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NARRATIVE REVIEW

Can pedometer data contribute to observing Public Health Physical Activity Guidelines?

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Abstract

Background: Some suggest that pedometer/ accelerometers encourage people to meet recommended daily minimum levels of habitual physical activity, but others find little relationship between pedometer counts and the meeting of activity targets. *Purpose:* To review the practical value of pedometer/accelerometers in assessing current behaviour and encouraging greater physical activity. *Methods:* Pedometer/accelerometer counts corresponding to minimum desirable levels of physical activity are examined, and the validity of individual estimates of activity levels is evaluated critically in the context of specific observations by White and associates. Alternative methods of monitoring physical activity are considered, and the motivational impact of wearing a pedometer/accelerometer is explored. *Results and Conclusions:* Estimates based on both theoretical considerations and the relationship of step counts to health outcomes suggest that largely sedentary individuals achieve counts of at least 4000 steps·day^{-1}. Counts of at least 7000 steps·day^{-1} are needed to meet minimum health objectives, and values up to 10,000 steps·day^{-1} should be encouraged. Pedometer/accelerometers are relatively accurate when assessing activity levels on a treadmill or a track, but they paint a less accurate picture in normal daily life; they do not reflect such activities as hill climbing, swimming, cycling and resistance exercise. One study of arthritic patients found little relationship between individual counts and achievement of activity goals. Multi-phasic monitors to date offer little advantage over simpler pedometer/accelerometers. The wearing of an activity monitor stimulates physical activity, and if specific goals are set this increase persists for at least 4 months. However, longer-term studies of health-promotional value are still required. **Health & Fitness Journal of Canada 2013;6(3):138-147.**

Keywords: Accelerometry; Activity monitors; Physical activity guidelines; Motivation; Pedometers

Introduction

A common public health recommendation in terms of the minimum desirable level of aerobic activity is to engage in 30 min of moderate exercise on most days of the week, with exercise taken in bouts of at least 10 min duration (U.S. Dept. of Health & Human Services, 2010). But can one provide correspondingly specific advice to a client who is using an activity monitor such as a pedometer or an accelerometer rather than relying upon his or her subjective impressions of the amount of physical activity that is being undertaken (Aoyagi and Shephard, 2009; Shephard and Aoyagi, 2013)? Those studying patterns of physical activity on large populations have become increasingly conscious that self-reports generally indicate much greater levels of physical activity than "objective" measurements such as pedometer/ accelerometer counts, and the two types of data set are often poorly correlated with each other (Beyler et al., 2008; Prince et al., 2008; Slootmaker et al., 2009). Discrepancies seem particularly large in adolescents (Slootmaker et al., 2009), and it has commonly been assumed that the activity monitors are providing more reliable and valid information than questionnaire responses (Beyler et al., 2008; Prince et al., 2008).

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Setting minimum standards of physical activity for pedometer and accelerometer users

Several approaches have been used when setting minimum levels of objectively measured physical activity. Estimates have been based upon theoretical considerations, the cumulative daily step counts, calibration of the accelerometer counting rate at specified intensities of activity, and empirical observations of resulting levels of health as seen in cross-sectional or longitudinal surveys of an entire community.

Theoretical considerations

On theoretical grounds, let us suppose that the daily requirement of aerobic exercise is taken in the form of deliberate walking; this is perhaps the commonest choice of older adults. To obtain the desired minimum of 30 min, a person should then aim to walk a distance of least 2.0-2.5 km·day^{-1}, at a pace of 4-5 km·hr^{-1}. Given a stride length of 0.7 m, this might seem to equate with a pedometer count of 2850 to 3570 steps·day^{-1}. However, the minimum recommended count must in fact be substantially higher than this, since minor incidental movements around the home, taken in bursts with a duration of 1 min or less, can generate at least 4000 impulses·day^{-1}. Thus, theoretical considerations suggest that a total count of at least 7000-7500 steps·day^{-1} is required to accumulate 30 min of aerobic activity in bursts lasting at least 10 min.

Cumulative daily step counts

An exhaustive survey of the literature for healthy adults looking at current step counts and relating the findings to health status (Tudor-Locke and Bassett, 2004) has suggested that behaviour can be characterized as sedentary (<5000 counts·day^{-1}), low-active (5000-7499 counts·day^{-1}), somewhat active (7500-9999 counts·day^{-1}), and active (>10,000 counts·day^{-1}), Review of a large pool of literature that included elderly individuals and special populations (Tudor-Locke et al., 2011) led to a refining of several of these categories and the conclusion that an average daily count of 7100 steps·day^{-1} was equivalent to accumulating 150 min of moderate intensity physical activity per week in bouts of 10 min and longer.

Interpretation of accelerometer data

The instantaneous rate of counting of many accelerometers is roughly proportional to the immediate intensity of physical activity (Freedson et al., 1998). Calibration of counting rates against varying speeds of treadmill walking in a group of young adults led to the following classification of the intensities of effort: light activity (an intensity <3 METs) <1952 counts·min^{-1}; moderate activity (an intensity of 3.00-5.99 METs) 1952-5724 counts·min^{-1}; hard activity (an intensity of 6.00-8.99 METs) 5725-9488 counts·min^{-1}; and very hard (an intensity >8.99 METs) >9498 counts·min^{-1}.

A community health approach

The empirical approach of examining the relationship between step counts and health outcomes has been applied extensively in the Japanese community of Nakanojo (Aoyagi and Shephard, 2009; Shephard and Aoyagi, 2013). In this survey, pedometer/accelerometer records have been obtained 24 hours per day from all healthy adults aged >65 years for periods of 5 years and longer. Cross-sectional analyses of these findings have established the optimum counts associated with various facets of good health (Aoyagi and Shephard, 2009). Generally, these have been greater for physical than for mental benefits. Thus, the step counts associated with a lower risk of mental health disorders including depression averaged >4,000 steps·day^{-1}, for a lower risk of impaired psychosocial health including a poor health-related quality of life >5,000 steps·day^{-1}, for lower risks of aortic arteriosclerosis, osteoporosis, and sarcopenia and a higher level of physical fitness >7,000-8,000 steps·day^{-1} and for a lower risk of hypertension and hyperglycemia >8,000 and >10,000 steps·day^{-1} in adults aged ≥75 and 65-74 years, respectively.

To date, two studies have evaluated longitudinal relationships between daily step counts and the risks of developing sarcopenia and osteoporosis. The onset of sarcopenia was judged from bioimpedance readings for appendicular lean tissue/height^2 that were more than 1 SD below the mean value for healthy young Japanese adults (Shephard and Aoyaji, 2013). Application of a multivariate-adjusted proportional hazards model predicted that over the 5 year study, men and women in the two lowest activity quartiles (<6700 and <6800 steps·day^{-1}) were, respectively, at 2.3 (1.4-4.5) and 3.0 (1.9-3.4) times greater risk of sarcopenia than those in the highest activity quartile (>9000 and >8400 steps·day^{-1}).

In terms of osteoporosis, an osteosonic index was calculated from the transmission and speed of passage of a sound wave through the tissue (Shephard and Aoyagi, 2013). The critical osteosonic index (OSI) for an increased risk of fracture was set at a t-score of -1.5 relative to that for young Japanese adults. A multivariate-adjusted proportional hazards model predicted that over the 5 year study the OSI values of men and women were, respectively, 2.6 (1.4-4.4) and 3.3 (2.1-5.3) and/or 2.8 (1.5-6.0) and 3.9 (2.6-6.9) times more likely to drop below the fracture threshold in the two lowest activity quartiles (<7000 and <6900 steps·day^{-1}) than in the highest quartile (>9100 and >8800 steps·day^{-1}).

Conclusions

The accelerometer approach of Freedson and associates (1998) cannot be compared directly with the target step counts set for the pedometer/ accelerometer data. However, there seems a fair unanimity among the other 3 methods of assessment that in order to satisfy minimum public health physical activity recommendations, the total pedometer/accelerometer count should be at least 7000 steps·day^{-1}, with the likelihood of further advantage accruing in some areas of health at counts of around 9000 steps·day^{-1}.

Critique of pedometer/accelerometer activity monitoring

How useful is a pedometer in enabling the individual client to judge whether he or she is developing an adequate daily level of physical activity? Early pedometers were based on watch escapement mechanisms, and depending upon the speed and the vigour of movement, they might record two, one or zero counts per step (Kemper and Verschuur, 1977). There is now a consensus that limitations inherent in the original pedometer design preclude any detailed analysis of the data (Meijer et al., 1991; Tudor-Locke et al., 2006). More recent pedometer/accelerometers are based upon piezo-electric recording systems, with a more precise filtering of the range of accelerations accepted as indicating the taking of a single deliberate step. Some proponents have claimed a remarkable accuracy and validity for the latest devices.

Reliability has been tested by wearing two instruments simultaneously, one being fitted to each side of a waist belt. Such assessments suggested a satisfactory level of reliability for such devices as the Yamax, Kenz, Omron, New Lifestyle and Digiwalker monitors (Bassett et al., 1996; Bassey et al., 1987; Welk et al., 2003). In terms of absolute accuracy, one study looked at the counts recorded when the monitor was mounted on a test rig (Bassey et al., 1987). The correlation between the actual oscillations of the rig and recorded impulses was 0.996; the threshold acceleration for activation of this particular instrument was 2 m/s^2, with a coefficient of variation of 1.5% (Bassey et al., 1987). Other reports have claimed an intra-model reliability (Cronbach's alpha) of 0.998, an accuracy of -0.2 ± 1.5 steps when counting 500 paces on a 400 m track (Crouter et al., 2003; Schneider et al., 2003; Schneider et al., 2004), and a systematic error of less than 2% when covering a 4.8 km walking course at either moderate or slow walking speeds (Bassett et al., 1996). An evaluation of 10 modern pedometer/accelerometer designs found that most were able to estimate the treadmill walking distance to within ± 10% and the gross energy expenditure to within ± 30% of the actual value at a pace of 4.8 km/h (Crouter et al., 2003; Schneider et al., 2003), but values were under-estimated at speeds of less than 4.8 km/h (Albright et al., 2006). Two of the better regarded instruments (the Kenz Lifecorder and the Actigraph) yielded step counts that were, respectively, 92 ± 6% and 64 ± 15% of the true value when walking slowly (54 $m \cdot min^{-1}$), but values were accurate to within 3% at higher speeds of walking (80-188 $m \cdot min^{-1}$) (Abel et al., 2008). Unfortunately, such validation does not guarantee success when seeking to record the varied movement patterns of daily life. When individuals can choose their own activity patterns rather than walking on a fixed course and/or at a fixed pace, there is likely to be a substantial decrease in both the reliability and the validity of activity monitors (McClain et al., 2007).

Other approaches to assessment of the absolute accuracy of pedometer/accelerometers have included comparisons against the impacts recorded from a heel-mounted resistance pad (Bassey et al., 1987)(where an error of 460 ± 1080 $steps \cdot day^{-1}$ was seen), against the directly measured oxygen consumption (Yokoyama et al., 2002) (where the Pearson correlation coefficient was 0.97, and mean error in estimated energy expenditure ranged from -3.2 to + 0.1 $kJ \cdot min^{-1}$), and against metabolic chamber data (where the error was 8% for active energy expenditure and 9% for total energy expenditure) (Kumahara et al., 2002).

When walking, errors arise particularly from a slow pace, a short stride length and abnormalities of gait (Cyarto et al., 2004). Miscounts are exacerbated if the instrument is tilted from the vertical, as when it is fitted to the waistband of an obese person (Ewalt et al., 2008). Pedometers and accelerometers also respond poorly to non-standard activities such as cycling, skating, load-carrying, and the performance of household chores (Sirard and Pate, 2001). Moreover, no account is taken of the additional energy expenditures incurred when climbing hills or making movements against external resistance, and artifacts may boost counts arise if a person is traveling in a vehicle over bumpy ground (Le Masurier and Tudor-Locke, 2003).

In summary, pedometer/ accelerometers are likely to provide a reasonable indication of aerobic activity in older people whose main source of deliberate exercise is moderately paced walking, but the daily activity of younger adults may be under-estimated by as much as 30-60% relative to doubly labelled water estimates (Leenders et al., 2001).

The specific critique of White and associates

The writing of this brief review was stimulated in part by an article of White and associates (White et al., 2013), who concluded that in an elderly population with or at risk of osteoarthritis of the knee, cut-points of 7000 or 10,000 steps·day^{-1} for an ankle-mounted physical activity monitor failed to discriminate between individuals who were taking the recommended amount of daily activity and those who were not. Moreover, only a small proportion even of those with a count of more than 10,000 steps·day^{-1} met minimum daily physical activity requirements.

Most evaluations of pedometer/ accelerometers have looked at the ability of these instruments to predict patterns in epidemiological studies, and the accurate determination of individual behaviour is inevitably more exacting. Nevertheless, the conclusions of White et al. are somewhat surprising, and their findings must be qualified by noting a number of important limitations to that particular study. The biggest issue is in terms of technique, since the same device was used both to indicate the individual's step count and to monitor the individual's compliance with the public health recommendations. Periods when the step count exceeded 100 steps·min^{-1} were assumed to indicate times when the subject was engaged in either moderate or vigorous physical activity, and bouts of such activity lasting longer than 10 min were summed over the course of the day. Data were also collected from the ankle rather than the waist; the number of "strides" was doubled to indicate steps, and counts were then arbitrarily reduced by 17-24% with the intent of making the data comparable with what White et al. assumed would have been seen when using a waist-mounted piezo-electric pedometer. Nevertheless, ankle monitoring has been said to provide an accurate step count for individuals walking at a cadence of greater than 100 steps·min^{-1} (Resnick et al., 2001; Storti et al., 2008). The population sample was also not well chosen for the evaluation, since only 5% of the women and 6% of the men were meeting minimum physical activity recommendations. Moreover, their subjects (individuals with osteoarthritis of the knee) were an odd choice for such an evaluation. Knee pain may have caused these people to walk in an awkward fashion, falsifying their step counts, and individuals with knee arthritis are in any event likely to opt for forms of aerobic activity that do not stress the knees, such as swimming.

Although White et al. (2013) have raised an important issue, their study needs repeating using standard waist-mounted pedometer/accelerometers in patients with a variety of clinical conditions, including a substantial proportion of individuals who are meeting physical activity guidelines, and adopting an independent method to provide the criterion data on habitual physical activity.

Alternative monitoring options

Given the limitations of pedometer/accelerometers, several suggestions have been made to increase their effectiveness as personal activity monitors. One commercially available accelerometer termed the "footpod" can be attached to the foot, detecting the impact associated with each stride. Another small inertia-sensing device can be attached to the ear lobe, providing information on posture and linear acceleration that can be used both to predict energy expenditures and to categorize the types of activity that are being performed (Atallah et al., 2011).

Other investigators have developed complex equations to enhance the interpretation of data from existing instruments, Thus, the Actical accelerometer requires use of a 3-part algorithm to determine the overall level of physical activity. There is an inactivity threshold; when the rate of counting falls below this threshold, an energy expenditure of 1 MET is assigned. A walk/run regression equation is adopted to interpret the intensity of activity if the rate of counting exceeds the inactivity threshold, but the coefficient of variation of impulses over four consecutive 15-s epochs remains <13%. Finally, data are fed into a third, lifestyle regression equation if the rate of counting surpasses the inactivity threshold and the coefficient of variation is >13% (Crouter et al., 2008).

Multiphasic devices have sought to enhance data interpretation, particularly when examining the energy expenditures associated with non-standard movements (Duncan et al., 2011; King et al., 2004). Some investigators have used triaxial accelerometers, and others have added to step test data information gained from recordings of heart rate, skin temperatures, heat flux, and galvanic skin response (Bernsten et al., 2010; Corder et al., 2007; Duncan et al., 2011; Haskell et al., 1993; Malavolti et al., 2007; Soric et al., 2011; Warren et al., 2010; Welk et al., 2007). A further recent trend has been to combine accelerometer data with GPS recordings (Duncan et al., 2009; Edgecomb and Norton, 2006; Maddison et al., 2010; Rodriguez et al., 2005; Troped et al., 2008). The GPS data have sometimes proven helpful in detecting side-effects from travel in motor vehicles, but signals are often lost among tall urban buildings and when travelling on the subway (Krenn et al., 2011).

When attempting to do more than simply record step counts, much depends on the choice of algorithm (Jakicic et al., 2004), and it remains a challenge to find formulae that are appropriate for all subjects and all circumstances. At present, multiphasic devices increase the cost and complexity of monitoring, without necessarily increasing the quality of the information that is obtained.

We must conclude that modern uniaxial pedometer/accelerometers can yield relatively accurate data for standard forms of laboratory exercise, and in groups such as the elderly where steady walking is the main source of energy expenditure they can provide useful epidemiological data. But in much of daily life, the individual's step count remains vulnerable to problems from external vibration and unmeasured sources of energy expenditure such as hill climbing and resistance activity. Multiphasic devices may in the future detect and measure less typical types of activity, but at present they are costly and complex to use, and do not seem to be any more accurate than simpler uniaxial pedometer/accelerometers.

Motivational aspects of wearing a pedometer/accelerometer

How effective are simple activity monitors in encouraging clients to conform to public health physical activity recommendations? Although on average, a person can be advised that a count of at least 7000 steps·day^{-1} is desirable for health, more than a half of the accumulated daily total seems attributable to external vibrations and incidental movements that have little health significance. Moreover, individuals differ greatly in their exposure to external vibrations and their tendency to fidget, so that the total count associated with an adequate dose of physical activity varies quite widely from one person to another.

The information provided by a pedometer/accelerometer only seems likely to be useful if the main source of aerobic activity is walking on level ground. Even then, rather than focusing upon an individual's total daily count, a more effective approach may be to determine the count for a day when little or no deliberate activity is undertaken, and then to recommend increasing this figure by at least 3500 and preferably 7000 steps·day^{-1}.

The short-term effect of wearing a pedometer is commonly to increase physical activity, particularly if the client can read the counter (Clemes et al., 2008). This is termed a reactive response to the instrument; it seems to persist for at least a week, and is greatest if subjects are asked to record their step counts. In such a situation, a person is likely to take at least 1000 steps·day^{-1} more than if the counts are concealed from the wearer (Clemes and Parker, 2009).

In a longer-term context, two independent meta-analyses (Bravata et al., 2007; Richardson et al., 2008) concluded categorically that the wearing of a pedometer could increase habitual physical activity by as much as 2500 steps·day^{-1}, with an associated reduction of body mass. However, to obtain such benefits it was necessary to set a personal goal, such as increasing activity by 2000 steps·day^{-1} or achieving a count of 10,000 steps·day^{-1} (Tudor-Locke and Lutes, 2009). Moreover, the majority of those studied have been women, many have been obese, and trials have only lasted for an average of 16 to 18 weeks. More studies of male subjects are needed, and trials should be extended beyond 18 weeks for both men and women.

Practical Conclusions

Personal activity monitors such as modern pedometer/accelerometers provide a more accurate indication of a client's habitual physical activity than most questionnaires., particularly if the main daily activity is walking. However, they fail to provide an accurate record of work performed in hill climbing, cycling, swimming and resistance activity. A substantial fraction of the daily step count is unrelated to health-giving activity, and rather than relying upon absolute counts, clients should be advised to increase their activity by 3500-7000 steps·day^{-1} relative to a day when they are totally inactive. If targets are set, activity monitoring substantially boosts activity levels for 3-4 months, but trials are still needed of longer-term effectiveness.

Author's Qualifications

The author's qualifications are as follows: Roy J. Shephard, M.B.B.S.; M.D. [Lond.]; Ph. D.; D.P.E.; LL.D.

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