Framework for Physical Activity as a Complex and Multidimensional Behavior

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Context: The selection of the most psychometrically appropriate self-report tool(s) to measure specific physical activity constructs has been a challenge for researchers, public health practitioners, and clinicians, alike. The lack of a reasonable gold standard measure and inconsistent use of established and evolving terminology have contributed to these challenges. The variation of self-report measures and quality of the derived summary estimates could be attributed to the absence of a standardized conceptual framework for physical activity. Objective: To present a conceptual framework for physical activity as a complex and multidimensional behavior that differentiates behavioral and physiological constructs of human movement. Process: The development of a conceptual framework can provide the basic foundation from which to standardize definitions, guide design and development of self-report measures, and provide consistency during instrument selection. Conclusions: Based on our proposed conceptual framework for physical activity, we suggest that physical activity is more clearly defined as the behavior that involves human movement, resulting in physiological attributes including increased energy expenditure and improved physical fitness. Utilization of the proposed conceptual framework can result in better instrument choices and consistency in methods used to assess physical activity and sedentary behaviors across research and public health practice.

Keywords: conceptual model, human movement, sedentary, self-report, measurement

The relations between physical activity, energy expenditure, and physical fitness with health outcomes are well established. The 2008 Physical Activity Guidelines for Americans (PAG) document the variety of physical activity types (eg, aerobic, moderate, vigorous, lifestyle, resistance/strengthening) that influence health status, quality of life, and physical functioning. As such, it becomes necessary to identify, validate, and track physical activity in individuals and populations. Importantly, a common foundation or framework with consistent interpretation and understanding must be established when measuring physical activity. Accurate assessment of physical activity is critical in efforts utilizing physical activity as an outcome-, exposure-, or confounding-variable when relating to health outcomes. Consistency in the understanding, usage, and assessment of physical activity and related terms can result in better interpretation of effects, outcomes, health-related decisions, and verification of effects.

Direct measures of physical activity currently exist; however, these technologies are often expensive and can be burdensome to individuals. In 2009, the National Cancer Institute (NCI) and American College of Sports Medicine (ACSM) conducted a conference on objective monitoring of physical activity. Logically, the following year, the NCI, ACSM, and other organizations including the Centers for Disease Control and Prevention (CDC), National Institutes of Health Office of Disease Prevention, and National Collaborative on Childhood Obesity Research conducted a similar conference on self-reported measurement of active and sedentary behaviors. The intent was to “close the gaps” on self-reported methodologies related to the assessment of physical activity and sedentary activities. The workshop objectives were to develop a framework, process, procedures, and recommendations to consider when using self-report physical activity measures. The goal was to establish informed guidelines and recommendations from an expert panel that could be used by a broader audience interested in self-report assessment of active and sedentary behaviors. This, in turn, would provide a systematic method for measurement decisions with the goal of optimizing the precision of self-reported estimates of physical activity and sedentary behaviors.

The evidence-based relationship between physical activity and many health outcomes is important enough for surveillance systems, such as the CDC’s Behavioral Risk Factor Surveillance System (BRFSS), National Health and Nutrition Examination Survey (NHANES), and Youth Risk Behavioral Surveillance System (YRBSS), to include physical activity questions.
in large-scale national risk factor assessments. Responses to these questions provide estimates of the prevalence of individuals accumulating sufficient physical activity to meet public health guidelines for physical activity within nationally representative samples of U.S. adults (eg, BRFSS and NHANES) and high school students (ie, YRBSS). Further, attempts have been made to develop generalized physical activity assessments worldwide. The International Physical Activity Questionnaire (IPAQ)\(^6^\)\(^7\)\(^8\) and Global Physical Activity Questionnaire (GPAQ)\(^9\) are illustrative of global surveillance self-report instruments. The application of self-report physical activity measures in research settings has existed for several decades.\(^6^\)\(^8\) However, confusion and misunderstanding about how to best quantify active and sedentary behaviors using self-report methods have permeated even the most well-designed health promotion efforts, public health research, or clinical studies. The cause of this confusion may stem from the use of nonstandardized definitions and individual-level misinterpretation of words or meanings that can result from differences in context or cultures. For example, in 2010, the annual BRFSS survey question for exercise was, “During the past month, other than your regular job, did you participate in any physical activities or exercises such as running, calisthenics, golf, gardening, or walking for exercise?” Therefore, this survey question ignores physical activity accumulated in domains other than leisure-time and provides no context on frequency, duration, or specific type (eg, walking vs. soccer) of physical activity. Transportation and occupation are important omissions. Further, the older adult who “walks down the lane” daily to the mailbox may report this 5-minute walk as “exercise” based on this questioning. Such interpretive errors can result in imprecise prevalence estimates of physical activity or inactivity in the population. For example, the CDC State Indicator Report on Physical Activity, 2010\(^10\) reports that 64.5% of U.S. adults are “physically active” \(\text{ie}, \geq 150 \text{ moderate-to-vigorous intensity physical activity (MVPA) min per week}\), 43.5% are “highly active” \(\text{ie}, \geq 300 \text{ MVPA min per week}\), and 25.4% engage in “no leisure-time physical activity.” Interestingly, Troiano et al, using NHANES accelerometer-derived physical activity data from 2003–2004, report that < 5% of the adult population accumulated enough MVPA to meet public health guidelines recommended at the time of data collection.\(^10\) This lack of congruency between self-report and accelerometer-derived prevalence estimates of meeting recommendations could be due to many reasons including misinterpretation of the question, reporting biases intrinsic to self-report measures (eg, recall, social desirability), the ability of the accelerometer to detect primarily ambulatory-like movement, and the slight differences in public health physical activity recommendations from 2003–2004 \(\text{ie}, 30 \text{ minutes or more of MVPA on most days of the week}\)(\(^10\)) and 2009–2010 \(\text{ie}, 150 \text{ minutes or more of MVPA per week}\)(\(^9\)). A 2009 report by Thompson et al\(^11\) further illustrates the discrepancies in physical activity status \(\text{ie}, \text{meeting vs. not meeting recommendations}\) that can occur depending on which public health recommendations for physical activity were applied.

Caspersen et al\(^12\) attempted to define and standardize the terminology that researchers, clinicians, and practitioners use to denote constructs related to physical activity to provide a common foundation for interpretation and comparison. Interestingly, despite that effort, confusion around the meaning of relevant terms continues 25 years later. Consider the definitions of physical activity contained in “Physical Activity and Health: A Report of the Surgeon General.”\(^11\) In this report, physical activity is defined as “bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure above the basal level” (page 20).\(^1\) On the next page, physical activity is defined as “bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure” (page 21).\(^1\) The first definition could include standing or light-intensity activities. Alternatively, depending on the interpretation of the term “substantially increases,” one may only think to report vigorous-intensity physical activity. In this single yet critically important example, the definition of physical activity literally differs from one page to the next. Thus, it is not surprising that confusion still exists today among researchers, health care and public health practitioners, health promotion experts, and the general population regarding physical activity.

### Physical Activity: A Complex and Multidimensional Behavior

Physical activity is a complex and multidimensional behavior that does not stand in isolation from other related constructs, including sedentary behavior, energy expenditure, and physical fitness. A conceptual framework, often visual in nature, is used to present a standardized approach to an idea, thought, or concept. This approach can be applied to physical activity research to provide the basic foundation from which to standardize definitions and guide instrument development for measurement and selection of appropriate tool(s) to quantify physical activity and related parameters in research, clinical, or community settings. Although several conceptual frameworks have been proposed, none have been widely adopted and used in physical activity research or related applications. To advance the field of physical activity measurement and related research, it becomes imperative to develop, standardize, and use a framework for physical activity that is both useful and applicable to all subdisciplines related to physical activity and exercise science.

We are not the first to propose a conceptual framework for physical activity. In describing the relationship between physical activity and health, Shephard and Bouchard\(^13\) proposed a framework centered on health-related fitness. Their framework implied a reciprocal relationship between physical activity and health-related fitness as well as a shared association between health-related fitness and health status. Further, the framework proposed by Shephard and Bouchard showed the potential...
contributions of heredity, personal attributes, lifestyle behaviors, and the social and physical environments on the relationships between physical activity, health-related fitness, and health.\textsuperscript{13}

Later, LaMonte and Ainsworth published a conceptual model for quantifying energy expenditure.\textsuperscript{14} Unlike the framework by Bouchard and Shephard, they proposed a model that could be used to identify appropriate instrumentation to measure constructs of interest. Within their framework, LaMonte and Ainsworth\textsuperscript{14} identified “movement” as the global construct, with physical activity and energy expenditure listed as 2 related dimensions. The authors further differentiate the 2 dimensions of movement as the behavior (ie, physical activity) and energy cost (ie, energy expenditure) of human movement. Examples of both direct and indirect measures of physical activity and energy expenditure were provided, with inference on how those dimensions could be extrapolated to a common unit of expression (ie, kilocalories) with which to compare with health outcomes.\textsuperscript{14}

Although both conceptual models used for our illustrative purposes contain useful and scientifically-sound principles, a framework that is applicable to the many subdisciplines of physical activity and exercise science has yet to be identified. Further, previous frameworks have not illustrated the direct relationship between the behavior and the physical and physiological results of that behavior. Finally, sedentary behavior was not addressed in previous conceptual frameworks.

Much like the conceptual framework proposed by LaMonte and Ainsworth,\textsuperscript{14} our global construct of interest is “human movement.” Unlike its predecessor, however, in the current framework a directional relationship is implied between the behavioral aspect of human movement, the characteristic of human movement, and the physiological result or consequence of movement (Figure 1). With this basic framework, we can begin to operationalize the components and expand on the main constructs of human movement.

**The Behavior of Human Movement**

The behavior of human movement can be conceptualized as active (ie, physical activity) and sedentary behavior (Figure 2). Both active and sedentary behavior can be influenced by upstream factors, including physiological, psychological, social, and environmental correlates. Within the behavior of physical activity, 4 main domains or types of activity have been identified. These activity domains include leisure-time physical activity; work- or school-related activity; household, domestic, or self-care activities; and activity for transport from place to place. Although exercise shares a number of similar qualities with physical activity, the terms are not synonymous and should not be used interchangeably. Exercise is considered a subcategory of physical activity and is often classified under the leisure-time physical activity domain. In the 1985 seminal paper by Caspersen et al,\textsuperscript{12} exercise was defined as “planned, structured, and repetitive bodily movement done to improve or maintain 1 or more components of physical fitness.” When quantifying total physical activity, or activity within a specific domain or activity type (eg, aerobic, muscle-strengthening, flexibility), using self-report methods, data often collected include frequency, intensity, duration, and sometimes specific activity type (Figure 3). Frequency can be defined as the number of times a given activity, or set of activities within a specific intensity range (eg, moderate-intensity), was performed within a predetermined time period. This time period can either be usual/typical or explicitly defined (eg, previous 7 days). Intensity can be defined as the level of effort or physiological demand needed to perform a specific activity. Duration is the amount of time (ie, minutes or hours) that the activity or activities within

\begin{figure}[h]
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\includegraphics[width=\textwidth]{Figure1.png}
\caption{The directional relationship between the behavior (physical activity) and consequence (physiological attributes) of human, musculoskeletal movement.}
\end{figure}
Figure 2 — A conceptual framework for physical activity as a complex and multidimensional behavior.

Figure 3 — Quantifying the behavior of human movement using self-report methods.
a given intensity range was performed. Duration can be used to quantify a single activity episode or reported as an average amount of time across a specific time period (ie, past 7 days).

When examining the total behavioral profile of human movement, one should also consider sedentary behavior. Sedentary behavior has emerged as a new field of focus in physical activity and public health research. Sedentary comes from the Latin word sedère, which means “to sit.” Sedentary behaviors can be categorized as nondiscretionary or discretionary. Nondiscretionary sedentary pursuits include activities such as sitting during work or school hours or while in a car driving, whereas discretionary sedentary activities include sitting while watching television, reading, playing video games, or computer use during nonwork or school-related hours. When quantifying sedentary behavior via self-report methods, the frequency and duration of individual sedentary behaviors (eg, television watching) or the total or average time spent in nonspecific sitting activities over a specific or usual period of time (ie, sitting time) is ascertained. Given that sedentary activities have similar associated metabolic equivalent (MET) values (ie, 1.0–1.5 METs), quantifying intensity level is not necessary.

Since the activities that define active and sedentary behavior are quite different, instruments that measure active behaviors should not be used to quantify or infer time spent in sedentary pursuits. For example, if an individual is considered low active when quantifying his/her leisure physical activity levels, it does not necessarily mean that she is highly sedentary. Although individuals can be both sedentary and physically inactive, there are many individuals with behavioral profiles in which physical activity and high sedentary time coexist (eg, active couch potato phenomenon). Therefore, sedentary behavior is not simply the opposite of physical activity and should be quantified separately. Further, sedentary behavior should not be ascertained by simply subtracting the time spent being physically active from total day hours.

Other than direct observation, there are no gold-standard or criterion measures of active and sedentary behavior. Thus, when attempting to quantify these behaviors using self-report methods, it is important to note that the derived summary variables are estimates of perceived, not actual, behavior. Traditionally self-reported physical activity estimates were largely derived from aerobic activities. However, given that other types of activities, such as muscle-strengthening and flexibility exercises, are encouraged in public health recommendations, more work is needed to either improve existing tools or develop new instruments to complement more conventional aerobic-centered measures.

The Characteristics of Human Movement

Physical activity involves human movement, whereas prolonged sitting (ie, sedentary behavior) involves skeletal muscle unloading characterized by the loss of local contractile stimulation. Standing activities involve little or no movement; however, these activities can be differentiated from sitting activities in that they require isometric contraction of the antigravity (ie, postural) muscles. To quantify human movement, often ambulatory-like activities are measured using activity monitors including pedometers and accelerometers. Through advancements in technology, many commonly used accelerometers now have the ability to capture activities that occur in 3 planes/axes that characterize human movement. Further, some accelerometer models contain inclinometers, which can detect changes in position, making it easier to differentiate sitting from standing or lying down. Therefore, accelerometers can be quite useful to measure the lack of movement characterized by sedentary activities.

The Consequences of Human Movement

Movement results in physiological attributes including increased energy expenditure and improved physical fitness. Total energy expenditure is comprised of resting metabolic rate, energy cost associated with thermogenesis (ie, thermic effect of food), and physical activity-related energy expenditure. The contribution of basal (or resting) metabolic rate and thermogenesis to total energy expenditure is relatively stable (ie, ~70% and ~10%, respectively). Physical activity-related energy expenditure is the most variable component of total energy expenditure and typically accounts for a relatively low percentage (ie, ~20%) of total day energy expenditure. Given the relative stability of the other components, the measurement of physical activity-related energy expenditure is commonly used to infer total energy expenditure. Regardless of whether total or a component of energy expenditure is of interest, energy expenditure is typically measured directly, often in a laboratory setting.

In addition to energy expenditure, human movement also results in improvements in the 5 dimensions of health-related physical fitness, including cardiorespiratory fitness, musculoskeletal fitness (ie, muscular strength and endurance), flexibility, balance and coordination, and body composition. Moreover, depending on the actual type of movement, benefits can accrue in 1 or more facets of physical fitness. Much like energy expenditure, physical fitness parameters are typically measured directly in a laboratory or clinical setting. However, if self-report measures use specific activities (eg, gymnastics) during recall, then certain fitness-related aspects of that activity might be inferred (eg, balance or flexibility).

Based on our conceptual framework for physical activity as a complex and multidimensional behavior, we propose that physical activity is more clearly defined as the behavior that involves human movement, resulting in physiological attributes including increased energy expenditure and improved physical fitness. In general, human movement is beneficially related to health, whereas the consequence, or lack of movement, is considered health compromising. Physiologically, sleep has different effects on health when compared with sedentary
behaviors; therefore, it is strongly recommended that time spent sleeping be excluded when examining associations between sedentary behaviors and health-related outcomes. As the role of sedentary behavior on health becomes more valued in physical activity and exercise science research, the question remains whether both active and sedentary behaviors need to be quantified to generate a profile of active and sedentary behavior or rather, is it satisfactory to ascertain one or the other (ie, physical activity levels in the absence of sedentary behaviors or vice versa). According to 2010 data from the National Time Use Survey implemented by the National Bureau of Labor Statistics, adults spend an average of 8.67 hours of the day sleeping. That leaves approximately 15.33 hours left in the day for work, domestic, and leisure-time activities. Based on these data, adults report spending approximately 1% of time in health-enhancing (ie, exercise) physical activity, 25% in sedentary pursuits, and the remaining 38% at work, which for some might be active and for others sedentary, and lower intensity domestic or leisure-time activities. Thus, considerable time and effort to date have been focused on a relatively small, yet important, aspect of daily life. However, there is a large proportion of daily life that self-report instruments might not be capturing. This example provides supportive evidence to measure both active and sedentary behavior.

Methodological Considerations When Quantifying Physical Activity and Sedentary Behaviors

Regardless of whether direct- or self-report instruments are used to quantify active and sedentary behavior, it is important to consider methodological issues that may limit the precision of the derived estimates (Figure 4). Researchers, clinicians, and health care practitioners alike must reflect on these issues before implementing a measurement strategy to reduce the risk of information bias in their efforts, a type of bias that can occur when the methods for obtaining information are inadequate, which can lead to erroneous estimates.

Specific types of information bias include recall, reporting, and misclassification bias. Issues related to recall and reporting biases are most relevant to self-report methods. Recall and reporting biases involve problems with cognitive processes that are necessary to retrieve relative physical activity and sedentary information stored in memory and generate a response in the format required for the answers. Misclassification bias could occur in physical activity-related research when a truly insufficiently-active individual is categorized as meeting recommended levels of physical activity. Specific to active and sedentary behavior measurement, nondifferential misclassification is particularly problematic. Nondifferential misclassification results from inaccuracies in the methods used to characterize active and sedentary behaviors. In most instances, nondifferential misclassification reduces the overall strength of association between the outcome of interest and estimation of active and/or sedentary behavior leading to spurious conclusions, including missed associations. That is, the true effect of physical activity on health outcomes may be even greater than currently reported or theorized.

Broadly defined, the methodological issues potentially limiting assessment of active and sedentary behavior include 1) study, 2) population, 3) instrument, and 4) activity characteristics (Figure 4). Each category is described in greater detail in the following sections. It is important to note, however, that the specific characteristics provided are meant to serve as examples; not as an exhaustive list of all items within that particular category.

Study Characteristics

Specific study characteristics that may impact instrument selection include study budget, staff resources, study design, population sample size, and study objectives. Further, whether physical activity and/or sedentary behavior will be used as an outcome, exposure, or confounding variable can also influence instrument selection. For example, in applications where researchers want to simply control for physical activity, a global questionnaire that elicits information on current physical activity status (ie, active vs. not active) might be all that is needed. Issues of seasonality might also impact physical activity estimates, particularly when measured over shorter time periods (eg, past 7 days) in geographical locations that experience variation in temperature or precipitation. In addition, a large prospective cohort study, with multiple data collection time points and study sites across the U.S., might not have the budget or staff resources necessary to use accelerometers. Further, the outcomes of interest in this example might develop over several years (eg, chronic conditions); therefore, implementing a self-report measure(s) that uses a historical or a longer time frame might be the most salient solution to measure active and/or sedentary behavior.

Population Characteristics

Individual- or population-level characteristics can influence the selection process and the quality of collected data. Factors including age, gender, race and/or ethnicity, cultural norms, primary or native language, socioeconomic status, highest educational attainment, cognitive ability, and general health status, including functional ability and disability status, can drive the assessment strategy. For example, complex self-report measures quantifying specific active and sedentary behaviors over the past year are not appropriate for children. Moreover, a self-report measure originally developed in English might not be appropriate for nonnative English speakers without first thoroughly examining the cultural relevancy of the specific items and adapting the measure accordingly to fit the needs of the population subgroup.

Instrument Characteristics

The specific elements of the instrument may also help direct researchers, clinicians, and health care practitioners decide what measurement tool(s) to use. For example,
some self-report instruments use specific activities as cues during recall, whereas other tools use broader, pooled categories based on intensity-level. Differences in the format of activities provided as recall cues may impact derived summary estimates. Further, the psychometric properties of the instrument (ie, reliability, validity, and sensitivity to behavior change over time), mode of administration (eg, interviewer- or self-administered), recall time frame (eg, usual, specific-time period, or historical), and the suitability of measured constructs to the study, clinical, or community population and outcome(s) of interest might also impact decisions regarding measurement tool selection. For example, it is important for a study evaluating the effectiveness of a 12-month walking intervention to reduce high blood pressure levels in older adults to use a questionnaire that specifically measures walking and is sensitive to detect changes in walking over time. Given the lower levels of computer literacy and cognitive issues related to the normal aging process, it might be prudent to use an interviewer-administered self-report measure that utilizes a shorter-recall time frame, collected multiple times during the 12-month intervention to measure walking and other active and sedentary behaviors in this group of older adults. The validity of derived estimates is typically higher when an interviewer- vs. self-administered format is used; however, interviewer-administered surveys are not always practical. Computer-assisted and online surveys are gaining popularity as an efficient (ie, time saving, low staff and participant burden and cost) solution. However, the “digital divide” (ie, computer literacy) must be considered in some population subgroups.

Activity Characteristics

As mentioned previously, aerobic, large muscle group activities were often the central (or only) focus of physical activity self-report measures. More recently, the importance of additional physical activity domains has been identified. The inclusion of occupational, lifestyle, transportation, and other types of physical activity behaviors is important in addition to the traditionally assessed leisure-time aerobic physical activities. What types of sedentary behaviors are being reported? For example, Figure 4 (bottom right) illustrates that a variety of physical activity types are currently assessed and tracked in different national-level surveillance systems. An important example includes resistance training and muscle strengthening activities related to musculoskeletal health. The 2008 PAG recommend adults engage in strengthening activities ≥2 days per week and for adolescents to do so ≥3 days per week. Yet, the interpretation of “strengthening activities” can vary. Does this include “resistance training” only or does it include Pilates, yoga, hand-held weights, exercise bands, calisthenics using body weight as the resistance, and other forms of musculoskeletal activities? Researchers must consider
what is included and what is omitted when delimiting their physical activity questioning. This logic extends to sedentary behaviors.

Conclusion
We propose a framework for basic and applied researchers, clinicians, behavioral scientists, and public health practitioners to use when quantifying physical activity and related constructs. While the original intent was related to self-report, the framework is valid for both direct and self-report instruments. Consistency of the interrelationship between related constructs and subsequent terminology is the sine qua non if measures are to be interpretable, generalizable, accurate, and used appropriately in research or for surveillance and tracking purposes. We provide study, population/individual, instrument, and activity considerations/characteristics that all must consider when assessing physical activity behaviors. The choices made by researchers and practitioners regarding instrument selection have important consequences. Inclusion of some constructs and omission of others have both intended and unintended consequences to the derived estimate. It is important that these consequences be fully understood.

In summary, the key to moving the field of physical activity assessment forward is to think about the nature of physical activity as a complex and multidimensional behavior. When selecting an assessment strategy, it is imperative to think about what parameters will be included and what will be omitted, and then think about how it will be interpreted by the respondent, researcher, or practitioner, and in the literature. Our proposed framework lays the foundation for the remaining papers in this supplement that guide researchers, clinical and public health practitioners, health promotion experts, and the general population when making decisions about instrument selection and interpretation of self-report physical activity behaviors through self-report.

Acknowledgments
The authors would like to thank Melba S. Morrow, MA, Cooper Institute, for her thoughtful review of this work. Material presented in this paper was originally presented at the Measurement of Active and Sedentary Behaviors: Closing the Gaps in Self-Report Methods workshop in Bethesda, Maryland on July 21–23, 2010.

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