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Energy Assessment: Physical Activity

M. Joao Almeida and Steven N. Blair

Introduction

Measuring physical activity is one of the most difficult tasks in physical activity research due to its complexity and the fact that it is based on individual behavior characterized by daily variability in practices and routines. A recent conference at the Cooper Institute focused on the Measurement of Physical Activity.[1] A major conclusion was that for field studies there is no single measure able to accurately assess physical activity in all groups of the population, in all settings, and for all aspects of physical activity. Although some methods are highly accurate and valid, it may not be feasible to use them in field settings, as the cost may be prohibitive. Another problem is the lack of a field criterion measure capable of testing the concurrent validity of current or newly developed methods for assessing physical activity. Choosing a method to assess physical activity is difficult and requires finding the balance between objectives of the study or project and the accuracy, validity, and feasibility of available instruments.

Concepts and Definitions

Physical activity is defined as bodily movement resulting in energy expenditure.[2] Total daily energy expenditure (TEE) has three components: resting metabolic rate (RMR), thermic effect of food (TEF), and energy expenditure by physical activity. Although RMR and TEF account for 60 to 80% of TEE, within-subject variability is very small. Physical activity energy expenditure is the component that can vary greatly from day to day for every individual; therefore, only activity-related energy expenditure will be considered in this section. Physical activity includes all types of bodily movement, from complex sports performance or hard labor in occupational tasks to simply fidgeting. However, physical activity is commonly characterized by its dimensions such as type, frequency, intensity, and duration. Some authors also consider the importance of the circumstances and purpose of activity[3] or its efficiency.[4]

Although physical activity results in energy expenditure, the latter can remain constant, whereas the activity may vary immensely; this may result in different physiological effects and health outcomes for various activities. Energy expenditure varies with body size, so individuals of different body sizes might be expending different amounts of calories while performing the same activity. Activity-related energy expenditure is determined by frequency, intensity, and duration and may be expressed in total kilocalories (or kilojoules) or kilocalories per kilogram of body mass.

- Type is a qualitative parameter of physical activity and can be categorized as:
  In adults: occupational physical activity, leisure-time physical activity, or house and yard work
  In children: formal vs. informal activities, or school vs. outside school activities.
- Intensity of activity can be defined as a qualitative (light, moderate, or vigorous) or quantitative (specific rate of energy expenditure [METs, Watts, or oxygen uptake]) variable of activity. Although it can be used as an outcome measure, intensity is more often used as an independent variable.
- The frequency of physical activity behaviors is usually expressed as bouts or sessions per day or per week.
- Duration of activity is generally described in minutes, hours, or percentage of time spent engaging in an activity.

Why it is Important to Assess Physical Activity

Epidemiological studies carried out over the past few decades strongly support a causal association between low levels of physical activity and increased risk of several chronic diseases such as cardiovascular disease, type 2 diabetes mellitus, obesity, and some forms of cancer.[5] These relationships have largely been established using self-reported physical activity, although aerobic fitness is used in some studies.[6,7] Reviews of studies examining the association between physical activity and breast cancer[8] and studies of physical activity determining the characteristics and effects of interventions[9] show that inconsistent findings could be related to the lack of precision of some physical activity measures. These authors emphasized the need to utilize standardized methods, and Melanson and Freedson[10] also emphasized the need for valid, reliable, non-reactive, and precise methods. Such instruments will facilitate determination of the specific type and amount of habitual physical activity necessary to gain protective effects against degenerative diseases. Further evaluation of existing methods and the development of new or alternative methods of activity assessment are required if we are to improve our understanding of critical activity-disease relationships.

It also is important to assess physical activity for surveillance purposes. We need to determine whether individuals of all ages are meeting public health physical activity recommendations and whether or not patterns are changing over time. Assessing physical activity will provide valuable information to public health professionals, teachers, researchers, policymakers, and others responsible for physical activity interventions.

Purpose

Many different physical activity assessments are available, and selecting a method for a particular project can be complicated. The purpose of this section is to provide guidance and suggestions for this process. Specifically, we will:

- Provide an overview of physical activity assessment issues
- Discuss relevant aspects to be considered when selecting a method for assessing physical activity
- Review the different methods available and present some advantages and disadvantages of each

The techniques available to measure daily physical activity and energy expenditure are summarized here, and more extensive recent reviews can be found in previous publications.[1,3,10-16] Although some methods estimate total energy expenditure, which is addressed in a different section of this handbook, we also will discuss them briefly here because they provide estimates of activity-related energy expenditure. In summary, this section aims to provide useful and practical information on the assessment of physical activity summarized from recent reviews and relevant published papers.

Important Aspects to Consider in Choosing the Most Appropriate Measure

Whether evaluating a physical activity intervention program, determining the prevalence of activity in a population, establishing the associations between physical activity and health outcomes, or determining whether activity guidelines are being met, it is necessary to choose an appropriate physical activity assessment method. A perfect method for assessing physical activity would be accurate, valid, simple, not time consuming, inexpensive, and suitable for use in a wide range of study participants. However, such a method has not yet been developed. Many of the available methods have acceptable validity and reliability, but all have limitations. Choosing the most appropriate method or methods depends on various factors.

Purpose of the Assessment

The purpose and objectives of a study or project are the primary factors to consider when selecting the physical activity assessment method. Depending on these factors, different measures present advantages and disadvantages that have to be considered. This is analogous to selecting a dietary assessment instrument, where the choice would be different if the purpose was to characterize the diet of a population than if the purpose was to provide information about the habitual dietary pattern of an individual.

We may want to assess physical activity to:

- Estimate the prevalence of activity in a population

- Determine the association between activity and health-related or performance-related outcomes
- Evaluate the effects of a physical activity intervention program

If the purpose is population surveillance of physical activity, it may be sufficient to classify individuals into broad activity categories such as sedentary, moderately active, or highly active. This can be accomplished by relatively simple and inexpensive methods such as completion of a short questionnaire on general activity patterns. Physical inactivity has been identified as an important public health concern for adults and children; therefore, assessing sedentary activities is maybe equally as important as measuring physical activity.

To investigate the relation of activity to health outcomes, additional issues must be considered. The specific health outcomes of interest often influence the activity assessment method that is most appropriate. If the health outcome is osteoporosis, specific attention should be given to weight-bearing and strength-building activities. For cardiovascular disease or diabetes outcomes, aerobic activity such as walking might be emphasized.

Intervention studies typically involve dozens or hundreds of participants, whereas population surveillance and epidemiological studies of physical activity and health require thousands or tens of thousands of participants. The small number of participants in intervention studies requires detailed information on physical activity to have sufficient statistical power to detect differences between groups. Another factor to consider in selecting a physical activity assessment method in an intervention study is the content of the intervention. If the study will emphasize fitting more walking into daily routines, a detailed questionnaire on walking times, amounts, intensity, frequency, and duration would be appropriate. In clinical counseling situations it is often important to assess an individual's activity level for the purposes of self-monitoring, goal setting, and evaluating progress. In this case it is necessary to have data that accurately reflect the person's activity, and it is not sufficient to place the participant into a broad activity group. This is analogous to dietary assessment for individual counseling.

What to Assess — Characteristics of Physical Activity

Specific dimensions of physical activity may have different effects on various health outcomes. For example, swimming would improve cardiorespiratory fitness but have little effect on bone density. Weight lifting might improve bone density but not influence colon cancer prevention. According to Goran and Sun[4] it is often important to characterize physical activity using both quantitative and qualitative methods (i.e., describing aspects such as type and purpose of physical activity), and quantifying intensity, efficiency, duration, frequency, and specific energy cost of the activity.

The overall amount or volume of physical activity is generally measured in terms of the energy expended, and is often expressed in kilocalories. Whole-room calorimetry and doubly-labeled water (DLW) are valid methods of measuring activity-related energy expenditure; however, the former cannot be used for assessing physical activity in free-living conditions, and the latter only allows estimating the daily mean total of energy expenditure over a number of days. Use of DLW will provide estimates of the specific energy expenditure of physical activity if one assumes that RMR and TEF remain constant. There are qualitative and quantitative aspects of physical activity that cannot be measured by DLW (i.e., type, duration, and frequency of physical activity) which may also be important in the regulation of energy balance and health.

Movement Pattern (Day, Week, Season, Year)

It may be important to know how the patterns of activity vary at different times. The majority of health benefits are acquired as chronic adaptations to exercise, which requires habitual patterns of physical activity to be measured. Adults generally have relatively regular daily patterns which may only change for different seasons or during holidays. They may not need to be assessed over longer periods as may be necessary for children. Climate may influence greatly the type and frequency of activities undertaken. Significant differences have been found between weekdays and weekends in type and amount of activity.

Underlying Mechanism of Effect

There are several health-related dimensions of physical activity such as caloric expenditure, aerobic intensity, weight bearing, flexibility, and strength.[17] A similar caloric expenditure in different activities may have a different effect on health outcome (i.e., weight training and swimming). Selecting an activity measure that will accurately assess the different health-related dimensions is required to find the true associations between physical activity and health outcomes. This is analogous to selecting different dietary measures for studies of cardiovascular disease, where saturated fat in the diet may be of prime importance, and for cancer, where fruit and vegetable intake may be of great interest.

Nature of the Study Population (Age, Gender, Culture)

The nature of the population to be examined is relevant for the choice of method. Methods developed for adults may not be appropriate for children. One reason for this is that children appear to have more variation than adults in patterns of activity. Children also often do not perform activities over extended periods. They may play at one activity for a few minutes, then abruptly switch to another activity for a few minutes before going on to something else. This intermittent and frequently changing pattern of activity requires that children's physical activity be assessed by using different intervals of assessment and outcome measures.[18] Physical activity has been assessed in children and adolescents by various methods including self-report by questionnaire or interview and report by proxies such as parents or teachers. Children have lesser ability than adolescents or adults to recall their activities accurately, which renders self-report questionnaires in children of limited value. Objective methods such as heart rate monitors, motion sensors, DLW, and indirect calorimetry have been used frequently in small-scale studies. A comprehensive approach to measurement issues in assessing children's physical activity was presented recently by Welk et al.[18] Points to be considered when selecting a physical activity measurement for children and adolescents are that seven days of monitoring are required to obtain stable estimates of overall activity patterns,[19] both weekend and weekdays need to be included in the assessement,[20] and motion sensors need to be worn for the entire day or at least for multiple times over the course of the day.[19]

Age and gender also need to be considered when selecting a physical activity assessment method for adults, and socioeconomic factors also may often be important. For example, activity patterns between female and male executives may be similar, whereas women who are homemakers with child care responsibilities may have very different activity patterns than men of the same social class. There has been little work on specific activity assessment methods for specific racial or ethnic groups, although such work is beginning to appear.[21] It is important to consider the various types of activity that are likely to be present in a population when planning what assessment method to use. If the study group is a general population sample, it will probably be necessary to include a wide range of activities, including occupational, household, caretaking, leisure time, walking or cycling for transportation to work or on errands, and sports. If the project is to be conducted in a group of business executives, it is probably reasonable to evaluate leisure time physical activity in detail, since these are activities that provide most of the energy expenditure beyond RMR and TEF in this group. For these executives, it is reasonable to give only limited attention to occupational and household activities.

Physical activity varies with age, with general population data showing a gradual decline and the highest prevalence of sedentary behavior observed in elderly persons, especially women.[5] However, there may be substantial differences in activity patterns in retired individuals. For some, most of the activity might be housework and yard work, for others it might be walking, and perhaps for those living in retirement centers the major activities might be recreational activities such as golf or dancing. It is not possible to select a single activity assessment method for use with older individuals, but it is important to consider the type of older population that will be included in the project.

In summary, the nature of the population to be monitored is important to consider when selecting a physical activity assessment method. In general, younger persons are more active than older individuals, men are more active than women, and members of minority groups tend to be less active than non-Hispanic whites. Nonetheless, it is not possible to simply select a method based on age, gender, or racial/ethnic group status. Many other factors such as educational level, health status, geography, climate, and occupational group must be considered. Ideally, it would be useful to collect some pilot data, perhaps by open-ended questionnaires, to obtain information on types of activity most often reported by the target population.

Sample/Population Size

The characteristics or the size of a sample must be taken into account before selecting the activity measure. A national survey or a large population study is not likely to use labor-intensive or high-cost techniques. A validation study or clinical trial with a relatively small sample means that the cost, time, logistical complexity, and other resources per person can be increased allowing the use of more sophisticated, time-consuming, and accurate techniques.

Period of Measurement

For instruments that measure activity over periods of time, an important question is the length of the monitoring period. This may differ for adults as compared with children and adolescents. According to Janz et al.,[22] four or more days of activity monitoring are needed to achieve satisfactory reliability, although Gretebeck and Montoye[23] suggested that at least five or six days of monitoring are needed to minimize intra-individual variance. More recently, Trost et al.[19] concluded that a seven-day monitoring period was required for accelerometers to assess usual activity in children and adolescents and account for apparent differences between weekday and weekend activity behaviors in the same way as within daily differences.

In addition to considering the length of the monitoring period, it also is necessary to consider whether multiple periods need to be monitored over the course of a year. It is obvious that seasonal or climatic effects could have an influence on physical activity, but this has not been studied adequately. Most epidemiological studies on physical activity and health have obtained activity measurements at one time point. However, some of these approaches have asked about activity over periods of various lengths — past week, past month, past three months, past year, or usual activity. It is not clear whether any single approach is better than any other, so at this time investigators should simply select the recall period that seems logical for their specific population.

Cost and Feasibility

Although objective measures are probably more accurate than self-reports for assessing physical activity, the high cost of these methods does not allow for them to be used in some studies. For example, the use of methods such as DLW is virtually impossible in epidemiological studies because of cost, participant burden, and the limited availability of the isotopes. Motion sensors (reviewed in more detail later) are objective and show promise, and the cost of such instruments has been decreasing. However, they still may be too expensive for use in some large studies, and technical support may be required, which further increases the cost. Many of the objective methods also impart a greater participant burden than questionnaire approaches. Use of DLW or motion sensors requires multiple visits to the study laboratory and requires participant cooperation and involvement over longer periods.

Summary

It is not possible to give a few simple guidelines for selecting a physical activity assessment method, and we have presented several factors that need to be considered when making a decision. The purpose of the study, type of physical activity that is of interest, nature of the study group, size and complexity of the study, and the available resources are all essential elements to be evaluated in order to select the most appropriate method for measuring physical activity. It is important to spend sufficient time in planning and selecting an assessment method to avoid later problems.

Methods Available

Extensive research has been carried out on methods for assessing physical activity, which has resulted in a great number of methods being developed and made available. We review several categories of activity assessment methods here. Techniques available for assessing physical activity can be grouped into two broad categories:

- Objective measures — calorimetry, direct observation, physiological markers, and motion sensors
- Subjective measures — self-report (self-administered questionnaire, interviews, diaries, or proxy reports)

Objective measures assess activity directly. They have been used in many studies to assess levels of physical activity in all age groups, and also have been used extensively to validate self-report measures. Continuing development and refinement of the different devices are beginning to overcome their high cost and complexity, facilitate their use in wider samples, and provide easier data entry, manipulation, and analyses. Subjective methods have been most frequently used in population surveillance and large population studies. These methods typically result in assigning individuals to one of a few broad categories of habitual activity — perhaps sedentary, low active, moderately active, or highly active.

Several recent reviews are available on the different techniques for assessing physical activity and energy expenditure in both field and laboratory settings.[1,3,10-15,24] Some of the available methods will be discussed here, with particular emphasis on methods that have been tested for validity and reliability.

Subjective Assessments

Subjective physical activity assessments rely principally on self-report of activity patterns by the study participant. This information may be obtained by structured interview, self-completed questionnaires, or diaries. Self-report methods have been widely used in studies on physical and health outcomes and for population surveillance of physical activity.

Self-report techniques such as physical activity diaries, recall surveys, quantitative history surveys, and proxy report (e.g., provided by parents, spouses, or teachers) are widely used to assess typical levels of physical activity. They rely on the subject (or proxy) to recall activities performed over a period of time that can vary from one day to one year (more often one week to one month) on the assumption that this period represents the individual's typical activity for most of the time. The complexity of the self-report measures may also vary immensely, in which the subject may be asked a few simple questions to very detailed information regarding type, frequency, time, duration, intensity, and perceived exertion. As result, levels of activity are expressed in different scoring systems, which makes it difficult to interpret and compare among studies.

Self-report methods are useful for adolescents and adults, but are not particularly appropriate for children. Self-report methods are unreliable in young children as they do not have the cognitive ability needed to recall and record type, duration, and intensity of physical activity, particularly over extended periods of time.[25] Furthermore, children seem to expend energy in diverse contexts and styles, such as those involved in spontaneous play. This diversity ranges between brief but frequent bouts of vigorous activity to activities of a longer duration such as walking or biking to school, and this diversity makes accurate recall difficult. According to Sallis et al.,[26] reliability and validity improve with increasing age, and validity is improved when the recall interval (i.e., time from the physical activity to the moment of report) is as short as possible. They conclude that recall instruments should only be used with children 10 years old or older.

Advantages of self-report methods are that they are:

- Useful to assign individuals to broad activity categories, which is appropriate in epidemiological studies and population surveys
- Relatively inexpensive
- Time efficient and have a low participant burden
- Applicable to mail-back or telephone surveys

Disadvantages of self-report methods are that:

- Accuracy is affected by the individual's recall errors and incorrect perceptions of activities

- Validity is limited by the ability of the subject (or proxy) to recall and report activity behaviors accurately[12]
- Intensity of activity is difficult to obtain

Interviews

Structured physical activity interviews may facilitate the recall of type, amount, frequency, duration, and intensity of activity episodes. However, even with this structure and guidance by the interviewer, it is still difficult for participants to recall and report all details of physical activity participation. A major problem is accurately classifying activity intensity and accurately reporting actual minutes spent in an activity. For example, a person may report swimming for an hour, when in fact they were at the beach for an hour and only swam for 10 minutes. When reporting minutes spent in an activity, it is difficult to know the minimum length of the bout that should be counted. It is reasonably easy to identify activity bouts of 10 to 15 minutes, but should repeated bouts of five minutes or two minutes be counted and summed over the course of the day? One of the most widely used structured interviews is the seven-day physical activity recall, which has been used in both community surveys and clinical trials.[27,28] A major disadvantage with the interview method for large studies is the increased cost incurred by the interviewers' time.

Self-Completed Questionnaires

Questionnaires are the most common instruments used in large-scale studies because of their low cost and ease of administration in large groups of subjects. One problem with the self-completed questionnaire approach is that study participants often overestimate the amount of their physical activity. However, even with their limitations, a large body of evidence from studies on physical activity and health outcomes has been based on self-completed activity questionnaires. There is good consensus from these studies, with the clear finding that sedentary individuals are more likely than their more active peers to develop chronic disease or die prematurely during followup. Thus, the relatively crude classifications of activity status by the questionnaires appear to be valid for predicting health outcomes. The various recent reviews of physical activity assessment methods include a detailed listing of questionnaires.[3,24] We encourage investigators to review these various instruments and select the one that logically appears to be best suited to the specific purposes and needs of the planned study. Most of the published questionnaires have acceptable reliability and validity for assigning individuals into broad activity categories.

One of the problems faced by public health officials is surveillance of physical activity in the population. Issues that can be addressed with a good surveillance system include trends in population physical activity over time and comparisons of activity in different regions. Many times it also would be desirable to make cross-national comparisons. Unfortunately, physical activity surveys in different countries have been performed with different methods and measurement strategies. In order to help standardize definitions and physical activity assessments across countries, the World Health Organization and the U.S. Centers for Disease Control and Prevention have convened an international group of experts to develop an International Physical Activity Questionnaire (IPAQ). Short and long versions of the questionnaire have been developed, reviewed, and revised, and are currently being tested for reliability and validity. Preliminary results of these studies are now available and are encouraging. The short and long versions of IPAQ can be administered by interview, self-completed questionnaire (in person or by mail-back survey), or by a telephone interview. Although the IPAQ may be revised in light of the ongoing studies, the final version should be available by 2001. Contact information for the Chair of the International Working Group and the U.S. coordinator is:

- Michael Booth
  mikeb@pub.health.su.oa.zu
- Michael Pratt
  mxp4@cdc.gov

Diaries

Some investigators have used physical activity diaries to classify study participants.[29] According to Bratteby et al.,[30] the activity diary method provides a reasonable estimate of total energy expenditure and physical activity levels in population groups. However, Sallis concluded that diary measures have strong validity but that the burden on subjects is high and compliance varies with the population being studied.[31] Diaries are not considered feasible in young children. Physical activity diaries are likely to be most useful when used in small studies or clinical trials. Participants in these studies are likely to be more motivated than participants in large population studies to accept the high participant burden involved in keeping a diary. Diaries are more likely to be successful when used for relatively short periods of a few days.

Objective Assessments

Several methods of physical activity assessment using objective approaches are available. These methods tend to require a higher participant burden than the subjective approaches, and the cost for objective methods is higher, often much higher. Nonetheless, these objective methods are extremely useful, especially for small and highly controlled clinical trials.

Calorimetry

Calorimetry involves measurement of calories expended. This can be done by directly measuring heat production by the body, but such methods are costly and are most applicable to a few studies where highly accurate measures of energy expenditure are required.[3] Indirect calorimetry is a method that determines energy expenditure from VO_2 consumption and VCO_2 production, and is frequently used in the laboratory to measure exercise metabolism. Calorimetry is usually used to validate other physical activity assessment methods in laboratory settings. Recent advances in instrumentation for portable metabolic analyzers have made these devices more suitable for field settings to evaluate the metabolic rate, and thus the energy cost of various free-living activities. These methods are still intrusive, have a high participant burden, require technically trained laboratory staff, and are relatively expensive. These approaches can be quite useful to validate other physical activity assessments in field settings, but have limited applicability in most clinical settings where activity assessment is desired.

Doubly-Labeled Water

DLW is considered the gold standard for validating other field methods of assessing total energy expenditure. The measurement of average daily metabolic rate, combined with a measurement of resting metabolic rate and an estimate of TEF, permits the calculation of energy expenditure for physical activity under normal daily living conditions.[32] This technique consists of administering an oral dose of $^{2}H_2{}^{18}O$, after which carbon dioxide production over time is calculated from the difference in the elimination rates of ^2H and ^{18}O, because the ^2H label is eliminated from the body only as water, while the ^{18}O label is eliminated as water and carbon dioxide. Goran et al.[33] indicate that studies examining the validity of the DLW method show the technique to be accurate within 5 to 10% when compared with data from subjects living in metabolic chambers. Although the DLW technique is considered the gold standard for validating field methods to assess energy expenditure, it is notable that it has never been validated in field settings because of the lack of a suitable reference criterion.[3]

The advantages of the DLW method are:

- It is unobtrusive and is unlikely to influence daily behaviors
- It allows for determination of energy expenditure in free-living conditions
- It provides an accurate quantification of the energy expenditure of physical activity over several days

Disadvantages of the DLW method are that:

- It requires specialized equipment and personnel, which makes it expensive
- The isotopes are very expensive and there is limited availability[34]
- It is necessary to ingest an isotope which may not be accepted by some individuals
- It provides no information about the type, frequency, duration, or intensity of specific bouts of activity

Therefore, although the method provides an integrated measure of energy expenditure over time, it does not provide information about how energy expenditure was accomplished. For example, total energy expenditure can be increased by small elevations in activity intensity over many hours or by participating in vigorous intensity activity over a few minutes, and these two patterns might have very different effects on health or functional outcomes.

Overall, the DLW method has the potential to be used as the criterion measure to validate more practical field methods.[3] It has already been used to validate some field methods such as activity diaries,[30] heart rate monitoring,[35] and accelerometers.[32,36]

Direct Observation

Direct observation consists of an observer coding the activities (type and intensity) performed by an individual during short periods of time. The observation usually takes place during specific periods such as playtime at school or physical education classes. It may be done in real time or by viewing videotapes. Direct observation has been used mainly to assess physical activity in children. It does not interfere directly with the activities, assesses multiple dimensions of physical activity, and can include information concerning contextual variables such as physical and social environments. Although the physical activity data collected are objective and reliable, times and places available to observe participants are limited. Thus, observation studies are done more often on preschool[37,38] than on school-age children.[39] Another disadvantage of direct observation studies is the fact that they require intensive training and monitoring of observers to maintain quality control. Direct observation is time-consuming and costly, which may explain its infrequent use. The method is used primarily with small samples, and also as a criterion measure to validate other instruments.

Heart Rate Monitoring

Heart rate monitoring is an objective method based on the well-established relationship between heart rate and metabolic demand; that is, as physical work increases, heart rate increases to provide increased circulation to the working muscles and the heart. There is a linear association between heart rate and energy expenditure over much of the heart rate range. Heart rate monitors are available that provide minute-by-minute recordings of heart rate over the course of the day, or even several days. This allows for plotting heart rate over time, and records physical activity at different intensities in short periods of time (e.g., minute by minute) and continuously over several days.

Heart rate is a common index of activity intensity that has been used in several studies in both adults and children.[22,25,40-43] However, the use of heart rate as an unbiased indicator of physical activity intensity has been questioned.[42,44] Heart rate monitoring provides useful information about physical activity amount and intensity within individuals, but is less useful for comparisons between individuals. This is because heart rate for a standard task, say walking at 3 mph on the level, is strongly influenced by a person's cardiorespiratory fitness. The fit individual might have a heart rate of 90 beats/minute during this walk, and the unfit person might have a heart rate of 120 beats/minute. The method can be used to compare an individual's activity from day to day, but not to compare multiple individuals unless the heart rate energy expenditure relationship is calibrated for each person by laboratory testing.

Riddoch and Boreham[15] reviewed 13 studies that used heart rate to assess activity levels in children, and they concluded that at higher exercise intensities, when heart rates tend to be high, heart rate monitoring could provide valid estimates of energy expenditure. However, at lower exercise intensities when fear, excitement, and other emotional states can significantly affect heart rates, the method was less accurate. Thus, if measurement of light and moderate intensity activities is intended, heart rate monitoring presents significant limitations.

In summary, heart rate monitoring is useful to determine whether an individual is changing his activity patterns from day to day, such as might be expected in a physical activity intervention study. Heart rate monitoring can be used to compare individuals if the individual heart rate energy expenditure curves are established, and it is especially useful for detecting moderately vigorous to vigorous activities. The heart rate monitoring approach is time consuming, requires close cooperation from study participants, requires equipment and technical expertise, and is not especially feasible for large population studies. The method is objective and can provide important information about the intensity of physical activity, and if summed over the course of the day provides an indication of overall amount of activity.

Activity Monitors

In the last few years, activity monitors have been increasingly investigated and used in cross-sectional and intervention studies and to validate other physical activity assessment instruments. Activity monitors can be simple, such as pedometers or step counters, or more complex, such as accelerometers.

Pedometers

Pedometers record the number of steps taken, which is provided as total volume during a period of time, such as one or several days' activity. Earlier pedometers operated on a pendulum principle, and there were major problems with reliability and validity of these instruments. Some more recent pedometers are electronic devices, which are substantially more accurate than the older pendulum models.

Advantages of the electronic pedometers are that they are:

- Inexpensive, with reliable instruments costing $20 or less
- Small and light in weight, no more than an ounce or two
- Unobtrusive
- Simple to operate

Disadvantages are that they:

- Do not provide chronological information regarding the distribution of steps over the recording period
- Do not provide data on physical activity intensity
- Do not provide data on pattern of activity over the course of the day
- Are not resistant to tampering

Overall, we find these devices useful for self-monitoring of physical activity in behavioral intervention programs and think that they provide objective data that allows for assignment to broad activity categories. Ordering information for a frequently used pedometer that has undergone extensive reliability and feasibility testing is given here.

Yamax DigiWalker
New LifeStyles, 5900 Larson Avenue, Kansas City, MO 64133 USA
Phone: U.S. 888-748-5377, outside U.S. 816-353-1852; Fax 816-353-9808
E-mail teresa@digiwalker.com; Website www.digiwalkerinfo.com

Accelerometers

Accelerometers are motion sensors that detect movement of the body. There has been extensive research and development of these instruments over the past several years, and several devices are currently available. Major advantages of accelerometers are:

- Their ability to record and store activity data on a minute-by-minute basis for extended periods of time under free-living conditions
- The objective measure of total body movement or limb movement respectively depending on whether they are placed on the torso or on the limbs
- The chronological recording of acceleration allows for evaluation of frequency, intensity, and duration of body movement; time spent in sedentary activities can also be determined
- The estimates of total energy expenditure

However, these devices also present limitations such as:

- They cannot be worn during any water activities since they are not developed to be exposed to water
- They are unable to discriminate the energy cost of activities such as carrying loads or walking upstairs, and do not distinguish between uphill and downhill walking or hiking[45]

- The cost of the equipment and the time needed to download and manipulate the data for some of these devices are too great for use in large-scale studies
- They have not been validated for the assessment of upper body activities such as throwing, catching, and lifting

When all things are considered, we think accelerometers offer great potential for physical activity assessment, especially for smaller studies such as clinical trials or clinical interventions. Because of the potential of these instruments and the large amount of recent and ongoing research on accelerometer measurement of physical activity, we will provide a more extensive review of this approach than we have for other methods presented in this section.

Accelerometers are available for measurement of movement in a single plane (usually the vertical plane) or in all three planes. The unidimensional Caltrac is the accelerometer that has been used most widely in physical activity research.[10] A second unidimensional accelerometer has been developed by Computer Science and Applications (CSA, Shalimar, FL). Janz et al.[22] found correlations of r = 0.50 to 0.74 between the CSA accelerometer and heart rate telemetry, with higher correlations found for more vigorous activities.

Presently, there are two tridimensional accelerometers, the Tracmor and the TriTrac-R3D (Hemokinetics, Inc., Madison, WI); however, only the latter is commercially available. Bouten et al.[46] report that tridimensional accelerometers predicted activity-related energy expenditure better than unidimensional accelerometers when young adults performed different types of activity (sedentary activities, walking). Tridimensional accelerometers should more accurately record activities that include extensive horizontal motion, bending, and twisting. However, some investigators find little difference between unidimensional and tridimensional accelerometers.

In a study of college students, Matthews and Freedson[47] compared results from the Tritrac accelerometer with self-reports of activity on a three-day log (r = 0.82) and a seven-day recall (r = 0.77). They concluded that although the Tritrac accelerometer underestimated daily energy expenditure, it provided more accurate results than the Caltrac accelerometer. The Tritrac accelerometer correctly classified 84% of the students into two groups: low active and high active. The ability of the Tritrac accelerometer to measure activity in one-minute intervals makes it possible to analyze data from specific time segments and allows determining total time spent at different activity intensities as well as sustained periods of moderate or vigorous activity.

There have been few investigations using the TriTrac-R3D with children and adolescents. Results of accelerometer studies may be different in adults than in children, because children are more likely than adults to expend vertical energy through jumping and climbing and have more frequent but short bouts of moderate to vigorous activity.[48] Welk and Corbin were among the first to report the use of the Tritrac accelerometer in children.[49] In a sample of 35 children (9 to 11 years old), they evaluated the TriTrac-R3D against heart rate monitoring and the unidimensional Caltrac accelerometer. The TriTrac-R3D was moderately correlated (r = 0.58) with the heart rate monitor and highly correlated (r = 0.88) with the Caltrac. The correlation of accelerometer data with heart rate was highest during free play and lowest when activity was more limited or structured.

Ordering information for accelerometers is included here.

- TriTrac-R3D
  StayHealthy, Inc, 222 East Huntington Drive, Suite 213, Monrovia, CA 91016
  Phone 626-256-6152
  Email pbylsma@stayhealthy.com; Website www.stayhealthy.com

- CSA
  Computer Science and Applications, Inc., 2 Clifford Drive, Shalimar, FL 32579
  Phone 850-651-4991; Fax 850-651-2816
  Email csainc@fwb.gulf.net; Website www.csa-ucc.com

Summary

Motion sensors and heart rate monitors overcome problems associated with inaccurate subject recall of activity and are less costly than direct observation. Objective measurements provided by heart rate monitors and accelerometers can be used across all age groups as long as their output is provided in raw scores. This is because estimates of energy expenditure provided by some devices have substantial errors due to the fact that the population from which the equations were derived is specific and may not represent the population to be studied. Investigators may need to develop their own energy expenditure equations based on their own study group. It is important to remember that these instruments can be prone to technical problems, are expensive, and they provide no information concerning specific activities or the context in which activities are performed.[12] Although they provide an objective measure of physical activity, accurate assessment relies on each participant complying to wear the device throughout the monitoring period.

Conclusions

We have reviewed several categories of physical activity assessment methods and discussed the strengths and weaknesses of each approach. Table 36.1 includes a listing of several physical activity assessment methods and indications of how each meets various factors that need to be considered when selecting the most appropriate method. The table combines information presented in preceding sections and should be a useful summary tool to help investigators and clinicians make decisions regarding physical activity assessment.

All physical activity assessment methods and instruments have strengths, limitations, advantages, and disadvantages. Our major recommendation is that the choice of a method to assess physical activity depends primarily on the purpose of the study and the dimensions to be assessed in order to answer the relevant questions. Other critical factors to be taken into account include the population to be evaluated, the size of the study group, and cost and feasibility issues.

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TABLE 36.1

Methods for Assessing Physical Activity

Instrument	Format of Assessment	Units of Measurement	Period of Measurement	Field Measure	Characteristics of Activity Assessed: Type	Frequency	Intensity	Duration	Total Volume of Activity	Sedentary	Context in which Activity Occurs: Leisure	Work	Household	Transport	Population: Children	Adolescents	Adults	Older adults	Cost	Sample Size
Objective Measures																				
DLW[1-3]	Ingestion of a known concentration of isotopes	EE (kj or kcal)	7 to 14 days	✓					✓						✓	✓	✓	✓	H	S
Whole-room indirect calorimeter	Re-create free-living conditions in a confined space	EE through measurement of heat production and/or respiratory gas exchange	A few days			✓	✓	✓	✓						✓	✓	✓	✓	H	S
Indirect calorimetry	Standardized protocols of exercise in a controlled environment	VO2 uptake EE	Minute or less intervals	✓			✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	H	S
HR monitor[4]	Wearing the monitor for all the measurement period	Beats/min	Intervals of 1 minute or less for up to several days	✓		✓	✓	✓	✓						✓	✓	✓	✓	M	M
Pedometer Yamax Digiwalker[5]	Wearing the device for all the measurement period	Steps		✓					✓							✓	✓	✓	L	L
Caltrac[6,7]	Wearing the monitor for all the measurement period	Movement counts/ kcal		✓					✓						✓	✓	✓	✓	M	L
CSA[8-10]	Wearing the monitor for all the measurement period	Counts		✓					✓						✓	✓	✓	✓	M	L

TriTrac-R3D[11,12]	Wearing the monitor for all the measurement period	Movement Counts/ kcal		✓					✓						✓	✓	✓	✓	M	
Tracmor[13]	Wearing the monitor for all the measurement period	Counts		✓					✓								✓	✓	M	
Direct Observation[14]	Observer rates the activity and intensity	Minutes of activity		✓	✓	✓	✓	✓	✓						✓	✓			H	S
Subjective Measures																				
7-Day Physical Activity Recall (PAR)[15]	Interview	Kcal/kg or kcal/day	7 days	✓		✓	✓	✓	✓		✓	✓				✓	✓		L	L
PAQ-C[16]				✓											✓	✓			L	
Leisure Time Exercise Quest. (LTEQ)[17]				✓											✓	✓				
PDPAR[18,19]		After school		✓											✓	✓				
Self-administered PA checklist (SAPAC)[20]				✓											✓	✓				
Child/Adol Activity Log (CAAL)[21]				✓											✓	✓				
4 x 1 day recalls	Interview		1 day repeated four times	✓		✓	✓	✓			✓				✓	✓			M	S
Diary[22]		Can be minutes, kcal, or other measures, depending on how diary structured		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	M	M

Cost: L = Low; M = Medium; H = High

Sample size: S = Small (this is typically a few dozen participants); L = Large (can be up to a few 100 participants)

1. Schoeller DA. *J Nutr* 118:1278; 1988. 2. Schoeller DA. *J Nutr* 129:1765; 1999. 3. Seale JL, Conway JM, Canary JJ. *J Appl Physiol* 74:402; 1993. 4. Murayama N, Ohtsuka R. *Am J Hum Biol* 11:647; 1999. 5. Eston RG, Rowlands AV, Ingledew DK. *J Appl Physiol* 84:362; 1998. 6. Bray MS, Wong WW, Morrow JR, Jr., et al. *Med Sci Sports Exerc* 26:1524; 1994. 7. Nichols JF, Patterson P, Early T. *Can J Sport Sci* 17:299; 1992. 8. Janz KF. *Med Sports Exerc* 26:369; 1994. 9. Melanson ELJ, Freedson PS. *Med Sci Sports Exerc* 27:934; 1995. 10. Trost SG, Ward DS, Moorehead SM, et al. *Med Sci Sports Exerc* 30:629; 1998. 11. Welk GJ, Corbin CB. *Res Q Exerc Sport* 66:202; 1995. 12. Nichols JF, Morgan CG, Sarkin JA, et al. *Med Sci Sports Exerc* 31:908; 1999. 13. Bouten CV, Westerterp KR, Verduin M, Janssen JD. *Med Sci Sports Exerc* 26:1516; 1994. 14. Rowe PJ, Schuldheisz JM, vanderMars H. *Pediatr Exerc Sci* 9:136; 1997. 15. Sallis JF, Buono MJ, Roby JJ, et al. *Med Sci Sports Exerc* 25:99; 1993. 16. Crocker PR, Bailey DA, Faulkner RA, et al. *Med Sci Sports Exerc* 29:1344; 1997. 17. Raudsepp L, Pall P. *Biol Sport* 14:199; 1997. 18. Trost SG, Ward DS, McGraw B, Pate RR. *Pediatr Exerc Sci* 11:341; 1999. 19. Weston AT, Petosa R, Pate RR. *Med Sci Sports Exerc* 29: 138; 1997. 20. Sallis JF, Strikmiller PK, Harsha DW, et al. *Med Sci Sports Exerc* 28:840; 1996. 21. Garcia AW, George TR, Coviak C, et al. *Internat J Behav Med* 4:323; 1997. 22. Bratteby LE, Sandhagen B, Fan H, Samuelson G. *Eur J Clin Nutr* 51:585; 1997.

References

1. __________ *Res Q Exerc Sport* 71(2), 1S. 2000.
2. Caspersen CJ, Powell KE, Christenson GM. *Pub Health Rep* 100:126; 1985.
3. Montoye HJ. *Measuring physical activity and energy expenditure*, Human Kinetics, Champaign, IL: 1996.
4. Goran MI, Sun M. *Am J Clin Nutr* 68: 944S; 1998.
5. __________ US Department of Health and Human Services. *Physical Activity and Health: A Report of the Surgeon General*, Atlanta, GA: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion; 1996.
6. Blair SN, Kohl HW, III, Paffenbarger RS, Jr, et al. *JAMA* 262: 2395; 1989.
7. Blair SN, Kohl HW, III, Barlow CE, et al. *JAMA* 273: 1093; 1995.
8. Ainsworth BE, Sternfeld B, Slattery ML, et al. *Cancer* 83:611; 1998.
9. Stone EJ, McKenzie TL, Welk GJ, Booth ML. *Am J Prev Med* 15:298; 1998.
10. Melanson EL, Jr., Freedson PS. *Crit Rev Food Sci Nutr* 36: 385; 1996.
11. Baranowski T, Bouchard C, Bar-Or O, et al. *Med Sci Sports Exerc* 24: 237S; 1992.
12. Heath GW, Pate RR, Pratt M, *Pub Health Rep* 108(1): 42; 1993.
13. Wareham NJ, Rennie KL. *Int J Obes Relat Metab Disord* 22: 30S; 1998.
14. Rowlands AV, Eston RG, Ingledew DK. *Sports Med* 24: 258; 1997.
15. Riddoch CJ, Boreham CA. *Sports Med* 1995; 19: 86; 1995.
16. Freedson PS. *Pediatr Exerc Sci* 1: 8; 1989.
17. Paffenbarger RS, Jr, Lee I-M, Kampert JB. *World Rev Nutr Diet* 82: 210; 1997.
18. Welk GJ, Corbin CB, Dale D. Measurement issues in the assessment of physical activity in children. *Res Q Exerc Sport* 71: 59S; 2000.
19. Trost SG, Pate RR, Freedson PS, Sallis JF, Taylor WC. *Med Sci Sports Exerc* 32: 426; 2000.
20. Sallis JF. *J Sch Health* 61: 215; 1991.
21. Masse LC, Fulton JE, Watson KL, et al. *Res Q Exerc Sport* 70: 212; 1999.
22. Janz KF, Witt J, Mahoney LT. *Med Sci Sports Exerc* 27: 1326; 1995.
23. Gretebeck RF, Montoye HJ. *Med Sci Sports Exerc* 24: 1167; 1992.
24. FitzGerald SJ, Kriska AM, Pereira MA, de Courten, MP. *Med Sci Sports Exerc* 29: 910; 1997.
25. Sallis JF, Buono MJ, Roby JJ, et al. *Med Sci Sports Exerc* 22: 698; 1990.
26. Sallis JF, McKenzie TL, Alcaraz, JE. *Am J Dis Child* 147: 890; 1993.
27. Blair SN, Haskell WL, Ho P, et al. *Am J Epidemiol* 122: 794; 1985.
28. Sallis JF, Haskell WL, Wood PD, et al. *Am J Epidemiol* 121: 91; 1985.
29. Bouchard C, Tremblay A, Leblanc C, et al. *Am J Clin Nutr* 37: 461; 1983.
30. Bratteby LE, Sanhagen B, Fan H, Samuelson GA. *Eur J Clin Nutr* 51: 585; 1997.
31. Sallis JF, Buono MJ, Roby JJ, et al. *Med Sci Sports Exerc* 25: 99; 1993.
32. Westerterp KR, Bouten CV. *Z Ernahrungswiss* 36: 263; 1997.
33. Goran MI, Poehlman ET, Danforth EJ, Nair KS. *Int J Obes Relat Metab Disord* 18: 622; 1994.
34. Stager JM, Lindeman A, Edwards J. *Sports Med* 19: 166; 1995.
35. Racette SB, Schoeller DA, Kushner RF. *Med Sci Sports Exerc* 27: 126; 1995.
36. Bouten CV, Verboeket-van d V, Westerterp KR, et al. *J Appl Physiol* 81: 1019; 1996.
37. Danner F, Noland M, McFadden M, et al. *Pediatr Exerc Sci* 3: 11; 1991.
38. DuRant RH, Baranowski T, Davis H, et al. *Med Sci Sports Exerc* 24: 265; 1992.
39. Bailey RC, Olson J, Pepper SL, et al. *Med Sci Sports Exerc* 27: 1033; 1995.
40. McKenzie TL, Sallis JF, Nader PR, et al. *J Appl Behav Anal* 24: 141; 1991.
41. Welk GJ, Corbin CB. *Res Q Exerc Sport* 66: 202; 1995.
42. Maffeis C. Pinelli L, Zaffanello M, et al. *Int J Obes Relat Metab Disord* 19: 671; 1995.
43. Sallis JF, Strikmiller PK, Harsha DW, et al. *Med Sci Sports Exerc* 28: 840; 1996.
44. Freedson PS. *J Sch Health* 61: 220; 1991.
45. DeVoe D, Gotshall RW. *J Hum Movement Studies* 34: 271; 1998.
46. Bouten CV, Westerterp KR, Verduin M, Janssen JD. *Med Sci Sports Exerc* 26: 1516; 1994.

47. Matthews CE, Freedson PS. *Med Sci Sports Exerc* 27: 1071; 1995.
48. Corbin SB. *J Am Coll Dent* 61: 17; 1994.
49. Welk GJ, Corbin CB. *Res Q Exerc Sport* 66: 202; 1995.