Practical physical activity measurement in youth: a review of contemporary approaches

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Background: **The accurate evaluation of physical activity levels amongst youth is critical for quantifying physical activity behaviors and evaluating the effect of physical activity interventions. The purpose of this review is to evaluate contemporary approaches to physical activity evaluation amongst youth.**

Data sources: **The literature from a range of sources was reviewed and synthesized to provide an overview of contemporary approaches for measuring youth physical activity.**

Results: **Five broad categories are described: self-report, instrumental movement detection, biological approaches, direct observation, and combined methods. Emerging technologies and priorities for future research are also identified.**

Conclusions: **There will always be a trade-off between accuracy and available resources when choosing the best approach for measuring physical activity amongst youth. Unfortunately, cost and logistical challenges may prohibit the use of "gold standard" physical activity measurement approaches such as doubly labelled water. Other objective methods such as heart rate monitoring, accelerometry, pedometry, indirect calorimetry, or a combination of measures have the potential to better capture the duration and intensity of physical activity, while self-reported measures are useful for capturing the type and context of activity.**

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Key words: **accelerometer; instrument; measurement; physical activity; youth**

Review article

Introduction

The accurate evaluation of physical activity levels amongst youth is critical for quantifying physical activity behaviors and evaluating the effect of physical activity interventions.[1] Accurate physical activity measures are a necessity in studies designed to document the frequency and distribution of physical activity in defined population groups, determine the volume and intensity of physical activity required to influence specific health parameters, identify the psychosocial and environmental factors that influence physical activity behavior in youth, monitor secular trends in behavior, and to evaluate the effectiveness of interventions to increase habitual physical activity.[1-3] This review focuses on physical activity evaluation approaches amongst youth aged 6-18 years.

Quantifying physical activity levels in free-living children and adolescents can be an extremely difficult undertaking. Unlike other health behaviors, physical activity lacks a precise biological marker, with cardiorespiratory fitness a moderate correlate at best.[4] Nonetheless, access to precise and user-friendly tools to measure physical activity amongst youth is critical for those looking to implement or evaluate interventions for increasing physical activity to address this key public health priority.[5] Selection of an appropriate physical activity measure depends not only on the specific purpose of evaluating physical activity, but also the characteristics of the population and the specificity with which type, duration, frequency, and intensity are to be evaluated.[4] Monitoring the physical activity levels of youth requires a valid measure that is

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age appropriate, easy to administer, and poses minimal participant burden.[6] A wide range of methods have been used to measure physical activity in children and adolescents.[7]

There is currently no "gold standard" approach for measuring all aspects of physical activity (energy expenditure, duration, intensity, context, etc). Therefore, the choice of validation standard is an important consideration for studies of physical activity assessment modalities.[1] The doubly labelled water technique represents an unobtrusive and non-invasive means to measure total daily energy expenditure in free-living children and adolescents.[8] When combined with the measurement of resting energy expenditure, the doubly labelled water technique can be used to estimate energy expenditure related to physical activity, and has been considered to be the "gold standard" and most valid and reliable criterion for the determination of energy expenditure under free-living conditions.[4,8-10] The doubly labelled water method is based on the kinetics of 2 stable isotopes of water, $2H_2O$ (deuterium-labelled water) and $H_2{}^{18}O$ (oxygen-18-labeled water). Deuterium-labelled water is lost from the body through the usual routes of water loss (urine, sweat, evaporative losses). Oxygen-18-labeled water is lost from the body at a slightly faster rate because this isotope is also lost via carbon dioxide production in addition to all routes of water loss.[4] The difference in the rate of loss between the 2 isotopes is therefore a function of the rate of carbon dioxide production, which is a reflection of the rate of energy production over time.[11]

Despite the accuracy of this biological measurement approach, there are limitations associated with the doubly labelled water technique. These limitations include excessive cost, difficulty in obtaining the stable isotopes of water, inability to assess activity patterns or partition the energy expenditure associated with physical activity, participant burden, and the logistics related to multiple urine collections and laboratory visits.[1,2,8] For this reason, doubly labelled water is primarily used in well-resourced research activities rather than health promotion or initiatives led at a school level.[9,12-14] Additionally, the doubly labelled water technique fails to capture the duration and intensity of physical activity, and cannot provide information regarding the type or context of physical activity behavior. It is for these reasons that a number of other approaches have been developed for measuring physical activity amongst youth populations. These can be broadly grouped into five categories: self-report, instrumental movement detection, biological approaches, direct observation, and combined methods.

Self-report methods

Self-report measures of physical activity are methods whereby participants either record or recall their activity over a given time frame. Recall time frames from as little as 1 day[15-17] to as much as 1 year[18-20] have been reported amongst youth. Self-report measures are commonly used in epidemiological research and surveillance studies.[5] They have a practical advantage over other approaches for studies with large sample sizes and restrictive budgets due to their relative ease of administration and low cost.[21] However, given that the reliability and validity of self-reported data are dependent on recall of prior activity, there may be some compromise on the accuracy of these results.[22]

Numerous questionnaires have been developed for varying populations, including youth, with considerable differences in length, type of activities reported and recall period used.[7,22] Due to the diversity in available questionnaires, it is not necessarily an easy task for researchers, educators and health professionals to determine which instrument is most suitable for their purpose. Three examples of widely used self-report instruments requiring differing recall timeframes include the International Physical Activity Questionnaire (IPAQ),[23] the Physical Activity Diary,[24] and the Previous Day Physical Activity Recall (PDPAR).[16]

International Physical Activity Questionnaire (IPAQ)

The IPAQ was designed by a multinational working group, for use as a universal instrument in epidemiological studies.[23] It is a self-report instrument that records the duration of physical activity for a habitual or past week. The short-version (9 items) is a dimension-based instrument, structured to capture 4 forms of physical activity, being vigorous, moderate, walking, and sitting.[23] The long-version (31 items) collects detailed information within the domains of household and yard work, occupational, self-powered transport, leisure-time, and sedentary activity.[23] The IPAQ has been used widely with mixed results in adolescents.[25-28] Rangul et al[25] administered the short version of the IPAQ twice amongst youth samples (8-12 days apart) to measure reliability. Interclass correlations ranging between 0.10-0.62 were reported between assessments across the various domains. Overall, findings from that study indicated moderate test-retest reliability. However, criterion validity was not strong amongst adolescents with predominantly weak Spearman's correlation coefficients between the physical activity intensity reported in the IPAQ and VO^2 Peak (r = 0.02-0.32), total energy expenditure (r

= -0.02-0.24), and physical activity level (r = 0.01-0.43) measured using an ActiReg activity monitor (an instrument that uses combined recordings of body position and motion to calculate energy expenditure and physical activity) over 7 consecutive days. Studies are yet to be conducted, validating energy expenditure derived from the IPAQ against the doubly labelled water technique, or examining the responsiveness of these instruments amongst youth samples.

The International Physical Activity Questionnaire for Adolescents (IPAQ-A) was developed from the IPAQ (long version) for use in adolescents. This adapted version also measures physical activity over the previous 7 days.[29] Questions about physical activity at work were replaced by physical activity at school, and it includes only 1 question about physical activity in the garden or at home (the IPAQ contains 3 questions in this area).[29]

Ottevaere et al[30] tested the IPAQ-A against an accelerometer and a non-wear activity diary, and found that the correlation coefficient between the IPAQ-A and accelerometer data increased when non-wear activity diary data were included.[30] Hagstromer et al[29] divided their sample into 2 groups of 12-14 year olds and 15-17 year olds, and administered both the IPAQ-A and accelerometers. Significant associations between the IPAQ-A and accelerometers amongst the older age group were observed for time spent walking, moderate and vigorous activities, as well as for total physical activity (r = 0.17-0.30).[29] However, these associations were not significant amongst the younger group.[29] These results indicate the need for more validations of the IPAQ-A using enhanced criterion measures (such as doubly labelled water) to further determine its appropriateness for measuring adolescent physical activity. Additionally, the reliability and responsiveness of the IPAQ-A amongst self-reporting youth have yet to be investigated and remain a priority for future research. In spite of this need for further validation, the IPAQ-A may well be a logical choice over the IPAQ (long or short adult version) for use amongst older youth given the commonsense nature and face validity of the modifications and the less than optimal reliability and criterion validity reported for adult versions of the IPAQ administered amongst youth.[25,28]

Physical Activity Diary

Keeping a regular physical activity diary for a set period of time is one approach that may overcome possible shortcomings of instruments requiring a retrospective recall of physical activity performed over a 7-day period (such as the IPAQ). A common method for physical activity diaries was first reported by Bouchard et al.[24] Bouchard's 3-day activity record was designed to estimate energy expenditure. The three-day summary includes any two weekdays and one day from a weekend, providing a more frequent recording of daily activities. Each day is divided into 96 periods of 15 minutes each. For each 15-minute period, energy expenditure is qualified on a scale from 1 to 9. Approximate median energy cost for each of the nine categories in kcal/kg per 15 minutes is applied to compute daily energy expenditure for each individual.[24] The Bouchard physical activity diary has been shown to have moderate correlations (r = 0.33-0.35) with accelerometers.[31] However, there have not been validation studies using doubly labelled water as a criterion measure amongst youth samples. Additionally, reliability and responsiveness of the Bouchard diary are also yet to be investigated amongst youth samples.

Physical activity diaries have the potential to provide valuable information regarding the amount and context of youth physical activity. However they have not been as widely used in physical activity research as other approaches.[22] Hofferth et al[32] found that diary estimates of the amount of time spent in active pursuits had a moderate yet significant association with moderate to vigorous physical activity measured by accelerometer counts (r = 0.37). The authors concluded that while self-reported physical activity diaries have merits, accelerometer measured physical activity levels are likely to be a more accurate indication of actual physical activity undertaken. Physical activity diaries are inexpensive and may have some accuracy advantages over instruments requiring a long recall.[21] However, they are considered less accurate than accelerometer data and the participant burden required to frequently record in the diary may result in some missing data amongst youth populations, or in certain contexts where frequent diary reporting may not be feasible.

Previous Day Physical Activity Recall (PDPAR)

An example of a self-report method for youth that has found middle ground between week long recall and frequent physical activity diary entries is the Previous Day Physical Activity Recall (PDPAR). The PDPAR is a self-report instrument designed specifically for the cognitive abilities of children and adolescents.[16] To help children and adolescents recall their past behavior more accurately, the previous day is divided into 30-minute time blocks that, in turn, are grouped into broader time periods such as morning, lunchtime, afternoon, and evening.[16] The list of activities appearing in the PDPAR can also be modified to accommodate the activity interests and cultural norms of different population groups.[4] Significant favorable findings of inter-rater reliability (r = 0.99) and test-retest reliability (r = 0.99) have been reported for the PDPAR. Similarly indicators of criterion validity with step count (pedometer) and measurement of body movement (accelerometer) are favorable (r = 0.88 and r = 0.77 respectively). The association between PDPAR and mean percentage heart rate reserve for 30 minute intervals has been reported as higher across subjects (r = 0.53) than within subjects (mean r = 0.32).[16] This suggests that participants could recall with accuracy the mode and intensity of their activity, but not necessarily the correct 30-minute block. A three-day version of the PDPAR, known as the 3-Day Physical Activity Recall (3DPAR), is now also used widely.[33-36] The flexibility of the PDPAR and 3DPAR has contributed to their use in numerous observational and intervention studies.[6,33-46] Several studies have reported favorable validity, reliability, and responsiveness in physical activity behavior[47,48] across a number of regions.[6,16,33,36,46] However, energy expenditure derived from either of these instruments has not been validated against the doubly labelled water technique.

Recalling physical activity is a complex cognitive task requiring retrieval of information about historical activity events, intensity and duration. The accuracy of this recollection may be questionable in some cases, particularly if the recall time is lengthy. Youth have a physical activity pattern that is much more variable and intermittent than that of adults,[49] and they are less likely to make accurate self-report assessments due to developmental differences, especially in the ability to think abstractly and recall detailed activity information.[21,50] Self-report methods may be subject to considerable recall bias, and caution must be exercised when attempting to use self-report instruments in children aged 10 years or younger.[1] It may help to include a practice administration in an effort to help familiarise youth with the survey procedures. Furthermore, multiple administrations of the instrument may be needed to obtain reliable estimates, due to the substantial intra-individual day-to-day variability in youth physical activity behavior.[6] Although available evidence indicates that self-report methods provide acceptable estimates of relative physical activity behavior in older groups of children, where possible more sophisticated measures of physical activity and sedentary behavior should be used, such as accelerometers, or direct observation.[6]

Instrumental movement detection methods

Instrumental measures with real time data storage capabilities offer a distinct advantage over self-report methods, in that they provide reliable information on patterns of physical activity within a given day or over several days.[51] While measuring physical activity in children and adolescents, it may be helpful to include an objective measurement tool to avoid dependency on recollection of previous activity information.[52] There has been an increased focus on the development, validation, and application of new tools to objectively monitor physical activity behaviors over the past two decades. As a result, there has been a rapid increase in both the number and type of objective physical activity assessment instruments.[53]

The wide range and availability of movement detection instruments to measure physical activity may lead to difficulty in selecting the most suitable instrument for the desired context of activity measurement.[54] Instrument selection may be complicated for those who study youth physical activity due to: (1) the challenges associated with detecting the typically short and sporadic nature of children's physical activity patterns;[49] (2) the range of developmental maturity/age among potential participants; and (3) inherent curiosity regarding wearable technologies and the associated potential for reactivity to monitoring. As a result, researchers and practitioners at times may make under-informed choices with regard to instrument selection.[54] Two widely used physical activity measurement instruments that are commercially available to researchers, practitioners, and consumers are accelerometers and pedometers.[53]

Accelerometers

Accelerometers are devices that measure body movements in terms of acceleration, which can then be used to estimate the intensity and duration of physical activity over time. Most contemporary accelerometers comprise piezoelectric sensors that detect acceleration(s) in one, two or three orthogonal planes (anteroposterior, mediolateral, and vertical). Processed data can be recorded to internal memory and then downloaded to computer based software for further analysis.[53] The raw outputs of physical activity monitoring accelerometers are known as counts. Counts can be produced in a number of ways: (1) as a digital counter which accrues the number of times the signal crosses a preset threshold, (2) via an algorithm to establish the maximum value for a selected period (otherwise known as an epoch) to represent the count for that time window, or (3) an area under the curve (integration or average) algorithm.[53] Regression analysis can then be implemented to establish ranges of accelerometer counts (cut-points) corresponding to predefined intensity levels.[55] Three examples of widely used accelerometer intensity cut-points for youth are those by Puyau,[56] Freedson,[55] and Ekelund.[57]

Accelerometry-based motion sensors have become one of the most commonly used methods for assessing physical activity in free-living individuals.[2] They can be used to evaluate the frequency, intensity, and duration of physical activity over specified time intervals such as days or weeks.[8] Their small size, robust design features, and relatively modest cost make them particularly attractive to investigators quantifying activity behavior in children and adolescents.[8] They may also present less burden to participants relative to other measures (such as heart rate monitors with electrodes and chest straps).

Evidence has shown that 7 days of wearing time are required for accelerometer data to have acceptable reliability.[51] Monitoring must also be performed continuously over this period of time, as it is important to ensure that both weekdays and weekends are included.[51] Accelerometer data have been shown to have a significant moderate association with doubly labelled water ($r = 0.39$),[9] and a strong positive and significant association with oxygen uptake (as a criterion measure of physical activity) in simulated free-living conditions both indoors and outdoors ($r = 0.77$).[58] Accelerometers have also shown to be responsive to different levels of intensity when tested amongst youth samples in laboratory settings.[59]

There are several recognized limitations of accelerometers. This includes their inability to account for the increased energy cost associated with walking up stairs or an incline, accurately measure activities such as cycling, lifting, or carrying objects,[2,8,55] and differentiate well between sitting and standing.[60] However, it has been proposed that the contribution of these activities to the overall physical activity in free-living youth is small. Additionally, the outputs from accelerometers can vary, based on the equations used to interpret accelerometer data, and the subsequent cut-point values.[46] This lack of standardization continues to plague physical activity research, particularly amongst youth samples.[61] Consequently, numerous studies using accelerometers have analysed their data providing options for a number of different cut-points.[30,46,62] Because of these limitations, accelerometers may underestimate total or physical activity energy expenditure in comparison to doubly labelled water.[9]

Pedometers

Pedometers offer a simple and low cost estimate of total volume of physical activity which is measured as the number of steps taken.[54] The electronic circuitry within a pedometer accumulates steps and displays this information on a digital screen. The majority of pedometer instruments currently available detect steps using a horizontal, spring-suspended lever arm which moves up and down with vertical accelerations of the hip.[63] An event (step) is recorded when a sufficiently forceful (above the sensitivity threshold of the specific pedometer) vertical hip acceleration deflects the lever arm to complete an electronic circuit.[63] Recently, piezoelectric pedometers have emerged within the commercial market. Briefly, this mechanism consists of a horizontal suspended beam and a piezoelectric crystal which directly measures vertical accelerations (similar to that of most accelerometers), recording a step if detected above manufacturer-defined sensitivity thresholds.[54,64]

There is some consensus among researchers that a cumulative record of steps over the course of the day is a suitable and effective gross indicator of the physical activity of youth.[4,52] Favorable findings in support of pedometer usage as a valid and reliable tool for assessing youth in free-living conditions have been reported.[65] Physical activity energy expenditure calculated from pedometers has a moderate correlation with energy expenditure calculated from the doubly labelled water method[66] and has demonstrated responsiveness to changes in physical activity amongst youth samples.[67] Pedometers have similar limitations to accelerometers in that they are quite insensitive to some forms of movements. The primary limitation however, when making comparisons between the two, is that pedometers are unable to record the magnitude of the movement. This means that any movement above a given threshold is counted as a step regardless of whether it occurs during walking, running, or jumping.[1,2] This is not the case with accelerometers, which can detect not only when that movement occurred, but also the intensity and duration of movement.

Pedometers are generally not designed to detect specific intensity categories (e.g., time in moderate to vigorous physical activity) and therefore are not an appropriate choice for end users whose specific research questions are focused on these parameters. With this in mind, pedometer manufacturers are beginning to offer additional features intended to provide estimates of activity time (e.g., accumulated time of stepping) and also time in moderate to vigorous physical activity (e.g., time accumulated above a specified stepping cadence).[54] However, further high-quality research is required before the assertion of validity and reliability of these pedometers for assessing physical activity intensity amongst children and adolescents can be made. A key feature of accelerometer-based activity monitors is their real-time storage capabilities. However most pedometers used in schools and health promotion programs do not possess real time storage capacity, and must rely on the participant's ability to record information at specific times (commonly at the end of each day).[4]

Biological methods

Biological measures rely on the detection of physiological processes associated with physical activity. This may be detected through the use of an instrument worn on the body (such as a heart rate monitor), or through as series of biological tests (such as doubly labelled water). Additionally, calorimetry is also a popular biological approach to measuring physical activity (and energy expenditure) amongst youth. The amount of physical activity undertaken over a set period of time can be extrapolated from the changes observed in the biological markers of interest.

Calorimetry

Direct calorimetry provides accurate assessments of energy expenditure via the amount of heat produced by participants. However, direct calorimetry requires that participants be sequestered in special chambers, making its use expensive and limiting participants to specific tasks. This makes the use of direct calorimetry impractical for studies of larger samples or for measuring free-living physical activity.[68]

Open-circuit indirect calorimetry measures energy expenditure from oxygen consumption and carbon dioxide production. Indirect calorimetry is used extensively and considered an accurate and valid measure of short-term energy expenditure during rest and exercise.[68,69] It is the most common criterion measure in laboratory-based studies, with doubly labelled water the most common in field-based studies.[55,70] Measurement of physical activity by means of indirect calorimetry requires that the participant wears a face mask or a mouthpiece with nose clip, and a container for the collection of expired air.[68] Due to the non-portable nature of the gas analysis equipment required, this method is impractical for studies of free-living conditions as they may alter or inhibit normal physical activity patterns.[22,68,69]

Heart rate monitors

Heart rate monitors provide an objective indicator of the physiological effect of physical activity. The devices are relatively inexpensive and can provide multiple-day storage capacity for minute-by-minute heart rates, which have made them a feasible method for assessing physical activity in children and adolescents.[71] Heart rate monitoring remains an attractive approach to assessing physical activity because of the linear relationship between heart rate and energy expenditure during steady-state exercise.[72,73] It has also received favorable findings when compared to the doubly labelled water technique.[72] However, there are a number of problems associated with this method. First, it is widely recognized that factors such as age, body size, emotional stress, cardiorespiratory fitness, and proportion of muscle mass used influence the relationship between heart rate and the volume of oxygen consumed (used to assess energy expenditure during physical activities).[8,74] Second, heart rate response tends to lag momentarily behind changes in movement and tends to remain elevated after the cessation of movement. This may mask the sporadic and intermittent activity patterns of children and adolescents,[75] affecting the precision and responsiveness of the instrument. Third, a large percentage of a child's day may be spent performing relatively stationary activities (such as school-based activities like sitting in a classroom). For these reasons heart rate monitoring may be of limited use in assessing total daily physical activity. These issues may contribute to considerable error when heart rate monitors are used for extended periods of monitoring.[8] However, techniques have been devised to address some limitations of heart rate monitoring. This primarily includes the use of heart rate indices that control for individual differences in resting heart rate and individualized heart rate to VO^2 calibration curves.[1,2]

In an effort to improve the precision of heart rate-derived estimates of free-living energy expenditure, several investigators have used a combination of heart rate monitoring and accelerometry.[1] Treuth et al[76] tested the validity of this approach in children by comparing energy expenditure estimated by a combination of heart rate monitoring and accelerometry to energy expenditure measured by whole-room calorimetry. Given the small magnitude of error, the authors concluded that the combination of heart rate monitoring and accelerometry provided an acceptable method for estimating energy expenditure not only for groups of youth but for individuals as well. However, increased burden placed on participants from wearing more than one device must also be taken into consideration.

Direct observation

The final broad non-combination approach to measuring physical activity is direct observation. This involves witnessing physical activity behavior while generally recording it on a coding form or through a handheld computer device to give an instantaneous rating of a child's physical activity level.[77] Direct observation has been used in a variety of naturalistic settings such as in home and school settings.[78-81] It is especially useful for studies of young children who have not yet developed the cognitive ability to accurately recall detailed information.[82] Additionally, direct observation itself has been considered as an appropriate criterion measure for the measurement of youth physical activity.[69]

Relative to other methods, direct observation has a number of important advantages. Observational procedures are flexible and allow researchers to quantify physical activity in relation to actual context or environment such as behavioral cues, availability of equipment, and presence of significant others.[83] Given its inherent flexibility, observation of physical activity can be used as either a process or outcome measure, and can therefore be useful to both researchers and practitioners. Direct observation has been shown to be a valid and reliable approach to measuring physical activity in children. McKenzie[84] reviewed 9 different protocols for observing physical activity behavior in children, with 8 of the 9 protocols having strong evidence of concurrent validity using accelerometry, heart rate monitoring, or energy expenditure assessed by indirect calorimetry as criterion measures. Additionally, inter-observer reliability was strong with reported kappa values greater than 0.90.

Direct observation has several limitations. It can be very expensive (labor intensive), and therefore may be impractical for studies requiring long periods of observation or using large populations. However, direct observation remains a useful approach when participants are confined to a defined space (e.g., classroom, school playground or gymnasium, home, or practice field).[83] Direct observation may be particularly useful when the influence of physical and social environments on youth activity behavior is under investigation.

Combination methods

Researchers looking to obtain accurate physical activity data may benefit from combining multiple approaches. Ottevaere et al[30] found a slightly stronger association between the IPAQ-A and accelerometer counts of physical activity when the accelerometer data were enhanced in combination with a non-wear activity diary. Going et al[50] used tri-axial accelerometers to measure the amount of activity, while using a specifically designed 24 hour physical activity recall questionnaire for assessing the frequency and type of activities in school children. Haerens et al[85] used a questionnaire in a total sample, while using accelerometers in a subsample to measure physical activity amongst adolescents to evaluate the effects of a physical activity intervention. Instruments incorporating combination measures of physical activity are also being made commercially available. One such device that integrates motion sensor data with a variety of heat-related sensors to estimate the energy cost of free-living activity is the SenseWear Armband.[53,86] It contains a series of sensors measuring accelerometry, heat flux, galvanic skin response, skin temperature, and near-body ambient temperature,[53] and has recently been shown to yield accurate assessments of energy expenditure in youth when compared with the doubly labelled water method.[87]

Emerging technologies

Other devices have been developed, which have potential to measure youth physical activity, while also being used as health promotion tools. The Gruve tri-axial accelerometer is a clip-on physical activity monitor whereby data are synchronized with the internet to measure the wearer's caloric intake and personal progress. The individual's progress is indicated by a changing LED color light at the top of the device. If the wearer's physical activity progress is below the set pre-determined goal, the monitor will vibrate as a reminder.[88] The Gruve monitor has been shown to reliably distinguish between sedentary and walking activity in laboratory conditions.[89] Another similar monitor is the Directlife tri-axial accelerometer (based on the Tracmor).[90,91] Directlife is lightweight (12 g), waterproof up to 30m depth, has a battery life of 3 weeks and an internal memory that can store data for up to 22 weeks.[92] The monitor also contains an indicator bar of light-emitting diodes showing the achievement of the day in terms of amount of physical activity as determined by pre-set goals. While the Directlife monitor has been shown to accurately assess energy expenditure when compared to doubly labelled water in adult populations,[90] these devices are relatively untested amongst youth in free living conditions, and further validation is a priority for future research.

Priorities for future research also include investigations reporting on practical information relating to the feasibility, not just the scientific validity or reliability of physical activity measurement approaches. For example, the ability to mail out physical activity measurement instruments to participants in remote locations would increase the feasibility of remote physical activity instrumental monitoring. However, the expected rate of instrument or data loss is currently unknown and is likely dependent on several factors (none of which have been investigated). The advancement of instrumental measurement approaches and their continued migration into commercial devices marketed for public and research usage, intensifies the need for researchers (independent of commercial entities) to validate these devices.

Conclusion

There will always be a trade-off between accuracy and available resources when choosing the best approach to measuring physical activity amongst youth. Unfortunately, cost and logistical challenges may prohibit the use of "gold standard" physical activity measurement approaches such as doubly labelled water. However, other objective methods such as heart rate monitoring, accelerometry, pedometry, indirect calorimetry, or a combination of measures have the potential to capture the duration and intensity of physical activity, but do not capture information about the type or context of this activity. Self-reported measures can capture the type and context of physical activity and have a practical advantage over other approaches due to their relative ease of administration and low cost. These practical advantages may come at the expense of precision due to dependence on recall of detailed historical activity information. However, this compromise is likely to be justified amongst large samples if the purpose of physical activity evaluation does not require a high degree of measurement precision for each individual.

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