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Physical activity and energy expenditure measurements using accelerometers in older adults

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Abstract

The purpose of this review is to address methodological issues related to accelerometer-based assessments of physical activity (PA) in older individuals. Special interest is also put on recently updated technology. No definitive evidence exists currently to indicate which are the more valid and reliable accelerometer models for use with older people. When it comes to selecting an accelerometer, issues of affordability, product reliability, monitor size, technical support, and comparability with other studies may be equally as important as the relative validity and reliability of an instrument. The accelerometer should be attached as close as possible to the body’s center of mass, and in the case of elders using walking aids, it should be placed on the same body side. Variability due to positioning can be reduced with careful training and supervision. Typically, the sampling period is between 3 and 7 days and it is not yet clear if variability exists between weekdays and weekend in the elderly. It is possible that aging effects on physical and cognitive health may limit the ability of an older adult to be compliant with an accelerometer protocol; in this line many methods have been suggested for increasing compliance to protocols for research studies. Accelerometers can provide reliable information on mobility and objective measurement of PA. These activity monitors have significant advantages when compared with other quantitative methods for measurement of energy expenditure. Accelerometers are currently used mainly in a research setting; however, with recent advances, incorporation into clinical and fitness practice is possible and increasing.

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Key words: Accelerometer. Elderly. Physical activity. Energy expenditure.

Resumen

El objetivo de esta revisión se centra en cuestiones metodológicas relacionadas con la medición de la actividad física mediante acelerómetros en personas mayores. Se pone un especial énfasis en la tecnología más reciente. Actualmente no existen pruebas definitivas que indiquen que un modelo es más válido y fiable que otro para su utilización con los ancianos. Al seleccionar un acelerómetro, la comodidad, la fiabilidad del producto, el tamaño, el apoyo técnico y la comparación con otros estudios pueden ser tan importantes como la validez y la fiabilidad del instrumento. Los acelerómetros deben colocarse lo más cerca posible del centro de masas del cuerpo y en el caso de que los ancianos utilicen ayudas técnicas para caminar se deben situar en el mismo lado del cuerpo. La variabilidad debida a la colocación puede reducirse con un cuidadoso entrenamiento y supervisión. Normalmente el periodo de registro es entre 3 y 7 días y todavía no está claro si existe suficiente variabilidad entre días de la semana y de fin de semana en ancianos. Es posible que los efectos del envejecimiento sobre la salud física y cognitiva puedan limitar la capacidad de un anciano de adaptarse al protocolo de utilización de un acelerómetro; en esta línea se han sugerido métodos para incrementar el cumplimiento de los protocolos en estudios de investigación. Los acelerómetros pueden aportar información fiable sobre la movilidad y medidas objetivas de actividad física. Estos monitores presentan ventajas significativas cuando se comparan con otros métodos cuantitativos utilizados en la actualidad para la medida de la actividad física habitual. Actualmente los acelerómetros se utilizan principalmente en investigación; sin embargo, con la incorporación de avances recientes, su empleo es posible y se está incrementando en clínica y para la mejora de la forma física.

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Introduction

Older individuals typically experience impairments in physical functioning and increasing incidence of chronic health problems such as cardiovascular disease or osteoporosis. Although some declines with age are inevitable, considerable evidence indicates that physically active older individuals maintain healthy functioning longer than do sedentary peers. Physical activity (PA), defined as any bodily movement produced by skeletal muscles that results in energy expenditure, has been identified as priority area in general health promotion. In older people, regular PA is important for the increase or preservation of aspects of physical function, which allows performance of more integrated functional tasks, such as muscle strength and power, balance, flexibility, endurance, or mobility, and in consequence for the maintenance of an independent living. Although beneficial effects of PA in older adults have largely been attributed to its impact on physical function, evidence is also emerging for positive effects on aspects of mental health. Accumulating data support the belief that PA is associated with psychological benefits, and a large number of studies have begun to document preventive effects for depression or neurodegenerative diseases.

Measurement of physical activity in older adults

Overall, there is a lack of valid and reliable methods available to measure PA in older adults because most of the measurement tools available today were designed to be used in a younger population. Accurate measurement of habitual PA is fundamental to both the epidemiological study of relations between PA and health, and the recommendation of an appropriate pattern of PA to maintain good health. PA is often assessed using self-reported measures. These measures are easily administered and can provide information on the types of activities performed, but there are some disadvantages to the use of self-report measures. They do not capture activity patterns throughout the day, and perceptions of the intensity of any stimulus depend on the experience and the stoicism of the person concerned. In older adults in particular, self-report may also be influenced by fluctuations in health status and mood, depression, or anxiety ability, and by problems with memory and cognition. Moreover, the activities older adults tend to engage in most frequently are of light to moderate intensity, such as leisurely walking, housework, and gardening. Unfortunately, these activities are often not assessed in self-report techniques that are age-neutral. Furthermore, even when these light to moderate intensity activities are assessed they tend to be difficult to measure reliably. In addition, older adults may engage in PA on a somewhat irregular basis, which complicates their ability to accurately recall PA on a survey or questionnaire. All of these factors make the measurement of PA more complex in the elderly.

To address some of these issues, several surveys have been developed specifically for use in older adults: the Yale Physical Activity Survey, the Physical Activity Scale for the Elderly, or the CHAMPS physical activity questionnaire, between others. However, because these surveys still rely on memory, criterion and objective methods of measuring PA in older adults are generally considered superior to these subjective methods. Objective PA measures have gained much attention lately to overcome limitations of self-report measures. Accelerometers, in particular, provide information on the amount, frequency, duration, and intensity of PA. In general, the use of accelerometers for measuring PA in older adults in epidemiological studies has been relatively uncommon.

This paper is focuses on the use of accelerometers in older population. Despite of the increased use of these monitors, methodological issues related to accelerometer-based assessments of PA in older individuals have not been adequately addressed. Special interest is also put on recently updated technology.

Accelerometers types

Using accelerometers to assess human body movement was first proposed in the 1950s. However, these devices were expensive, bulky and unreliable; therefore, unsuitable for ambulatory monitoring techniques. However, in the past decade a revolution has taken place in the fabrication of accelerometers, primarily driven by the automotive industry for use in airbag release systems. This new generation of accelerometers was designed to satisfy the extremely stringent quality and reliability requirements of that industry, as well as meeting the demand for high-volume, low-cost manufacturing.

The most commonly used accelerometers have piezo-electric sensors (fig. 1). Piezo-electric sensors measure acceleration due to movement and there are two main types, the cantilever beam and the integrated circuit chip. The cantilever beam technology is named for the beam that is attached to a support at one side that contains a piezoelectric element and a seismic mass. When acceleration is detected by the seismic mass, it causes the piezoelectric element in the beam to bend and record a voltage signal. The amplitude of the voltage signal is in proportion to the acceleration detected. The integrated chip technology (fig. 1) is in many of the newer generations of activity monitors. It also has a piezoelectric element and seismic mass that detect acceleration, but the sensor is fully enclosed in a package that is directly affixed on an electronic circuit board. This is advantageous in particular because it enhances durability and repeatability of the monitors.
Table I shows the most common accelerometer brands and provides information for some specifications. Although there is a body of literature on the validity and reliability of these monitors, not all have been validated on older persons, despite widespread use of accelerometers to objectively monitor PA among the elderly. Most literature on daytime PA using accelerometry involves the use of the Actigraph (Actigraph LLC) brand monitors, where most literature on nighttime activity and sleep patterns involves the use of Actiwatch (MiniMitter Co) brand.21

<table>
<thead>
<tr>
<th>Name</th>
<th>Manufacturer</th>
<th>Size and weight</th>
<th>Type</th>
<th>Placement</th>
<th>Epoch length</th>
<th>Memory</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actical</td>
<td>Mini-Mitter Sunriver, OR</td>
<td>2.8 x 2.7 x 1.0 cm 17.5 G</td>
<td>Uniaxial; Omni-directional</td>
<td>Wrist, ankle or hip</td>
<td>Records epochs from 15 s to 1 min.</td>
<td>Stores up to 45 d using 1 min. epochs</td>
<td>Activity counts, Step counts, Energy expenditure</td>
</tr>
<tr>
<td>Actiwatch</td>
<td>Mini-Mitter Sunriver, OR</td>
<td>2.8 x 2.7 x 1.0 cm 16 g</td>
<td>Uniaxial; Omni-directional</td>
<td>Wrist or hip</td>
<td>Records epochs 15 s to 15 min</td>
<td>AW16 records up to 11 d using 1 min. epochs; AW64 up to 45 d</td>
<td>Activity counts, Sleep quality</td>
</tr>
<tr>
<td>Spectrum</td>
<td>Mini-Mitter Sunriver, OR</td>
<td>4.9 x 3.7 x 1.4 cm 29.8 g</td>
<td>Uniaxial; Omni-directional</td>
<td>Wrist</td>
<td>Records activity in 15 s to 1 min. epochs</td>
<td>Records up to 36 d when using 1 min. epochs</td>
<td>Activity counts, Sleep quality</td>
</tr>
<tr>
<td>Actiwatch 2</td>
<td>Mini-Mitter Sunriver, OR</td>
<td>4.4 x 2.3 x 1 cm 16.1 g (with band)</td>
<td>Uniaxial; Omni-directional</td>
<td>Wrist</td>
<td>Records activity in 15 s to 1 min. epochs</td>
<td>Records up to 30 d when using 1 min. epochs</td>
<td>Activity counts, Sleep quality</td>
</tr>
<tr>
<td>Actitrac</td>
<td>IM Systems Baltimore, MD</td>
<td>5.6 x 3.8 x 1.3 cm 34 g</td>
<td>Biaxial</td>
<td>Wrist</td>
<td>Records epochs 2s to 2min</td>
<td>Records up to 44 d when using 1 min. epochs</td>
<td>Activity counts</td>
</tr>
<tr>
<td>Biotrainer</td>
<td>IM Systems Baltimore, MD</td>
<td>7.6 x 5 x 2.2 cm 51.1 g</td>
<td>Biaxial</td>
<td>Hip</td>
<td>Records activity in 15 s to 5 min. epochs</td>
<td>Records up to 22 d when using 1 min. epochs</td>
<td>Activity counts, Converted into ‘g’ units or kilocalories expended</td>
</tr>
<tr>
<td>Actigraph Model 7164 [formerly CSA, MTI]</td>
<td>Actigraph LLC Pensacola, FL</td>
<td>5.1 x 4.1 x 1.5 cm 45.5 g</td>
<td>Uniaxial</td>
<td>Usually hip, also ankle/wrist</td>
<td>Records activity in epochs of 1 s to several minutes</td>
<td>Records up to 22 d when using 1 min. epochs</td>
<td>Activity counts, Energy expenditure</td>
</tr>
<tr>
<td>GT1M Actigraph</td>
<td>Actigraph LLC Pensacola, FL</td>
<td>3.8 x 3.7 x 1.8 cm 27 g</td>
<td>Biaxial</td>
<td>Hip or waist</td>
<td>Records activity in epochs of 1 s to several minutes</td>
<td>Records up to 378 d when using 1 min. epochs</td>
<td>Activity counts, Step counts, Energy expenditure, Sleep quality</td>
</tr>
<tr>
<td>GT3X Actigraph</td>
<td>Actigraph LLC Pensacola, FL</td>
<td>3.8 x 3.7 x 1.8 cm 27 g</td>
<td>Triaxial</td>
<td>Wrist or waist</td>
<td>Records activity in epochs of 1/30 s to 4 min</td>
<td>Records up to 1 year when using 1 min. epoch.</td>
<td>Activity counts, Step counts, Energy expenditure, Sleep quality</td>
</tr>
<tr>
<td>RT3-Triaxial Research Tracker [formerly R3D]</td>
<td>Stayhealthy Inc. Monrovia, CA</td>
<td>7.1 x 5.6 x 2.8 cm 65.2 g</td>
<td>Triaxial</td>
<td>Hip or waist</td>
<td>Records activity in 1 s to 1 min. epochs</td>
<td>Records up to 7 d when using 1 min. epochs</td>
<td>Activity counts for each plane, Energy expenditure</td>
</tr>
</tbody>
</table>

Adapted from Murphy²¹
Validity/reliability of accelerometers

There are no studies evaluating all brands and models of accelerometers, and not all brands and models have been validated. Mostly, these kind of studies have put the attention to determine if accelerometers provide valid assessments of PA and/or energy expenditure in older persons. The results of this research question are summarized below because it is a main factor to select an accelerometer.

Gardner and Poehlman\(^2\) compared PA assessed by Caltrac accelerometer with the criterion method of PA using doubly labeled water in free-living peripheral arterial occlusive disease older patients. The activity value from the accelerometer was highly correlated with energy expenditure of PA calculated by doubly labeled water, yielding a regression equation of energy expenditure of PA (kcal/day) = 81.6 + (0.599 X accelerometer kcal/day); R = 0.834, R\(^2\) = 0.696, standard error of estimate = 77 kcal/day, p = 0.001. None of the PA questionnaires was significantly correlated with energy expenditure of PA, as the correlation coefficients ranged between 0.037 and 0.326.

Although the most relevant studies are those which are validated against doubly labeled water, the high cost of this technique reduces their number. A recent research\(^2\) investigated the reliability and validity of using an accelerometer system (Activitx system) to quantify the PA level of elderly subjects against a commercially used PA questionnaire (Minnesota Leisure Time Physical Activity Questionnaire). The accelerometer system was found to be reliable (intraclass correlation coefficient, 0.978). The system was able to differentiate young adults and active elderly from sedentary elderly subjects (p < 0.001). The results showed a moderate but significant correlation with scores on the questionnaire (r = 0.850; p < 0.001). In line with those data it was concluded that the Activitx system can be used as an objective tool to quantify the PA level of the elderly.

The validity of the CSA activity monitor has been examined among older adults with chronic disease by Focht and colleagues.\(^2\) In order to assess concurrent validity, 10 volunteers wore both a CSA accelerometer and a Cosmed K4 portable gas-analysis unit during 30 min of rehabilitative exercise. The results revealed significant (p < 0.01) positive correlation between CSA activity counts and oxygen uptake (r = 0.72). The study concluded that CSA activity monitor is an effective objective measure of PA.

Basset et al.\(^25\) evaluated the relative validity of three accelerometers (Computer Science and Applications [CSA] 7164; Caltrac; and Kenz Select 2) for measuring energy expenditure during moderate intensity PA in field and laboratory setting in 81 participants from 19 to 74 years. Authors selected task from six general categories (yard work, housework, occupation, family care, conditioning, and recreation) listed in the 1993 Compendium of Physical Activities. During each activity, energy expenditure was measured using a portable metabolic measurement system. For the CSA device, three previously developed regression equations were used to convert accelerometer scores to energy expenditure. The mean error scores (indirect calorimetry minus device) across all activities were: CSA1, 0.97 MET; CSA2, 0.47 MET; CSA3, 0.05 MET; Caltrac, 0.83 MET; Kenz, 0.96 MET. The correlation coefficients between indirect calorimetry and motion sensors ranged from r = 0.33 to r = 0.62. The energy expenditure for power mowing and sweeping/mopping was higher than that listed in the 1993 Compendium of Physical Activities (p < 0.05), and the cost for several household and recreational activities was lower (p < 0.05). Authors concluded that motion sensors tended to over-predict energy expenditure during walking. However, they under-predicted the energy expenditure of many other activities because of an inability to detect arm movements and external work. These findings illustrate some of the limitations of using motion sensors to predict energy expenditure in field settings.

Choosing an accelerometer

Although many questions on how best to use accelerometers to measure PA remain unanswered, a considerable amount is known about monitor selection, quality, and dependability.\(^2\) The decision to purchase a particular make and model of accelerometer is influenced by a multitude of factors. In general, no one monitor is superior to others, and selection depends primarily upon the research interest. However, for most researchers, the relative validity and inter-instrument reliability of a given accelerometer product is of primary importance. According to Trost,\(^22\) evidence indicates that some accelerometers may perform better than others under certain conditions, but the reported differences are not consistent or sufficiently compelling to single out one brand or type of accelerometer as being superior to the others.

Issues of affordability should be considered, because in a study of Conn and coworkers,\(^2\) participants wore the TriTrac units 78% of the requested days and under-reported time not wearing the TriTrac. In this case, authors concluded that researchers should provide for the possibility of damaged TriTrac devices. Therefore, when it comes to selecting an accelerometer, issues of affordability, product reliability, monitor size, technical support, and comparability with other studies may be equally as important as the relative validity and reliability of an instrument.

Placements of monitors

The relative position of the accelerometer on the body is another important consideration, given that the
output from an accelerometer is dependent on the positioning on the body and its orientation. Because of this, different acceleration signals are recorded depending on placement as well as the inherent mechanical properties of the sensor.

Monitors record acceleration in different axes or planes of movement. These monitors are often described as uniaxial, biaxial, or triaxial for the axis or plane in which the monitor is most sensitive at detecting acceleration. Most commonly used cantilever beam monitors are usually referred to as “uniaxial” because they are most sensitive in the axis of bending (vertical). Studies have demonstrated that accelerometers can be calibrated for different positions on the body. Ideally, the accelerometer should be attached as close as possible to body’s center of mass. One advantage of the current accelerometer technology is its small, compact size, making it wearable on many body locations (ankle, wrist, hip...). To date, a small number of studies have specifically addressed the issue of monitor placement. Little evidence suggests that one position is better than another. Pragmatic guidelines, such as comfort and ease of use, have taken precedence. However, the trunk location (hip or lower back) has become by far the most common placement for the monitors. When measuring energy expenditure, the hip or waist is the most common site to wear an accelerometer although accelerometer output may vary even with position about the hip. Researchers should consider manufacturer’s instructions on how to place the monitors and may recommend wearing the monitor over one hip or anywhere on the waist.

According to a study the accelerometer should be used on the same side of the body. This research aimed to examine the effect of accelerometer placement, use of walking aids, and different types of PA on Stay健康发展 RT3 triaxial accelerometer readings in older people. The authors found significant differences between counts generated by the left and right hip positions. The intraclass correlation coefficient of RT3 counts between left and right hip positions was 0.48, 0.39 and 0.99 for sedentary tasks (standing, sitting and rest), stair and walking tasks respectively. Positioning of the monitor should be an important issue when data are collected over a series of days because of less supervision and guidance on wearing it appropriately. Variability due to positioning can be reduced with careful training and supervision.

Number of days worn

The minimum number of days individuals need to wear an accelerometer has important implications for compliance and overall study costs; in consequence the length of time they are worn should be considered. Researches need to measure for a sufficient number of days so that the average PA reflects a habitual level of PA. Finally, the number of monitoring days required to achieve a desired level of reliability based on the expected between and within subject variance.

Compliance to accelerometer protocols

Accelerometers are reliable and valid tools for measuring PA for research studies, provided that individuals participating in the study are compliant with wearing it as directed by the study protocol. As was indicated previously in this paper, some research has suggested that a minimum number of days of monitoring is needed in order to produce an accurate assessment of the PA patterns of an individual. As a result, participants in research studies who fail to meet the minimum number of valid days of accelerometer wear are excluded from any analysis related to PA, because their PA level cannot be calculated. It is possible that aging effects on physical and cognitive health may limit the ability of an older adult to be compliant with an accelerometer protocol. Unfortunately, no study focused on the factors that predict compliance to accelerometer protocols in older adults has been carried out. It is important, therefore, to identify factors that predict compliance to ensure that older adults with certain characteristics are not consistently excluded from analyses related to PA measured by an accelerometer in research studies.

Many methods have been suggested for increasing compliance to accelerometer protocols. The most important recommendation for improving compliance appears to be education. Table II shows strategies to promote compliance with activity monitoring in field-based studies.

Limitations of accelerometers

The main limitation of accelerometers to approximate energy expenditure is the impossibility to detect the full energy expenditure of certain activities such as walking, carrying a load or walking uphill, because acceleration do not change under these conditions. It is still not clear where the accelerometer should be placed to produce an accurate recording of the activity level of the whole body. In elderly people PA could be underestimated if accelerometer is placed on hip, waist...
Compliance strategies

– Ask to complete an activity monitoring log.
– Display written material/flyers on visible places to prompt wearing the accelerometer.
– Make reminder calls.
– Provide tips or list of frequently asked questions on how to wear accelerometers correctly.
– Show an example of an output to demonstrate that one can know when they are not wearing the accelerometer.
– Provide rewards for compliance, such as gift certificate, extra credit, coupons…
– Inform on the study in advance to caregivers and educate them about wearing protocols.

Adapted from Trost, McIver and Pate27

o lower back. Wrist placement allows to capture the kind of activity that is common in late life, in particular the fine, upper body movements involved in such everyday activities that occur while both sitting (e.g., sewing, playing cards) or standing (e.g., washing dishes).35 A small number of studies had examined whether additional accelerometers worn on the wrist or ankle can improve the accuracy of energy expenditure predicted with a single accelerometer on the hip or lower back. In a study by Swartz and colleagues36 in which participated seventy subjects between 19 and 74 years old, the equation based on the results of accelerometer worn on hip explained only 32% of the variance, meanwhile the combination of output from accelerometer worn on hip and wrist resulted in a slight increase in explanatory power (an additional 2.6% of the variance in METs).

Other minor limitations include financial cost of monitors and staff time-consuming to process and analyze data.

Conclusions

Recent technological developments have led to the production of inexpensive, miniature accelerometer sensors with potential for use in older people. These sensors can provide reliable information on mobility and objective measurement of PA. Accelerometers have significant advantages when compared with other quantitative methods. Accelerometers are currently used mainly in a research setting, however, with recent advances, incorporation into clinical and fitness practice is possible and is increasing. It is envisaged that the number and type of applications for this technology will increase as its potential is recognized. For instance, the miniature nature of accelerometers has made their incorporation into clothing possible by integrating the sensors into fabric,23 which would facilitate compliance in long-term mobility monitoring.

References


