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Ambulatory Activity Monitoring in Youth: State of the Science

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Abstract

Purpose—More than 75% of youth in grades 4 through 12 in the United States do not engage in vigorous physical activity daily. Clinicians and researchers need valid and reliable measures of physical activity to address this public health concern. The purpose of this paper is to review the history of activity monitoring in pediatrics and synthesize the current literature on ambulatory physical activity monitoring in youth.

Summary of Key Points—For this review, ambulatory physical activity monitoring is defined as direct measurement of the amount of walking and/or steps taken over time. An overview of commercially available pedometers and accelerometers is presented with implications and recommendations for practice and research.

Recommendations—Ambulatory activity monitoring has the potential to affect current pediatric health concerns related to inactivity and clear indications for a broad spectrum of research methodology.

Keywords

monitoring/ambulatory/instruments; data collection/methods; child; adolescent; physical fitness; walking/physiology

INTRODUCTION

Regular physical activity is advocated in *Health People 2010* to maintain a healthy body, enhance psychological well-being, and prevent premature death.¹ In adults, physical activity is well documented to reduce the incidence of chronic diseases such as coronary heart disease (CHD), obesity, osteoporosis, hypertension, and atherosclerosis with proposed influence on some cancers, stroke, and non-insulin-dependent diabetes.^{2,3} Although CHD is not common in youth, the risk factor of fatty streaks begins to appear in the coronary arteries by 10 years of age.⁴

In the United States, more than 75% of youth in grades 4 through 12 do not engage in vigorous physical activity daily.⁵ Physical activity levels in childhood may in part determine

adult levels of physical activity. In 1992, a survey of 6,000 adults documented that 25% of those active at age 14 to 19 years remained active as adults, whereas only 2% of those who were inactive at the same ages were active as adults.⁶ A 1997 national survey documented that fewer than 25% of youth surveyed participate in even 30 minutes daily of any type of physical activity.⁵

Valid measures of physical activity are essential to researchers and clinicians to discern the relationship between activity level and health outcomes as well as to document treatment effectiveness.⁷ The purposes of this review are fourfold. First, we review the history of activity monitoring in youth. Second, we synthesize the literature on ambulatory physical activity (walking) measurement in youth. Next, we compare the validity of commercially available monitors. Finally, we discuss the practice and research implications of activity monitoring in youth.

CRITERIA FOR ARTICLE SELECTION

To focus the scope of this review, ambulatory physical activity monitoring was defined as the direct measurement of the amount of walking and/or steps taken over time.⁸ In an extensive discussion of activity measurement, Tyron⁹ states that “the step is the preferred unit of measure, since it is the natural unit of ambulation.” Tyron placed specific emphasis on human ambulatory activity because of its obvious clinical relevance and because it can be achieved longitudinally by a person's natural lifestyle.

This review includes studies that used commercially available pedometers and the newer single and multiple plane accelerometers that record steps or activity counts per time unit. The population for this review includes only youth younger than 21 years of age. This age group was selected to capture the breadth of published activity monitoring applications (ie, from elite athletes to youth with obesity). All literature reviewed was published in English. Only published literature including abstracts and reviews from journals and conference proceedings was sought by an electronic search of the full MEDLINE, CINAHL, and Current Contents databases from 1980 to March 2003. The key words “ambulatory,” “physical activity,” “monitor,” “step activity,” “accelerometer,” “pedometer,” “youth,” “adolescents,” and “children” were employed in the electronic search process. Selected articles were reviewed for 1) study sample characteristics and ages, 2) type of instrument employed and attachment site, 3) comparison standard and sampling epoch, 4) key correlation findings, and 5) average step/activity counts per time period.

ACTIVITY MONITORING IN PEDIATRICS

Historically, direct observation, questionnaires, and heart rate (HR) monitoring have been used to assess patterns of pediatric physical activity.¹⁰ Although HR monitors are not a direct measure of physical activity, HR can be reliably measured over long periods of time and provides an indication of cardiovascular status. Disadvantages associated with HR monitors are their high cost and extensive time to download. Another concern is the potential influence of other factors such as emotional stress and body position, on the data, which may not truly reflect activity levels and patterns.¹¹ HR response also tends to lag behind changes in physical movement. The rapid transition between activities associated

with child and adolescent movement patterns is a measurement challenge. HR monitors may in fact mask potentially important information during pediatric monitoring such as duration of burst of activity and patterns of movement over time.^{10,11}

Activity and step count monitors were developed in response to poor reliability of self-report measures in youth, the intrusiveness of direct observation, and the complexity of HR monitoring.¹² As the technology of accelerometer-based monitors evolved, most validation work has been completed in adults first by indirect calorimetry or calibrated in the metric of resting metabolic equivalents (MET). Established adult MET values may be inaccurate for youth since the resting metabolic rate of youth declines by approximately half between five and 18 years of age.¹³

Relatively simple electronic devices, pedometers are designed to estimate mileage walked and/or steps taken over a period of time. The older mechanical-style pedometers are less accurate than the more recent electronic pedometers. Today, pedometers are battery operated and contain a spring-suspended horizontal level arm that moves up and down. An electrical circuit is opened and closed by the movement of this lever arm in response to the vertical movements of the pelvis or other body parts during walking (waist attachment). Electronic circuitry allows summation of steps taken and provides a digital readout.

In contrast to pedometers that detect overall body movement, accelerometers are more complex electronic devices that specifically measure accelerations produced as a body segment or limb part moves. Acceleration is the change in velocity over time of the body part as it moves (ie, ankle during stepping). Electric transducers and microprocessors convert recorded accelerations into digital signals, which are the “counts” or steps.

Sirard and Pate¹⁴ suggest that the frequently employed, single (vertical)-plane accelerometer, the Caltrac (Muscle Dynamics Fitness Network, Inc., Torrance, CA), may be potentially limited in its ability to detect the variable movement patterns of youth. Single-plane accelerometers introduced in the late 1990s, such as the CSA (Model 7164; Computer Science and Applications, Inc., Fort Walton Beach, FL), are now reported in the physical activity monitor validation literature for adults and youth. A three-dimensional accelerometer, the TriTrac (Professional Products, Reining International, Madison, WI) may be a more accurate assessment of physical activity in youth due to its ability to sense movement in three directions.¹⁴ The StepWatch employs a specialized two-plane accelerometer designed to be sensitive to a variety of walking patterns, thus measuring specifically steps per period of time.¹⁵

Over the past decade, physical educators have shifted their focus from fitness testing of youth to a focus on physical activity. The current National Association for Sport and Physical Education's definition of a “physically educated person” addresses physical activity in four of seven content standards in physical education.¹⁶ These standards include 1) demonstration of competency in many movement forms and proficiency in a few movement forms, 2) application of movement concepts and principles to the learning and development of motor skills, 3) showing evidence of a physically active lifestyle, 4) achieving and maintaining a health-enhancing level of physical fitness, 5) demonstrating responsible

personal and social behavior in physical activity settings, 6) demonstrating understanding and respect for difference among people in physical activity settings, and 7) understanding that physical activity provides opportunities for enjoyment, challenge, self-expression, and social interaction. This conceptual shift is based on research that documented that negative feedback from fitness testing *per se* can lead to a reduction in a child's level of intrinsic motivation for physical activity.¹⁷

METHODOLOGICAL CONSIDERATIONS

A consideration in measuring ambulatory activity is the choice of measurement units. Number of steps taken, total distance traveled, and calorie expenditure all have been reported as outcomes of ambulatory activity.⁸ To calculate distance traveled or caloric expenditure from a step or activity count, a number of variables such as stride length, weight, and age are required, thus introducing levels of error for varying speeds of walking or stride length. As measured by pedometers and accelerometers, activity researchers have recently proposed the Total Daily Step Count as the most accurate descriptor of ambulatory activity.^{8,18} An additional advantage of using “raw” step counts is that instrument performance can be calibrated directly to the field criterion of observed steps taken.

Researchers and clinicians must also take into account the monitoring time frame needed to provide a confident estimate of the typical ambulatory activity of the target population. The measurement time frame appears to be dependent on the measuring device, population, and/or research question.⁸ Data recording and collection procedures will also affect the monitoring duration. Issues of reliable recording by participants, masking of investigators and/or participants to decrease bias, the methods of returning the monitor (ie, via the US Postal Service), and adherence to wearing the device will all affect the study of daily step/activity counts.

SYNTHESIS OF THE LITERATURE

Our electronic search of the literature located 54 English-language articles that addressed the measurement of ambulatory physical activity in youth younger than the age of 21 years. Thirty-nine of these papers did not specifically report walking activity as steps or counts per unit of time. This systematic review focuses on 15 articles that met the criteria for this review and document validation data for commercially available monitors. Data are organized by the type of device: pedometers (Table 1) and accelerometers (Table 2).

PEDOMETERS

Nishikido et al¹⁹ compared the Yamasa AM-5 pedometer (Yamax Inc., Tokyo, Japan) to direct observation of activity in 1982. Correlations with direct observations of activity by mothers and teachers were low, at 0.14 and 0.25, respectively. In contrast, a strong association (r [H11005] 0.97) was documented by Kilanowski et al²⁰ between the Digiwalker DW-200 pedometer (Yamax Inc.) and a direct observation system, the Children's Activity Rating Scale. When compared with HR and oxygen consumption (VO_2), Eston et al²¹ reported correlations with the Digiwalker DW-200 pedometer of 0.82 and 0.78, respectively. In a replication of the Eston et al study, Louie et al²² documented correlations

of 0.77, 0.68, and -0.45, respectively, for this pedometer with hip, ankle, and wrist attachments during treadmill walking activity compared with oxygen uptake scaled for body mass (SVO_2) for Chinese boys in Hong Kong. The negative correlation suggests that the wrist attachment may not be a valid placement for measuring ambulatory activity with this pedometer.

ACCELEROMETERS

Direct observations, using the Fargo Activity Time-Sampling Survey, has been compared with the Caltrac personal activity monitor.²³ Reasonable correlations of 0.50 and 0.37 were documented, during walking and running, respectively, with total counts per 10 hours of observation ranging from 85 to 142. These data were obtained in a sample of 30 children aged two to four years. The low counts and correlations suggest that the Caltrac underestimates ambulatory activity. Trost and et al²⁴ compared the CSA model 7164 with HR, VO_2 , and energy expenditure during treadmill walking. After monitoring 30 youth aged 10 to 14 years, the authors reported strong correlations of 0.86, 0.77, and 0.86, for HR, VO_2 , and energy expenditure, respectively. Counts per minute increased from approximately 2,500 to 7,200 as the speed of treadmill walking/ running changed from three to six miles per hour. Strong correlations to HR (r [H11005] 0.85) and VO_2 (r [H11005] 0.88) were documented by Eston et al²¹ in 1998 in a group of 30 youth aged eight to 11 years using the TriTrac R3D model T303.

Rowlands et al¹⁸ also reported a comparison of the TriTrac R3D model T303 with the Digiwalker DW-200 and HR measures. Three-day total moderate activity counts were greater for boys than girls, with the average total vigorous counts reported as 116.2 for boys and 80.2 for girls. Louie et al²² compared the CSA model 7164 and the TriTrac R3D to VO_2 measures during four-minute treadmill walking and running activities in a sample of 21 Chinese boys aged eight to 10 years in Hong Kong. Correlations with VO_2 were reported as slightly stronger for the TriTrac ($r = 0.93$) when compared with the CSA ($r = 0.81$). Step counts were similar for 4-minute walking with the CSA, measuring a larger relative count range (5,991–6,737) than the TriTrac (4,653–5,192). The Mini-Logger 2000 (Mini Mitter Co., Bend, OR) was validated against VO_2 and HR in 31 youth, ages 10 to 16 years, by Troutman et al.²⁵ The authors documented good reliability for hip and ankle placement during treadmill walking and running. The hip placement was consistently less reliable ($r = 0.61$ – 0.66) than the ankle placement ($r = 0.84$) for both treadmill activities.

McDonald et al²⁶ compared the StepWatch activity monitor (Cymatech, Seattle, WA) measurement accuracy with manual counts of steps taken by direct observation in 21 boys and 21 girls, aged seven to 21 years. Documenting a strong measurement accuracy correlation ($r = 0.99$), preliminary normative data for this monitor were presented. The authors reported an average total steps per day of 5,428 steps, with a low, medium, and high activity level minutes per day of 246, 82, and 53 minutes, respectively. The same research team reported discriminative validity for the StepWatch in a study describing the step activity of 20 obese and 27 nonobese youth aged eight to 10 years.²⁷ High activity minutes and percentage of high activity minutes per day for the obese youth was approximately one half of the results documented for the nonobese youth. Total steps per day for the nonobese

youth were reported to be 6,037 (SD ± 359), while obese youth averaged 3,898 steps (SD ± 516). Obese youth spent, on average, 1,480 minutes per day in a high activity level compared with 2,590 for the nonobese youth.

Employing a two-week sampling period, Bjornson et al²⁸ collected a total of six weeks of daily StepWatch data on 20 youth in the age groups five to seven years and nine to 11 years, equally distributed by gender. Further support for StepWatch measurement accuracy was documented for walking and running with correlations of 0.97 and 0.96, respectively, when compared with directly observed steps. Total steps per day ranged from 4,864 to 14,591, suggesting that the longer monitoring time sample may be indicated to capture the variability of daily step activity. For a two-week monitoring sample, the average percentage of time spent at low, medium, and high activity levels was 67.7%, 21.7%, and 23.7%, respectively.

Ott et al²⁹ reported a comparison of both the CSA model 7164 and the TriTrac R3D with both HR and resting MET. The TriTrac demonstrated higher correlations with HR and MET than the CSA. In contrast, the average counts per day for walking and running were higher for the CSA monitor. A direct comparison of the two types of monitors found a correlation of 0.86, suggesting that they are similar in capacity to record ambulatory activity. Ekelund et al³⁰ assessed seven adolescent speed skaters with the CSA during off-season and preseason training activities on a tread-mill. Off-season training activities focused primarily on running, while preseason activities focused on physical training activities (eg, in-line skating, weight training, skate imitation). Correlations of the CSA monitor with total daily energy expenditure thus were stronger during the off-season ($r = 0.93$ versus 0.46). The differences in activity counts for running were substantially different than the other training activities, suggesting that this monitor was more sensitive to ambulation activity.

Puyau et al¹² compared the CSA model 7164 and the Mini Mitter Actiwatch for VO_2 and HR during 10-minute samples of treadmill walking, jogging, and track walking and jogging. The Actiwatch demonstrated slightly higher correlations with VO_2 and HR than the CSA monitor. A comparison of the two monitors at two attachment sites (hip and head of the fibula) documented a correlation of 0.88 for the hip and 0.89 for the leg. The CSA monitor documented higher average counts per day for walking compared with the Actiwatch regardless of attachment site. There was a large discrepancy in counts between the CSA (7,354) and the Actiwatch (2,959) for the leg placement. CSA hip versus leg attachments were also found to have a large difference in counts (8,804 versus 26,562), suggesting that the leg placement is picking up more than four times more movements than the hip attachment. For the Actiwatch, the leg attachment also was found to have a larger average daily count than the hip (5,644 versus 3,318).

VALIDITY FOR MEASUREMENT OF AMBULATORY (WALKING) PHYSICAL ACTIVITY

Dale et al³¹ acknowledge that the current major challenge in physical activity assessment is the lack of a true gold standard of measurement. As presented in this review, the prevalent validation of physical activity measurement has been the reporting of the concurrent validity

of a device as compared with other devices and/or physiological parameters. In an extensive review of physical activity assessment in adolescents and youth, Sirard and Pate¹⁴ stated that “direct observation of movement seems to be the most appropriate standard for physical activity assessment.” They propose that the criterion standards of activity measures for validation purposes should be first direct observation, followed by doubly labeled water and indirect calorimetry such as oxygen consumption (VO_2). Secondary measures of activity (ie, HR, pedometers, and accelerometers) should be validated directly with the criterion standards if possible.

The studies reviewed in this article suggest that the newer pedometers (specifically the Digiwalker DW-200) are reusable and appear to be objective and valid measures of ambulatory activity in youth between the ages of seven and 12 years. Since pedometers detect only total counts of steps over the observation period, they do not assess the intensity or pattern of activities performed. Having participants’ record their activity counts on a regular basis may address this issue, but that can also decrease objectivity due to transcription error.

Validated against direct observation of ambulatory activity, the Caltrac and StepWatch demonstrated a large discrepancy in their accuracy with correlations of 0.50 versus 0.97–0.99. When compared with VO_2 , the CSA, TriTrac R3D, Mini-Logger, and Actiwatch monitors all demonstrated strong correlations to direct observations of walking, supporting their application to measure walking activity. The leg attachment for the CSA and Actiwatch appears to lead to stronger correlations with VO_2 than the hip placement of the monitors. The leg placement consistently documented more counts per day compared with a hip placement. These results are consistent with the findings of Puyau et al,¹² suggesting improved true “step” measurement accuracy with a leg placement. The TriTrac to CSA correlations ranged from 0.86 to 0.94, while the Actiwatch to CSA were strongly correlated for either leg or hip placement with coefficients of 0.88 and 0.89, respectively. These data suggest similar validity for ambulation activity for the TriTrac, CSA, and Actiwatch when compared with VO_2 . Demonstrating the strongest correlation with direct observation of steps taken, the StepWatch appears to be the most sensitive monitor for the measurement of step (walking) activity specifically in youth.

IMPLICATIONS FOR PRACTICE AND RESEARCH

In an analysis of adult health issues 55 years after participation in the Harvard Growth Study, Must et al³² reported that obesity in adolescence increased the risk of disease and death regardless of subsequent adult body composition. In the past 20 years, the percentage of youth between the ages of six and 11 years who are overweight has doubled and the percentage of those aged 12 to 19 years who are overweight has tripled.^{33,34} In response, a priority action of the Surgeon General's Call to Action to Prevent and Decrease Overweight and Obesity is to build physical activity into regular routines and playtime for youth and families. The proposed recommendation is for at least 60 minutes of moderate intensity activity per day for youth.³⁵

Clinicians and researchers interested in surveillance, screening, program evaluation, and intervention require valid physical activity measures.⁸ Selection of a measurement device relates to the particular purpose of the study, the clinical question, and the population measured.⁷ For example, a large population-based longitudinal study tracking physical activity in youth would require a device of lower cost and of high durability that provides total activity counts. The pedometers reviewed in this article would all be appropriate. For intervention studies in which general movement and ambulation are the outcome (ie, a study of a medication to treat hyperactivity), any of the accelerometers reviewed have the ability to be sensitive to the expected treatment effects.

If the interventions and/or impairment of a specific population (ie, cerebral palsy, muscular dystrophy) were related to ambulation, then the CSA, TriTrac, and Step-Watch would all be appropriate, with the StepWatch appearing to have the strongest sensitivity for specific steps. When ambulatory activity patterns are of interest, the same three monitors appear to have the ability to clearly capture the desired outcome. Preference for a particular monitor may then be driven by the software capabilities to allow a variety of sampling and/or analysis epochs depending on the research questions. If a comparison of activity level during school hours and nonschool hours was desired, the StepWatch application currently allows selection of subsets of step data for analysis.

Besides the monitor, clinicians and researchers will need to determine the most appropriate duration of sampling to answer the specific clinical or research question. In a study directed at documenting age-related trends, Trost et al²⁴ found that seven days of consecutive monitoring would provide sufficient estimates of daily activity. The two-week samples of step data documented by Bjornson et al²⁸ support a similar duration of sampling.

FUTURE DIRECTIONS

Normative validation of monitor application in typically developing youth is warranted due to the transitory nature of youths' physical activity and lack of sustained exercise. Pediatric activity researchers have not been able to document even 10 to 20 minutes of continuous activity in youth.³ Bailey et al³⁶ documented the median duration of low- and medium-intensity activity at a mere 6 seconds, with high-intensity activity of 3 seconds duration and neither of those levels longer than 22.5 seconds. It appears that youth transition in and out of levels of activity faster and do not maintain prolonged activity as a part of their natural activity pattern. Saris³⁷ proposed that this pattern of activity might be due to the shorter attention span naturally found in youth, which may have negatively biased previously reported activity levels in youth. Documentation of the durability of devices for prolonged monitoring periods (ie, a week to months) and the potential for damage during daily wear and/or handling is needed since several of the monitors are of significant cost.

Monitor-specific norms will allow description of levels of impairment and mobility across a variety of pediatric diagnoses (eg, cystic fibrosis, asthma, cerebral palsy, juvenile arthritis, muscular dystrophy, spina bifida, spinal cord injury). Habitual physical activity may also be a function of culture and environment.²² Patterns of physical activity may be quite different between youth living in North America, Europe, and Asia. Macfarlane³⁸ documented lower

habitual activity measuring HR in Chinese youth living in Hong Kong compared with youth in the United Kingdom, North America, and Singapore. Normative studies of habitual physical activity across various cultures and socioeconomic groups will also help clarify potential differences.

Despite the US Surgeon General's call for a minimum of 60 minutes of moderate intensity activity per day for youth, there is currently no evidence-based standard for optimal activity level by age for optimal health. Based on an extensive review by Tudor-Locke and Myers⁸ as well as data referenced in this paper, it appears that measured daily step counts of youth eight to 10 years of age can vary widely (4,800–16,000) depending on the measurement device employed. Additional evidence using standardized methods, pedometers, and accelerometers is needed to define normative values. This work would lay the foundation for further research to define the threshold values for classifying inactive pediatric populations and define the optimal number of steps per day necessary to produce various health benefits. Tudor-Locke and Myers⁸ suggested a common metric of measurement, consistent instrumentation, and similar measurement protocols to facilitate the accumulation of this critical information. This knowledge is imperative to the health professionals addressing the public health concerns of inactivity with resultant obesity in the United States today.³⁵

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REFERENCES

1. US Department of Health and Human Services. [November 10, 2002] Healthy People. 2010. Available at www.health.gov/healthypeople/.
2. Bouchard, C.; Shephard, R.J.; Stephens, T., editors. Physical Activity, Fitness and Health: International Proceedings and Consensus Statement. Human Kinetics Publications; Champaign, IL: 1994.
3. Rowlands AV, Eston RG, Ingledew DK. Measurement of physical activity in youth with particular reference to the use of heart rate and pedometry. *Sports Med.* 1997; 24:258–272. [PubMed: 9339494]
4. Strong JP, McGill HC. The pediatric aspects of atherosclerosis. *J Atheroscler Res.* 1969; 9:251–265. [PubMed: 5346899]
5. International Life Sciences Institute. Improving Children's Health Through Physical Activity: A New Opportunity. International Life Sciences Institute; Atlanta: 1997.
6. Allied Dunbar National Fitness Survey. Health Education Authority/Sports Council; London: 1992. Activity and Health Research..
7. Mahar, M.T.; Rowe, D.A. Construct validity in physical activity research.. In: Welk, G.J., editor. Physical Activity Assessments for Health-Related Research. Human Kinetics; Champaign, IL: 2002. p. 51-72.
8. Tudor-Locke CE, Myers AM. Methodological considerations for researchers and practitioners using pedometers to measure physical (ambulatory) activity. *Res Q Exerc Sport.* 2001; 72:1–12. [PubMed: 11253314]
9. Tyron, W.W. Activity Measurement in Psychology and Medicine. Plenum Press; New York: 1991.
10. Kohl HW, Fulton JE, Caspersen CJ. Assessment of physical activity among children and adolescent: a review and synthesis. *Prev Med.* 1999; 31:S54–S76.

11. Trost SG. Objective measurement of physical activity in youth: current issues, future directions. *Exerc Sport Sci Rev.* 2001; 29:32–36. [PubMed: 11210445]
12. Puyau MR, Adolph AL, Vohra FA, et al. Validation and calibration of physical activity monitors in children. *Obes Res.* 2002; 10:150–157. [PubMed: 11886937]
13. Schofield WN. Predicting basal metabolic rate, new standards and review of previous work. *Hum Nutr Clin Nutr.* 1985; 39(Suppl 1):5–41. [PubMed: 4044297]
14. Sirard JR, Pate RR. Physical activity assessment in children and adolescents. *Sports Med.* 2001; 31:439–454. [PubMed: 11394563]
15. Coleman KL, Smith DG, Boone DA, et al. Step activity monitor: longer, continuous recording of ambulatory function. *J Rehabil Res Dev.* 1999; 36:8–18. [PubMed: 10659890]
16. National Association for Sport and Physical Education. *National Standards for Physical Education: A Guide to Content and Assessment.* Mosby; St. Louis: 1995. Moving into the Future..
17. Whitehead JR, Corbin CB. Youth fitness testing: The effect of percentile-based evaluative feedback on intrinsic motivation. *Res Q Exerc Sport.* 1991; 62:225–231. [PubMed: 1925047]
18. Rowlands AV, Eston RG, Ingledew DK. Relationship between activity levels, aerobic fitness, and body fat in 8 to 10 year-old children. *J Appl Physiol.* 1999; 86:1428–1435. [PubMed: 10194232]
19. Nishikido N, Kashiwazaki H, Suzuki T. Preschool children's daily activities: direct observation, pedometry or questionnaire. *J Hum Ergol.* 1982; 11:214–218.
20. Kilanowski CK, Conslavi AR, Epstein LH. Validation of an electronic pedometer for measurement of physical activity in children. *Pediatr Exerc Sci.* 1999; 11:63–68.
21. Eston RG, Rowlands AV, Ingledew DK. Validity of heart rate, pedometry, and accelerometry for predicting the energy costs of children's activities. *J Appl Physiol.* 1998; 84:362–371. [PubMed: 9451658]
22. Louie L, Eston RG, Rowlands AV, et al. Validity of heart rate, pedometry and accelerometry for estimating the energy cost of activity in Hong Kong Chinese boys. *Pediatr Exerc Sci.* 1999; 11:229–239.
23. Klesges LM, Klesges RC. The assessment of children's physical activity: a comparison of methods. *Med Sci Sports Exerc.* 1986; 19:511–517. [PubMed: 3683156]
24. Trost SB, Ward DS, Moorehead SM, et al. Validity of the computer science and applications (CSA) activity monitor in children. *Med Sci Sports Exerc.* 1998; 30:629–633. [PubMed: 9565947]
25. Troutman SR, Allor KM, Hartmann DC, et al. Mini-logger reliability and validity for estimating energy expenditure and heart rate in adolescents. *Res Q Exerc Sport.* 1999; 70:70–74. [PubMed: 10100337]
26. McDonald CJ, Walsh D, Widman L, et al. Use of the step activity monitor for continuous objective 3-day physical activity monitoring of children. *Dev Med Child Neurol.* 1999; 41:36.
27. McDonald CJ, Walsh D, Widman L, et al. Use of the step activity monitor for continuous objective physical activity assessment in children with obesity. *Dev Med Child Neurol.* 2000; 42:22–23.
28. Bjornson KF, Song K, Coleman K, et al. Application of the step activity monitor to define normal activity levels in children. *Dev Med Child Neurol.* 2000; 42:23.
29. Ott AE, Pate RR, Trost SG, et al. The use of uniaxial and triaxial accelerometers to measure children's "free-play" physical activity. *Pediatr Exerc Sci.* 2000; 12:360–370.
30. Ekelund U, Yngve M, Westerterp K. Field evaluation of the Computer Science and Application's Inc. activity monitor during running and skating training in adolescent athletes. *Int J Sports Med.* 2000; 21:586–592. [PubMed: 11156280]
31. Dale, D.; Welk, GJ.; Mathews, CE. Methods for assessing physical activity and challenges for research.. In: Welk, GJ., editor. *Physical Activity Assessments for Health-Related Research.* Human Kinetics; Champaign, IL: 2002. p. 19-34.
32. Must A, Jacques PF, Dallal GE, et al. Long-term morbidity and mortality of overweight adolescents. *N Engl J Med.* 1992; 327:1350–1355. [PubMed: 1406836]
33. Pastor, PN.; Makuc, DM.; Reuben, C., et al. *Health, United States. National Center for Health Statistics; Hyattsville, MD: 2002. Chartbook on Trends in the Health of Americans..*
34. US Department of Health and Human Services. [November 10, 2002] *Physical Activity Fundamental to Preventing Disease.* Available at www.health.gov/healthy-people/.

35. US Department of Health and Human Services. Surgeon General's Call to Action to Prevent and Decrease Overweight and Obesity. Public Health Service, Office of the Surgeon General; Rockville, MD: 2001.
36. Bailey RC, Olson J, Pepper SL, et al. The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc.* 1995; 27:1033–1041. [PubMed: 7564970]
37. Saris WHM. Habitual activity in children: methodology and findings in health and disease. *Med Sci Sports Exerc.* 1986; 18:253–263. [PubMed: 3523101]
38. Macfarlane DJ. Some disturbing trends in the levels of habitual physical activity in Hong Kong primary school children: preliminary findings. *Hong Kong J Sports Med Sports Sci.* 1997; 5:42–45.

TABLE 1

Summary of Pedometer Studies in Youth for Ambulatory Monitoring Listed Chronologically

Study	Sample/Ages	Instrument and Attachment	Comparison Standard/Sampling Epoch	Key Correlations	Average Steps/ Activity Counts Per Time Period
Nishikido et al. ¹⁹	N = 49, 25 males, 24 females, 5–6y	Yamasa AM-5	Mother and teacher's direct observation steps/min, 2 d	Mother, $r = 0.14$ Teacher, $r = 0.25$	Percentage time: walking, 14.3–21.5; running, 12.6–15.5
Eston et al. ²¹	N = 30, 15 boys, 15 girls, 8–11 y	Digiwalker DW-200: wrist/ankle/hip	HR, VO ₂ : treadmill walking, total counts 4 min	HR, $r = 0.82$ VO ₂ , $r = 0.78$	Walking (counts/4 min across speeds): wrist, 113.4–140.5; ankle, 150.2–201.5; hip, 137.9–210.0
Louie et al. ²²	N = 21 boys, 8–10 y	Digiwalker DW-200: wrist, ankle, hip	VO ₂ : total counts treadmill walking, 4 and 6 km/h; running, 8 and 10 km/h 4 min	Wrist, $r = -0.45$; ankle, $r = 0.68$; hip, $r = 0.77$	Walking (counts/4 min across speeds): wrist, 116.7–209.2; ankle, 137.3–164.4; hip, 127.6–151.6
Kilanowski et al. ²⁰	N = 10, 7 boys, 3 girls, 7–12y	Digiwalker DW-200: waist	Mean counts/min: CARS TriTrac R3D Model T303, active recreational activities, 60 min	CARS, $r = 0.97$; TriTrac, $r = 0.98$	Recreational activities (counts/minute): 41.0 ± 19.3

CARS = Children's Activity Rating Scale.

TABLE 2

Summary of Accelerometer Studies in Youth for Ambulatory Monitoring Listed Chronologically

Study	Sample/Ages	Instrument and Attachment Site	Comparison Standard/Sampling Epoch	Key Correlations	Average Steps/Activity Counts Per Time Period
Klesges et al. ²³	N = 30, 17 boys, 13 girls, ages 2–4 y	Caltrac: waist	Fargo Activity Time sampling survey, direct observation 10 h	Walking, $r = 0.5$, running, $r = 0.37$	Total counts for 10 h observation: 85–142
Trost et al. ²⁴	N = 30, 19 boys, 11 girls, 10–14 y	CSA Model 7164 (or “MTI Actigraph”): hip	VO ₂ , EE, HR; treadmill, 5 min; walking, 3 and 4 mph; jogging, 6 mph	VO ₂ , $r = 0.86$, EE, $r = 0.86$, HR, $r = 0.77$	Treadmill (CSA counts/min): 3 mph, 2,500; 4 mph, 4,100; 6 mph, 7,200
Eston et al. ²¹	N = 30, 15 boys, 15 girls, 8–11 y	TriTrac R3D Model T303: waist	HR, VO ₂ ; treadmill walking, total counts: 4 min	HR, $r = 0.85$, VO ₂ , $r = 0.88$	Walking (counts/4 min): 4 mph, 1,594; 6 mph, 2,825; running (counts/4 min): 8 mph, 4,545; 10 mph, 5,097
Rowlands et al. ¹⁸	N = 34, 17 boys, 17 girls, 8.3–10.8 y	TriTrac R3D Model T303: waist	Digiwalker DW-200, count/d: HR, treadmill, 3 min, 1.7 mph, 10% grade to 6.0 mph, 22% grade	Digiwalker, $r = 0.85$ – 0.88 ; HR, $r = 0.63$	3-d avg total counts, moderate activity: boys, 369,057; girls, 289,594; vigorous activity: boys, 116.2; girls, 80.2
Louie et al. ²²	N = 21, 21 boys, 8–10 y	CSA Model 7164, TriTrac R3D Model T303: wrist, ankle, hip	VO ₂ ; pedometer CSA and TriTrac; total counts/4-min sample; treadmill walking 4 and 6 km/h; running 8 and 10 km/h	VO ₂ : CSA, $r = 0.81$; TriTrac, $r = 0.934$	CSA (total counts/4 min across speeds): walking, 1,630–2,931; running, 5,991–6,737; TriTrac, walking; 1,566–2,705; running, 4,653–5,192
Troutman et al. ²⁵	N = 31, 16 boys, 15 girls, 9.8–15.7 y	Mini-Logger 2000: hip, ankle	VO ₂ ; HR, total counts/min; treadmill: walk, 2.0 mph; run, 4.5 mph; 2-min sample at the end of a 6-min period	Walking: VO ₂ , $r = 0.99$; HR, $r = 0.89$; ankle, $r = 0.84$; hip, $r = 0.61$; running: VO ₂ , $r = 0.99$; HR, $r = 0.84$; ankle, $r = 0.84$; hip, $r = 0.66$	Walking (counts/min): hip, 154; ankle, 109; running: hip, 178.5; ankle, 137
McDonald et al. ²⁶	N = 42, 21 boys, 21 girls, 7–21 y	StepWatch: right ankle	Manual counted steps/10-min walk, total step cts/10-min walk, self-selected pace, 3-d activity levels: low, 1–15 steps/min; medium, 16–30 step/min; high, >30 steps/min	Manual counts, $r = 0.99$	Avg total steps/d: 5,428; activity level min/d: low,

Study	Sample/Ages	Instrument and Attachment Site	Comparison Standard/Sampling Epoch	Key Correlations	Average Steps/Activity Counts Per Time Period
					246; medium, 82; high, 53
McDonald et al. ²⁷	N = 47, 20 obese, 10 boys, 10 girls, 27 nonobese controls matched for age/gender 8–10 y	StepWatch: right ankle	Total step counts/10-min walk, self-selected pace, activity levels: low, 1–15 steps/min; medium, 16–30 steps/min; high, >30 steps/min; 3-d sample	High activity (min/d): obese, 37; nonobese, 63; %/d in high activity: obese, 2.8%; nonobese, 4.8%	Total activity (steps/d): obese, 3,898; nonobese, 6,037; high activity (min/d): obese, 1,480; nonobese, 2,590
Bjornson et al. ²⁸	N = 20, 10 children per groups: 5–7 and 9–11 y, 5 boys, 5 girls/group	StepWatch: right ankle	Accuracy: manual counted steps/10-min walk; three 2-wk samples >6 wk apart, activity levels: low, 1–15 steps/min; medium, 16–30 step/min; high, >30 steps/min	Manual counts: walking, $r = 0.97$; running, $r = 0.96$	Steps/d: 4,864–14,591 avg total steps/d: girls 5–7 y, 9,804; girls 9–11 y, 6,662; boys 5–7 y, 8,157; boys 9–11 y, 8,738; activity level (%/day): low, 57.7; medium, 21.7; high, 23.7
Ott et al. ²⁹	N = 28, 20 boys, 8 girls, 9–11 y	CSA Model 7164, TriTrac R3D Model T303: waist	HR, MET, CSA, TriTrac: walking, 3 mph; running, 12-m course	HR: CSA, $r = 0.64$; TriTrac, $r = 0.73$; MET: CSA, $r = 0.43$; TriTrac, $r = 0.66$; CSA to TriTrac, $r = 0.86$	CSA (avg counts/d): walking, 2,363; running, 3,089; TriTrac: walking, 1,621; running, 2,395
Ekelund et al. ³⁰	N = 7, boy athletes (speedskaters) 17.1–19.3 y	CSA Model 7164: lower back	TDEE off and preseason: treadmill: 4.5, 6.5, 10.0 mph, 8d	Off-season training TDEE, $r = 0.93$; Preseason training TDEE, $r = 0.46$	Counts/min treadmill: 4.5 mph, 2,337; 6.5 mph, 4,807; 10.0 mph, 9,544; running, 10,500; in-line skate/bike, 4,000
Puyau et al. ¹²	N = 14, 2 boys, 12 girls, 6–16 y	CSA Model 7164 and Mini Mitter Actiwatch, Model AW16: hip, head of fibula	VO ₂ , HR (total counts/min): treadmill, walk, 3.5–4.0 mph/age group for 10 min; jog, 4.5–6.0 mph/age group for 10 min; track, walk for 5 min; jog for 5 min	VO ₂ : CSA hip, $r = 0.66$; CSA leg, $r = 0.73$; MM hip, $r = 0.78$; MM leg, $r = 0.80$; HR, CSA hip, $r = 0.57$; CSA leg, $r = 0.63$; MM hip, $r = 0.66$; MM leg, $r = 0.67$; CSA vs MM: hip/hip, $r = 0.88$; leg/leg, $r = 0.89$	Walking (avg counts/d): CSA hip, 3,465; CSA leg, 7,364; MM hip, 1,179; MM leg, 2,959; jogging: CSA hip, 8,804; CSA leg, 26,562; MM hip,

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					3,318; MM leg, 5,644

TDEE = total daily energy expenditure.