REVIEW ARTICLE

Validation of accelerometry for measuring energy expenditure: a systematic review

Christiane Riedi Daniel[1], Linamara Rizzo Battistella[2]

ABSTRACT

Objective: The primary objective of this review was to examine the quality of the validation studies of the accelerometry tool as compared with measuring maximal oxygen uptake (VO_2max). A secondary objective was to present the main characteristics of the studies and of the main models of accelerometers tested. **Method:** After searching the MedLine, LILACS, Embase e CLINAHL databases with the descriptors "Oxygen Consumption" OR "Energy Metabolism" AND "Accelerometry" AND "Validation Studies," the two authors made the selection according to the title, the abstract, and the full text. After that, the quality of the articles was assessed by the QUADAS-2 tool for risk of bias and for concerns regarding the applicability of the test. **Results:** We selected 10 studies that fit the inclusion criteria. The QUADAS-2 analysis showed that for the risk of bias there were problems with identification, particularly with regard to the proposed test and with the gold standard. In relation to the applicability, in most studies the risk was low. The most used accelerometers were the Actgraph and the SenseWear Armband Pro3 that was tested in 3 studies. **Conclusion:** This systematic review concluded that more information is needed about the proposed methodology in studies to classify their quality and that accelerometry is a valid alternative to measure energy metabolism in conditions of free-living and controlled activities, regardless of the accelerometer.

Keywords: Accelerometry, Energy Consumption, Validation Studies

[1] Physiotherapist, Doctoral candidate at the Medical School of the Universidade de São Paulo; Assistant Professor, Universidade Estadual do Centro Oeste.
[2] Physiatrist, Tenured Professor, Faculdade de Medicina da Universidade de São Paulo.

Mailing address:
Instituto de Reabilitação Lucy Montoro
Christiane Riedi Daniel
Rua Jandiatuba, 580
São Paulo - SP
CEP 05716-150
E-mail: christiane_riedi@usp.br

Received on April 23, 2014.
Accepted on July 26, 2014.

DOI: 10.5935/0104-7795.20140019

INTRODUCTION

Physical activity is considered an important indicator of health, and its regular practice has an impact on the prevention of cardiovascular risk factors and on the development of diseases such as heart diseases, diabetes type 2, cerebral vascular accidents, and colon and uterine cancers, which is directly related to the energy expended during physical activity and to the total energy expended.[1,2]

Physical activity as a form of regular and standardized therapeutic exercise is also important in the rehabilitation program for the cardiovascular and neuromuscular aspects and from the perspective of motor control and cortical plasticity.[3]

Based on this, it is necessary to investigate tools that are simple, practical, not too invasive, and that have the appropriate sensitivity to measure the level of physical activity (PA) and energy expenditure (EE), either in controlled conditions (laboratory) or in free-living activities. From that perspective, the accelerometer is an instrument that evaluates the EE and the level of PA through real time estimates of the frequency, intensity, and duration of that activity,[4] and that being portable and easy to handle[5] makes the collection of these measurements possible under the most varied conditions.[6,7]

The initial objective of this study was to review validation studies of the accelerometer in the measurement of EE in people with strokes who, due to the disease, presented a decrease in mobility and functional capacity and an increase in fatigue, thus generating a cycle of physical inactivity;[8] however, with the descriptors established by the Mesh, it was not possible to find validation studies for that population, therefore, the research was expanded to any population, which is justified by the great variety of accelerometer models currently on the market.

OBJECTIVE

The primary objective of this review was to examine the quality of validation studies of the accelerometer compared with maximum oxygen uptake (VO_2max) in the measurement of EE and, as a secondary objective, to present the main characteristics of the studies included and the models of accelerometers tested.

METHOD

General criteria for the studies of this review

Types of study
Validation studies.

Types of participants
Adults (older than 18 years), healthy or with any pathology.

Types of tools investigated
Studies were investigated that used accelerometry as a tool to evaluate the energy expenditure of individuals, as compared with the VO_2max.

Research methods to identify the studies

Search strategy
The eligible studies were identified after research in the MedLine, LILACS, Embase, and CLINAHL data banks. The two authors evaluated the studies based on the inclusion criteria and on the quality of the studies. The descriptors chosen to perform the research were: "Oxygen Consumption" OR "Energy Metabolism" AND "Accelerometry" AND "Validation Studies".

Selection criteria
All the works found in English, Portuguese, and Spanish from the last ten years until the first half of February, 2014 were included.

Selection of articles
The selection and evaluation of the articles was made by two independent authors. Articles not related to the theme according to their title and abstract were excluded. From the articles selected, the researchers evaluated the complete texts, classifying their quality and inclusion criteria. After the articles were selected, the authors met to decide which studies should be included and which should be excluded from the review. Had there been any disagreement between the reviewers, a third researcher would have been asked to solve the problem; however, that was not necessary.

Evaluation of the articles' quality
Because this was a review of articles that validated tools for measuring energy expenditure, the QUADAS-2 method was chosen for being an instrument that evaluates the quality of accuracy studies, investigating the risk of bias of those studies and the concerns regarding the applicability of the test investigated. For the risk of bias, a checklist with four domains was used: selection of patients, test investigated, gold standard, and the study flow. For the applicability of the test, only the first three domains would be analyzed. In order to facilitate the classification of the studies, some standardized questions (signaling questions) should be answered. The studies are classified as either low, high, or no detected risk of bias and applicability.[9]

RESULTS

The search revealed 39 articles at MedLine from which 29 were identified as possible studies to be included. Nine articles were excluded because they dealt with children and four that dealt with adolescents, leaving 16 articles to be analyzed. After the complete reading of these studies, six were excluded because they used accelerometry to validate other tools, which did not serve the objective of the present study.

In the LILACS and Embase databases there were no results found for the descriptors chosen. In the CLINAHL database there were 28 possibilities, but only one was included in this review, since 12 of them were not validation studies, 10 used the accelerometer as a reference to test other forms of measuring physical activity and energy expenditure, and five used only the maximum consumption of oxygen as an evaluation tool.

Therefore, a quality analysis of the 11 studies was made through the QUADAS-2 tool and the results were presented according to the four items proposed by the tool: selection of patients, test investigated, use of the gold standard, and the flow and timing of the study.

Figure 1 shows the QUADAS-2 analysis for risk of bias and it can be seen that the risk is low in the patient selection and flow and timing items, and that the critical point of this review is the lack of clarity in the information about the use of the test proposed and the gold standard.

Figure 2 shows the methodological quality referring to concerns with applicability of the proposed test and one can observe that only 9.1% of the studies presented a problem in the patient selection and the clinical question.

After the qualitative evaluation, the characteristics of the participants in the studies included in this review were identified (Table 1).

In Table 2, one can observe the main characteristics of the studies, as well as the statistical methodology used.

DISCUSSION

Despite the vast literature on the use of accelerometry as a form to measure the EE, the validation studies of this equipment are few and, when made on pathologies, are even fewer.

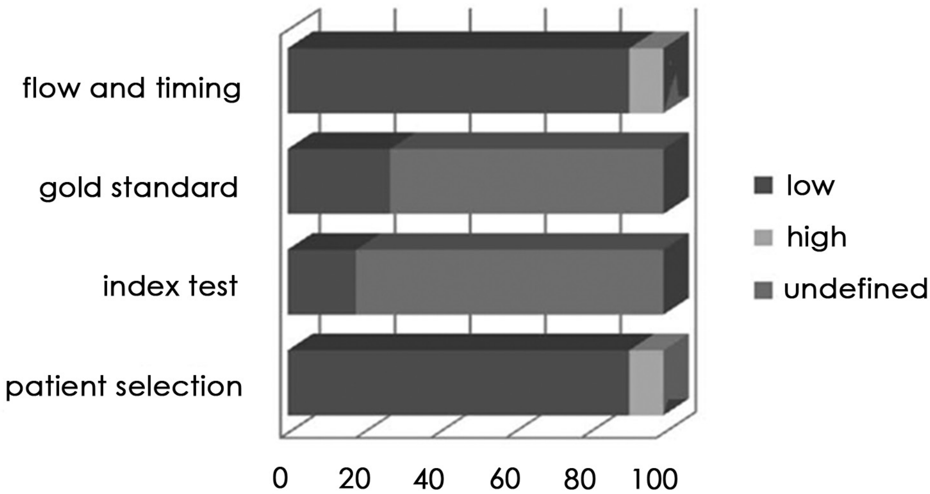

Figure 1. Methodological quality for the risk of bias

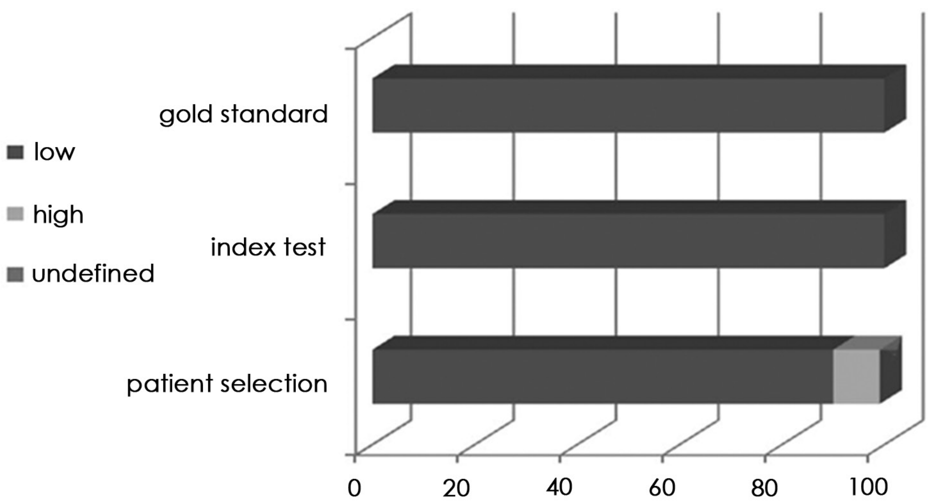

Figure 2. Methodological quality for concerns regarding the applicability of the test

Table 1. Characteristics of the participants in the studies analyzed

Study	Characteristic of the sample	N Gender	Age (years)	Weight (Kg)	Height (cm)	BMI (Kg/m²)
Item-Glatthorn et al.[5]	Osteoarthrosis of the hip	26 M	54 ± 9	84 ± 11	176 ± 6	27.18 ± 8
Villars et al.[2]	Healthy	35 M	27.6 ± 6.5	82.3 ± 14.4	NI	25.2 ± 4
Tweedy & Trost[10]	Elderly in the community	11 M/3 F	32 ± 8	NI	NI	NI
Soric et al.[11]	Students	19 M	28 ± 6	69 ± 11	173 ± 8	23 ± 3
Kuffel et al.[12]	Healthy	14 M/16 F	28 ± 7.7	NI	NI	24.6 ± 3.6
Kumahara et al.[13]	Healthy	28 M/51 F	38.5 ± 12	60.8 ± 10.2	164.35 ± 0.05	22.4 ± 2.7
Horner et al.[14]	Military	114 M/41 F	20.6 ± 3.9	67.9 ± 12	171 ± 0.10	23.25 ± 2
Bharathi et al.[15]	Healthy	94 M	39 ± 13	NI	NI	21 ± 3
Johansson et al.[16]	Healthy	6 M/2 F	28-63	61.2-120.5	166-188	NI
Patel et al.[17]	COPD	4 M/4 F	61.5 ± 4.3	84 ± 19	NI	30.2 ± 5.8
Johannsen et al.[18]	Healthy	15 M/15 F	38.2 ± 10.6	71.2 ± 13.7	171 ± 7	24 ± 3.4

BMI: body mass index; M: male; F: female; NI: not identified; COPD: chronic obstructive pulmonary disease.

The initial objective of this work was to investigate validation studies on accelerometry on the maximum consumption of oxygen in people afflicted with stroke in any phase of the disease (acute, subacute, or chronic). This option occurred because the physical lack of activity resulting from the motor sequelae limits the deambulation, the functional capacity, and the performance of daily life activities in this population.[19] However, difficulty was found in the selection of articles related to the subject, which shows that, despite studies like Manns Haennel[20] that evaluate accelerometry with stroke patients, many of these articles are not actual validation studies.

The Mesh words were chosen for it being a controlled vocabulary used for its indexing at MedLine and other databases. This choice is positive in the consistent recovery of information and negative because the other studies that do not use these descriptors may not appear in the research.

The limited number of validation studies found for stroke patients shows the need to develop research that investigates the validity of accelerometry for this population. The accelerometry in this case makes it possible to evaluate stroke patients as much in controlled conditions such as in laboratory as in free-living and daily activities.

The studies included in this review were evaluated by the QUADAS-2 tool and difficulty in extracting information can be verified, especially related to the interpretation of the tests-for the proposed tests as well as for the gold standard. According with Withing et al.[9] for the QUADAS-2 tool, if the signaling questions are answered with a "yes", the risk of bias is low and when the questions are answered with a "no", the risk already exists. The use of the undefined term must only be made if the data are insufficient to allow the judgment of what was found in this review, as much in the proposed tests as in the gold standard.

In a study by Item-Glatthorn et al.[5] it was not possible to identify the form of patient selection offering some bias. Also, in a study by Villars et al.[2] the risk of bias occurred due to the exclusion of patients for problems in the registry of the equipment.

In relation to applicability, it is possible to verify that all the studies included in this review show concern regarding the applicability of the test as well as of the study. Only the study by Item-Glatthorn et al.[5] showed concern with the patient selection item.

From a total of 498 individuals in these reviews, most were male (366) with a great

Table 2. Characteristics of the main studies and the statistical methodology used

Study	Comparison	Method	Variables analyzed	Statistical analysis	Conclusion
Item-Glatthorn et al.[5]	Intelligent Device for Energy Expenditure and Activity (IDEEA) x Gaitrite	Gait and gait phases	Cycle of gait (s) Balance (s) Double support (s) Length of step (cm) Cadence (steps/min) Velocity (m/s)	ICC (LOA) 0.99 (0.07; 0.016) 0.92 (0.2*; 0.06) 0.81(-0.86; 0.23) 0.78 (-7.3; 11.2) 0.99 (0.5; 1.9) 0.93 (0.16; 0.19)	Indicated for the quantitative analysis of the temporal parameters; however, for the evaluation of double support and length of step it must be used with caution
Villars et al.[2]	Actiheart and RT3 triaxial accelerometer x double water column	Daily free-living activities	TEE EER PAEE	Ac x DCH_2O: ICC: < 0.01 LOA: 42.3; 24.4 R^2 = 0.06 Ac/FC x DCH_2O: ICC: < 0.3 LOA: 37; 31.2 R^2 = 0.11	Good level of agreement between the accelerometer and the heart rate with double water column in the energy expenditure in free-living activities
Tweedy &Trost[10]	Actgraph MTI accelerometer x indirect calorimetry	Comfortable Walk (CW), accelerated (AW) and brisk (BW)	METs	Pearson Coefficient: CW: 0.58* AW: 0.64* BW: 0.7*	Index valid to measure the energy expenditure in all the walking activities
Soric et al.[11]	Indirect calorimetry x Sensewear Armband Pro3 accelerometer	Recreational Skating	EE METs	Linear regression METS: $R^2 = 0.73$ p: 0.001 EE: $R^2 = 0.81$ p: 0.001 [partial] LOA: 42.3; 24.4 METS: -0.24; -0.23 EE: -0.34; -0.14	Lack of sensitivity in evaluating vertical activity of recreational skating
Kuffel et al.[12]	Indirect calorimetry x Actgraph GT1M accelerometer analyzed in two ways (2006 and redefined analysis (RA))	Deambulation at 20 and 40 s/min	EE	Anova: 20s: $p = 0.001$ 40s: $p = 0.01$ [partial] LOA: 42.3; 24.4 2006: -2.4; 2.2 AR: -1.5; 1.8	The current model for predicting energy expenditure is more sensitive than the older model
Kumahara et al.[13]	Plethysmography x uniaxial accelerometer	Free-living activities Walks on treadmills	TEE PAEE EET	Linear regression equation TEE $R^2 = 0.92$ $p < 0.001$ PAEE $R^2 = 0.56$ $p < 0.01$ EET $R^2 = 0.8$ $p < 0.001$	The accelerometry was useful to research the daily physical activity and the energy expenditure in non-controlled conditions.
Horner et al.[14]	Double water column x 3DNX triaxial accelerometer	Free-living activities	TEE PAL EEp PALp	TEE x EEp $R^2 = 0.65$ $p < 0.001$ PAL x PALp R^2 0.41 $p < 0.01$	The accelerometry increases the accuracy in the estimation of the energy expenditure of people in the military service.
Bharathi et al.[15]	Uniaxial accelerometry x indirect calorimetry	Exertion test Free-living activities	PAL EE	Correlation of Pearson PAL x EE r = 0.28 $p = 0.01$	The energy expenditure of the free-living activities measured through the accelerometer can offer an accurate measurement.
Johansson et al.[16]	Accelerometer Actgraph Cardiac monitor with movement sensor Gas analyzer Double marked water	Free-living activities Walks in different velocities Run	EE FC/AC x DMW EE FC x DMW EE AC x DMW	Bland-Altman + Pearson EE FC/AC x DMW $r^2 = -0.26$; $p = 0.53$ LOA (-3.2; 6.8) EE FCFlex x DMW $r^2 = -0.62$; $p = 0.1$ LOA (6.2-7.9) EE AC x DMW $r^2 = 0.03$; $p = 0.93$ LOA (-5.8; -6.6)	The Method associated with the FC and accelerometry, as well as the accelerometer isolated have the potential to be used as a tool to measure the energy expenditure in free-living activities.
Patel et al.[17]	Accelerometer SenseWear Pro Physical activity meter Gas analyzer	6-minute walking test Shuttle test	EE AC EE AC + PAL EE VO_2	Bland-Altman EE AC x VO_2 $R^2 = 0.68$; $p < 0.001$ EE AC + PAL x EE VO_2: R^2 0.86; $p < 0.001$ Reproducibility [partial] Shuttle x TC6 test 2 r 0.84 $p < 0.05$ Shuttle x TC6 test 2 r = 0.86 $p < 0.05$	The accelerometry and the physical activity monitor are reproducible and accurate to measure the EE during the low to moderate velocity walk in COPD with moderate functional limitation.
Johannsen et al.[18]	SenseWear Pro, SenseWear mini double marked water	Daily free-living activities	Daily EE TEE	Bland-Altman Daily EE SenseWear Pro x DMW R^2 0.68 $p < 0.001$ SenseWear Mini x DMW R^2 0.71 $p < 0.001$ TEE SenseWear Pro x DMW R^2 0.8 $p < 0.001$ SenseWear Mini x DMW R^2 0.85 $p < 0.001$	The SenseWear pro 3 and the SenseWear mini are accurate to measure the energy expenditure in daily free-living activities.

ACC: accelerometry; AC: accelerometer; PAL: physical activity level; PALp: physical activity level predicted; DMW: double marked water; AW: accelerated walk; CW: comfortable walk; BW: brisk walk; EE: energy expenditure; PAEE: physical activity energy expenditure; EET: energy expenditure on the treadmill; EEp: energy expenditure predicted; EER: energy expenditure at rest; TEE: total energy expenditure; ICC: intraclass correlation coefficient; LOA: limit of agreement; METS: metabolic equivalent; * statistically significant.

variation in the number of individuals researched between the studies; however, according with Kottner et al.[21] who proposed guidelines for reliability and agreement studies indicating that the samples are not usually very large, but that is necessary that the study's design be appropriate to answer the question correctly. The difference between the genders is not highlighted in these guidelines. In the studies evaluated, the design was considered appropriate to delineate the research.

As for the characteristics of the participants, 72.7% (8) studies were made with healthy individuals, 9.1% (1) with sufferers of osteoarthritis, 9.1% (1) with the elderly, 9.1% (1) with COPD, and as each pathology has different characteristics in its clinical manifestation, the need for a greater number of validation studies for different populations is highlighted.

While verifying the types of accelerometers, it was possible to observe that of the seven brands tested, the Actgraph accelerometer was the most used (3 studies). This accelerometer was tested in walks with different velocities,[10] with deambulation at 20 and 40 s/min. However, comparing two ways of reading the accelerometer[12] and in walks of different velocities and runs[16] under these three conditions, the accelerometer proved sensitive and was recommended by the authors. In a study by Kuffel et al.[12] the redefined analysis used in the accelerometry was considered more sensitive than the older model, and this is important, for it demonstrates that the form of analysis used influences the results of the studies.

The SensewearArmband Pro3, accelerometer was also used in three studies. Soric et al.[11] analyzed the accelerometer during recreational skating and verified the deficiency of the equipment in capturing measurements for vertical activities such as recreational skating; Patel et al.[17] investigated the use of the accelerometer in sufferers of moderate COPD, and in this condition the accelerometry was considered reproducible and accurate to measure the energy expenditure. Johannsen et al.[18] used the Sensewear Armband Pro3 together with the Sensewear Mini with the double marked water in daily life activities.

The other three triaxial accelerometers used were IDEEA[5] during the gait and its phases, RT3[2] and 3DNX[14] both in daily free-living activities, and the three pieces of equipment were recommended by the researchers. The IDEEA, although recommended by the researchers for the quantitative analysis of the energy expenditure of the temporal parameters, must be used with caution in the measuring of the EE in the double support and length of step phases.

The two uniaxial accelerometers were used in the studies by Kumahara et al.[13] and Bharathi et al.,[15] who evaluated free-living activities and exercises on the treadmill. They concluded that this type of accelerometer can be used to evaluate free-living activities, as well as to increase accuracy in the prediction of the energy expenditure.

In this this systematic review, it was possible to detect that, despite the results being considered appropriate for the recording of the energy expenditure in most of the proposed conditions, in specific situations such as in gait phases and vertical oscillations they must be used with caution. This reflects the need to verify the validation of the tool in the type of measuring to be made before using the accelerometer in the clinical routine, and also for the population to be investigated according to its particularities.

CONCLUSION

It is concluded, through this systematic review, that more studies are needed for the methodology proposed in the studies to classify the quality of the studies themselves and that accelerometry is a valid alternative to measuring the EE in conditions of free-living and controlled activities, regardless of the type of accelerometer. Accelerometry could become a support tool in the rehabilitation program, however, the need for more validation studies of this instrument in pathological conditions due to the particularities of its clinical manifestations should be emphasized.

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