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Revisiones

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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UTILIZACIÓN DE LOS ACELERÓMETROS PARA LA MEDIDA DE LA ACTIVIDAD FÍSICA Y EL GASTO ENERGÉTICO EN PERSONAS MAYORES

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,[1] Physical activity (PA), defined as any bodily movement produced by skeletal muscles that results in energy expenditure,[2] has been identified as priority area in general health promotion .[3] 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,[4] such as muscle strength and power, balance, flexibility, endurance, or mobility,[5] 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 popular belief that PA is associated with psychological benefits,[6] and a large number of studies have begun to document preventive effects for depression or neurodegenerative diseases.[7]

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,[8] and the recommendation of an appropriate pattern of PA to maintain good health.[9] 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,[10] and perceptions of the intensity of any stimulus depend on the experience and the stoicism of the person concerned.[11] In older adults in particular, self-report may also be influenced by fluctuations in health status and mood, depression, or anxiety ability,[12] and by problems with memory and cognition.[13,14] 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.[14,15] Furthermore, even when these light to moderate intensity activities are assessed they tend to be difficult to measure reliably.[15] 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.[13] 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,[4] the Physical Activity Scale for the Elderly,[15] or the CHAMPS physical activity questionnaire,[14] 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.[16] 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.[17,18] 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.[19] The amplitude of the voltage signal is in proportion to the acceleration detected.[20] 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.

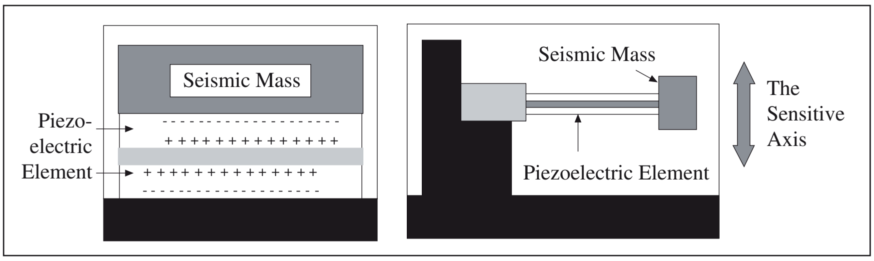

Fig. 1.—Left: Integrated chip sensor. Right: Cantilever beam.

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 I
Overview of commonly-used accelerometers

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

Adapted from Murphy[21]

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 putted 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[22] 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[23] investigated the reliability and validity of using an accelerometry system (Actiwatch system) to quantify the PA level of elderly subjects against a commonly used PA questionnaire (Minnesota Leisure Time Physical Activity Questionnaire). The accelerometry 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 = 0.830; $p < 0.001$). In line with those data it was concluded that the Actiwatch 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.[24] 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.[26] 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 anothers, and selection depends primarily upon the research interest. However, for most researchers, the relative validity and inter-instrument reliability of a given accelerometry product is of primary importance. According to Trost,[27] 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,[28] participants wore the TriTrac units 78% of the requested days and underreported 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[29] and its orientation.[20] 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).[21]

Studies have demonstrated that accelerometers can be calibrated for different positions on the body.[30] Ideally, the accelerometer should be attached as close as possible to body's center of mass.[26] 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.[31] 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[32] 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-Healthy 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.[29]

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 will depend on the setting (e.g., occupational or leisure time), the study resources (e.g., low budget vs well funded), and the research questions (e.g., the need for population-level vs individual-level estimates of PA behaviors), although typically the sampling period is between 3 and 7 days.[27] Although Gretebeck and Montoye[33] suggested that weekdays and weekend days need to be sampled, it is not yet clear if sufficient variability between this kind of days exists in the elderly.

Variance partitioning is a commonly-used technique to determine the number of monitoring days required to achieve a desired level of reliability based on the expected between and within subject variance.[27]

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.[27] 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.[34] 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

Table II
Proposed strategies to promote compliance with activity monitoring

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 with 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 Pate[27]

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 colleagues[36] 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 the hip and wrist resulted in an 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,[37] which would facilitate compliance in long-term mobility monitoring.

References

1. Landi F, Onder G, Carpenter I, Cesari M, Soldato M, Bernabei R. Physical activity prevented functional decline among frail community-living elderly subjects in an international observational study. *J Clin Epidemiol* 2007; 60 (5): 518-24.
2. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep* 1985; 100 (2):126-31.
3. US Department of Health and Human Services. 2000. Healthy People 2010: Understanding and Improving Health. Washington, D.C: U.S. Government Printing Office.
4. DiPietro L. The epidemiology of physical activity and physical function in older people. *Med Sci Sports Exerc* 1996; 28 (5): 596-600.
5. Taylor AH, Cable NT, Faulkner G, Hillsdon M, Narici M, Van Der Bij AK. Physical activity and older adults: a review of health benefits and the effectiveness of interventions. *J Sports Sci* 2004; 22 (8): 703-25.
6. Garatachea N, Molinero O, Martínez-García R, Jiménez-Jiménez R, González-Gallego J, Marquez S. Feelings of well being in elderly people: relationship to physical activity and physical function. *Arch Gerontol Geriatr* 2009; 48 (3): 306-12.
7. Rovio S, Kareholt I, Helkala EL, Viitanen M, Winblad B, Tuomilehto J, Soininen H, Nissinen A, Kivipelto M. Leisure-time physical activity at midlife and the risk of dementia and Alzheimer's disease. *Lancet Neurol* 2005; 4 (11): 705-11.
8. Macera CA, Powell KE. Population attributable risk: implications of physical activity dose. *Med Sci Sports Exerc* 2001; 33 (6 Suppl.): S635-9; discussion 640-631.
9. Bouchard C. Physical activity and health: introduction to the dose-response symposium. *Med Sci Sports Exerc* 2001; 33 (6 Suppl.): S347-50.
10. Davis MG, Fox KR. Physical activity patterns assessed by accelerometry in older people. *Eur J Appl Physiol* 2007; 100 (5): 581-9.
11. Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. *Res Q Exerc Sport* 2000; 71 (2 Suppl.): S1-14.
12. Rikli RE. Reliability, validity, and methodological issues in assessing physical activity in older adults. *Res Q Exerc Sport* 2000; 71 (2 Suppl.): S89-96.
13. Harada ND, Chiu V, King AC, Stewart AL. An evaluation of three self-report physical activity instruments for older adults. *Med Sci Sports Exerc* 2001; 33 (6): 962-70.
14. Stewart AL, Mills KM, King AC, Haskell WL, Gillis D, Ritter PL. CHAMPS physical activity questionnaire for older adults: outcomes for interventions. *Med Sci Sports Exerc* 2001; 33 (7): 1126-41.
15. Washburn RA, McAuley E, Katula J, Mihalko SL, Boileau RA. The physical activity scale for the elderly (PASE): evidence for validity. *J Clin Epidemiol* 1999; 52 (7): 643-51.
16. Steele BG, Belza B, Hunziker J, Holt L, Legro M, Coppersmith J, Buchner D, Lakshminaryan S. Monitoring daily activity during pulmonary rehabilitation using a triaxial accelerometer. *J Cardiopulm Rehabil* 2003; 23 (2): 139-42.
17. Saunders JB, Inman VT, Eberhart HD. The major determinants in normal and pathological gait. *J Bone Joint Surg Am* 1953; 35-A (3): 543-58.
18. Gage H. 1964. Accelerographic analysis of human gait. Washington: American Society for Mechanical Engineers.
19. Chen KY, Bassett DR Jr. The technology of accelerometry-based activity monitors: current and future. *Med Sci Sports Exerc* 2005; 37 (11 Suppl.): S490-500.
20. Mathie MJ, Coster AC, Lovell NH, Celler BG. Accelerometry: providing an integrated, practical method for long-term, ambulatory monitoring of human movement. *Physiol Meas* 2004; 25 (2): R1-20.

21. Murphy SL. Review of physical activity measurement using accelerometers in older adults: considerations for research design and conduct. *Prev Med* 2009; 48 (2): 108-14.
22. Gardner AW, Poehlman ET. Assessment of free-living daily physical activity in older claudicants: validation against the doubly labeled water technique. *J Gerontol A Biol Sci Med Sci* 1998; 53 (4): M275-80.
23. Gao KL, Tsang WN. Use of Accelerometry to Quantify the Physical Activity Level of the Elderly. *Hong Kong Physiotherapy Journal* 2008; 26: 18-23.
24. Focht BC, Sanders WM, Brubaker PH, Rejeski WJ. Initial validation of the CSA activity monitor during rehabilitative exercise among older adults with chronic disease. *Journal of Aging and Physical Activity* 2003; 11: 293-304.
25. Bassett DR Jr, Ainsworth BE, Swartz AM, Strath SJ, O'Brien WL, King GA. Validity of four motion sensors in measuring moderate intensity physical activity. *Med Sci Sports Exerc* 2000; 32 (9 Suppl.): S471-80.
26. Ward DS, Evenson KR, Vaughn A, Rodgers AB, Troiano RP. Accelerometer use in physical activity: best practices and research recommendations. *Med Sci Sports Exerc* 2005; 37 (11 Suppl.): S582-8.
27. Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc* 2005; 37 (11 Suppl.): S531-43.
28. Conn VS, Minor MA, Mehr DR, Burks KJ. Recording Activity in Older Women With TriTrac. *American Journal of Health Behavior* 2000; 24 (5): 370-8.
29. Welk GJ. Principles of design and analyses for the calibration of accelerometry-based activity monitors. *Med Sci Sports Exerc* 2005; 37 (11 Suppl.): S501-11.
30. Bouten CV, Sauren AA, Verduin M, Janssen JD. Effects of placement and orientation of body-fixed accelerometers on the assessment of energy expenditure during walking. *Med Biol Eng Comput* 1997; 35 (1): 50-6.
31. Yngve A, Nilsson A, Sjostrom M, Ekelund U. Effect of monitor placement and of activity setting on the MTI accelerometer output. *Med Sci Sports Exerc* 2003; 35 (2): 320-6.
32. Sumukadas D, Laidlaw S, Witham MD. Using the RT3 accelerometer to measure everyday activity in functionally impaired older people. *Aging Clin Exp Res* 2008; 20 (1): 15-8.
33. Gretebeck RJ, Montoye HJ. Variability of some objective measures of physical activity. *Med Sci Sports Exerc* 1992; 24 (10): 1167-72.
34. Welk GJ. 2002. Use of accelerometry-based activity monitors to assess physical activity. In: Welk GJ, editor. Physical activity measurement for health related research. Champaign: Human Kinetics, pp. 125-41.
35. Chipperfield JG, Newall NE, Chuchmach LP, Swift AU, Haynes TL. Differential determinants of men's and women's everyday physical activity in later life. *J Gerontol B Psychol Sci Soc Sci* 2008; 63 (4): S211-S218.
36. Swartz AM, Strath SJ, Bassett DR Jr, O'Brien WL, King GA, Ainsworth BE. Estimation of energy expenditure using CSA accelerometers at hip and wrist sites. *Med Sci Sports Exerc* 2000; 32 (9 Suppl.): S450-6.
37. Huang WT, Chen CH, Chang YJ, Chen YY, Huang JL, Yang CM, Yang TL. Exquisite textiles sensors and wireless sensor network device for home health care. *Conf Proc IEEE Eng Med Biol Soc* 2008; 2008: 546-9.