The term ‘physical activity’ has been described as referring to any bodily movement produced by the skeletal system and muscles that results in energy expenditure\(^1\). Free-living physical activity behaviours in children and adolescents are considered one of the most complex domains to assess. Usually, physical activity domains include all types of activities performed during free-time or leisure-time, transportation activities, all tasks performed in the home environment, physical education sessions and break-time at school. Further, physical activity behaviours can be characterised according to the dimensions of type, intensity, frequency and duration. Thus, measuring physical activity behaviours in children and adolescents is extremely difficult, making it necessary to have valid and reliable tools that are capable of including all of the relevant dimensions and domains\(^1\).

Several classification units are used in measuring physical activity behaviours. These include the ratio of the activity energy expenditure to the resting energy cost, oxygen consumption per unit of body mass per unit of time (mL/kg/min), multiples of resting metabolism or ‘metabolic equivalents’ (METs)\(^4\), duration of activity bout spent at sedentary, light, moderate and vigorous intensity levels and the total time spent in bouts of moderate-to-vigorous physical activity (MVPA) combined\(^1\).

**SELF-REPORT MEASURES**

Self-reporting is one of the most common subjective methods used in epidemiological and surveillance studies. When surveying children, this method includes self-administered recalls, interviewer administered recalls, direct and proxy reports completed by either parents or teachers. Self-report measures vary considerably with respect to the quantity and quality of information they can provide for the type, frequency, duration and intensity of the activity. Available evidence indicates that self-report measures have many advantages such as the ability to record physical activity type and context in a historical way, at low cost and with ease of administration\(^1\). Despite the positive points of self-report methods, studies have documented that children aged 10 years and younger are unable to recall their previous activities accurately\(^6,7\) because the activity bouts are often very short and spontaneous, making recall difficult\(^8\). Janz et al\(^9\) illustrated that self-report questionnaires completed by young children had a poor-to-moderate correlation for activity level compared with objective measurement (accelerometers) \(r=0.03\) compared with \(r=0.51\). Children were also unable to quantify the duration of the activities they had performed\(^6\). Sallis et al\(^7\)
evaluated 23 self-report measurements and illustrated that on average children had lower reliability and validity coefficients compared to adolescents when using self-report measures. Further, it was found that children aged 10 or younger did not understand the concept of physical activity. Trost investigated the ability to understand the concept of physical activity in Year 4 (8 year-old) children. Results suggested that 60% of Year 4 children were unable to differentiate between sedentary activity (e.g. computer games) and active leisure pursuits (e.g. outdoor games). Children are less able than adults to self-report physical activity, as they have lower cognitive function than adults, making them less accurate in recalling the activity frequency, duration and intensity. Generally, self-report measurements revealed a low validity coefficient in measuring children’s physical activity. As such, it is necessary to use more appropriate objective methods to measure physical activity in children, particularly in children of primary-school age.

DIRECT OBSERVATION

Direct observation is considered one of the most appropriate means of measuring physical activity and monitoring patterns of activity. Generally, direct observation involves observing the physical activity behaviours of a child at school or at home for a specified period. Children’s physical activity behaviour is usually recorded into a coding form at a regular interval, ranging from 5 seconds to 1 minute. Typically, this method usually involves observing a child’s behaviour in real life or using video recording for a certain period. The data recorded can then be converted to a score. One of the important advantages of direct observation is the ability not only to record the activity type but to capture the activity pattern, frequency, duration and intensity, as well as the physical and social context (i.e. environment) in which the physical activity occurs.

There are several different observational systems available to measure physical activity. A number of these systems are specific for use during physical education sessions, including the Children’s Physical Activity Form (CPAF) and the System for Observing Fitness Instruction Time (SOFIT). However, other systems can be used in different settings, for example, the Children’s Activity Rating Scale (CARS), the Fargo Activity Time-sampling Survey (FATS) and the Behaviour of Eating and Activity for Children’s Health Evaluation System (BEACHES). The most recent and widely used direct-observation systems are the System for Observing Play and Leisure Activity in Youth (SOPLAY) and the Observational System for Recording Physical Activity in Children–Preschool Version (OSRAC-P). Direct observation has proven to be a valid and reliable method of measuring physical activity in children, as it has been validated against heart rate (HR) \( r=0.61 \) to 0.72\(^2\) and against oxygen uptake (VO\(_2\))\(^3\). Nevertheless, these methods are costly in due to the investment required to train observers and required length of the observation period. In addition, the
unexciting data and coding requirements are considered one of the most significant limitations to direct observation of physical activity. These methods require high experimental effort physically and financially, and this is why they are not generally used in large population studies. Children may also change their behaviours due to the presence of the observer.

DIRECT AND INDIRECT CALORIMETRY

Direct and indirect calorimetry are considered to be primary objective measures of physical activity. In fact, in 1890, Atwater and Rosa used the first direct-calorimetry measurements in humans. This method is based on measuring the heat produced by the body as a direct measurement of energy expenditure. The direct-calorimetry method uses a closed chamber attached to associated equipment where subjects can live, eat, sleep and exercise while heat production is measured. Direct calorimetry is well known as the ‘gold-standard’ measurement tool of human energy expenditure; however, in practice, it is an expensive, complex and time-consuming method and restricted to use under laboratory conditions.

The indirect-calorimetry method was developed based on the knowledge that the body’s metabolic reactions are ultimately dependent on oxygen. Therefore, measuring oxygen consumption means it is possible to provide an indirect but accurate estimation of energy expenditure that is comparable with direct-calorimetry measurements. There are two different applications of indirect calorimetry: closed-circuit and open-circuit spirometry. Closed-circuit spirometry is usually employed under laboratory conditions, as the subject needs to breathe oxygen from a prefilled container of 100% oxygen. Given the circuit is closed during the measurements, the carbon dioxide is measured in the exhaled air and oxygen consumption is recorded. One of weaknesses of the closed-circuit method of indirect calorimetry is that the subject must remain close to the circuit equipment during the measurement period, which means it is not suitable for use with field studies.

In the field, open-circuit spirometry uses a portable device that is commonly used for measuring energy expenditure. This method measures oxygen consumption by the subject directly breathing a constant composition of ambient air using a breathing valve, with the expired air exiting through a gas meter. The difference between the percentages oxygen and carbon dioxide in the inspired air and expired air indirectly expresses the energy expenditure during the monitoring period. Open-circuit spirometry uses lightweight equipment, which means there is more opportunity for it to be used under different conditions to measure different types of physical activity intensities and modes of activity, making it more versatile than closed-circuit spirometry. In addition, no differences have been found between the results provided by the direct- and indirect-calorimetry methods. As such, indirect calorimetry can be considered easier to employ and less costly compared to direct calorimetry.

DOUBLY LABELLED WATER

The doubly labelled water (DLW) technique is an objective, potentially gold-standard method to estimate energy expenditure related to physical activity in free-living children and adolescents. DLW has been well described and validated in adults and children against indirect calorimetry. Although DLW can be easily used in normal daily life, it is quite difficult to implement with children, as it is difficult to obtain consent due to the need for direct supervision/monitoring by parents over multiple days of calorimeter measurements. In addition, DLW has several major weaknesses. For example, isotopes of water are very expensive and difficult to obtain, which means this technique is not suitable for large studies. Despite the need for an accurate dietary record during measurement periods of energy expenditure, DLW does not provide any information on physical activity patterns and can only obtain the calculation of the total energy expenditure.

HEART-RATE MONITORING

HR monitoring is widely used as an objective method to measure physical activity in children and adolescents. It is also frequently used to define children’s physical activity patterns, estimate energy expenditure (both in controlled and free-living environments) and to validate other methods used to assess energy expenditure and physical activity (e.g. accelerometers). HR monitoring is a simple, relatively inexpensive method of monitoring physical activity that causes

Free-living physical activity behaviours in children and adolescents are considered one of the most complex domains to assess
little inconvenience to the subject. It is also suitable for use under laboratory and field conditions and is appropriate for use with young children as it requires no input from the child other than wearing the monitor. HR monitoring has the ability to provide multiple day, minute-by-minute (or more frequent observations of up to 5-second intervals) HR data that include the frequency, intensity, duration and exact time of day that an individual has been participating in physical activity.

Principally, HR measures the relative amount of stress that is being applied to the cardiopulmonary system by physical activity. Therefore, it does not directly measure physical activity but it is based on the linear relationship that exists between HR and VO2. The linear relationship between HR and VO2 is maintained during MVPA, and this is used to measure energy expenditure. A strong linear relationship between HR and VO2 has been reported in children. However, using this method could be less reliable at lower levels of physical activity intensity because an individual's HR can be affected by several factors during low intensity activities without a corresponding increase in energy expenditure.

To limit the influence of the above factors on the HR-VO2 relationship, the HR FLEX approach has been developed. This method is based on distinguishing between resting HR and active energy expenditure by measuring an individual's HR in conjunction with their VO2. Simply, the HR FLEX method can be defined as the calculation of both the mean of the highest HR during resting activity and the lowest HR during the activity. However, in children, the median durations of low-to-moderate-intensity and vigorous-intensity activities were found to be 6 and 3 seconds respectively. Therefore, HR responses may not be able to provide a comprehensive picture of the tempo of physical activity due to the rapid transition between activities in children.

The HR monitor's response usually lags behind changes in the body's movement and remains elevated once activity diminishes. Consequently, HR monitors should be set to record data in small interval bouts, such as 5 seconds, to capture the short, sporadic and spontaneous bursts of energy that children usually exhibit.

Generally, HR monitors have proven to be a valid method of estimating energy expenditure and monitoring physical activity patterns in free-living conditions. However, there are several limitations with HR monitoring. For example, HR data cannot provide any information on the type of physical activity undertaken. In addition, HR monitors suffer from practical difficulties such as missing data due to loss of connection. Moreover, children can interfere with the technology and view their HR response during testing, or touch the receiver buttons or remove the transmitter before sufficient data has been received. However, despite these limitations, HR monitors have been extensively used in the recent literature as an objective method for estimating energy expenditure and evaluating other instruments such as accelerometers.

MOTION SENSORS

Pedometers

A pedometer is a small device that senses the body's motion (a prototype of today's pedometer was first designed approximately 500 years ago by Leonardo da Vinci). Technically, the pedometer counts footsteps over a period using turned-pendulum technology or a 'spring mechanism' to detect vertical movement. Thus, during ambulatory movement such as walking, the spring-lever arm deflects with the up-and-down motions of the hips, and the result of detection is then digitally displayed on the front feedback screen of the pedometer.

There are many commercial electronic pedometers available; however, the DigiWalker pedometer manufactured by the Yamax Model Corporation of Tokyo is the most commonly used by researchers and has been shown to be the most accurate in step-counting.

The pedometer is an objective, simple and inexpensive device that has been found to be a reliable tool for measuring body motion through number of steps. However, compared to accelerometers (discussed later), pedometers are unable to...
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<td>Janz, 1994</td>
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<td>Trost et al., 1998</td>
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<td>Ekelund et al., 2001</td>
<td>n=26</td>
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<td>Puyau et al., 2002</td>
<td>n=26</td>
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<td>6 hours of room respiration calorimetry measured during treadmill walking at 2.5 km/hour, 3.5 km/hour, 4 km/hour, running at 4.5 km/hour, 5 km/hour, 6 km/hour, and free-living structured activities.</td>
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<td>Corder et al., 2007</td>
<td>n=30</td>
<td>ActiGraph GT1M</td>
<td>7 consecutive days measured of free-living activities.</td>
<td>ActiGraph GT1M</td>
<td>ActiGraph GT1M detected 9% lower counts per minute than that been detected by 7164 model.</td>
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<tr>
<td>Al hadabi., 2012</td>
<td>n=14</td>
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<td>10 minutes of TV-watching, arts-crafts, slow and brisk forward walking, slow backward walking, forward running, aerobics and step-ups</td>
<td>Energy expenditure</td>
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</tr>
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**Table 1:** A summary of validation studies using accelerometers to assess PA in children and adolescents. Subjects: M=male, F=female. Epoch: s=seconds. Main results: EE=energy expenditure, AEE=activity energy expenditure.
identify either the intensity or the pattern of the activity\(^n\). Moreover, the pedometer, like the accelerometer, is unable to measure non-ambulatory activities such as cycling, swimming and weight training\(^m\). It is limited in measuring type, duration, frequency and intensity of the performed activities. Studies such as Trost’s\(^l\) have illustrated that pedometer step-counts are influenced by a number of factors such as body mass, height and movement speeds, and therefore, researchers should be mindful when using pedometers with growing children.

**Accelerometers**

Accelerometers are a commonly used objective method to measure physical activity in children and adolescents\(^n,p,q,r,s\). Accelerometers measure the body’s movements in acceleration, which can then be used to determine activity counts and to estimate physical activity intensity\(^\). Acceleration directly reflects energy expenditure because it is proportional to the involved net external force\(^t\). The majority of accelerometers used for monitoring physical activity incorporate one or more piezoelectric sensors that enable the accelerometer to measure the body’s acceleration from 0.05 to 2.1 G. Human movements can then be distinguished from other vibrations by using the accelerometer’s 0.1 to 3.6 analogue passband filter, which improves the output of the signal that has been measured\(^u\). Accelerometer signals are then digitised at a sampling rate of 10 samples per second and summed over a specified time interval (epoch)\(^v\). There are two main types of accelerometers, uniaxial and triaxial. Uniaxial accelerometers measure the acceleration in one plane, which is vertical in direction, while triaxial accelerometers measure accelerations in three planes: vertical, mediolateral and anteroposterior\(^w\). However, with the wide variety of accelerometer types currently available, there is no single study that has simultaneously examined the reliability and validity of all accelerometers that currently exist\(^x\).

**Accelerometer validation**

‘Validity’ is known as the degree to which a test measures what it purports to measure (rather than measuring something else)\(^y\). In the context of accelerometers, validity refers to the process that is used to convert the raw accelerometer signals/count into significant and understandable units comparable with biological variables such as energy expenditure, VO\(_2\) and HR\(^z\). Accelerometer output data derived from these biological parameters can be used to estimate physical activity intensity levels via regression modelling and establishing a range of accelerometer cut-off points or thresholds for exercise intensity domains\(^a\). The output provided by accelerometers is based on biomechanical principles; however, converting raw data into energy expenditure or oxygen uptake is more challenging, as these are both biological parameters and this becomes more complex when children and adolescents are the target population\(^b\).

In practice, calibrating accelerometer signals into biological variables such as energy expenditure, VO\(_2\) and HR in children and adolescents can be influenced by many factors such as growth and maturation, where body mass affects the daily active energy expenditure (kcal/day). Schutz et al\(^c\) reported that metabolic economy movements in children with a high body mass resulted in the expenditure of more energy compared to children with a smaller body mass.

Many studies have validated accelerometer (ActiGraph) activity counts in both laboratory and free-living environments in children and adolescents using HR, energy expenditure and VO\(_2\) as criteria. Some studies have focused on calibrating walking and running activities using only a treadmill under laboratory conditions\(^d,e,f\). However, others have included some free-play, structured and free-living activities in the calibration process in the laboratory and field environments\(^g,h,i,j,k,l\). Table 1 provides a summary of some of the validation studies that use the ActiGraph accelerometer models 7164 and GT1M to assess physical activity in children and adolescents.

According to the previous validation studies presented in Table 1, there are different objective criteria that have been used to assess the validity of accelerometer counts in children and adolescents, for example, HR, DLW and respiration calorimetry. The majority of the studies that have been validated using the ActiGraph accelerometer model 7164 have reported a moderate-to-high correlation between the accelerometer counts and the criterion measures, ranging from 0.39 to 0.87\(^m,n,o,p,q,r,s,t,u,v,w,x,y,z\). However, Corder et al\(^u\) found that the ActiGraph GT1M detected 9% lower counts per minute than the 7164 model. Laboratory-based validation studies using locomotion activities such as treadmill walking and running only have reported a higher correlation: \(r=0.86\) to 0.87\(^m,n,o,p,q,r,s\); compared to validation studies that have included only free-living activities or studies that have combined both laboratory and free-living structured activity types, which reported \(r=0.39\) to 0.81\(^m,n,o,p,q,r,s,t\). The high level of validity shown in the laboratory studies can be interpreted as due to the measurement of ambulatory movements (e.g. forward walking and running activities), as these activities usually involve vertical movement that has been accurately detected by the accelerometers; however, free-living activity types can be more difficult to accurately record and interpret using accelerometers.

**CONCLUSION**

There is an extensive range of methods currently available to measure physical activity in children and adolescents. It is important to remain aware of their advantages and disadvantages considering factors such as cost, convenience, suitability for intended use, validity and reliability. Accurate and practical tools can be used to address key areas of scientific research such as measuring current physical activity levels, frequency and pattern of physical activity in defined population groups. These tools can assist in determining the amount of physical activity required for specific health benefits, evaluating the effectiveness of intervention programmes (particularly programmes that are designed to increase physical activity levels), and identifying the psychosocial and environmental variables that could influence physical activity behaviour in children and adolescents.