Validity of physical activity monitors in adults participating in free living activities

Sveinung Berntsen, Rune Hageberg, Anders Aandstad, Petter Mowinckel, Sigmund A Anderssen, Kai-Hakon Hakon Carlsen and Lars Bo Andersen

Br. J. Sports Med. published online 15 Jul 2008;
doi:10.1136/bjsm.2008.048868

Updated information and services can be found at:
http://bjsm.bmj.com/cgi/content/abstract/bjsm.2008.048868v1

These include:

Rapid responses
You can respond to this article at:
http://bjsm.bmj.com/cgi/eletter-submit/bjsm.2008.048868v1

Email alerting service
Receive free email alerts when new articles cite this article - sign up in the box at the top right corner of the article

Notes

Online First contains unedited articles in manuscript form that have been peer reviewed and accepted for publication but have not yet appeared in the paper journal (edited, typeset versions may be posted when available prior to final publication). Online First articles are citable and establish publication priority; they are indexed by PubMed from initial publication. Citations to Online First articles must include the digital object identifier (DOIs) and date of initial publication.

To order reprints of this article go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to British Journal of Sports Medicine go to:
http://journals.bmj.com/subscriptions/
Validity of physical activity monitors in adults participating in free living activities

Sveinung Berntsen 1,2, Rune Hageberg 1, Anders Aandstad 3, Petter Mowinckel 2, Sigmund A. Anderssen 1, Kai-Håkon Carlsen 1,4,5 Lars Bo Andersen 1.

1 Department of Sports Medicine, Norwegian School of Sport Sciences; 2 Department of Paediatrics, Woman-child division, Ullevål University Hospital; 3 Defence Institute, Norwegian School of Sport Sciences; 4 Faculty of Medicine, University of Oslo; 5 Voksentoppen, Department of Paediatrics, Rikshospitalet University Hospital; Oslo, Norway.

The study is performed within the ORAACLE (the Oslo Research Group of Asthma and Allergy in Childhood; the Lung and Environment) which is part of the Ga²len network.

Address for corresponding author and reprint request:
Sveinung Berntsen,
Norwegian School of Sport Sciences,
PO. Box 4014 Ullevaal Stadion,
NO-0806 Oslo
Norway
Tel: +47 23 26 20 00
Fax: +47 22 23 42 20
E-mail: sveinung.berntsen@nih.no

Title for running head: Validity of physical activity monitors

Keywords: accelerometer, energy expenditure, indirect calorimetry, measurement, motion sensor.

The Corresponding Author has the right to grant on behalf of all authors and does grant on behalf of all authors, an exclusive licence (or non exclusive for government employees) on a worldwide basis to the BMJ Publishing Group Ltd and its Licensees to permit this article (if accepted) to be published in Journal (British Journal of Sports Medicine) editions and any other BMJPGL products to exploit all subsidiary rights, as set out in our licence (http://bjsm.bmjournals.com/misc/ifora/licenceform.shtml).

We hereby confirm that the work has been seen and approved by all co-authors. Regional ethics committee (east Norway) approved the protocol and the study. The study was conducted in accordance with the Declaration of Helsinki.

COMPETING INTEREST
None of the authors have any competing or conflicts of interests with regard to this manuscript.
ABSTRACT

**Background:** For a given subject, time in moderate to very vigorous intensity physical activity (MVPA) varies substantially among physical activity monitors.

**Objective:** The primary objective of the present study was to determine whether time in MVPA recorded with SenseWear™ Pro2 Armband (Armband), ActiGraph, ikcal and ActiReg® is different compared to indirect calorimetry. The secondary objective was to determine whether these activity monitors estimate energy expenditure different compared to indirect calorimetry.

**Material and methods:** Fourteen men and six women wore the activity monitors and a portable oxygen analyzer for 120 minutes doing a variety of activities of different intensities. Resting metabolic rate (RMR) was measured with indirect calorimetry. The cut off points defining moderate, vigorous and very vigorous intensity were 3, 6 and 9 times RMR.

**Results:** Armband and ActiGraph overestimated time in MVPA by 2.9 and 2.5% and ikcal and ActiReg® underestimated time in MVPA by 11.6 and 98.7%, respectively. ActiReg® ($p=0.004$) and ActiGraph ($p=0.007$) underestimated energy expenditure in MVPA and all monitors underestimated total energy expenditure (by 5 to 21%).

**Conclusions:** Recorded time in MVPA and energy expenditure varies substantially among physical activity monitors. Thus, when comparing physical activity level among studies, it is essential to know the type of physical activity monitor being used.
INTRODUCTION

In the currently published physical activity recommendations for adults it is stated that to promote and maintain health, all healthy adults aged 18-65 yr need moderate intensity aerobic (endurance) physical activity for a minimum of 30 min on five days each week or vigorous intensity aerobic physical activity for a minimum of 20 min on three days each week.[1] Physical activity is characterised by its intensity, duration, frequency and mode of activity.[2] Ideally, all these aspects should be recorded during physical activity measurements. Direct measurement of energy expenditure by heat production, or indirect by oxygen consumption (\( \text{VO}_2 \)), is limited to small populations or short time periods because of the cost of assessment to both the investigator and the participant.[3] Assessment of oxygen consumption has the advantage that it is possible to compare minute by minute data, which is not possible when devices are compared with heat production. A portable oxygen analyser - as used in the present study - costs approximately $40 000 and a bomb calorimeter or respiratory chamber costs millions. Still, such measurements are useful as criteria for evaluating other methods of physical activity recordings. In a daily free living setting, doubly labelled water is recognised as a reference method for the assessment of total energy expenditure; however, doubly labelled water only gives an integrated assessment of total energy expenditure during the measurement period.[4] This method does not assess day-to-day or hour-by-hour energy expenditure, or information of duration, frequency and intensity of moderate to very vigorous physical activity,[5] as oxygen consumption measurements do. MetaMax II (Cortex Biophysic, Leipzig, Germany), a portable oxygen analyzer validated against the Douglas-bag technique,[6,7] is suitable for measurements of \( \text{VO}_2 \) in subjects participating in free living activities.

The validity of newly introduced monitors needs to be carefully examined.[8] A number of studies have simultaneously evaluated the validity of two or more different makes and models of activity monitors in adults [9-13]. Notably, the majority of these studies have addressed the question of whether multiaxial accelerometers as Tritrac-R3D (RT3 Triaxial Research Tracker (StayHealthy, Inc., Monrovia, CA, USA)) provide more valid assessments of physical activity and/or energy expenditure than do single axis accelerometers as ActiGraph (7164, LLC, Fort Walton Beach, FL, USA) or included loco motor movement activities in a laboratory setting.[14] Since different activity monitors record different aspects of physical activity such as acceleration, position changes, heart rate etc., comparisons of physical activity data may be complicated. It is important to investigate the validity of activity monitors when comparing physical activity data among studies using different monitors. To date, a comparison of the activity monitors ActiGraph 7164, ActiReg®, iKal and SenseWear™ Pro2 Armband (Armband) in a free living condition including direct measurements of oxygen consumption is unavailable. It is therefore difficult to make informed decisions regarding which monitor might be optimal when conducting epidemiological studies. The present study focuses only on reporting time in MVPA and estimated energy expenditure across monitors, not to develop calibration equations and determining activity cut off points for specific intensities or types of physical activity.

The primary objective of the present study was to determine whether time in MVPA recorded with ActiGraph, ActiReg®, iKal and SenseWear™ Pro2 Armband is different compared to indirect calorimetry. The secondary objective was to determine whether these activity monitors estimate energy expenditure different compared to indirect calorimetry.
MATERIAL AND METHODS

Participants
Fourteen men and six women (19-56 years of age) volunteered to participate in the present study.

All participating subjects were of Caucasian origin without any overt disease or use of medications which could have influenced results such as energy expenditure. All participants were non-smokers.

The Regional Medical Ethics committee and the Data Inspectorate approved the study. The study subjects signed an informed consent form after being given oral and written information about the study objectives and methods.

Procedures
Prior to measurements, participants had their stature and body mass measured (in light clothing, without shoes) using a stadiometer and a physician’s scale, respectively. Measurements were performed at the participant’s work or home indoors and/or outdoors. The four activity monitors were attached to the body of the participant according to the instructions of the manufacturer. The best resolution data was collected with each monitor. All devices were synchronized with a digital clock prior to measurement. One of the monitors, ikcal, was calibrated according to the manufacturer’s instructions after being attached to the body. After finishing this calibration procedure, the portable oxygen analyzer and the breathing mask were attached to the participant and the measurement started. The measurement period lasted for 120 minutes during daytime. During this period the participants performed various lifestyle and sporting activities such as conditioning- and strength exercises, ball games, home repair, occupational- and home activities. We did not limit type and intensity of activities except being in contact with water. The test leader was on-site, but not supervising the activities. Type and estimated length of activities were registered after completion of the measurement period by interviewing the participant. In addition to the main measurements, we also performed a measurement of RMR in the morning, on another day, according to international guidelines and using the same oxygen analyzer.[15]

Indirect calorimetry
MetaMax II was used for measurements of $\overline{V}O_2$. Expired gases were collected via a breathing mask. A gas calibration of the $O_2$ and $CO_2$ analyzers, volume calibration of the volume transducer and calibration of the pressure analyzer were performed before all tests according to manufacturer. Data was analyzed with Metasoft v1.1 (Cortex Biophysic, Leipzig, Germany).

Activity monitors
ActiGraph 7164 accelerometer
ActiGraph 7164 measures acceleration in the vertical plane and has been validated in several studies; however, these validation studies are population specific.[16] ActiGraph was calibrated against a standardized vertical movement. The monitor was attached using an elastic belt at the participants’ hip, near spina iliaca anterior superior. The amount of energy expenditure and the cut off points defining moderate, vigorous and very vigorous intensity were calculated by the formula of Freedson et al. as recommended by the manufacturer.[17]
ActiReg®
ActiReg® (PreMed AS, Oslo, Norway) measures body position and body motion and has been validated against doubly labelled water.[18] The monitor has two pairs of body position sensors and two pairs of body motion sensors connected by cables to a battery-operated storage unit fixed to a waist belt. One of the position- and motion sensors was attached by medical tape to the chest and the other one to the front of the right thigh. The position codes and the amount of position changes were downloaded with software developed by the manufacturer (ActiCalc 32, PreMed AS, Oslo, Norway).

ikcal
ikcal (Teltronic AG, Biberist, Switzerland) measures heart rate and acceleration in the vertical and horizontal planes and has to our knowledge been validated in studies using whole-body indirect calorimetry and indirect calorimetry; however, the studies have not been published. The monitor was attached to the chest using an elastic belt around the sternum according to instructions of the manufacturer. Data from the monitor was downloaded with software developed by the manufacturer.

SenseWear™ Pro2 Armband
SenseWear™ Pro2 Armband (BodyMedia Inc., Pittsburgh, PA, USA) has been validated against doubly labelled water and includes a two-axis accelerometer, a heat flux sensor, a galvanic skin response sensor, a skin temperature sensor and a near-body ambient temperature sensor.[19] The monitor was worn on the right arm over the triceps brachii muscle at the midpoint between the acromion and olecranon processes. The data from the monitor was downloaded with software developed by the manufacturer (Innerview Professional Research Software Version 5.1, BodyMedia Inc., Pittsburgh, PA, USA).

Data processing
Data from the direct measurements of VO₂ and the four activity sensors were imported into Microsoft Excel® and synchronized for further analysis. All data were computed at one minute intervals. Absolute VO₂ data were transformed into kcal·min⁻¹ multiplying VO₂ in l·min⁻¹ with the factor 4.82.[20]

Statistical analysis
Sample size calculation was based on a standard deviation (SD) of time in MVPA of 25 minutes and a significance level of 0.05 with 80% power. We needed 17 subjects to detect a mean difference of 25 minutes between the activity monitors.

Bland-Altman plots were constructed to show the relationship of the mean differences (activity monitor minus indirect calorimetry) for accumulated energy expenditure and time in MVPA. The mean differences and limits of agreements were calculated according to Bland and Altman.[21] A two-way mixed, single measure, intra class correlation (ICC(3,1)) was performed for evaluating the extent of agreement between the physical activity monitors and indirect calorimetry for accumulated energy expenditure and time in MVPA. A two-way analysis of variance was performed to determine differences in accumulated energy expenditure and time in MVPA obtained with the activity monitors and indirect calorimetry. Tukey post hoc testing was performed to locate significant differences.

To test if the activity monitors underestimated or overestimated the energy expenditure in each intensity level, we calculated the absolute value of the difference at each time point (120 measurements, one per minute). For each individual, the cut off points defining moderate, vigorous and very vigorous intensity were 3, 6 and 9 times RMR. We calculated the mean of the absolute differences for each individual at the three levels of
intensity. The mean for the 20 individuals serves as an estimate of the error with which each activity monitor misses the energy expenditure measured with indirect calorimetry at each intensity level. To test if the activity monitors underestimated or overestimated energy expenditure measured with indirect calorimetry, we applied a standard one-sample t-test for the absolute values for each activity monitor. In addition, for each individual and the three levels of intensity, we calculated the percentage the activity monitors underestimated or overestimated energy expenditure measured with indirect calorimetry. For the mean of these percentages, we applied the central limit theorem and performed a normal test to establish whether there is a tendency to underestimate or overestimate the energy expenditure in each intensity level.

Level of significance was set to 0.05. Analyses were conducted in SAS® (SAS Institute Inc., Version 9.1.3, North Carolina, USA) and SPSS® (Statistical Package for Social Sciences, Version 15 for Widows. SPSS Inc. Chicago, USA, 2006).
RESULTS
The physical characteristics of the participants are shown in table 1.

**Table 1. Physical characteristics of the 20 participating subjects (Mean, standard deviation (SD) and minimum (Min) and maximum (Max))**

<table>
<thead>
<tr>
<th></th>
<th>Males (n=14)</th>
<th>Females (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>Mean 31 SD 9.6 Min-Max 19-56 Mean 39 SD 7.6 Min-Max 27-46</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>Mean 78 SD 9.6 Min-Max 66-102 Mean 71 SD 21.3 Min-Max 51-110</td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>Mean 181 SD 5.7 Min-Max 173-191 Mean 170 SD 8.9 Min-Max 159-184</td>
<td></td>
</tr>
<tr>
<td>BMI (kg⋅m(^{-2}))</td>
<td>Mean 24 SD 2.3 Min-Max 21-28 Mean 24 SD 6.1 Min-Max 20-36</td>
<td></td>
</tr>
<tr>
<td>RMR (kcal⋅min(^{-1}))</td>
<td>Mean 1.3 SD 0.26 Min-Max 0.8-1.8 Mean 1.1 SD 0.12 Min-Max 1.0-1.3</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: Body Mass Index, BMI; Resting Metabolic Rate, RMR

A variety of activities and intensities were performed by the participants. Eleven participants carried out conditioning exercises like brisk walking, running or bicycling whereas sedentary activities, home activities, home repair or occupation activities were performed by all 20 participants. Strength training or ball games were carried out by five participants.

**Time in moderate to very vigorous intensity physical activity**
The coefficient of variation for time in MVPA during 120 minutes activity were 43% for indirect calorimetry and 74, 95, 53 and 52% for ActiGraph, ActiReg®, Armband and ikcal, respectively. The mean differences and limits of agreements from the Bland-Altman plots for time in MVPA were 2.5 ±83.5, -34.2±52.9, 1.1 ±49.9 and -4.9 ±44.6 min (mean differences ±1.96 SD of the differences) for ActiGraph, ActiReg®, Armband and ikcal, respectively (fig 1). The Armband and ActiGraph overestimated time in MVPA with 2.9 and 2.5%, whereas ikcal and ActiReg® underestimated with 11.6 and 98.7% respectively. The ICC were 0.54 (95% CI; 0.13-0.79) and 0.54 (0.15-0.79) for Armband and ikcal (p=0.007 and 0.006); however, the ICC between Armband and ikcal was 0.84 (0.63-0.93). There was no statistical agreement (p>0.05) for time in MVPA between indirect calorimetry and ActiGraph or ActiReg®.

**Energy expenditure during moderate, vigorous and very vigorous intensity physical intensity**
Energy expenditure calculated from the Freedson equation for the ActiGraph-data significantly underestimated energy expenditure in moderate, vigorous and very vigorous intensity physical activity (all p<0.001) whereas the ActiReg® significantly underestimated energy expenditure in vigorous and very vigorous intensity physical activity (both p<0.001) (fig 2). Energy expenditure during moderate, vigorous and very vigorous intensity physical activity were underestimated in 67, 80 and 90% of the time points for ActiGraph vs. 68 and 91% for ActiReg®. The ikcal significantly overestimated energy expenditure in moderate intensity physical activity (p=0.03) and underestimated vigorous (p=0.02) and very vigorous intensity physical activity (p<0.001) (fig 2). Energy expenditure during moderate intensity physical activity was overestimated in 57% of the time points whereas 56 and 87% of the points were underestimating energy expenditure in vigorous and very vigorous intensity physical activity. The Armband significantly overestimated energy expenditure in moderate intensity physical activity (p=0.02) and underestimated very vigorous intensity physical activity (p<0.001) (fig 2). Energy expenditure during very vigorous intensity physical activity was underestimated in 92% of the time points. When examining underestimation of energy expenditure in MVPA, only ActiGraph (p=0.004) and ActiReg® (p=0.007) were significantly different from indirect calorimetry. Energy expenditure during MVPA was underestimated in 73 and 74% of the time points.
Total energy expenditure
The coefficient of variation for accumulated energy expenditure during 120 minutes of activity were 35% for indirect calorimetry and 47, 29, 34 and 32% for ActiGraph, ActiReg®, Armband and ikcal, respectively. Comparing accumulated energy expenditure during 120 minutes of activity, the mean differences and limits of agreements from the Bland-Altman plots were -50.0 ±396.7, -111.1 ±298.2, -43.4 ±261.0 and -33.9 ±265.2 kcal for ActiGraph, ActiReg®, Armband and ikcal, respectively (fig 3). ActiGraph, ActiReg®, Armband and ikcal underestimated total energy expenditure by 15, 21, 9 and 5% respectively. ActiReg® significantly underestimated the accumulated energy expenditure ($p<0.02$) compared to the other monitors. The ICC were 0.73 (0.44-0.88) and 0.71 (0.41-0.87) for Armband and ikcal (both $p<0.001$), vs. 0.55 (0.16-0.79) and 0.47 (0.02-0.75) for ActiGraph and ActiReg® ($p=0.005$ and 0.004).

Figure 4 shows an individual plot of minute-by-minute energy expenditure for a male participant performing 40 minutes brisk walking outdoors, 40 minutes bicycling on a regular bicycle and then walking around for another 40 minutes. The male individual in figure 5 is performing brisk walking the first 25 minutes, then 15 minutes running, 30 minutes playing table tennis, and 50 minutes carrying books and papers. The figures illustrate the large variations of energy expenditure for a given subject.
DISCUSSION

The Armband and ActiGraph overestimated time in MVPA, and ikcal and ActiReg® underestimated time in MVPA, respectively. ActiReg® and ActiGraph underestimated energy expenditure in MVPA and all activity monitors underestimated total energy expenditure.

Time in moderate to very vigorous intensity physical activity

Time in MVPA assessed with the activity monitors was somewhat less precise compared to assessment of total energy expenditure. On the basis of ICC, we noted that for Armband and ikcal, 53 and 54% of the variation were explained by differences among individuals and 47 and 46% by differences by the two different physical activity monitors. Eighty four per cent of the variation between the two monitors for assessment of time in MVPA was explained by differences among individuals. The deficiency of statistical agreement between indirect calorimetry and ActiReg® and ActiGraph was supported by the absolute differences analysis at each time point, comparing underestimation of energy expenditure in MVPA. An explanation for the low agreement could be limitations of uniaxial accelerometers and motion sensors, since accelerometers are insensitive to certain types of activities such as bicycling and strength training.[16]

Information on reported time in MVPA among diverse makes and models is lacking; however, Strath et al. compared five ActiGraph accelerometer cut off points for predicting time spent in different intensity categories.[22] Different accelerometer cut off points gave substantially different estimates of time in MVPA. Errors of energy expenditure prediction and cut off points defining MVPA activity could lead to misclassification of duration and frequency of physical activity. Leenders et al. found no difference in time spent in light, moderate and vigorous intensity physical activity during a seven days assessment using ActiGraph, a pedometer and a triaxial accelerometer.[13]

Total energy expenditure

Despite an average percentage underestimation of estimated accumulated energy expenditure from 5 to 21%, the activity monitors ActiGraph, Armband and ikcal provided relatively similar results. ActiReg® significantly underestimated estimated energy expenditure compared to indirect calorimetry as well as compared to the other three activity monitors. The ICC of 0.73 and 0.71 for Armband and ikcal vs. 0.55 and 0.47 for ActiGraph and ActiReg® illustrates that for Armband and ikcal, a larger part of the variance was explained by differences among individuals.

To our knowledge, no studies have reported on comparisons of energy expenditure assessed with Armband or ikcal with indirect calorimetry in free living conditions; however, St-Onge et al. reported mean estimated energy expenditure to be significantly lower for Armband than measured with doubly labelled water.[19] The ICC, 0.81, was somewhat higher compared to the present study. King et al. compared estimated energy expenditure using ActiGraph and Armband with indirect calorimetry, during treadmill walking and running.[11] ActiGraph was the best estimate of total energy expenditure at walking and jogging speeds whereas Armband was the best estimate of total energy expenditure. ActiReg® was recently validated against doubly labelled water and indirect calorimetry in a sample of adults. Some underestimation of energy expenditure was present, but to a smaller degree compared to the present study.[18] ActiGraph has been validated against indirect calorimetry in several studies; however, a majority of the studies were conducted in the laboratory, including participants performing activities like treadmill walking and running.[16] In the literature, correlation coefficients between physical activity monitors estimating energy expenditure and indirect calorimetry, seem to be lower during life style activities compared to walking and running at submaximal intensities.[16] The ICC of 0.55 in the present study...
between ActiGraph and indirect calorimetry in a free living condition, is in line with results reported by others [9,10,23,24].

**Strengths and limitations**
The present study has strengths and limitations. A wide range of activities of different intensities were performed among the participants, and energy expenditure during activities as well as at rest (RMR) was measured with the same portable oxygen analyzer. It may not be feasible to wear a breathing mask for longer periods and was together with the power supply or capacity of the batteries the main reasons for 120 minutes of measurement.

MetaMax is found to overestimate oxygen consumption with three to five per cent compared to the Douglas Bag technique, [6,7] and calculation of energy expenditure from oxygen consumption data should ideally adjust for which substrates that are undergoing oxidation.[25] In addition, the energy demand during very vigorous intensity physical activity may be covered through anaerobic energy-yielding metabolic processes not measurable with oxygen consumption. These factors may influence the evaluation of activity monitor compared to indirect calorimetry, but not the comparison among activity monitors.

Our participants were limited to a relatively small sample of 19-56 year old men and women mainly recruited from the Norwegian School of Sport Sciences and the Norwegian Military Academy in Oslo, Norway. The intention was to include men and women of different ages with a wide variety of BMI covering the adult population which the currently published physical activity recommendations include.[1] We can not generalize findings to other ethnic and age groups, which should be included in further studies.

In the present study we did not assess reliability of the activity monitors. To our knowledge, reproducing the same type, duration and intensity of activities in our subjects participating in free living activities is quite demanding.

There are limitations to the use of accelerometers, as well as other activity monitors such as those included in the present study, in predicting energy expenditure and time in MVPA in free living individuals. No single regression equation appears to accurately predict energy expenditure based on acceleration scores for all activities because of the unique relationships between movement and energy expenditure for different activities [10,26]. The use of a portable oxygen analyzer as in the present study covering a wide range of activities that people perform in their daily lives, may provide the most useful way to capture the appropriate balance between locomotor activities and free-living activities.

Direct observational methods are especially useful in studies that aim to go beyond pure assessment of physical activity to include the study of physical and social environmental influences.[27] The main reason for not observing mode of activity in the present study is because indirect calorimetry was used as a “gold standard” for energy expenditure. Indirect calorimetry gives a more valid and reliable information of energy expenditure compared to direct observation.[28] In addition, direct observation is impractical on a population basis.[3]

Different sampling intervals (Epoch) among the monitors may have influenced our results; however, Armband and ActiReg® have 60 seconds as default epoch, while ikcal has 10 seconds epoch respectively. The empirical evidence for whether different epochs influence recorded time in MVPA is limited.[29] One exception to this might be physical activity above vigorous intensity.

Measurement of RMR was performed in the morning on another day and may have influenced our results. The reason for measurement of RMR another day was that assessment periods in most participants took place in the afternoon. International guidelines recommend fasting for at least 6 hours before measurement of RMR, and repeated measures of RMR vary three to five percent over 24 hours and up to 10% over weeks or months.[15]
Conclusion
When comparing time in MVPA and total energy expenditure among studies and when doing follow ups, it is essential to consider type of physical activity monitor, since for a given subject time in MVPA and total energy expenditure varies substantially among physical activity monitors. Based on the present study, we can not single out one physical activity monitor as being superior to the others; however, some evidence indicates that ActiReg® is less valid in estimating energy expenditure as well as very vigorous intensity physical activity. Additional comprehensive studies comparing physical activity monitors with indirect calorimetry under free living conditions in children, adolescents and adults are needed to evaluate the validity of previous and next generation’s physical activity monitors.

What is already known on this topic
• Objective methods to assess physical activity using various types of activity monitors have been recommended as an alternative to self-report because they are not subject to many of the sources of error associated with self-report measures.

What this study adds
• When comparing time in moderate to very vigorous intensity physical activity and total energy expenditure among studies and when doing follow ups, it is essential to consider type of physical activity monitor, since for a given subject time in moderate to very vigorous intensity physical activity and total energy expenditure varies substantially among physical activity monitors used.
FIGURE LEGENDS

Figure 1. Bland-Altman plots depicting mean differences for minutes in moderate to very vigorous intensity physical activity during 120 minutes of activity (activity monitor minus indirect calorimetry) for ActiGraph (a), ActiReg® (b), Armband (c) and ikcal (d). The solid line represents the mean, and the dashed line represents the 95% confidence intervals of the observations.

Figure 2. Mean difference in energy expenditure (kcal · min⁻¹) in moderate, vigorous and very vigorous intensity physical activity during 120 minutes of activity between ActiGraph, ActiReg®, Armband, ikcal and indirect calorimetry. A negative value indicates underestimation whereas positive values indicate overestimation. *p<0.05 and #p<0.001.

Figure 3. Bland-Altman plots depicting mean differences for accumulated energy expenditure during 120 minutes of activity (activity monitor minus indirect calorimetry) for ActiGraph (a), ActiReg® (b), Armband (c) and ikcal (d). The solid line represents the mean, and the dashed line represents the 95% confidence intervals of the observations.

Figure 4. Individual plot of minute-by-minute energy expenditure (32 yr old male) during 120 minutes of activity. The participant walked for 40 minutes, followed by 40 minutes of bicycling (regular bicycle) and then walking around for 40 minutes.

Figure 5. Individual plot of minute-by-minute energy expenditure (34 yr old male) during 120 minutes of activity. The participant perform brisk walking the first 25 minutes, then 15 minutes of running, 30 minutes playing table tennis, and 50 minutes carrying books and papers.
REFERENCES


