



Review Article

## Measurement of physical activity in obese persons: how and why? A review

EINAS AL-EISA, PhD<sup>1)</sup>, AHMAD H. ALGHADIR, PhD<sup>1)</sup>, ZAHEEN A. IQBAL, MPT<sup>1)</sup>\*

<sup>1)</sup> Rehabilitation Research Chair, College of Applied Medical Sciences, King Saud University: P.O. Box 10219, Riyadh 11433, Saudi Arabia

**Abstract.** [Purpose] Overweight and obesity are major risk factors for poor health, especially in children. Reduced physical activity, prompted by a sedentary lifestyle, is a major contributor. Hence, it is important to assess physical activity using standardized methods in public health to identify the risks associated with obesity. There have been no recent reports comparing such modalities for use by clinicians and researchers. In this article, some of these methods for use in the assessment of physical activity are reviewed, and their advantages and disadvantages are described. [Subjects and Methods] Electronic databases including PubMed, Medline, and Google Scholar were searched for literature, using key words Obesity, Physical activity, and Physical Behavior Monitoring. [Results] With advances in technology, various novel methods have been developed to assess physical behavior, but conventional methods are still relevant and easy to administer. [Conclusion] There are various measurement options available. Researchers may choose devices providing more accurate measurements, while clinicians may prefer portability and affordability for patients.

**Key words:** Obesity, Physical activity, Physical activity assessment

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### INTRODUCTION

Actions performed by individuals in their daily lives, such as sleeping, walking, exercising, and watching television, are described as physical behavior. Monitoring of such behavior has helped researchers to broaden their perspective about prevention and rehabilitation of patients with various diseases and disorders<sup>1,2)</sup>. With advances in technology, various novel methods have been developed to assess physical behavior, but conventional methods are still relevant and easy to administer<sup>3-5)</sup>.

Overweight is a major risk factor for poor health in children<sup>6)</sup>, and various studies have reported a significant rise in the incidence and prevalence of obesity in overweight children<sup>7-10)</sup>. Overweight children are likely to become overweight adults, with associated cardiovascular and metabolic diseases<sup>11-13)</sup>. Change in physical behavior as a component of lifestyle modification in treatment of obesity has been widely recommended<sup>14)</sup>, but its role as a risk factor in the development of obesity has not been well documented. Lack of physical activity may be a cause of overweight, and may be associated with a sedentary lifestyle, including increased duration of TV watching and internet use<sup>15)</sup>. Time spent while using such media comprises sedentary activity, and is negatively correlated with physical activity scores and positively correlated with body composition indices, which lead to overweight<sup>16)</sup>. Sedentary behavior is an independent risk factor for development of overweight and associated risk factors that may differ with gender<sup>17)</sup>. Although it is a relative term, more time spent in sedentary activities does not necessarily mean less physical activity<sup>18)</sup>.

Besides genetics, diet, and hormonal levels, the level of physical activity is also a major determinant of normal growth, development, and maturation in children<sup>19,20)</sup>. Physical activity also lowers the genetic predisposition to increased body mass index (BMI) that in turn leads to obesity<sup>21,22)</sup>. Physical activity increases the resistance to physical stressors and protects against mental stress<sup>23)</sup>. Hence it is important to assess physical activity using standardized measures in public health to identify the risk factors associated with obesity, especially in children<sup>1,24)</sup>. Assessment of physical activity can include

\*Corresponding author. Zaheen A. Iqbal (E-mail: z\_iqbal001@yahoo.com)

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intensity, frequency, duration, type, or mode<sup>25</sup>). Appropriate methods for assessment also depend on the setting (indoors or outdoors), and location and reason (leisure, work, etc.) for activity<sup>26</sup>).

Various subjective and objective methods have been used to measure daily physical activity<sup>27,28</sup>). These include physiological methods such as oxygen consumption and heart rate, and behavioral tools such as questionnaires and interviews.<sup>27,29–31</sup>). For better generalizability of data on physical activity, these measures should be reliable, valid, and easy to administer, to meet the needs of global cultural diversity<sup>4,10</sup>). There have been no recent reports comparing such modalities for use by clinicians and researchers<sup>32</sup>). Hence, this article reviews some of the methods used to assess physical activity, and describes their advantages and disadvantages. The list of methods presented in this article is inclusive but not exhaustive, and there are no commercial relationships with manufacturers.

## SUBJECTS AND METHODS

Databases including PubMed, Medline, and Google Scholar were searched for literature, using the key words Obesity, Physical activity, and Physical Behavior Monitoring. References in retrieved articles were also searched for cross references. The search was limited to articles in English.

## RESULTS

After elimination of duplicate papers, relevant papers published in the last 20 years were studied. These included randomized clinical trials, cohort studies, and systematic reviews.

## DISCUSSION

In this section, we evaluate physical activity monitoring methods based on type, accuracy, ease of administration, cost, availability, and quality, for use in daily living. The choice of method used to measure physical activity depends on the type, duration, and reason for the physical activity.

Self-reporting methods: These include subjective measures such as 24-hour recall through questionnaires, interviews, and activity diaries<sup>33</sup>). These are widely used to assess physical activity, but have advantages and disadvantages<sup>34,35</sup>). Their affordability, adaptability, and ease of use allow them to obtain both qualitative and quantitative data about the level of physical activity for a larger population<sup>10</sup>). However, there is a possibility of overestimation<sup>36,37</sup>), with errors in reporting, validation of data, and repeatability of measurement<sup>38,39</sup>). Although various questionnaires are available, their reliability and validity has not been reported<sup>35,40</sup>). Two of the most popular self-reporting methods are the following:

1. The International Physical Activity Questionnaire (IPAQ) is a popular method of measuring physical activity patterns, and can be administered by telephone interview or self-reporting<sup>2,35</sup>). It can measure the nature of physical activity with a minimum duration of 10 minutes at moderate and vigorous intensity levels<sup>35</sup>). Various studies have demonstrated its reliability and validity, mostly in developed countries<sup>41</sup>). Literacy rate, cultural differences, and climate induce differences in the nature of physical activity in developing and developed countries<sup>42</sup>), that lead to the need for a more globally acceptable questionnaire.

2. The Global Physical Activity Questionnaire (GPAQ) was developed by the World Health Organization in 2002<sup>3</sup>). It was based on the IPAQ and consists of 19 questions regarding physical activity under domains of work, transport, and discretionary activities<sup>42</sup>). Studies have indicated that GPAQ is a suitable, reliable, and widely accepted instrument for physical activity assessment in large populations across different cultures<sup>10</sup>).

Immaturity, difficulty in recall, and variable patterns of activity in children<sup>25</sup>), and general decline in the elderly make self-reported physical activity assessment different in these groups<sup>43</sup>). Methods of self-reporting cannot provide accurate data in these cases<sup>44</sup>). The Children's Physical Activity Questionnaire and the Youth Physical Activity Questionnaire were devised for younger age groups, but studies were unable to establish accurate estimates of the time spent in moderate and vigorous intensity physical activity and energy expenditure<sup>45</sup>). For the elderly, the Modified Baecke Questionnaire and the Yale Physical Activity Survey have been discussed in the literature, but individual cognitive levels and a wide range of activity patterns are expected to affect the data<sup>46</sup>).

Pedometry: Pedometers are motion sensors that are typically worn on the waist to count the number of steps during locomotion<sup>47</sup>). They are designed to capture vertical motion of the hip joint with movement<sup>48</sup>). Objectivity, small size, easy availability, and low cost make pedometers popular among physicians who prescribe them for patients for self-monitoring and providing feedback on daily physical activity<sup>49,50</sup>). Unlike self-reporting methods, these give a better picture of physical activity by measuring footsteps<sup>37</sup>). However, they cannot capture activities that do not involve displacement, like lifting weights, isometric exercises, or activities that involve variable speed or upper body motion only, such as cycling or swimming<sup>47</sup>), and cannot measure temporal variables of movement, distance traveled, and intensity and duration of physical activity<sup>51,52</sup>). Various popular smart phones are also equipped with this application.

Various studies that compare different available models on the market report wide variation in their measurements<sup>53,54</sup>), which must be considered in research<sup>55</sup>). However, there are also studies that report these methods to be valid for physical

activity measurement in comparison to accelerometers, observation, and self-reporting methods<sup>56, 57</sup>).

**Accelerometry:** Accelerometers are the most objective method for measurement of physical activity, especially in outdoor settings<sup>33</sup>). These devices use various technologies such as piezoelectric effects to measure acceleration along a movement axis<sup>58</sup>). Depending on the model, they can be worn on the wrist, waist, or foot; they have a comparatively lower cost and are easy to use<sup>59</sup>). Newer variants also have the capacity to measure acceleration in vertical, horizontal, and mediolateral planes<sup>60, 61</sup>). In addition to providing feedback, they can also measure temporal parameters and allow data transfer for further calculations and later use<sup>62</sup>). Sedentary activity is classified as <100 counts/min, while <1,952 counts/min, 1,952–5,724 counts/min, and >5,724 counts/min are regarded as light, moderate, and vigorous physical activities, respectively<sup>63</sup>). These values are different for a younger age group<sup>64</sup>). These devices must be worn continuously throughout the recording period<sup>42</sup>).

Despite being widely used, accelerometers lack the capacity to measure physical activity that involves only upper body movements, such as the vertical motion component during cycling, and activity while carrying loads, and they underestimate recording while walking on inclined surfaces<sup>47, 65</sup>). Studies have shown differences in recording within and between models<sup>66</sup>), and in use in the pediatric age group<sup>67</sup>).

**Heart Rate monitors:** Heart rate is used in exercise prescriptions as it increases linearly with moderate to strenuous physical activity<sup>68</sup>). It can also be used to calculate energy expenditure<sup>69</sup>). Small size and low cost of monitors make these popular for measurement of habitual physical activity with or without displacement<sup>47</sup>). Commonly available heart rate monitors are attached to the chest with a strap or electrodes, and are not always feasible for use, as they are difficult to mount without assistance, and because electrode placement may leave irritation and marks on the skin<sup>70</sup>).

Although these devices are shown to have high reproducibility<sup>71</sup>), there are reports that they are less accurate during low intensity physical activity and in cases where the heart rate is affected by factors other than activity, e.g., high temperature, humidity, or stress<sup>72</sup>). Absolute heart rate values and heart rate indices, including activity heart rate, are reportedly derived from actual readings to obtain more meaningful values and overcome such limitations<sup>73</sup>). Heart rate monitors have also been shown to interfere with other electronic devices.

**Combination devices:** Each of the methods mentioned above have their own advantages and disadvantages. To make the most out of the data recorded and recent advances in technology, two parameters can be combined to obtain a better outcome<sup>33</sup>). It was first reported in 1988 that the combination of heart rate and motion analysis can be more meaningful than the individual measurements<sup>74</sup>). Since then, various studies have found that such devices can improve accuracy of measurement during activities of daily living<sup>75</sup>). These may combine heart rate and movement sensors, movement and temperature sensors, or multiple sensors to record motion of different body segments<sup>25</sup>).

In a situation in which low physical activity takes place at high speed (e.g., riding in a car), use of an accelerometer along with heart rate measurement would provide a more meaningful estimate than either alone<sup>47</sup>). Multi-sensor devices can be complex at times, involving various circuits and wires, and are costlier than currently available devices, making them difficult to use in research involving a large number of subjects<sup>25</sup>). Although such devices can provide more accurate results, their feasibility, reliability, and validity should be verified before they are more widely used, especially in research<sup>25</sup>).

In conclusion, physical inactivity often leads to serious health hazards, especially in overweight people. The latest methods are required in research, clinical use, and daily life applications for physical behavior monitoring and tracking of changes in physical activity patterns in overweight and obese patients. There are various options available in the market. Researchers may choose devices providing more accurate measurements, while clinicians may prefer portability and affordability for patients.

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## REFERENCES

- 1) Luis Grieria J, María Manzanares J, Barbany M, et al.: Physical activity, energy balance and obesity. *Public Health Nutr*, 2007, 10: 1194–1199. [[Medline](#)] [[CrossRef](#)]
- 2) Booth M: Assessment of physical activity: an international perspective. *Res Q Exerc Sport*, 2000, 71: 114–120. [[Medline](#)] [[CrossRef](#)]
- 3) Global recommendations on physical activity for health. WHO, 2010.
- 4) Pratt M, Macera CA, Wang G: Higher direct medical costs associated with physical inactivity. *Phys Sportsmed*, 2000, 28: 63–70. [[Medline](#)] [[CrossRef](#)]
- 5) Armstrong T, Bonita R: Capacity building for an integrated noncommunicable disease risk factor surveillance system in developing countries. *Ethn Dis*, 2003, 13: S13–S18. [[Medline](#)]
- 6) Finucane MM, Stevens GA, Cowan MJ, et al. Global Burden of Metabolic Risk Factors of Chronic Diseases Collaborating Group (Body Mass Index): National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. *Lancet*, 2011, 377: 557–567. [[Medline](#)] [[CrossRef](#)]
- 7) Burns R, Hannon JC, Brusseau TA, et al.: Indices of abdominal adiposity and cardiorespiratory fitness test performance in middle-school students. *J Obes*, 2013, 2013: 912460. [[Medline](#)] [[CrossRef](#)]

- 8) Dencker M, Thorsson O, Karlsson MK, et al.: Daily physical activity in Swedish children aged 8–11 years. *Scand J Med Sci Sports*, 2006, 16: 252–257. [[Medline](#)] [[CrossRef](#)]
- 9) Butte NF, Puyau MR, Adolph AL, et al.: Physical activity in nonoverweight and overweight Hispanic children and adolescents. *Med Sci Sports Exerc*, 2007, 39: 1257–1266. [[Medline](#)] [[CrossRef](#)]
- 10) Bull FC, Maslin TS, Armstrong T: Global physical activity questionnaire (GPAQ): nine country reliability and validity study. *J Phys Act Health*, 2009, 6: 790–804. [[Medline](#)]
- 11) Troiano RP, Flegal KM, Kuczmarski RJ, et al.: Overweight prevalence and trends for children and adolescents. The National Health and Nutrition Examination Surveys, 1963 to 1991. *Arch Pediatr Adolesc Med*, 1995, 149: 1085–1091. [[Medline](#)] [[CrossRef](#)]
- 12) Prentice AM, Jebb SA: Obesity in Britain: gluttony or sloth? *BMJ*, 1995, 311: 437–439. [[Medline](#)] [[CrossRef](#)]
- 13) Velasquez-Mieyer PA, Perez-Faustinelli S, Cowan PA, et al.: Interactions among enteroinsular activity, blood pressure and lipid profile in overweight African-American youth. *Diabetes*, 2005, 54: A662–A663.
- 14) Wadden TA, Webb VL, Moran CH, et al.: Lifestyle modification for obesity: new developments in diet, physical activity, and behavior therapy. *Circulation*, 2012, 125: 1157–1170. [[Medline](#)] [[CrossRef](#)]
- 15) Alghadir AH, Gabr SA, Iqbal ZA: Television watching, diet and body mass index of school children in Saudi Arabia. *Pediatr Int*, 2016, 58: 290–294. [[Medline](#)] [[CrossRef](#)]
- 16) Alghadir AH, Gabr SA, Iqbal ZA: Effects of sitting time associated with media consumption on physical activity patterns and daily energy expenditure of Saudi school students. *J Phys Ther Sci*, 2015, 27: 2807–2812. [[Medline](#)] [[CrossRef](#)]
- 17) Leatherdale ST, Wong SL: Modifiable characteristics associated with sedentary behaviours among youth. *Int J Pediatr Obes*, 2008, 3: 93–101. [[Medline](#)] [[CrossRef](#)]
- 18) Marshall SJ, Gorely T, Biddle SJ: A descriptive epidemiology of screen-based media use in youth: a review and critique. *J Adolesc*, 2006, 29: 333–349. [[Medline](#)] [[CrossRef](#)]
- 19) Ortega FB, Ruiz JR, Hurtig-Wennlöf A, et al.: Cardiovascular fitness modifies the associations between physical activity and abdominal adiposity in children and adolescents: the European Youth Heart Study. *Br J Sports Med*, 2010, 44: 256–262. [[Medline](#)] [[CrossRef](#)]
- 20) Cooper DM: Evidence for and mechanisms of exercise modulation of growth—an overview. *Med Sci Sports Exerc*, 1994, 26: 733–740. [[Medline](#)] [[CrossRef](#)]
- 21) Makabe S, Makimoto K, Kikkawa T, et al.: Reliability and validity of the Japanese version of the short questionnaire to assess health-enhancing physical activity (SQUASH) scale in older adults. *J Phys Ther Sci*, 2015, 27: 517–522. [[Medline](#)] [[CrossRef](#)]
- 22) Ahmad T, Lee IM, Paré G, et al.: Lifestyle interaction with fat mass and obesity-associated (FTO) genotype and risk of obesity in apparently healthy U.S. women. *Diabetes Care*, 2011, 34: 675–680. [[Medline](#)] [[CrossRef](#)]
- 23) Alghadir AH, Gabr SA: Physical activity and environmental influences on adrenal fatigue of Saudi adults: biochemical analysis and questionnaire survey. *J Phys Ther Sci*, 2015, 27: 2045–2051. [[Medline](#)] [[CrossRef](#)]
- 24) Levi F, Lucchini F, Negri E, et al.: Trends in mortality from cardiovascular and cerebrovascular diseases in Europe and other areas of the world. *Heart*, 2002, 88: 119–124. [[Medline](#)] [[CrossRef](#)]
- 25) Corder K, Ekelund U, Steele RM, et al.: Assessment of physical activity in youth. *J Appl Physiol* 1985, 2008, 105: 977–987. [[Medline](#)] [[CrossRef](#)]
- 26) Wareham NJ, Rennie KL: The assessment of physical activity in individuals and populations: why try to be more precise about how physical activity is assessed? *Int J Obes Relat Metab Disord*, 1998, 22: S30–S38. [[Medline](#)]
- 27) Hancox RJ, Milne BJ, Poulton R: Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study. *Lancet*, 2004, 364: 257–262. [[Medline](#)] [[CrossRef](#)]
- 28) Melanson EL Jr, Freedson PS: Validity of the Computer Science and Applications, Inc. (CSA) activity monitor. *Med Sci Sports Exerc*, 1995, 27: 934–940. [[Medline](#)] [[CrossRef](#)]
- 29) Myers L, Strikmiller PK, Webber LS, et al.: Physical and sedentary activity in school children grades 5–8: the Bogalusa Heart Study. *Med Sci Sports Exerc*, 1996, 28: 852–859. [[Medline](#)] [[CrossRef](#)]
- 30) Epstein LH, Saelens BE, Myers MD, et al.: Effects of decreasing sedentary behaviors on activity choice in obese children. *Health Psychol*, 1997, 16: 107–113. [[Medline](#)] [[CrossRef](#)]
- 31) Marshall SJ, Biddle SJ, Gorely T, et al.: Relationships between media use, body fatness and physical activity in children and youth: a meta-analysis. *Int J Obes Relat Metab Disord*, 2004, 28: 1238–1246. [[Medline](#)] [[CrossRef](#)]
- 32) Bonomi AG, Westerterp KR: Advances in physical activity monitoring and lifestyle interventions in obesity: a review. *Int J Obes*, 2012, 36: 167–177. [[Medline](#)] [[CrossRef](#)]
- 33) Andre D, Wolf DL: Recent advances in free-living physical activity monitoring: a review. *J Diabetes Sci Technol*, 2007, 1: 760–767. [[Medline](#)] [[CrossRef](#)]
- 34) Sallis JF, Saelens BE: Assessment of physical activity by self-report: status, limitations, and future directions. *Res Q Exerc Sport*, 2000, 71: 1–14. [[Medline](#)] [[CrossRef](#)]
- 35) Mäder U, Martin BW, Schutz Y, et al.: Validity of four short physical activity questionnaires in middle-aged persons. *Med Sci Sports Exerc*, 2006, 38: 1255–1266. [[Medline](#)] [[CrossRef](#)]
- 36) Rzewnicki R, Vanden Auweele Y, De Bourdeaudhuij I: Addressing overreporting on the International Physical Activity Questionnaire (IPAQ) telephone survey with a population sample. *Public Health Nutr*, 2003, 6: 299–305. [[Medline](#)] [[CrossRef](#)]
- 37) Shephard RJ: Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med*, 2003, 37: 197–206, discussion 206. [[Medline](#)] [[CrossRef](#)]
- 38) Irwin ML, Ainsworth BE, Conway JM: Estimation of energy expenditure from physical activity measures: determinants of accuracy. *Obes Res*, 2001, 9: 517–525. [[Medline](#)] [[CrossRef](#)]
- 39) Jakicic JM, Polley BA, Wing RR: Accuracy of self-reported exercise and the relationship with weight loss in overweight women. *Med Sci Sports Exerc*, 1998, 30: 634–638. [[Medline](#)] [[CrossRef](#)]
- 40) Marcus BH, Eaton CA, Rossi JS, et al.: Self-Efficacy, Decision-making, and stages of change—an integrative model of physical exercise. *J Appl Soc Psychol*, 1994, 24: 489–508. [[CrossRef](#)]

- 41) Craig CL, Marshall AL, Sjöström M, et al.: International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc*, 2003, 35: 1381–1395. [[Medline](#)] [[CrossRef](#)]
- 42) Trinh OT, Nguyen ND, van der Ploeg HP, et al.: Test-retest repeatability and relative validity of the Global Physical Activity Questionnaire in a developing country context. *J Phys Act Health*, 2009, 6: S46–S53. [[Medline](#)]
- 43) Kohl HW, Fulton JE, Caspersen CJ: Assessment of physical activity among children and adolescents: a review and synthesis. *Prev Med*, 2000, 31: S54–S76. [[CrossRef](#)]
- 44) Sallis JF: Self-report measures of children's physical activity. *J Sch Health*, 1991, 61: 215–219. [[Medline](#)] [[CrossRef](#)]
- 45) Corder K, van Sluijs EM, Wright A, et al.: Is it possible to assess free-living physical activity and energy expenditure in young people by self-report? *Am J Clin Nutr*, 2009, 89: 862–870. [[Medline](#)] [[CrossRef](#)]
- 46) Washburn RA: Assessment of physical activity in older adults. *Res Q Exerc Sport*, 2000, 71: S79–S88. [[Medline](#)] [[CrossRef](#)]
- 47) Freedson PS, Miller K: Objective monitoring of physical activity using motion sensors and heart rate. *Res Q Exerc Sport*, 2000, 71: S21–S29. [[Medline](#)] [[CrossRef](#)]
- 48) Welk GJ, Differding JA, Thompson RW, et al.: The utility of the Digi-walker step counter to assess daily physical activity patterns. *Med Sci Sports Exerc*, 2000, 32: S481–S488. [[Medline](#)] [[CrossRef](#)]
- 49) Tudor-Locke CE, Myers AM: Challenges and opportunities for measuring physical activity in sedentary adults. *Sports Med*, 2001, 31: 91–100. [[Medline](#)] [[CrossRef](#)]
- 50) Crouter SE, Schneider PL, Karabulut M, et al.: Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Med Sci Sports Exerc*, 2003, 35: 1455–1460. [[Medline](#)] [[CrossRef](#)]
- 51) Bassett DR Jr: Validity and reliability issues in objective monitoring of physical activity. *Res Q Exerc Sport*, 2000, 71: S30–S36. [[Medline](#)] [[CrossRef](#)]
- 52) Beighle A, Pangrazi RP, Vincent SD: Pedometers, physical activity, and accountability. *JOPERD*, 2001, 72: 19–29.
- 53) Le Masurier GC, Lee SM, Tudor-Locke C: Motion sensor accuracy under controlled and free-living conditions. *Med Sci Sports Exerc*, 2004, 36: 905–910. [[Medline](#)] [[CrossRef](#)]
- 54) Schneider PL, Crouter S, Bassett DR: Pedometer measures of free-living physical activity: comparison of 13 models. *Med Sci Sports Exerc*, 2004, 36: 331–335. [[Medline](#)] [[CrossRef](#)]
- 55) Tudor-Locke C, Sisson SB, Lee SM, et al.: Evaluation of quality of commercial pedometers. *Can J Public Health*, 2006, 97: S10–S15, S10–S16. [[Medline](#)]
- 56) Tudor-Locke C, Williams JE, Reis JP, et al.: Utility of pedometers for assessing physical activity: convergent validity. *Sports Med*, 2002, 32: 795–808. [[Medline](#)] [[CrossRef](#)]
- 57) Melanson EL, Knoll JR, Bell ML, et al.: Commercially available pedometers: considerations for accurate step counting. *Prev Med*, 2004, 39: 361–368. [[Medline](#)] [[CrossRef](#)]
- 58) Melanson EL Jr, Freedson PS: Physical activity assessment: a review of methods. *Crit Rev Food Sci Nutr*, 1996, 36: 385–396. [[Medline](#)] [[CrossRef](#)]
- 59) Trost SG, McIver KL, Pate RR: Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc*, 2005, 37: S531–S543. [[Medline](#)] [[CrossRef](#)]
- 60) Bouten CV, Verboeket-van de Venne WP, Westerterp KR, et al.: Daily physical activity assessment: comparison between movement registration and doubly labeled water. *J Appl Physiol* 1985, 1996, 81: 1019–1026. [[Medline](#)]
- 61) Bouten CV, Westerterp KR, Verduin M, et al.: Assessment of energy expenditure for physical activity using a triaxial accelerometer. *Med Sci Sports Exerc*, 1994, 26: 1516–1523. [[Medline](#)] [[CrossRef](#)]
- 62) Plasqui G, Westerterp KR: Physical activity assessment with accelerometers: an evaluation against doubly labeled water. *Obesity (Silver Spring)*, 2007, 15: 2371–2379. [[Medline](#)] [[CrossRef](#)]
- 63) Freedson PS, Melanson E, Sirard J: Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc*, 1998, 30: 777–781. [[Medline](#)] [[CrossRef](#)]
- 64) Baquet G, Stratton G, Van Praagh E, et al.: Improving physical activity assessment in prepubertal children with high-frequency accelerometry monitoring: a methodological issue. *Prev Med*, 2007, 44: 143–147. [[Medline](#)] [[CrossRef](#)]
- 65) Haymes EM, Byrnes WC: Walking and running energy expenditure estimated by Caltrac and indirect calorimetry. *Med Sci Sports Exerc*, 1993, 25: 1365–1369. [[Medline](#)] [[CrossRef](#)]
- 66) Welk GJ, Blair SN, Wood K, et al.: A comparative evaluation of three accelerometry-based physical activity monitors. *Med Sci Sports Exerc*, 2000, 32: S489–S497. [[Medline](#)] [[CrossRef](#)]
- 67) Reilly JJ, Penpraze V, Hislop J, et al.: Objective measurement of physical activity and sedentary behaviour: review with new data. *Arch Dis Child*, 2008, 93: 614–619. [[Medline](#)] [[CrossRef](#)]
- 68) Rowlands AV, Eston RG, Ingledew DK: Measurement of physical activity in children with particular reference to the use of heart rate and pedometry. *Sports Med*, 1997, 24: 258–272. [[Medline](#)] [[CrossRef](#)]
- 69) Keytel LR, Goedecke JH, Noakes TD, et al.: Prediction of energy expenditure from heart rate monitoring during submaximal exercise. *J Sports Sci*, 2005, 23: 289–297. [[Medline](#)] [[CrossRef](#)]
- 70) Forrest AJ, Blanton CA, Gale BJ, et al.: Subject compliance using digital activity log, accelerometer and heart rate monitor to record physical activity. *FASEB J*, 2004, 18: A112–A112.
- 71) Strath SJ, Swartz AM, Bassett DR Jr, et al.: Evaluation of heart rate as a method for assessing moderate intensity physical activity. *Med Sci Sports Exerc*, 2000, 32: S465–S470. [[Medline](#)] [[CrossRef](#)]
- 72) Crouter SE, Albright C, Bassett DR Jr: Accuracy of polar S410 heart rate monitor to estimate energy cost of exercise. *Med Sci Sports Exerc*, 2004, 36: 1433–1439. [[Medline](#)] [[CrossRef](#)]
- 73) Sirard JR, Pate RR: Physical activity assessment in children and adolescents. *Sports Med*, 2001, 31: 439–454. [[Medline](#)] [[CrossRef](#)]
- 74) Avons P, Garthwaite P, Davies HL, et al.: Approaches to estimating physical activity in the community: calorimetric validation of actometers and heart rate monitoring. *Eur J Clin Nutr*, 1988, 42: 185–196. [[Medline](#)]
- 75) Strath SJ, Bassett DR Jr, Thompson DL, et al.: Validity of the simultaneous heart rate-motion sensor technique for measuring energy expenditure. *Med Sci Sports Exerc*, 2002, 34: 888–894. [[Medline](#)] [[CrossRef](#)]