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ACCELEROMETER USE WITH CHILDREN, OLDER ADULTS, AND ADULTS WITH FUNCTIONAL LIMITATIONS

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Abstract

Accurately assessing physical activity behavior in children, older adults, and adults with functional limitations is essential to further our understanding of determinants of physical activity behavior in these populations, and to designing, implementing, and evaluating interventions designed to increase physical activity participation. Objective methodologies to assess physical activity behavior, due to improvements in accuracy and precision over self-report measures, have become common in research and practice settings. This paper reviews the current use of objective methods to assess physical activity in observational, determinant, and intervention studies for children, older adults, and adults with functional limitations. Important considerations are presented when adopting prediction algorithms developed on one population, and using in another population that is markedly different in age, health, and functional status. Best practices are presented, along with future recommendations for research to advance this area of scientific inquiry.

Keywords

Accelerometer; motion sensor; exercise; behavior; children; older adults; elderly; disability; function

INTRODUCTION

Regular engagement in physical activity is an essential behavior to promote health and prevent chronic disease for persons of all ages and those with and without functional limitations. The ability to accurately measure physical activity in a free-living environment is crucial to any investigation in which physical activity is an outcome or exposure variable of interest. However, physical activity is a complex behavior with high levels of inter-individual and intra-individual variation, making it a difficult construct to measure. Techniques for measuring physical activity need to be able to distinguish different characteristics of activity, namely the frequency, duration, intensity, and type, in order to further our understanding of population levels of physical activity. Measurement techniques

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also are needed for determining the relationship between physical activity and disease/ disability, and to be able to document the efficacy of interventions designed to increase physical activity participation.

Despite advances in the use and development of accelerometers to measure physical activity, careful consideration is needed when deciding to apply objective monitoring methods to certain populations, especially children, older adults, and adults with a functional limitations, as methods are not "one size fits all." Factors to consider include: 1) the physical activity indicators of interest; 2) the application of objective physical activity monitoring in these populations; and 3) whether calibration and validation studies support the application in the population of interest.

This paper addresses each of the above considerations with an aim toward describing the current use of accelerometers with children, older adults, and adults with functional limitations, describing best practices for future applications, and recommending future research to advance the use of objective monitoring technology. For the purposes of this paper, discussion is limited to children aged 3 to 18 years, older adults (65 years and older), and adults with functional limitations.

DERIVING INDICATORS OF PHYSICAL ACTIVITY FROM OBJECTIVE MONITORS

Understanding basic terminology is important to understand the applicability of accelerometers for selected study designs, and measures of interest within selected populations. Physical activity is conventionally defined as any bodily movement produced by the contraction of skeletal muscle that results in energy expenditure (10). It is important to recognize that physical activity is a behavior that results in energy expenditure. Whereas physical activity is quantified by characteristics of frequency and duration, energy expenditure reflects the sum of all metabolic processes involved to support the physical activity in question. Several factors influence energy expenditure, including age and functional status.

If one assumes human mechanical efficiency to perform an activity to be similar across populations, then energy expenditure would generally be constant, and volume indicators such as kilocalories per day, MET-min per day, or MET-hr per day would be comparable across different populations. If one cannot assume a similar mechanical efficiency across populations, however, an unwanted source of variation in the measurement of physical activity is introduced, obscuring meaningful interpretation and comparison of findings. Many disabilities (stroke, spinal cord injury, Parkinson's) affect neuromuscular and movement-related functions that collectively affect movement itself. Ability to engage in physical tasks can therefore become mechanically altered and more physiologically demanding to an individual. When considering such facts, many practical issues arise when considering the use of objectivephysical activity monitoring in this population subgroup. For example, using a commercially available algorithm to extrapolate accelerometer counts per day into kilocalories per day for a stroke survivor with gait abnormalities is unlikely to yield precise estimates for total or physical activity-related energy expenditure for that individual.

Furthermore, additional unwanted variation is introduced when one does not consider absolute versus relative intensity differences for individuals. Figure 1 highlights differences between absolute and relative intensity for selected walking activities across different levels of physical fitness. Absolute intensity may assume a similar mechanical efficiency (e.g., walking at 3 mph represents a similar activity irrespective of fitness level), but relatively speaking this could constitute a light-intensity activity for an individual with a 12 MET capacity and a vigorous-intensity activity for an individual with a 6 MET capacity. Age-related decreases in the average fitness level (21), and absolute versus relative physical activity intensity differences are amplified, and necessitate consideration when evaluating indicators of physical activity derived from objective monitors. Further, this issue becomes particularly important when examining the child and adolescent population, given that growth and maturation can affect several factors that may be related to the ability of accelerometers to detect movement (e.g., body size, relative length of body segments, fitness).

Such factors as noted above are essential to consider when using objective monitors to assess physical activity behavior in different subpopulations. The next section describes the current application of accelerometers in children aged 3 to 18 years, older adults, and adults with functional limitations. We focus on observational, intervention, and determinant studies, with further categorization by school level (preschool, elementary, middle, and high school) for studies of children. It is important to note that the available body of literature regarding children and adolescents is more extensive than the available body of literature for older adults and adults with functional limitations; thus, this review is not intended to be comprehensive for the child and adolescent population.

CURRENT APPLICATION OF OBJECTIVE PHYSICAL ACTIVITY MONITORING

Children

Observational Studies—Due partly to the growing public health concern about childhood obesity, the number of investigations examining physical activity in children has increased over the past decade. Evidence from most observational studies of preschool children indicates that accelerometer-assessed levels of moderate-to-vigorous physical activity tend to be low, while the amount of time spent in sedentary and/or light activity is high (7, 57). Population-based accelerometry studies of elementary school children have shown varied results regarding prevalence of meeting physical activity recommendations. In the United States, data from the 2003-2004 National Health and Nutritional Examination Survey (NHANES) indicated that 42% of children ages 6 to 11 years met physical activity recommendations. Studies of children in the United Kingdom show extremes in prevalence of meeting physical activity recommendations, from 7% in the northeast of England (41) to almost 70% in the middle east section of England (72). Another recent investigation from England showed that, on average, children were achieving 60 minutes of physical activity per day (60). This same investigation also examined bouts of activity and the effects of seasonality, which are constructs deserving more attention in future research. Regarding the middle and high school populations, 2003-2004 NHANES data showed 8% of youth ages 12 to 19 years met physical activity recommendations. Taken together, the results corroborate the long-standing belief, first observed in self-report studies, that physical activity declines with age. Although accelerometry has confirmed the self-report results, discrepancies exist between self-report and accelerometer-based estimations of physical activity.

Population-based accelerometery studies provide essential statistics for public health planning and intervention, but Gidlow et al. (26) demonstrated prevalence estimates change drastically when different cutpoints to define physical activity intensity levels are used. Comparison among studies would be easier if researchers adopted standard methods for population assessment by accelerometer. Despite the cutpoint issue, accelerometers allow investigators to examine facets of physical activity not previously measurable by self-report instruments, and they offer an additional degree of accuracy. Accelerometer data from the Study of Early Child Care and Youth Development showed a decline of 38 minutes per year in weekday and 41 minutes per year in weekend moderate-to-vigorous physical activity (46). The authors estimated age 12.8 years (girls) and 14 years (boys), averaged across weekdays and weekend days, to be the ages at which adolescents dropped below the recommended levels. Before the use of accelerometers, accurate estimates such as these were not possible.

Intervention Studies—Accelerometers have been used in a number of physical activity intervention investigations involving children and youth, and they are emerging as useful tools for comparing effectiveness across interventions.

Only a few studies of interventions in the preschool population exist in the published literature, but it appears accelerometers can be used to assess changes in physical activity in preschool children. Specker et al. found children who participated in the gross motor portion of an intervention spent a higher percentage of time post-intervention in vigorous physical activity than those who participated in the fine motor portion (63). Cardon et al. discovered that supplying physical activity equipment and creating playground markings did not affect moderate-to-vigorous physical activity during recess (9). However, the addition of playground equipment positively affected light physical activity and moderate-to-vigorous physical activity in another investigation (30). Increases in preschooler physical activity also have been detected for interventions that implemented curricula to increase classroom time spent in moderate-to-vigorous physical activity (68).

Intervention strategies with elementary school children have ranged from multi-component school-based approaches (including physical education, classroom-based, and extracurricular physical activities and playground adjustments) (74) to individual approaches, such as rewarding physical activity participation with time for television viewing (28). Additionally, an innovative investigation aimed at creating an “activity permissive” environment during the school day used accelerometry for the main outcome measure (38). Similar to the interventions in younger populations, accelerometers have been used in a number of investigations involving middle school and high school children and youth. Some interventions have been clinically-based (52), even including behavioral economics strategies (16). Others have included newer, innovative strategies such as use of the internet and Boy Scout troop badges (34) and active video games (47). Accelerometers have been demonstrated to be reliable and feasible for use in these types of studies, and have allowed investigators to examine more complex variables such as in-school versus after-school physical activity in a more reliable manner than previous recall-based investigations.

Determinant Studies—The body of literature including correlates and/or determinants of accelerometer-assessed physical activity is too vast to be thoroughly discussed here. Most investigations have shown that demographic variables such as age, sex, race, and preschool attended are associated with preschoolers’ physical activity (53), as well as weight status (70), and psychosocial correlates such as parent perception of child’s athletic competence (53). A few studies have examined other correlates, such as bone area and mass (76). Aside from demographic variables, the literature examining determinants of physical activity has not consistently shown many factors to be related to physical activity in preschool children, warranting more work in this area in future investigations.

One of the first investigations of correlates of accelerometer-assessed physical activity in elementary school children published in 1991 showed a relationship between family members’ physical activity and child physical activity (23). Many biological variables related to physical activity in elementary school children have been examined, including weight status (1), visceral fat (14), insulin (1) and appendicular bone mineral density (32). Psychosocial variables appear to be less-studied in this age group. However, Roemmich and colleagues showed that liking and relative reinforcing values were associated with accelerometer-assessed physical activity in children ages 8 to 12 years (59), and Shoup and colleagues demonstrated that less active children had lower quality-of-life scores (62). Psychosocial factors related to accelerometer-assessed physical activity in elementary school-aged children are less clear than biological variables.

In contrast to the elementary school group, more psychosocial factors have been investigated in middle and high school age groups. Self-efficacy for physical activity (69), participation with community organizations (69), parent physical activity (69), and active transportation to school (71) are all positively related to accelerometer-assessed physical activity in older children. Perceived access and proximity to commercial physical activity facilities also have been associated with physical activity, particularly in adolescent girls (61). Biological variables such as maturation also potentially appear to be related to physical activity in this age group (2).

Despite currently published data examining determinants and correlates of accelerometer-assessed physical activity, a core group of variables upon which to intervene has yet to be identified. In part, this may be due to the lack of standard methodology for collecting and analyzing accelerometer data for children.

Older Adults

Observational Studies—Knowing that the number of older adults in the U.S. population is rapidly increasing, and that advancing age is accompanied with a greater risk of chronic disease and disability, monitoring free-living physical activity behavior among older adults is crucial. Accelerometer data from NHANES 2003-2004 revealed that older adults are the least active segment of the population, with adults ages 60 to 69 years accumulating 12 to 17 minutes of moderate-to-vigorous physical activity per day and adults ages 70 years and older accumulating 5 to 9 minutes of moderate-to-vigorous physical activity per day (67). Other studies employing accelerometers have documented an age-associated decrease in physical activity (35), but the absolute volume of physical activity reported by studies varies depending on the methods for analyzing accelerometer data. The NHANES data were analyzed using a cutpoint of 2020 counts per minute (cpm) to delineate moderate physical activity, whereas Johannsen and colleagues used a lower 574 cpm and reported U.S. adults aged 60 to 74 years engaged in 126 minutes of moderate-to-vigorous physical activity per day (35). In addition to discrepancies introduced by use of various intensity level cutpoints, analyzing accelerometer data in “accumulated bouts” results in drastically reduced population estimates of physical activity (13). Not surprisingly, given the low level of activity performed in bouts, one report suggests less than 3% of U.S. older adults are currently attaining sufficient physical activity to meet public health recommendations (67).

Intervention Studies—Very few intervention studies employing objective monitoring have been conducted with older adults. Pruitt et al. (55) explored the ability of accelerometry to differentiate between intervention groups using a measure of physical activity relative to individual functional capacity. Individually-determined accelerometer cpm thresholds were derived from performance on a 400m walk test, and this relative measure of physical activity was able to distinguish that the physical activity intervention increased activity levels above those obtained by a non-exercise health education program. These early data are promising, both in their ability to detect intervention differences, and in overall practicality and application to design and implementation.

Determinant Studies—Recent studies have shown many different variables to be related to accelerometer-assessed physical activity in older adults. Studies consistently show demographic variables of age and sex to be associated with physical activity (35, 67), as well as functional variables such as balance and gait speed (25, 35) and psychosocial variables—notably quality of life and general mental health indices (50). Investigators also have begun to document associations between outdoor temperature and daily activity levels (5). Other literature examining biological factors such as bone mineral density (25) have not shown consistent relationships. Despite the growth of work published thus far pertinent to older adults, more data are needed to establish core intervening variables for this group of the population that has been shown to be the least active in the Nation.

Adults with Functional Limitations

Observational Studies—Studies have documented the feasibility and use of objective monitoring to assess physical activity levels in many different populations with functional limitations, including those with multiple sclerosis (29), osteoarthritis (19, 45), peripheral arterial occlusive disease (24), heart transplant (17) and stroke (56). This is a rapidly expanding literature set, all using different activity monitors, different protocols for wearing the activity monitors, and different physical activity indicators.

In a recent study by Farr et al. (19), a hip-worn accelerometer was used to assess the activity levels of patients with early knee osteoarthritis. Using a cutpoint value averaged from the calibration literature to demarcate physical activity intensity levels, they found individuals engaged in approximately 24 minutes per day of moderate physical activity, approximately 1 minute per day of vigorous physical activity, and that 70% of those sampled did not meet physical activity recommendations. Studies with hip-worn uniaxial and triaxial accelerometers have also shown adults with kidney disease (36) multiple sclerosis (29), stroke (56) and Parkinson’s disease (29), are considerably less active compared to healthy adults. Other comparison studies have been conducted with wrist-worn accelerometers. For instance, Kop et al. (37) compared individuals with fibromyalgia and chronic fatigue syndrome with healthy controls. Similar to that previously reported by others in different populations (29) activity levels in these patient populations were upward of 50% lower than the healthy controls. Comparisons across populations and studies are cumbersome due to differences in monitors and site placements. It is not clear whether the same cutpoints generated on healthy adults should apply to populations with functional limitations.

Intervention Studies—Similar to other populations, intervention studies that use objective monitors to measure physical activity are lacking in adults with functional limitations, but evaluation of treatment therapies, rehabilitation effectiveness, and other potential intervention effects is possible with objective assessment. The application of objective monitoring in therapy and rehabilitation could be particularly helpful to document time to recover, diurnal fluctuations, and non-impaired limb compensation. In a recent study by Reiterer et al. (58), a wrist-worn accelerometer was used to objectively examine the recovery process of 38 patients during stroke rehabilitation. Activity levels of both arms were assessed at four different time points after stroke—24 to 36 hours, 5 to 7 days, 3 months, and 6 months. Wrist activity levels at the impaired side significantly increased during the course of rehabilitation. A growing body of literature in individuals with lower extremity osteoarthritis is beginning to document the association between pacing as a therapy to reduce pain and its association with accumulated levels of physical activity as documented by wrist-worn actigraphy (45). Objective measurement of physical activity would aid evaluation of intervention components that are presently difficult to assess with self-report methods.

Determinant Studies—As in studies of the other populations, investigations have shown several demographic variables, such as sex, age, and disease/disability type to be associated with accelerometer-assessed physical activity (29, 56). A recent investigation by Sumukadas et al. (65) also showed day length, mean maximal outdoor temperature, and sunshine duration to independently predict physical activity engagement. Investigators also have begun to document associations between physical activity and functional correlates in individuals with fibromyalgia and chronic fatigue syndrome (37). Psychosocial correlates, such as overall quality of life and self-efficacy, have been observed in individuals who have undergone heart transplant (17). Evangelista et al. (17) documented inverse associations between hypertension, hyperlipidemia, and obesity and overall physical activity levels in individuals having undergone heart transplant. More work is warranted in this area to corroborate findings from other literature sets, and document the relationship of physical activity to aspects of metabolic, vascular, bone health, and other known health correlates, as well as the impact of broader macro level influences, such as the built and social environment.

VALIDATION AND CALIBRATION STUDIES

The goal of validation and calibration studies is to establish the relationship between the signals generated from objective monitors and the actual physical activity performed. Papers in the current supplement discuss different types of validation and calibration principles, and also discuss the need to cross-validate established equations and prediction parameters in independent samples. For the purpose of the current paper, we will primarily focus on review of the literature pertaining to the criterion-referenced validity of accelerometers for assessing physical activity among children, older adults, and adults with functional limitations.

Children

Many different calibration and validation studies have been conducted across the full age span of childhood and adolescence, using different criterion measures (indirect calorimetry, doubly-labeled water, direct observation) and different accelerometer brands. Since the 2004 accelerometry meeting in Chapel Hill, NC (75), calibration studies with indirect calorimetry as the criterion measure have been published for the preschool population for the ActiGraph (LLC, Fort Walton Beach, FL) (51) and Actical (Mini Mitter Co., Inc., Bend, OR) (54). For elementary children, Evenson et al. (18) created ActiGraph and Actical physical activity count cutpoints, and other investigators, such as Hussey et al., have provided calibration and/or validation studies for the RT3 (StayHealthy, Inc., Monrovia, CA) (or other triaxial monitor) (33). The Hussey et al. study also applied to middle school ages (33).

Although indirect calorimetry has primarily been used as a criterion measure, some studies since 2004 have used doubly-labeled water (39) and direct observation (40) to evaluate the criterion validity of objective monitors in younger children. Studies comparing accelerometry to pedometry (8), parent proxy (4), and heart rate (31), have provided construct validation data. Additionally, reliability (66) and stability (49) of accelerometry have been examined. Thus, many investigations have contributed to the body of knowledge regarding calibration, validation, and reliability of accelerometry as a measure of physical activity for children.

Older Adults

Criterion-referenced validity studies with older adults have been distinctly lacking. Although recent reviews exist on the use of accelerometry in older adults (44), the lack of data specific to this population means that conclusions have been drawn largely from the general adult literature. One laboratory-generated calibration study of older adults reported strong correlations between treadmill walking and measured oxygen consumption (r=0.6) (11);

other studies compared objective monitors to self-report measures, providing information about construct validity (50, 55).

In 1992, Nichols et al. (48) examined the validity of the Caltrac (Muscle Dynamics, Torrence, CA) accelerometer in 28 young (mean age ~26 years) and 28 older (mean age ~65 years) men and women, and determined that treadmill walking assessed by an accelerometer worn on the upper back was significantly correlated to measured net kilocalories obtained by indirect calorimetry. Reported relationships, although all significant, were weaker in the older group versus the younger group, and were weaker for women versus men. In a follow-up study conducted by Fehling et al. (20) the criterion-referenced validity of two waist-mounted accelerometers (Caltrac and Tritrac [StayHealthy, Inc., Monrovia, CA]) to measure energy expenditure was assessed against indirect calorimetry in a group of 86 older adults (mean age ~71 years). Both accelerometers significantly misestimated energy expenditure.

Miller et al. (43) examined the criterion-referenced validity of the hip-worn ActiGraph to measure treadmill walking and running for adults ages 20 to 29 years, 40 to 49 years, and 60 to 69 years, and found no differences in accelerometer output (expressed as cpm) across age groups for a given walking or running speed. These results highlight that age may not be an important factor in using objective monitoring with healthy older adults when evaluating accelerometer data output. No consensus exists on applicable cutpoints to delineate physical activity intensity for older adults.

Other criterion-referenced validation studies exist among older adults that have employed doubly-labeled water. Starling et al. evaluated the Caltrac in a sample of women up to age 84 years (64), and showed the Caltrac significantly underestimated PAEE under free living conditions. Meijer et al. (42) evaluated a triaxial low-back-worn accelerometer and found strong correlations with doubly-labeled water (r=0.78).

Adults with Functional Limitations

Studies employing indirect calorimetry as a criterion-referenced calibration standard against objective monitoring are fairly scarce in this population. Ekelund et al. evaluated an ActiGraph worn on the lower back in a group of patients with coronary artery disease during level walking (15). Accelerometer counts were significantly correlated with speed (r=0.92), measured oxygen consumption (r=0.87), and energy expenditure (r=0.85). Equations to derive energy expenditure, using body weight and accelerometer counts, explained 75% of the variance in measured energy expenditure, and mean differences (-0.2 kcals/min) between measured and predicted energy expenditure values were not significant. The individual limits of agreement were greater, a finding generally consistent with the overall accelerometry literature in any population, which suggests that estimates are better for group or pooled data than they are for individuals. A follow-up study by Focht et al.(22) also examined the validity of a hip worn ActiGraph, among older adults with documented chronic disease. Results confirmed those of previous studies, reporting strong significant correlations between accelerometer data and indirect calorimetry. Free-living investigations comparing objective measures to doubly-labeled water also have found strong correlations between energy expenditure and data obtained from the Caltrac in older adults with peripheral arterial occlusive disease (r=0.8) (24) and data obtained from a triaxial accelerometer in adults with chronic low back pain (r=0.7) (73).

Comparison of objective monitors with direct observation is another approach that has been used to establish criterion-validity, including visual analysis of simultaneous video recordings (6) and motion capture systems in a laboratory environment (27). This latter approach is particularly useful if raw movement or motion is the objective monitoring outcome desired. Gironda et al. (27) compared motion and acceleration scores from the

Actiwatch placed at three sites (wrist, waist, and ankle) with an optical three-dimensional motion capture system for typical physical therapy exercises and a walking trial. Overall, all accelerometer site placements were significantly associated with the motion capture system, but different placements performed better depending on the task undertaken.

Studies such as these continue to contribute to the scientific knowledge in this area. Other studies have reported on aspects of reliability adding much needed content to this growing literature set (27).

Strengths and Weaknesses of Validation and Calibration Studies

Existing validation and calibration studies have strengths and weaknesses that are important to consider. A large validation and calibration literature base exists, but this literature base is considerably more developed for children than in older adults or adults with functional limitations. A strength of the existing literature is that many studies have employed rigorous designs with appropriate criterion-reference standard measures. Although the validation and calibration literature is expanding, it is questionable whether the creation of additional single-regression prediction equations can assist with moving the field forward. Having too many equations creates a “cutpoint conundrum” and leaves researchers and practitioners wondering which set is “correct,” particularly when they yield vastly different answers when classifying physical activity intensity. Unfortunately this issue has no one good solution. Predicting physical activity behavior from single-regression equations may be too simple an approach to use in examining complex physical activity behaviors. Walking calibration studies conducted in the laboratory work well for walking and locomotion, but may misclassify other types of activity (12).

Although it is commonly recognized that validation and calibration studies should be population-specific, it is not known how specific they truly need to be. The answer depends on the outcome variable of interest. For instance, Miller et al. (43) demonstrated that age is not a classifying variable for calibration, as they saw no differences in raw accelerometer output across multiple walking speeds spanning different ages in healthy adults. But the role of age is not clear when attempting to classify physical activity levels or derive energy expenditure, and the issue is considerably more complex when considering individuals with functional limitations and children and adolescents who are undergoing growth and maturation. Knowing that the mechanical efficiency of an activity can be markedly changed across different populations, employing prediction equations generated on one population and applying to another is likely to produce erroneous estimates of activity.

Consensus on site placement also is needed. Although, there appears to be a good agreement within the child and adult literature that waist-mounted devices are the site placement of choice, this does not extend to all populations. Specific site placement studies in individuals with functional limitations are lacking, thereby limiting conclusions that can be drawn. A good example of this pertains to recent studies published in *Arthritis & Rheumatism*. In 2008, two papers were published on activity levels in individuals with osteoarthritis (19, 45). Both studies used different activity monitors, employed different site placements (one on the wrist, the other on the waist), and reported different outcomes (raw movement and time spent in physical activity intensity levels). Results of these studies are not comparable, limiting the ability to pool studies to draw conclusions about activity levels in this population.

Along similar lines, standard time sampling intervals (epoch lengths) are not uniformly applied. Researchers believe that young children are active in shorter, potentially more intense bouts of activity than are older children and adolescents. Part of the problem is that the effects of growth and maturation have not previously been accounted for in existing studies. Maturation is subject to timing (when it occurs) and tempo (rate at which it occurs) (3). Thus, variance in variables such as limb segment length, muscle activity, and neural development could all play significant roles in locomotor patterns at different ages.

BEST PRACTICES

In light of the strengths and weaknesses of the use of objective monitoring in youth and underserved populations, we recommend several best practices to move this field of research forward.

- Always clearly define the outcome of interest when determining how to use objective measures of activity.
- Discontinue the creation of single linear regression calibration equations and count cutpoints. The addition and repetition of studies in this area presents confusion.
- Establish and employ standard methods for obtaining, cleaning, and analyzing data for all activity monitors. Clearly outline this in all disseminated work.
- Employ shorter time sampling intervals (epoch length). To date, data obtained by 1-second epochs may not be informative on their own but can be summed to create 10-, 15- , or 30-second increments until the field develops a better understanding of data obtained from short sampling intervals.

FUTURE DIRECTIONS

Here we suggest avenues that could be pursued to advance future research in physical activity monitoring among these and other understudied populations.

- Adopt more complex mathematical modeling strategies for detecting patterns of movement, such as hidden Markov models and artificial neural networking. In addition to improving prediction of outcomes such as energy expenditure, these models also have the capability to identify specific activities. The type of activity may be a more appropriate outcome for some studies, rather than the amount of energy expended.
- Gain understanding about how transitions between activities affect accelerometer output and the agreement between device output and criterion measures of energy expenditure.
- Direct efforts to study children and adolescents with mental or physical disabilities, pregnant women, toddlers, obese individuals, and adults with chronic medical conditions, and how differences in these population subgroups affect monitor output.
- Explore the effects of growth and maturation on monitor output.
- Explore classifying groups where appropriate. For instance, gait speed could help classify many different functional limitations. Such an approach, or better methods for classifying individuals could remove the need for multiple population-specific algorithms.
- Account for relative and absolute intensity differences in studies. Given the differences in physical fitness level in the population, a difference typically highlighted with aging or functional limitations/disability, this effort becomes paramount.
- Encourage research groups to work in unison rather than in isolation to foster progress and optimize the use of objective monitoring in diverse populations.

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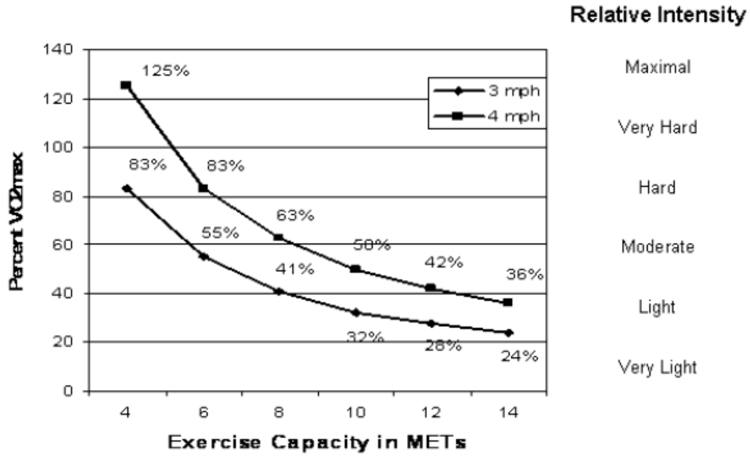

Figure 1.

Differences between absolute and relative intensity for selected walking activities across different levels of physical fitness. Adapted from the Physical Activity Guidelines Advisory Committee Report, 2008 (http://www.health.gov/PAGuidelines/committeereport.aspx)