Physical Activity monitors: Limitations to measure physical activity in the free-living environment

Monitores de Actividad Física: limitaciones para medir la actividad física en la vida cotidiana

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Resumen

Teniendo en cuenta las limitaciones de los métodos de auto informe para medir patrones de actividad física con precisióny la forma poco práctica de la observación directa, a través de los años investigadores han desarrollado medidas objetivas que son válidasy confiables para estimar la actividad física. Acelerómetros y podómetros proporcionan estimaciones precisas de la actividad física en ambientes controlados y en la vida cotidiana. Sin embargo, estos dispositivos tienen limitaciones que deben ser consideradas antes de su uso. Acelerómetros proporcionan una gran cantidad de información (por ejemplo, actividad, intensidad, las estimaciones de gasto-de energía), sin embargo, son caros y requieren un gran conocimiento y habilidad técnica para ser utilizados con éxito. Podómetros requieren menos habilidad técnica y son menos costosos, pero la mayoría se limitan al número de pasos dados por un individuo.

Palabras Clave: podómetros, acelerómetros, monitores de actividad física, vida cotidiana, caminar

Abstract

Considering the limitations of self-report methods to accurately measure physical activity patters, and how impractical direct observation is, researchers have developed objective measures to estimate physical activity that are valid and reliable. Accelerometers and pedometers provide accurate estimates of physical activity in controlled and free-living environments. However, these devices have limitations that must be considered prior to their use. Accelerometers provide the most information (e.g. activity, intensity, energy expenditure estimates); however, they are expensive and require significant technical knowledge and skill for successful use. Pedometers require less technical skill and are less expensive, but their output data is limited to the number of steps taken by an individual.

Keywords: Pedometers, Accelerometers, Physical Activity Monitors, Free-Living Environment, Walking

Introduction

Accurately measuring physical activity (PA) has been important to investigators over the years. Today, surveillance systems throughout the world use objective measures to estimate secular trends in physical activity among adults and children (Hawkins & col., 2009; Riddoch& col., 2004; Tremblay& col., 2007; Troiano& col. 2008). Even though direct observation is considered the best way to measure a person's activity

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Cómo citar este artículo: Feito Y. (2013). Physical Activity monitors: Limitations to measure physical activity in the free-living environment. En: Revista Educación física y deporte. Vol. 32-2 p.1523-1532

level, this method is neither practical nor realistic; therefore, investigators have relied on self-report methods (e.g. surveys, diaries) to assess PA patterns (Sallis & Saelens, 2000). However, these methods tend to be limited, as purposeful, more intense activities are more easily recalled than everyday activities, which could provide imprecise estimates of overall daily physical activity (Ainsworth& col. 1994; Baranowski, 1988; Sallis & Saelens, 2000; Warnecke& col., 1997). Hence, researchers have suggested using devices, such as pedometers and accelerometers, which provide objective measures and can more accurately measure PA levels throughout the day (Sallis & Saelens, 2000).

Considering that walking is a common and inexpensive mode of physical activity, available to people throughout the world (Hallal& col., 2012), pedometers and accelerometers provide a small and portable way to measurement PA levels, while being minimally intrusive to an individual. The validity and reliability of these devices has been widely studied with good results (Bassett, 2000; Bassett& col., 1996; Bassett& col., 2000; Crouter& col., 2003; Schneider& col. 2004; Schneider& col., 2003), and their use in PA interventions has been shown to be beneficial (Bravata& col., 2007; Richardson& col., 2008). However, some limitations exist, which may limit the applicability of these devices for all populations (i.e. elderly, obese). Primarily, there seems to be a speed threshold below which these devices lose accuracy and tend to underestimate activity levels, as the magnitude of the vertical accelerations recorded tends to be below the devices' sensitivity thresholds (Crouter& col., 2003; Esliger& col., 2007; Rothney& col., 2008; Schneider& col., 2004). Additionally, abdominal adiposity seems to have a negative effect on some accelerometers and spring-levered pedometers, causing them to significantly underestimate PA in overweight and obese individuals. On the other hand, piezoelectric monitors do not seem to be affected by abdominal adiposity or tilt-angle, thereby making them more appropriate to measure PA among overweight and obese individuals (Crouter& col., 2005; Melanson& col., 2004; Shepherd& col., 1999). As a result of these limitations, some investigators have suggested the use of ankle-borne devices in order to avoid these limitations and provide more accurate estimates of physical activity, as these devices are not affected by slow walking speed or adiposity (Foster& col., 2005; Karabulut& col., 2005).

The purpose of this article is to identify and review several activity monitors that are most commonly used in research. In addition, it will summarize several of their limitations giving the reader a greater understanding of how these devices can be used to accurately measure physical activity in the free-living environment.

Activity Monitors

Accelerometers

The accelerometers used in physical activity research are designed to measure human movement through changes in acceleration, which can then be used to estimate PA over time. Advances in technology have allowed the development of small, portable, and minimally intrusive devices that accurately assess movement patterns and record PA and energy expenditure (Chen & Bassett, 2005; Tudor-Locke & col., 2002). However, these devices tend to have a relatively high cost, require a high level of technical expertise to access and interpret their data, as well as, the need for additional hardware and software, which may limit their usefulness for large-scale studies and most investigators (Tudor-Locke& col., 2002).

Although different type of accelerometers exists (e.g. piezoelectric crystals, piezoresistive and electronic piezoelectric sensors), most devices use a variation of a spring mass system containing a seismic mass and a piezoelectric sensor in a cantilever beam, or integrated chip sensor design. In either design, when acceleration is applied, the seismic mass responds by applying force to the piezoelectric sensor, causing it to bend or compress (Chen& col., 2005; Mathie& col., 2004). Accelerometers designed to measure ambulatory activity use one or more piezoelectric sensors that respond to changes in acceleration in either a single or multiple orthogonal planes (anteroposterior, mediolateral, and vertical)

(Chen & Bassett, 2005). The piezoelectric sensor is most sensitive in a vertical direction; therefore, it is often referred to as uniaxial, as it primarily records acceleration in the vertical plane (Chen & Bassett, 2005). Devices that contain two or more accelerometers that measure accelerations in the anteroposterior and/or lateral planes are said to be biaxial or triaxial. Omnidirectional devices theoretically assess accelerations in multiple planes, but are most sensitive to movement in a single plane (Chen & Bassett, 2005).

During physical activity, the raw accelerations are converted to "activity counts" by the summation of acceleration absolute values, through a specified period of time (i.e. counts·min^{-1}) (Actigraph, 2011; Chen & Bassett, 2005). These accelerations are proportional to muscular forces and thus these counts can hypothetically translated into energy expenditure (EE) (Freedson & Miller, 2000). The general consensus is that accelerometers provide an accurate assessment of physical activity, but less accurate prediction of EE; especially in the free-living environment (Welk, 2002).

ActiGraph

The ActiGraph (AG) GT3X+ (ActiGraph, LLC. Pensacola, FL), and its wireless counterpart the wGT3X+, are relatively small (4.6cm x 3.3cm x 1.5cm, 19 g) (Figure 1) and record accelerations in the range of 0.05 – 2.0 G's. This device digitizes PA through a 12-bit A/D converter at 30 – 100 Hertz in 10 Hz increments, providing three times more sampling capabilities than its predecessor. Sampling intervals (epochs) can be set as low as 1 second, to as high as 60 seconds. The AG's are capable of measuring activity counts and activity levels, steps taken, and energy expenditure. They have a memory capacity of 512 MB, which allows for up to 40 days of continuous measurement (Actigraph, 2011).

The AG is most commonly used accelerometer in PA research today, and although several versions have been introduced throughout the years it has shown to be a valid and reliable to measure physical activity (Bassett, 2000; Hendelman& col.,2000; Janz, 1994; Melanson & Freedson, 1995), and to estimate energy expenditure (Crouter& col., 2006; Crouter& col., 2010; Freedson& col., 1998; King& col.,2004; Rothney& col.; Swartz& col., 2000).

Actical

The Actical (AC, Phillips Respitronics, Bend, OR) is considered an "omni-directional" device, capable of recording in multiple directions, although is most sensitive in the vertical plane (Heil, 2006). This device is the smallest device available (2.9 x 3.7 x 1.1 cm) weighting only 16 g (Figure 2). It has the capability to record up to 44 days of data time in 1-minute epochs. Even though the device can be worn on multiple sites (i.e. wrist, hip, or ankle), the hip is the preferred wearing site. The Actical detects low frequency accelerations in the range of 0.05 – 2 G (0.35 – 3.5 Hz) common to human movement (Heil, D.P., 2006). Similarly to the ActiGraph, this device sampling intervals (epochs) can be set to a minimum of one-second, and as high as 60 seconds. The accelerations recorded by the internal mechanism generate an analog voltage that is filtered, amplified, and digitized through an A/D converter at 32 Hz. The device is initialized and downloads data through a serial port reader (Actireader), which allows the device to be completely waterproof (Mini Mitter Co., 2004).

Similar to the ActiGraph, the Actical has been subject to various reliability and validity studies (Esliger& col., 2007; Esliger & Tremblay, 2006; Paul& col., 2007; Rothney& col., 2008). Currently, Canada is using the device as an objective measure of physical activity through the incorporation of the device in the Canadian Health Measures Survey, which was developed to collect health information of a representative sample of the Canadian population (Tremblay& col., 2007; Tremblay& Gorber, 2007).

Pedometers

Even though pedometers are limited to measuring only ambulatory activity (Bassett, 2000), cannot provide accurate estimates of PA energy expenditure (Bassett, 2000), and have limited accuracy when measuring physical activity at slower (e.g. shuffling) or faster (e.g. running) speeds (Freedson & Miller, 2000), they provide a small, easy to use, and inexpensive way to promote physical activity that has been shown to be effective (Bravata& col., 2007; Richardson& col., 2008).

Most pedometers today use an electronic circuit that responds to changes in vertical accelerations when a person walks. Pedometers are designed to measure ambulatory activity providing a simple and a user-friendly output measure commonly known as a step count, or step. Most pedometers are usually worn on the waist and house a spring-suspended lever arm, which moves up and down as a result of vertical accelerations produced at the waist during walking (Bassett, 2000; Tudor-Locke & Lutes, 2009). Pedometers are designed to provide a sum of accumulated steps during walking; however, a step is recorded when an acceleration above a manufacturer-design threshold (e.g. 0.35 g) causes the lever arm to move up and down opening and closing an electrical circuit (Bassett, 2000; Tudor-Locke & Lutes, 2009).

Step Activity Monitor

The Step Activity Monitor, or Step Watch-3 (SW), (OrthoCare Innovations, Seattle, WA) is a slightly larger device than most (7.0 x 5.0 x 2.0 cm, 38 g); it is waterproof and attaches to the ankle, unlike the AG and AC, which usually attach to the waistline (Figure 3). The SW continuously records steps during a user specified period of time at specific intervals (epochs). The minimum sampling interval is 6 seconds allowing for a total of 1.12 days of ambulation data. The maximum sampling interval is 25.5 min, providing for 285.6 days of continuous monitoring (Coleman& col., 1999). At one-minute epochs, the SW can store step data for up to 2 months before requiring data to be downloaded (Stunkard& col., 1986). The software provided by the manufacturer allows for the adjustment of the sensitivity to movement, frequency with which steps are detected during walking, and the acceleration required to record steps.

DigiWalker

The DigiWalker (Yamax Corp., Tokyo, Japan) is a small (5.2 x 3.9 x 1.9 cm) (Figure 4), inexpensive and simple to use pedometer that has been used extensively in research (Bassett& col., 1996; Crouter& col., 2003; Schneider& col., 2004; Schneider& col., 2003; Swartz& col., 2003). Unlike all other devices previously described, the DigiWalker has a simple display which records steps taken and reset button to clear steps at the end of a sampling period (e.g. a day). The DigiWalker may be the simplest and easiest to use of all the pedometers.

Limitations

Compared to pedometers, accelerometers have several limitations that may limit their use. Primarily, accelerometer cost more than pedometers; they require greater amount of time to initialize, download and interpret the recorded data, and they demand a greater level of expertise to interpret their output. On the other hand, most pedometers do not require initialization, other than perhaps entering the participant's age, weight and the time of day depending on the model. Their "simplicity", of course, limits the information provided by pedometers, as most only record steps accurately, while others provide some estimate, albeit not very accurate, of energy expenditure and distance traveled. This section will expand on some of these limitations.

Accelerometers

Several of the early investigations demonstrated that accelerometers measure physical activity accurately and can even detect changes in walking speed while walking (Janz, 1994; Melanson & Freedson, 1995). In addition, they showed how accelerometer estimated energy expenditure was moderately correlated ($r = 0.80$; $P < 0.01$) with levels of measured energy expenditure during walking (Melanson & Freedson, 1995); however, this correlation seen reduced ($r = 0.55 – 0.59$) when the estimated EE was compared in the free-living environment, due to the monitor's inability to measure upper body movements, changes in terrain during ambulation and/or loading activities that might take place during the free-living environment throughout the day (Bassett& col., 2000; Hendelman& col., 2000).

Even though some of these early investigations were primarily performed using the AG, Lyden & col. (2011) recently showed these limitations exist for a number of other devices as well. In addition, Crouter & col.(2010) and Rothney& col.(2008) concluded that a single equation was unable to estimate EE for all activities performed throughout the day, and most equations developed for walking would be most accurate for ambulating activity, but not for most other activities.

In addition, some accelerometers have shown to be significantly affected by levels of adiposity. Feito & col.(2011, 2012) demonstrated that the Actical activity monitor is significantly influenced by adiposity when the device is tilted forward more than 10º, recording higher activity counts for obese participants compared to normal individuals (Feito& col., 2011.). This difference was not seen for the ActiGraph device at any tilt angle (Feito& col., 2011).

Pedometers

Several investigators have measured the accuracy of several types of electronic pedometers for measuring steps and distance on a controlled or free-living environment (Bassett& col., 1996; Crouter& col., 2003; Feito& col., 2012; Feito& col., 2012; Schneider& col., 2004). All investigators concluded that most electronic pedometers are most accurate in measuring steps taken at speeds above 67 m·min-1; they will usually overestimate distance traveled at slower speeds, and underestimated at faster speeds. In addition, those devices that estimate EE seem to significantly overestimate actual values of gross and net EE during treadmill walking. Researchers concluded that the vertical accelerations acting on the waist at speeds below 67 m·min-1 are below the threshold (i.e. 0.35 g, for the DigiWalker) needed to record a step. Moreover, abdominal adiposity significantly hinders the ability for spring-levered pedometers, but not piezoelectric devices, to accurately measure steps, as the magnitude of accelerations recoded at the waist is reduced (Bassett& col., 1996; Crouter& col., 2003; Feito& col., 2011; Feito& col., 2012; Schneider& col., 2004). Although these limitations may hider hinder the applicability of pedometers, pedometers have shown to be highly correlated (r > 0.70) with accelerometers based activity monitors in controlled and free-living environments (Le Masurier & Tudor-Locke, 2003; Tudor-Locke& col., 2002).

Unlike most pedometers, which are worn on the waist, the Step Watch is the only pedometer worn on the ankle during ambulation. This design, allows the device to accurately measure ambulatory activity for apparently healthy individuals and those with chronic conditions, including those with amputations (Coleman& col., 1999; Foster& col., 2005; Karabulut& col., 2005; Mudge& col., 2007; Shepherd& col.,1999; Storti& col., 2008). Regardless of the population studied, the SW has shown to accurately record within 2% of steps taken, making the most accurate, reliable instrument to measure ambulatory activity on a wage range of individuals (Coleman& col.,, 1999). Investigators concluded that the SW was a highly accurate, reliable, instrument that can be used to perform long-term step monitoring on a wide range of subjects and activities (Coleman& col., 1999). When compared to waist worn pedometers, the SW measures within 1% of steps taken, where most pedometers are within 3% (Hatano, 1993; Shepherd& col., 1999). Foster & col. (2005) examined the accuracy of the SW to estimate energy expenditure, as this feature has been limited with other pedometers (Crouter& col., 2003; Tudor-Locke& col., 2002). When the calculated EE's were compared with the measured values, EE was within 11% of the measured values for all walking speeds. Thus, suggesting that the SW was a precise and accurate device for measuring EE during walking among a range of different velocities for individuals of different body compositions.

Conclusion

Overall, the use of objective measures of physical activity is important in the promotion of an active lifestyle. As expected, all measuring tools have their limitations, and it is up to the researcher to determine what device is best suited for their purposes. Whereas direct observation of physical activity would provide the most accurate measurement of overall physical activity, this measurement is not practical, as investigators would have to follow and document every movement a participant preforms throughout the day.

Using accelerometers and pedometers provide an accurate and valid way to assess physical activity in control and free-living environments. Whereas accelerometers provide the greatest amount of information (activity counts, intensity and estimated energy expenditure) they are expensive and require a significant amount of technical skill to accurately measure physical activity. Pedometers, on the other hand, are much simpler to use and cost less; however, the information provided is primarily limited to steps taken, as they are not very accurate measuring distance walked or energy expenditure throughout the day. Yet, if used regularly, they can serve as a motivational tool to increase ambulatory activity throughout the day.

Figures

Figure 1 – ActiGraph GT3X+

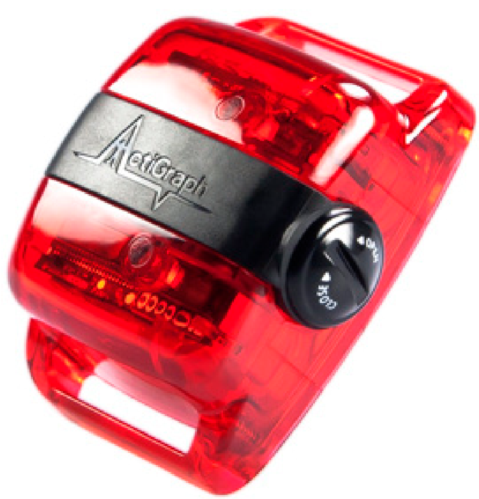


Figure 2 – Actical

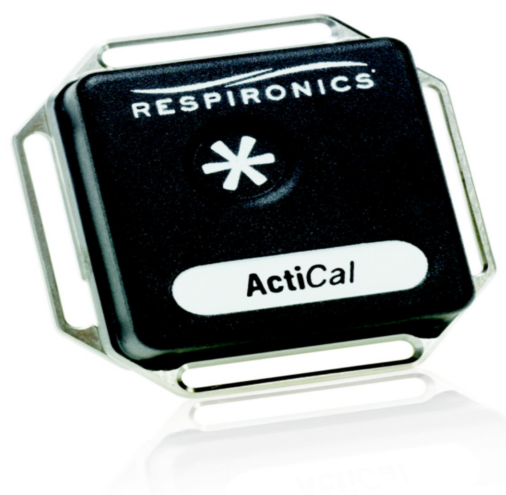


Figure 3 – DigiWalker

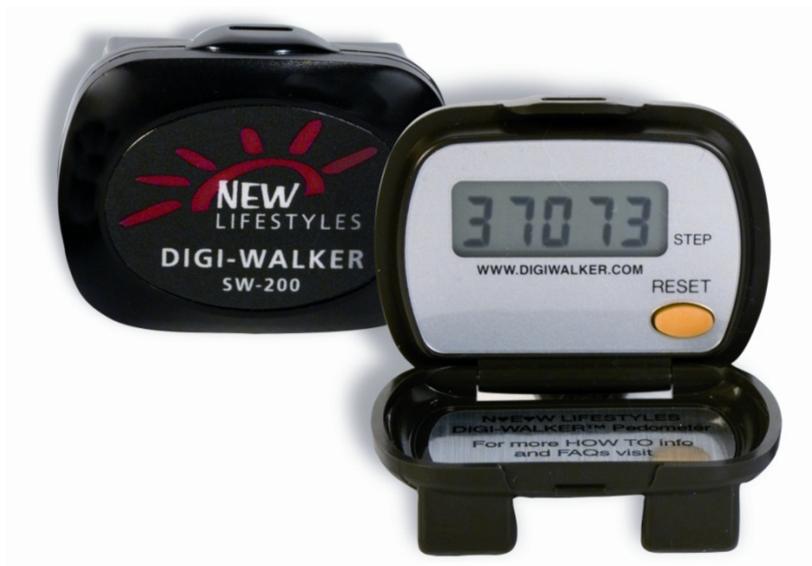
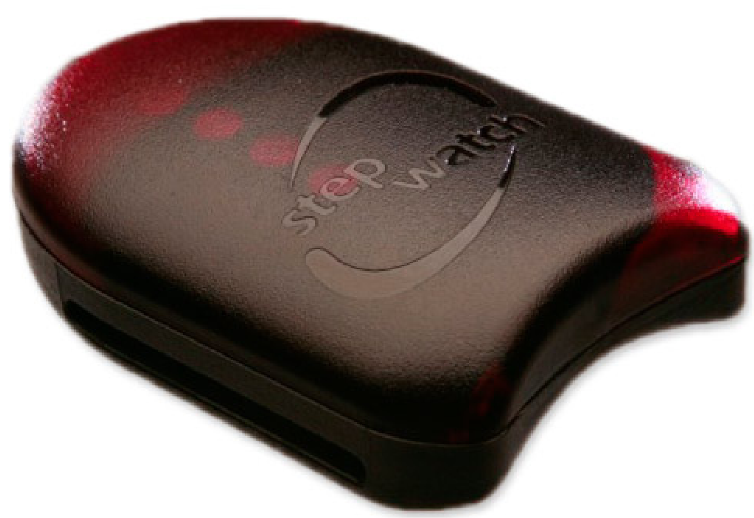


Figure 4 – Step Activity Monitor



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