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D. R. Bouchard & F. Trudeau

Département des sciences de l'activité physique, Université du Québec à Trois-Rivières, Trois-Rivières, Quebec G9A 5H7, Canada

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Estimation of energy expenditure in a work environment: Comparison of accelerometry and oxygen consumption/heart rate regression

D.R. Bouchard and F. Trudeau*

Département des sciences de l’activité physique, Université du Québec à Trois-Rivières, Trois-Rivières, Québec G9A 5H7, Canada

The aim of this study was to compare estimation of energy expenditure (EE) in working environments, either from accelerometry or from an individual oxygen consumption/heart rate (VO₂/HR) regression curve. The study participants were 46 volunteer workers aged 27 ± 6 years old. A significant correlation between EE predicted by the VO₂/HR curve and the accelerometer was observed (r = 0.78, p < 0.01). However, more disparities were observed between the two methods when the mean job intensity was not within 16% and 23% higher than resting HR. The accelerometer overestimated by a mean of 34.4% the prediction by VO₂/HR regression if the intensity of the task was lower than a total of 1000 kcal/shift and underestimated the prediction by a mean of −24.9% if EE estimation of the work shift was higher than a total of 1500 kcal/shift. Despite a high correlation between both methods in the whole group, EE evaluated by accelerometry does not correspond to EE predicted by the VO₂/HR regression curves when evaluated individually.

Keywords: indirect measurement; work field; accelerometer; energy expenditure; HR monitoring

1. Introduction

Assessing energy expenditure (EE) and levels of physical activity in free-living conditions with non-invasive techniques remains a challenge (Kumahara et al. 2004). In the work environment, EE measurement can help evaluate task intensity, shift duration, number and length of breaks or to establish a threshold of fitness needed for a return to work. A variety of methods has been used to quantify physical activity level, including self-report by questionnaires and interviews, direct observation, monitoring of heart rate (HR), measurement of oxygen uptake (VO₂) and isotope ratio mass spectrometry called doubly labelled water (DLW) (Schulz and Deurenberg 1996). The ideal instrument would have to be easy to administer to large groups, be unobtrusive to test participants (especially in work environments), accurate and affordable (Freedson and Miller 2000). Two methods already used to achieve a fairly good estimation of EE are motion detection and HR monitoring. The relationship between VO₂ and HR measured in the laboratory is often taken to estimate EE during various tasks in the field. By determining the relationship between VO₂ and HR with a regression equation, it is relatively easy and cost-effective

*Corresponding author. Email: Francois.Trudeau@uqtr.ca
thereafter to measure HR in the field and to predict/estimate \( \dot{V}O_2 \) by interpolation. Schulz et al. (1989) have reported correlation coefficients up to 0.73 between EE, quantified by DLW and EE using the \( \dot{V}O_2/HR \) relationship. It is already known that HR and \( \dot{V}O_2 \) are closely related and exhibit a linear relationship, particularly when HR ranges between 110 and 150 beats per min (bpm) (Freedson and Miller 2000). Since HR rarely increases beyond 150 bpm in a workplace, this method could be helpful for field research. On the other hand, accelerometers represent a practical and cheaper tool for estimating EE, especially uniaxial accelerometers, which are inexpensive. The use of accelerometers could be a practical, easy and an affordable way to adequately estimate job intensity and EE without affecting habitual employee assignments. Whilst there are several studies comparing EE with a variety of methods, only a few have been carried out in a work environment (Balogun et al. 1986).

The primary aim of this study was to compare EE estimated by uniaxial accelerometry vs. EE estimated by the \( \dot{V}O_2/HR \) regression method in a work environment. It is important to evaluate limitations of both methods and, more importantly, the factors in which these two methods vary, since the portable calorimetric system and DLW are both expensive methods and hard to assess in a whole day at work.

2. Methods
2.1. Participants
A total of 46 participants (24 women and 22 men aged between 18 and 45 years) volunteered to participate in the study. They were recruited from university staff and by advertisements on local notice boards. A large variety of jobs was included in the protocol. Teachers, trainers, cooks, nurses and lifeguards are some examples of occupations found in the study. Their job shift duration was between 6 and 12 h. The project was approved by the Human Research Ethics Committee of Université du Québec à Trois-Rivières. Participants gave their informed consent prior to participation.

2.2. Protocol
Participants came to the laboratory on two different days separated by at least one week. On the first visit, all participants gave their informed consent and completed the Physical Activity Readiness Questionnaire. Their physical activity level was calculated using the Physical Activity Participation Questionnaire (PAPQ) according to Canadian Society for Exercise Physiology (1996) procedures. The PAPQ helped to select the protocol (active or sedentary) for the treadmill test to be performed at the next session, to make sure that the test participants reached at least 85% of theoretical maximal HR (220-age). Participant anthropometry (stature, weight and waist circumference) was evaluated according to standard protocol (Canadian Society for Exercise Physiology 1996). Weight was measured with a calibrated balance beam scale (Detecto-medic; Detecto Scales Inc., Brooklyn, NY, USA). The participants had to come back one week later to the exercise physiology laboratory, at least 1 h before starting their work shift to perform a treadmill test to determine an individual \( \dot{V}O_2/HR \) relationship curve. Table 1 shows the exercise protocol. During the treadmill test, \( \dot{V}O_2 \) was measured with expired gases quantified with a vacuumed gas analyser (Vacumed, Ventura, CA, USA), calibrated before each use.
2.3. Measurement procedures

2.3.1. Accelerometry

A uniaxial ActiGraph Model 256 TEMP (MTI Health, Health Services, Pensacola, FL, USA) was placed on the hip to assess motion over a normal day at work. This small and lightweight instrument detects acceleration from 0.05 to 2 g while rejecting other forms of movement, such as vibrations (Bassett et al. 2000). The acceleration signal is filtered by an analogue band-pass filter and digitised by an 8-bit analogue/digital converter at a sampling rate of 10 samples per second. Data were stored at 1-min intervals.

2.3.1.1. Groups according to difference between both kcal estimation methods. Participants were separated according to differences between kcal estimated by accelerometry and kcal estimated from the regression curve. Therefore, participants were divided into three groups: 1) participants whose accelerometry underestimated VO$_2$/HR regression curve (UE group); 2) participants whose kcal estimated from both methods was similar (mean difference of –32 kcal of difference between both methods) (S group); 3) participants whose accelerometry overestimated VO$_2$/HR regression curve (OE group).

2.3.2. Heart rate measurement

During the day at work, participants wore a Polar S810 i HR monitor (Polar Electro Oy, Kempele, Finland) with a memory receptor to measure work intensity and to interpolate HR on the regression line to estimate their VO$_2$ in work field. As for accelerometry, counts HR data were stored at 1-min intervals.

2.3.3. Resting heart rate

Resting HR was identified by the lowest score measured by the HR monitor in the day at work or (if lower) participants resting HR after being at rest in the laboratory.

2.3.4. Energy estimation conversion

Individual regression equations have been developed to estimate EE from raw MTI count data (Freedson et al. 1998, Hendelman et al. 2000, Swartz et al. 2000) The most
commonly used equation developed by Freedson et al. (1998) was applied in the present study.

\[
EE (\text{METS}) = 1.439088 + (0.000795 \times \text{total counts per min/no. of total min})
\]

Data were transformed thereafter into kcal with the following formula:

\[
\text{Kcal/shift from accelerometry} = \frac{[(\text{mean METS} \times 3.5)/1000] \times [(\text{weight (kg) \times min worked}) \times 5 \text{ kcal}]}{\text{min worked}}
\]

This equation predicted EE from the accelerometry data for each participant.

A personal regression equation was created for each participant from the \(\dot{V}O_2/HR\) relationship measured in the laboratory before a regular work shift. \(\dot{V}O_2\) averaged per min was then calculated for the whole day and, finally, an estimation of total EE was obtained as follows:

\[
\text{kcal/shift from HR} = [(\text{mean } \dot{V}O_2/\text{min} \times 5 * \text{kcal/litre O}_2) \times (\text{min worked})]
\]

*Assuming that 5 kcal = 1 litre O\(_2\) per min according to Wilmore and Costill (2004).

### 2.4. Statistical methods

All data are presented as mean ± SD unless indicated otherwise. Because no significant difference was observed between the accelerometry results and \(\dot{V}O_2/HR\) regression between genders, all subsequent analyses were done with the entire sample. Pearson’s correlation analyses were used to determine the association between the two methods (\(n = 46\)). T-tests were performed to evaluate differences between EE in kcal estimated by accelerometry and the \(\dot{V}O_2/HR\) regression curve. ANOVA analysis followed by a Tukey post hoc test was used to identify significant differences in percent of mean HR at work over resting HR, difference of kcal estimation and descriptive characteristics such as age, waist circumference, BMI and weight between the three groups (OE, S, UE). Statistical analyses were undertaken with SPSS software, version 11.5 (SPSS Inc., Chicago, IL, USA). A threshold of \(p < 0.05\) was considered for statistical significance.

### 3. Results

There was no significant difference for physical characteristics (except height) between the three groups, OE, S and UE (Table 2).

Table 2. Descriptive characteristics of the participants in each category.

<table>
<thead>
<tr>
<th>Characteristics (Mean ± SD)</th>
<th>Overestimated (n = 11)</th>
<th>Similar (n = 14)</th>
<th>Underestimated (n = 21)</th>
<th>(p) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>25.4 ± 3.1</td>
<td>26.3 ± 4.7</td>
<td>29.5 ± 8.2</td>
<td>NS</td>
</tr>
<tr>
<td>BMI</td>
<td>26.5 ± 5.9</td>
<td>24.0 ± 3.1</td>
<td>27.4 ± 6.4</td>
<td>NS</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>165.0 ± 6.0</td>
<td>171.0 ± 7.0</td>
<td>174.0 ± 10.0</td>
<td>0.02</td>
</tr>
<tr>
<td>Waist (cm)</td>
<td>82.3 ± 11.4</td>
<td>79.3 ± 8.8</td>
<td>89.7 ± 17.4</td>
<td>NS</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>71.5 ± 12.2</td>
<td>70.6 ± 12.2</td>
<td>83.4 ± 20.6</td>
<td>NS</td>
</tr>
</tbody>
</table>
The correlation between kcal calculated by accelerometry and kcal calculated by the \( \dot{VO}_2/HR \) regression curve was significant \( (r = 0.78, p < 0.001) \) (Figure 1). However, t-tests revealed the presence of a significant difference between the methods \( (p < 0.001) \). The mean difference between the two methods was \( 170 \pm 386 \) kcal \( (p < 0.001) \).

Total EE estimation seems to be a key factor to predict the difference between accelerometer and \( \dot{VO}_2/HR \) regression curve (Figure 2). Participants who reported a total

![Figure 1. Relationship between energy expenditure estimated by accelerometry or the oxygen consumption/heart rate regression curve (n = 46).](image1)

![Figure 2. Energy expenditure (EE) (kcal) predicted by accelerometry and the oxygen consumption (\( \dot{VO}_2 \))/heart rate (HR) regression curve in a normal work shift for each participant. Note: Each tick label on the X axis represents individual participants mean work intensity (%HR over resting HR) in increasing order for EE estimated with the \( \dot{VO}_2/HR \) curve (squares) and then compared with EE from accelerometry (diamonds).](image2)
EE estimation from the VO$_2$/HR regression curve inferior to 1000 kcal/shift tend to overestimate accelerometry result. However, EE estimation (mean of 34.4%) in participants who reported a total EE over 1500 kcal/shift tend to underestimate accelerometry result EE estimation (mean of −24.9%).

In fact, in 11 cases, accelerometry overestimated EE compared to the VO$_2$/HR regression curve. In 14 cases, predicted EE was similar between accelerometry and the VO$_2$/HR regression curve and, in 21 cases, accelerometry underestimated VO$_2$/HR regression. The differences of EE estimation between the two methods are presented in Table 3.

There was a significant difference between the three groups in intensity (mean HR at work compared with resting HR). The mean number of bpm over resting HR was $20.5 \pm 4.4$ for the OE group, $24.9 \pm 5.7$ for the S group and $27.9 \pm 6.2$ for the UE group ($p = 0.005$). The mean HR/HRmax ratio was respectively 16%, 19% and 23% higher at work than resting HR for the OE, S and UE groups. The Tukey post hoc test revealed that the intensity (% bpm over resting HR) difference between OE and UE groups was highly significant ($p < 0.003$).

### 4. Discussion

The primary aim of this study was to compare EE estimated by uniaxial accelerometry vs. the VO$_2$/HR regression method in a work environment. Despite a good correlation between both methods ($r = 0.78$) there was a significant difference between both methods when evaluated individually. It is clear that both measurements are giving different individual estimations of EE, depending mostly on the total EE of the work shift.

In most instances (21 cases), the Actigraph accelerometer underestimated EE compared to the VO$_2$/HR regression curve. The number of bpm over resting HR of the two groups with the lowest total EE estimation (OE and S) may not seem really important, but in a working environment a mean increase of HR (even if it is less than 10 bpm) could be really demanding, especially if the shift lasts over several hours.

Balogun et al. (1986) used accelerometry in a similar study and reported a total EE ranging from 933.6 to 1689.6 kcal during a work shift without a significant difference between age, stature and work-shift duration. In this study, EE during the work shift ranged from 552 to 2741 kcal. In the Balogun et al. (1986) study, all participants were physical therapists, whereas the present sample included different types of jobs at various intensities, which may explain the higher mean EE value in the present results.

As suggested by Haskell et al. (1993), individual VO$_2$/HR regression curves were calculated instead of an averaged VO$_2$/HR curve for the whole group to take into account

<table>
<thead>
<tr>
<th></th>
<th>Overestimated (OE group)</th>
<th>Similar (S group)</th>
<th>Underestimated (UE group)</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE with accelerometry (kcal)</td>
<td>$1100.1 \pm 290.6$</td>
<td>$1208.8 \pm 229.9$</td>
<td>$1526.3 \pm 471.1$</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>$825.4 \pm 174.3$</td>
<td>$1240.0 \pm 138.1$</td>
<td>$2022.3 \pm 466.3$</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EE with VO$_2$/HR regression (kcal)</td>
<td>$280.3 \pm 218.5$</td>
<td>$128.4 \pm 80.7$</td>
<td>$497.2 \pm 244.6$</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Difference between two methods (kcal)</td>
<td>$280.3 \pm 218.5$</td>
<td>$128.4 \pm 80.7$</td>
<td>$497.2 \pm 244.6$</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

VO$_2$ = oxygen consumption; HR = heart rate.
variation between participants. The regression formula was then applied to HR recorded min by min on the field. Strath et al. (2003) compared the accuracy of five published regression equations based on accelerometry and reported that the Freedson equation overestimated resting/light activity by 13% and underestimated moderate activity by 60%. However, in the present results, overestimation of EE at low intensity by the accelerometer was on average 34.6% away from the VO₂/HR regression curve, while underestimation of EE at moderate tasks was 25.7%. Troiano (2006) reported that, in general, equations primarily based on walking will underestimate the energy cost of activities involving substantial upper body activity, such as raking or sweeping. In this study, a wrist accelerometer was not added because Swartz et al. (2000) concluded that addition of accuracy gained from the wrist accelerometer was offset by the extra time required to analyse the data and the cost of the extra accelerometer. Although each method used to predict EE has inherent limitations, the simultaneous use of HR and motion sensors may increase the accuracy of EE estimates (Strath et al. 2000). For their part, Plasqui et al. (2005) concluded that HR monitoring added to accelerometry provides a good estimation of VO₂ with a standard error of the estimate (SEE) of 13.7%. Recently, Crouter et al. (2006) used the concept of coefficient of variation to better predict EE from accelerometer counts. This approach could help address the disparities in the relationship between counts and EE related to activity. This method should be evaluated in field work to better predict EE from accelerometry. Furthermore, it would be interesting to investigate the potential of introducing a constant to help adjust the variation of accelerometry vs. VO₂/HR regression curve.

Some limitations of the present study need to be addressed. First, statistical analyses in a small number of individuals may limit the potential for generalisation of the results to other populations, such as older workers. However, a variety of types of occupations was present in this study compared to other studies on the participants. A second factor was that workers were only followed on a single shift. Nonetheless, Balogun et al. (1986) examined the repeatability and validity of accelerometry between different days at work and revealed a correlation of 0.91 between days. Taken together, these characteristics of the study have contributed to the knowledge of the capacity to evaluate the individual EE in field work with a simple and non-expensive method.

In summary, EE estimation measured in different work environments with these two methods is quite simple and practical, but the individual results are usually different from each other, especially when mean task is below or above moderate intensity (lower than 16% or higher than 23% bpm from resting HR). More research is needed to understand the difference between these two methods and compare them with a gold standard measurement before using them as a replacement of more expensive and invasive methods.

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