CPAF DO[16]	r = 0.87	61
CSA®	Mean counts.min^{-1}	19 boys, 11 girls; 10-14y	Left hip *vs* right hip; R = 0.87	$\dot{V}O_2$	r = 0.77-0.87	62
CSA® Tritrac®	Mean counts.min^{-1}	15 boys, 15 girls; 8-10y	N/A	$\dot{V}O_2$	CSA®: r = 0.69-0.85; Tritrac®: r = 0.74-0.93	29
CSA® Tritrac®	Mean counts.min^{-1}	21 Chinese boys; 8-10y	N/A	$\dot{V}O_2$	CSA®: r = 0.81-0.88; Tritrac®: r = 0.93-0.94	30
Tritrac®	Counts.period^{-1}; (classroom and PE)	32, 10-12y	N/A	CARS DO[13]	Classroom: r = 0.70; PE: r = 0.77	63
Mini-logger®	Mean counts.min^{-1}; (ankle and hip placements)	16 boys, 15 girls; 10-16y	7-13 day test-retest; cycling: R = 0.05-0.75; treadmill: R = 0.61-0.84	$\dot{V}O_2$	Cycling: r = 0.06-0.15; treadmill: r = 0.37-0.67	32
Mini-mitter 2000®	Mean counts.min^{-1}	10 boys, 10 girls; 8-12y	N/A	24-hour whole room calorimetry; (kJ.day^{-1})	–2.9 ± 5.1%	64

CARS = Children's activity rating scale; **CPAF** = children's physical activity form; **CSA®** = uni-axial accelerometer; **DO** = direct observation; **FATS** = Fargo activity timesampling survey; **LSI®** = large scale integrated physical activity monitor; **Mini-logger®** = uni-axial accelerometer; **Mini-mitter®** = uni-axial accelerometer; **PE** = physical education; **r** = Pearson product-moment correlation coefficient; **R** = intraclass correlation coefficient; **Tritrac®** = tri-axial accelerometer; $\dot{V}O_2$ = oxygen consumption.

with the CSA® accelerometer has not been well established.

3. Subjective Techniques

Survey methods of estimating physical activity levels in children are considered subjective because they rely on responses from the child. The sporadic nature of children's physical activity[14] makes these activities difficult to recall, quantify and categorise. Also, the lower cognitive functioning of children compared with adults reduces their ability to accurately recall intensity, frequency and especially duration of activities.[65,66] Survey techniques should be validated against more stringent measures of physical activity (primary- or secondary-level methods) before extensive use. The techniques in this category are classified into 4 groups: self-report questionnaires, interviewer-administered questionnaires, proxy-report questionnaires and diaries.

3.1 Self-Report Questionnaires

Table VI summarises information about questionnaires listed by the strength of the criterion measure.[58,65,68-75] The 'Time Frame' column in tables VI–VIII indicates the time frame for which physical activity was assessed. There is a wide range (r = –0.10 to 0.88) of correlation coefficients between these self-report measures and direct observation, heart rate, or motion detection. Such wide variability is indicative of the many different instruments and criterion measures used. Studies from the Family Health Project[65,67] are the only studies that validated surveys against direct observation and found agreement ranging from 73.4% in 24 participants[65] to 86.3% in 812 participants.[67] Craig et al.[68] observed a correlation of r = 0.47 between a 1-year MVPA recall and 2-weeks of EE measured by DLW. The inclusion of younger children in the Janz et al. study[71] may have lowered the correlations because of their limited ability to accurately recall their intensity and duration of physical activity. Also, compared with adults, young children have lower sweat rates given the same environmental stress.[76] Therefore, it may be inappropriate to use a sweat recall to estimate physical activity in preadolescent children.

Weston et al.[73] obtained the highest correlations with the Previous Day Physical Activity Recall (PDPAR). The PDPAR was positively associated with both a pedometer (r = 0.77) and Caltrac® accelerometer (r = 0.88) in 8th-11th grade students. In contrast, Trost et al.[70] found associations between the PDPAR and the CSA® accelerometer ranging from r = 0.19 to 0.39 in 5th grade children. The lower correlations observed in the Trost et al. study[70] may be because of the much smaller sample size and the younger age of the children.

Relatively inexpensive self-report measures offer researchers a means of estimating physical activity levels in large numbers of individuals while maintaining low investigator and respondent burden. The greatest limitation with these types of measures is the subjectivity inherent when individuals are asked to respond to questions about their behaviour. The issues of recall errors, deliberate misrepresentations, social desirability and other biases are particularly important when dealing with children. Although the PDPAR and several others appear to be promising tools, more research using primary standards as criterion measures is needed to clarify their full potential. Also, the number of administrations needed to estimate 'usual' physical activity is not clear for most of the 1-day questionnaires.

3.2 Interviewer-Administered Questionnaires

The results from studies evaluating 7 interviewer-administered surveys are presented in table VII.[31,58,77-79] Although providing a trained administrator may improve a child's cognition and accuracy, there is still a wide range of correlations for these techniques. Wallace and McKenzie[77] used 1 week of direct observation as a criterion measure and found 75% agreement between this and a 7-day physical activity recall. Sallis et al.[78] obtained relatively high correlations using the Godin-Shephard Survey and a simple activity rating compared with heart rate recordings (r = 0.81 and 0.89, respectively). These authors[78] also observed lower correlations with a 7-day recall, which may indicate

Table VI. Validation of self-reports used to assess young people's physical activity

Instruments	Time frame	Participants	Reliability	Criterion measure	Validity	Reference
6 different forms[a]	1 day	24, 3rd-6th grade	N/A	DO	73.4% agreement across all forms	65
MVPA recall	1 day	422 boys, 390 girls; 3rd and 4th grades	N/A	DO	86.3% agreement between reported and observed number of MVPA bouts > 10 minutes	67
1-year physical activity recall for MVPA	1 year	49 girls; mean age = 10y	2-week test-retest; r = 0.70	AEE_{DLW}	r = 0.47	68
Modifiable activity questionnaire	1 week	48 boys, 53 girls; mean age = 5.3y	N/A	AEE_{DLW}	Nonsignificant correlations with AEE_{DLW}	69
Previous day physical activity recall (PDPAR)	1 day	18 boys, 20 girls; 5th grade	N/A	CSA®	r = 0.19-0.39	70
Activity rating	Normative scale	15 boys, 15 girls; 7-15y	1-month test-retest R = 0.85	CSA®	r = –0.04-0.17	71
3-day aerobic recall	3 day		R = 0.54		r = 0.46-0.51	
3-day sweat recall	3 day		R = 0.30		r = 0.05-0.39	
Computerised activity recall (CAR)	5, 1 day recalls	20 boys, 25 girls; 6th-8th grade	1-2 week test-retest; R = 0.95 for TEE; R = 0.82 for AEE	1 day Tritrac®	r = 0.51 w/ TEE; r = 0.20 w/ AEE	72
Previous day physical activity recall (PDPAR)	1 day	119; 8th-11th grade	1-hour test-retest; R = 0.98	pedometer	r = 0.77	73
				Caltrac®	r = 0.88	
				HR	r = 0.37-0.63	
Self-administered physical activity checklist (SAPAC)	1 day	55 boys, 70 girls; 5th grade	N/A	Caltrac® HR	r = 0.28-0.60; r = 0.02-0.32	58
Yesterday activity checklist	1 day	34 boys, 35 girls; 4th grade	3-day test-retest R = 0.60	1 day Caltrac®	r = –0.22-0.33	74
Weekly activity sum	1 week		R = 0.51	3 day Caltrac®	r = –0.15-0.40	
Weekly activity checklist	1 week		R = 0.74	3 day Caltrac®	r = –0.26-0.34	
7-day activity tally	1 week		R = 0.68	3 day Caltrac®	r = –0.10-0.11	
Physical activity questionnaire for older children (PAQ-C)	7 day	38 boys, 51 girls; 4th-8th grade	N/A	Caltrac®	r = 0.39	75

a 6 different forms: daily self-monitoring, daily, daily segmented, daily exact, daily dichotomous and daily trichotomous.

AEE = activity energy expenditure; **Caltrac®** = uniaxial accelerometer; **CSA®** = uni-axial accelerometer; **DLW** = doubly labelled water; **DO** = direct observation; **HR** = heart rate; **MVPA** = moderate to vigorous physical activity; **normative scale** = self-assessment compared with others of same age and gender; **r** = Pearson product-moment correlation coefficient; **R** = intraclass correlation coefficient; **TEE** = total energy expenditure; **Tritrac®** = tri-axial accelerometer.

the increased difficulty of remembering more than the previous day's activities. As a whole, these studies indicate that 1-day or simpler measures of 'usual' physical activity provided greater correlations. The greater correlations for the 5th graders compared with 3rd graders in the Simons-Morton et al. study[79] indicates that older children may be better able to complete these types of instruments. Further evidence supporting the use of these and other surveys should be obtained by using direct observation or an accelerometer as the criterion measure.

Table VII. Validation of interviewer-administered self-report measures used to assess young people's physical activity

Instrument	Time frame	Participants	Reliability	Criterion measure	Validity	Reference
7-day physical activity recall	7 days	11 boys; 11-13y	N/A	DO	75% agreement for intensity	77
Same day recall	Previous 10 hours	20 boys, 15 girls; 8-13y	1-day test-retest; r = 0.06	Caltrac®	Day 1: r = 0.49; day 2: r = 0.39	31
				HR	Day 1: r = 0.25; day 2: r = 0.52	
Physical activity checklist interview (PACI)	7 days	55 boys, 70 girls; 5th grade	N/A	Caltrac®	r = 0.22-0.54	58
				HR	r = 0.10-0.38	
7-day recall interview (PAR)	7 days	36 5th grade, 36 8th grade, 30 11th grade	R = 0.54-0.77	HR	r = 0.44-0.53	78
Godin-Shepard survey (GS)	7 days		2-week test-retest R = 0.81		r = 0.81	
Simple activity rating	Normative scale		R = 0.89		r = 0.89	
Physical activity interview (PAI)	1 day	34 3rd grade 30 5th grade	N/A	HR	r = 0.50-0.57 r = 0.72	79

Caltrac® = uniaxial accelerometer; **DO** = direct observation; **HR** = heart rate; **normative scale** = self-assessment compared with others of same age and gender; **r** = Pearson product-moment correlation coefficient; **R** = intraclass correlation coefficient.

Interviewer-administered surveys possess many of the same strengths and limitations as self-report measures. An interview format may slightly improve results but the presence of the interviewer may introduce additional bias. Any potential benefits of this method must be weighed against the increased cost and burden to the researcher, as well as the potential for response bias.

3.3 Proxy-Reports

Validation studies of proxy-reports of children's physical activity are presented in table VIII.[56,80,81] Noland et al.[56] observed little or no correlation between direct observation and either a teacher's or a parent's rating of the child's activity. Two other studies, however, observed significant associations using either a teacher report[80] or a parent report.[81] Overall, there is limited information for this type of physical activity measure in children and adolescents.

Although it is tempting to think that parents would provide an accurate assessment of their child's activity, this does not always seem to be the case.[56] Part of the problem with proxy-reports is the type of information sought. Questions that assess subjective behaviours (e.g. physical activity) rather than objective facts (e.g. eye colour) may produce lower agreement between the criterion measure and the proxy respondent.[82] Also, the characteristics and perceptions of the proxy respondent may introduce additional sources of bias.[83,84] By using the parent or teacher as a proxy respondent for young children, however, researchers can avoid recall errors caused by children's cognitive limitations. Proxy reports appear promising and would be suitable for large study populations if a valid and reliable instrument can be developed.

3.4 Diaries

Because of the relatively high participant burden, few studies have used the diary method for estimating young people's physical activity. Bouchard et al.[85] reported associations between a 3-day activity log and several physiological measures in 150 children (mean age = 14.6 ± 2.9 years) and 150 adults. For the entire sample (n = 300), correlations between EE from the diary (TEE_{diary}) and the Physical Work Capacity 170 cycle ergometer test ranged from 0.23 to 0.70. The TEE_{diary} was weakly correlated with the sum of 6 skinfolds (r =

-0.08) and percent body fat (r = -0.13). Seliger et al.[86] used a 24-hour diary 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.[87] found a mean difference of 1.2% between TEE_{diary} and TEE_{DLW} in 15-year-olds. Garcia et al.[88] reported high test-retest reliability (R = 0.94) using the Child/Adolescent Activity Log (CAAT). These investigators state that the CAAT was validated against the Caltrac® accelerometer, but these data were not presented.

The activity diary is considered one of the most accurate subjective techniques for adults. Based on the participant burden required to maintain an activity diary, however, this technique has limited uses in a paediatric population. While adolescents may be able to complete the diary, the accuracy of their reports should be viewed with caution. It has been noted that survey methods in children under the age of 10 years are not advisable[66] and the same limitation should be applied to the use of activity diaries.

4. Future Research

Survey methods of assessing young people's physical activity are very cost effective but lack objectivity. Many have not been validated against direct observation or measured EE (DLW or $\dot{V}O_2$), although most have been validated against some objective measure. Validation of these methods and other new instruments against direct observation would truly assess their validity. National surveys are used to assess the physical activity of the entire population and provide a basis for funding of activity-related programmes and research. These instruments, however, may lack acceptable validity when they are compared with a more stringent criterion. Such surveys may produce erroneous values. Therefore, further work is needed to identify valid and reliable items that are appropriate for inclusion into a national survey format. In addition, there is a lack of valid proxy-report instruments available for measuring physical activity in children. Since this method would be an efficient means of obtaining physical activity information for young children, new proxy-report instruments need to be developed and validated appropriately. The Digiwalker DW-200 pedometer correlates well with short term direct observation and laboratory measures of oxygen consumption and heart rate. Further work is needed to validate these pedometers in more realistic settings. Accelerometers are an attractive technique for physical activity assessment because of their objectivity and high validity. More research is needed on the validity of accelerometers in free-living children and the possibility of improving their accuracy by combining accelerometry with either heart rate or survey techniques.

5. Conclusion

To understand why some young people are more active than others and how to encourage them to be more active, we need to measure physical activity accurately and reliably. Valid methods of estimating physical activity in children and adolescents are critical to understanding the dose-response re-

Table VIII. Validation of proxy reports used to assess young people's physical activity

Instrument	Time frame	Participants	Reliability	Criterion measure	Validity	Reference
6-item parent survey	1-day	11 boys, 10 girls; 3-5y	N/A	20-min video	r = -0.19-0.06	56
6-item teacher survey				6-h DO	r = -0.13-0.04	
Teacher ratings of activity	1-day	33 boys, 25 girls; mean age = 2.5y	N/A	activity recorder	r = 0.41-0.66	80
Teacher report	5-day	17 boys, 22 girls; 6y	2-week test-retest Spearman r = 0.84	HR	Spearman r = 0.07-0.59	81
Parent report	3-day		Spearman r = 0.27-0.53		Spearman r = 0.72-0.82	

DO = direct observation; **HR** = hear; **r** = Pearson product-moment correlation coefficient.

lationship between physical activity and chronic diseases and associated risk factors. Accurate knowledge of physical activity levels allows us to develop physical activity intervention programmes and to assess their effectiveness.

Although the ideal method of assessing physical activity in children (and adults) remains elusive, direct observation is currently the most appropriate criterion standard. When direct observation is not possible because of long measurement time periods or personnel or monetary constraints, accelerometers provide a promising alternative. When possible, new survey instruments should be validated against a more stringent technique before they are widely used. The goal of physical activity research is to better understand the role of physical activity in disease and health. Attainment of this goal depends on the sensitivity of the measurement tools. Technological advances such as heart rate monitoring and accelerometry will make this goal increasingly attainable in the near future.

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