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A Practical Guide to Measuring Physical Activity

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Considerations for Measuring Physical Activity

Research has demonstrated the benefits of physical activity (PA) and the negative consequences of sedentary behavior for physical and mental wellbeing [1–5]. Thus, PA has become increasingly prominent as an intervention tool; however, research is often hindered by the challenge of employing a valid, reliable measure that also adequately satisfies the research question or design [1, 4–7]. The doubly labeled water method (DLW) remains the gold standard for assessing total energy expenditure; however, it is not often used for research studies as it is expensive, has high subject burden, is time-intensive, and cannot capture qualitative data [8–9]. The aim of this commentary is to summarize the main methods of measuring PA as well as offer examples of their uses in research trials [10–12].

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Methods of Measuring PA

Self-Report Questionnaires

These questionnaires are the most common method of PA assessment [13] and rely on participants' recall ability. Questionnaires vary by what they measure (e.g., mode, duration, or frequency of PA), how data are reported (e.g., activity scores, time, calories), quality of the data (e.g., measures of intensity, differentiating between habitual and merely recent activities, inclusion of leisure and non-leisure activity), and how data are obtained (e.g., paper and pencil assessment, computerized questionnaire, interview) [11, 14]. Validation studies comparing self-report questionnaires to DLW are inconsistent [9]; however, their advantages include cost effectiveness, ease of administration, and accuracy in measuring intense activity [15–16], determining discrete categories of activity level (e.g., low, moderate, high)[16], ranking individuals or groups in their PA[17], providing details about the PA, and showing improvement across groups or individuals [14, 18–19]. Potential disadvantages are that self-report questionnaires are less robust in measuring light or moderate activity [14], assessing energy expenditure [18–19] and may be limited by the dependency on written language (i.e., questions) [20] and external factors (i.e., social desirability, complexity of the questionnaire, age, and seasonal variation) [21–25]. Self-report questionnaires are significantly more reliable at the group than the individual level [9, 17–19] as well as when the questionnaire is structured chronologically and with discrete periods [26].

In Table 1, we provide details on seven well-studied, commonly used self-report questionnaires: Modifiable Activity Questionnaire (MAQ) [27], Previous Week Modifiable Activity Questionnaire (PWMAQ) [28], Recent Physical Activity Questionnaire (RPAQ) [29], International Physical Activity Questionnaires (IPAQ) [3, 30], Previous Day Physical Activity Recall (PDPAR) [31], and 7-day Physical Activity Recall (PAR) [2, 32].

Self-Report Activity Diaries/Logs

Self-report diaries require participants to record PA in real time which provides the most detailed data [11, 26] and can overcome some limitations of questionnaires (i.e., less susceptible to recall errors, social desirability bias, measurement bias) [26, 33]. To illustrate, Bouchard's Physical Activity Record (BAR) [34] is a widely used diary in which participants report PA for each 15 minute interval over three days. Activities are rated on a scale of 1 to 9 (1 = sedentary activity, 9 = intense manual work or high intensity sports) to yield a total energy expenditure score; however, the diary is burdensome, particularly for individuals with cognitive dysfunction [30]. In addition, questionnaires not completed in real time could be subject to memory bias as well as participant reactivity, the phenomenon of behavior change due to awareness of being observed [35–37].

Direct Observation

In direct observation, an independent observer monitors and records PA [38–39]. This method of assessment is often used when activity is restricted to a delineated space (e.g., a classroom) [39–41]. It is also a popular method for young children as they have difficulty recalling their PA [42]. This flexible method is valuable in gathering contextual information (e.g., preferred location, time, and clothing) and details of the PA (e.g., type, personalized variations to activities). Disadvantages include high cost of time and energy [30], potential reactivity [35–37], difficulty obtaining ethical approval [37], and the lack of objective measures of energy expenditure [37].

Devices: Accelerometers

In recent decades, accelerometers have gained popularity given their accuracy, ability to capture large amounts of data, and ease of administration, particularly in large studies [9].

Accelerometers measure acceleration (counts) in real time and detect movement in up to three orthogonal planes (anteroposterior, mediolateral, and vertical) [30, 43]. These counts are then translated into a metric of interest, which can be biological (e.g. energy expenditure) or PA patterns (e.g. stationary) [44]. Devices can be worn in numerous places on the body, including waist, hip, and thigh. Table 2 summarizes commonly-used triaxial accelerometers.

As demonstrated in large studies, such as the ongoing National Health and Nutrition Examination Survey (NHANES) conducted by the National Center for Health Statistics (part of the Centers for Disease Control and Prevention), investigators can use accelerometer data to compute physical activity volume, rate, and time spent in different intensities of exercise, and can be used for broader characterizations such as achievement of public health guidelines and classification by physical activity levels [45]. New accelerometers demonstrate better validity, compared to DLW, than older models. For example, the Tracmor_D has improved validity over the Tritrac R3D [46–47]. Strengths of accelerometers include minute-by-minute on-line monitoring [12], capturing intensity level [48–50], feasibility with young children [51], accuracy with static and dynamic behaviors [14, 20, 52], and large memory capacities [53]. However, accelerometers are expensive [6] and require technical expertise, specialized hardware, software, and individual programming [6]. Accelerometers also lack a standard protocol for managing or reducing data [37], can induce a reactivity bias [30], and do not provide any contextual information. Additionally, some accelerometers are unable to differentiate body position (i.e., sitting, lying, standing) or walking intensity [37]. Notably, the relationship between accelerometer activity counts and energy expenditure depends on the count cut-point applied to the data; choosing different cut-points can differentially influence measurements of physical activity intensity [54].

Devices: Pedometers

Pedometers measure number of steps taken with a horizontal, spring-suspended lever arm which is deflected when the subject's hip accelerates vertically with a force beyond a chosen threshold. Pedometers correlate strongly with uniaxial accelerometers, and directly observed duration of activities [30, 55–57]. Their simplicity, relatively low cost, and ability to pick up short durations of PA (often missed by self-report measures) make these devices popular. Pedometer data also tend to be correlated with biological outcomes and predictors (e.g. age, BMI) [58]. Pedometers appear to yield the most accurate data for running and moderate walking, as these behaviors require forward vertical motion. Disadvantages of pedometers include inability to record PA involving horizontal motion occurring during periods of inactivity, leisure activity, or solely upper body movements [59–60]. Pedometer brands differ in the set vertical acceleration threshold needed to register a step, which necessarily yield varying PA sensitivity and thus different outputs [18]. Pedometers do not record intensity, frequency, or duration of PA [53, 61], have significantly less data storage capacity than accelerometers [53], and can also induce reactivity in subjects [30, 35, 62]. Pedometers work best for documenting relative changes in PA or ranking individuals [61]. Table 2 includes a summary of widely used pedometers.

Devices: Heart-Rate Monitors

Heart rate [63] monitoring is a physiological indicator of PA and energy expenditure [64], providing real-time data on the frequency, duration, and intensity of PA in an unobtrusive (e.g., they can be worn as watches or on the chest), low-effort way for periods up to one month [12, 65–66]. HR monitors capture energy expenditure during activities not involving vertical trunk displacement that many accelerometers and pedometers miss [67] and are best suited to categorize subjects' PA levels (i.e., highly active, somewhat active, sedentary) as opposed to the exact amount of PA. These devices tend to show discrepancies particularly at very high and low intensities [1, 53, 65–66, 68]. Discrepancies are due to HR and energy expenditure not sharing a linear relationship at rest and low-intensity (as the PA is confounded by unrelated factors such as caffeine, stress, body position) or high intensity PA [69]. Age, body composition, muscle mass, gender, and fitness level also affect this linear relationship or reduce its accuracy [61].

Devices: Armbands

In recent years, armband technology has been developed and validated using DLW [70] in an effort to address the limitations of other devices. Several versions of the armband exist (e.g., SenseWear, HealthWear, bodybugg) [71] and they use motion and heat-related sensors (i.e., heat flux, galvanic skin response, skin temperature, body temperature) to measure energy expenditure and monitor metabolic PA [71]. This dual measurement strategy (i.e., body temperature and motion) is more sensitive to assessing the energy expenditure associated with complex and non-ambulatory activities, such as walking while carrying a heavy load [72–73]. Thus, armbands have proven to be excellent devices for tasks of daily life (or low to moderate activity), but have not been ideal for higher intensity exercise [74]. Thus, researchers have developed exercise-specific algorithms to correct this error in armband technology [75]; however, it can still be a limitation especially if the type and duration of exercise are unknown.

Choosing a Measure of PA

Four key features of a PA measure should be considered when choosing one for a research study: (1) quality of PA measured (e.g. activity type, intensity, frequency, duration), (2) objectivity of the data, subject burden (e.g. time and/or effort required to complete), (3) cost/ burden to administer, and (4) specific limitations, discussed above. To further assist in choosing a PA assessment, we considered the main factors of a study population (i.e., age, gender, body weight, co-morbid conditions) that may impact choosing a PA measure.

Age

Age groups differ in regards to activity level (i.e., frequency and duration), PA type, cognition, and ability to focus or sustain attention. For example, children typically exhibit intense, but sporadic bursts of PA [39, 76]. Thus, self-report measures limited to total time of activities [76], accelerometers that assume a consistent intensity of exercise [61], and HR monitors which would record sustained elevated HR [61] are not ideal for younger study participants. Accelerometers (e.g. actigraph, activPal) [77], several self-report questionnaires (i.e., PDPAR, IPAQ, PAR, BAR), and direct observation have been validated for children. Armbands have been validated only at sedentary, low, and moderate levels of activity for children with child-specific algorithms applied to the data [78–79].

Adults are more likely to demonstrate consistently low, but steady PA (e.g., walking) and high sedentary activity at work [13], whereas the elderly often have physical restrictions that narrow their scope and type of PA [80]. Therefore, tools that do not accurately record walking may not be best for adult or elderly groups. Pedometers, which often fail to record slower, shuffling gates, will not adequately reflect the PA of older, frailer populations [46]. Thus, the PAR [81], PDPAR [82–83], IPAQ, and accelerometers (e.g. activPal, Tritrac) [84–86] have been validated in elderly populations.

Furthermore, adults have demonstrated adequate recall ability for self-reported PA assessments [87], but children and the elderly have more difficulty with this type of assessment [10–11, 21, 88]. Self-report measures specifically for children and elderly include those that employ prompts, cued recall, or recognition rather than spontaneous generation [89], divide questionnaires or logs into discrete, logical time periods [90] or cover fewer days.

Gender

Making gender-specific assumptions about exercise regimes can be difficult given the many confounding factors (e.g., weight, medical comorbidity, age) and that gender differences can vary by culture and/or country. However, studies in the United States and Canada have identified some trends for women versus men that could help elucidate why certain PA assessment tools have not proven valid or reliable for women. For example, women tend to walk and participate in light PA more so than men and men tend to partake in vigorous PA more so than women [32, 91–93]. As such, for women, some accelerometers (e.g. Tritrac accelerometer [94]), BAR [92], and some HR monitors (e.g. Polar S410 [67]) have failed validity tests given their limitations with light activity. Other accelerometers (e.g. activPal), HR monitors, and pedometers are likely to be more accurate. Similarly, self-report measures such as the RPAQ and MAQ may not be ideal for women as they do not account for many forms of light PA, while the PDPAR and PAR do.

Body Weight

High body mass index (BMI) can reduce accuracy of devices, particularly pedometers [32] armbands [75, 95], and HR monitors [61]. Additionally, studies have found under- [22] and overestimation [96] of self-report PA among obese participants as compared to non-obese respondents. Research has shown that obese individuals, in addition to having significantly higher BMIs, tend to be less active than the rest of the population [22, 97]. In general, recall of PA among inactive individuals is less accurate [98]. Furthermore, because of the relatively low engagement in PA, self-report measures like the MAQ and RPAQ that only encompass leisure activities and do not include unstructured daily activities, such as housework, are ill-advised [88, 93], whereas the PDPAR is recommended because it captures such domains and has been validated for an obese population [99]. Some accelerometers, like the activPal, but not all (e.g. Tritrac), have been validated for this clinical population [100–101]. The combination of high BMI and inactive lifestyle poses a unique challenge in identifying accurate methods of estimating one's energy expenditure.

Psychiatric and Medical Co-morbidities

When studying a population with severe mental illness, certain characteristics should be considered, such as low levels of leisure PA [20, 36, 102–104] and cognitive impairment, including shorter attention span, memory deficits, and errors in comprehension and reporting [24, 105–106]. Thus, it is suggested that measurements account for frequency, varying intensity and duration, and all possible contexts (e.g. structured exercise, housework) of the PA [6, 105, 107–108]. Self-reports like the MAQ and RPAQ that only account for structured leisure time may not be advantageous [88]; additionally, the PAR has demonstrated questionable validity in this population [105]. Cognitive impairments restrict the feasibility of self-reports [24], particularly complex or lengthy questionnaires [102], but the IPAQ has been validated for participants with severe mental illness [109–110]. Furthermore, specific psychiatric conditions are associated with varying frequency of PA; for example, lower PA can be associated with anxiety and depression, while greater PA can be associated with eating disorders and alcohol abuse [109, 111]. As noted above, different levels of habitual PA intensity merit different measures. In general, objective measures such as accelerometers or pedometers are suggested as the primary assessment tool for such populations [105].

For individuals with serious medical co-morbidities, ability to exercise is a key moderator of PA [6], making structured leisure activities and moderate to vigorous PA often difficult. As such, the MAQ and RPAQ are not ideal for individuals with a high medical burden [88], but the PAR questionnaire is recommended [112]. Furthermore, accelerometers can fail to distinguish between standing and sitting, a distinction that may be crucial for disabled participants; the activPal specifically has been validated with elderly individuals with impaired walking [84]. Additionally, armband monitors have had inconsistent results for users with serious medical co-morbidities [113–115].

Conclusions

PA is a multi-dimensional construct and thus, there is no measure that can assess all facets of PA. Thus, investigators should approach PA measure selection with a clear concept of the type of data they intend to collect. For many studies, combining multiple PA assessments is recommended [8, 116], however, it is possible multiple measures may not be necessary if an investigator is only interested in one facet of PA. Given that further research is needed to validate individual PA measures for different populations, it is difficult to determine an optimal PA assessment. Thus, investigators when selecting a PA measure need to pay close attention to each assessment's strengths and limitations. We recommend consulting with a provider who has expertise in the area of PA assessment prior to choosing a measure, but hope that this commentary provides the knowledge base for investigators without this expertise to ask the questions that most pertain to their area of study.

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Table 1

Summary of self-report questionnaires to measure physical activity

Measure	Period(s) of Interest	Categories of Activity Included	Input	Output	Special Notes
MAQ [27]	Lifetime, Past year Past week	Leisure Occupation Transport	Duration Frequency	Number of hours (or MET hours) per week of PA	Includes no measure of intensity
PWMAQ [28]	Past week	Leisure Television Computer use Disability-related inactivity	Duration Frequency	Number of hours (or MET hours) per week of PA	Modified version of the MAQ Includes no measure of intensity
RPAQ [29]	Past 4 weeks	Leisure Occupation Transport Home	Duration Frequency	Total energy expenditure PA energy expenditure	Includes no measure of intensity
IPAQ-S [3, 30]	Habitual or past week	Vigorous PA Moderate PA Walking Sitting	Duration Frequency	Total PA scores for each category	Designed to be easily adapted in many languages and countries
IPAQ-L [3, 30]	Habitual or past week	Leisure Occupation Transport Home Yard & garden Sitting	Duration Frequency	Total PA scores for each category	Versions exist for specific populations (e.g. youth, elderly, and foreign language speakers [117–118])
PDPAR [31]	Past day, 3 or 7 days 3:00–11:00pm 30 minute intervals	Eating Sleeping/bathing Transport Work/school Spare time Play/recreation Exercise/workout	Primary activity per interval Relative intensity rated on repeated scale (containing verbal & cartoon descriptors)	Daily total energy expenditure Total energy expenditure during specific time periods Total energy expenditure during specific activities	Designed for children and adolescents Contextual cues and prompts intended to enhance memory of PA and intensity
PAR[2, 32]	Past week	Sleep Moderate PA Hard PA Very hard PA	Duration	Total energy expenditure	Calculations assume that the unaccounted for time was spent in light activity

Note. MET = Metabolic equivalent of task (1 MET represents 3.5 ml/kg/min oxygen consumption) [7], MAQ = Modifiable Activity Questionnaire, PWMAQ = Previous Week Modifiable Activity Questionnaire, PAR-Q = Physical Activity Readiness Questionnaire, RPAQ = Recent Physical Activity Questionnaire, IPAQ-S = International Physical Activity Questionnaire (Short Version), IPAQ-L = International Physical Activity Questionnaire (Long Version), PDPAR = Previous Day Physical Activity Recall, PAR = 7-day Physical Activity Recall.

Table 2

Summary of devices to measure physical activity (PA)

Measure	Location	Data Recorded	Output	Special Notes
Accelerometers				
activPal [119], *a*	Thigh	Time spent in sedentary behavior, standing, and walking Count of sit-to-stand transitions Total number of steps for a given period	Energy expenditure per behavior	Distinguishes between standing, sitting, and lying Differentiates various intensities of walking
Tritrac [120], *b*	Hip	Composite movement score (vector magnitude)	Energy expenditure per minute of movement Estimate of resting metabolic rate	Questionable validity
$Tracmor_D$ [121], *c*	Lower back	Activity counts per minute	Total energy expenditure PA energy expenditure Physical activity level Activity energy expenditure per body mass	Waterproof Comfortable Reduces interference from spontaneous activity
Actigraph [47], *d*	Waist/hip	Activity counts (amplitude and frequency of acceleration over each sampling period)	Activity intensity categories Time spent in sedentary, low, moderate, and intense activity	Improves sensitivity to low intensity movement (with the Low- Frequency Extension application) Inaccurate count of steps
Pedometers				
Yamax Digi-Walker [122], *e*	Waist	Step counts per minute	Distance travelled Total energy expenditure	Underestimates step counts at slow activity speeds Widely used in research studies
StepWatch-3 [123], *f*	Ankle	Step counts per minute	Distance travelled Total energy expenditure	Degree of accuracy not affected by activity speed or BMI Sensitive to small movements (e.g., fidgeting)
Heart-Rate Monitors				
Polar S410 [67], *g*	Wrist and chest (two locations)	Beats per minute	Heart-rate per unit time Percentage of the age-based maximum heart-rate estimate Time spent in low, medium, or high intensity activity	No movement measurement
Actiheart [124–125], *h*	Chest (two locations)	Beats per minute Activity counts	Physical activity intensity PA energy expenditure	Combines heart-rate and movement sensors Higher noise rates in women
Arm-Band Technology				
SenseWear [71], *i*	Upper Arm	Beats per minute Temperature	Total energy expenditure Metabolic Equivalent of Task	Objective measure of time worn Algorithms specific to vigorous activity and children

Note.

[a]PAL Technologies Ltd, Glasgow, UK

[b]Professional Products, Madison, WI

[c]Philips New Wellness Solutions, Lifestyle Incubator, the Netherlands

[d]ActiGraph™, Pensacola, CA

[e]Yamax Corporation, Tokyo, Japan

[f]SW-3Ankle; Cymatech Inc., Seattle, WA

[g]Polar Electro, Inc., Lake Success, NY

[h]Cambridge Neurotechnology, Cambridge, UK

[i]BodyMedia, Inc., Pittsburgh, PA, USA. HealthWear (Roche Diagnostics, Indianapolis, IN) and bodybugg (Apex Fitness, San Ramon, CA) are private label versions of BodyMedia's SenseWear technology, meaning that they can be used interchangeably with the SenseWear device.