Validation of CALTRAC™ Accelerometer During Simulated Multi-Geared Cycling At Different Work Rates

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ABSTRACT

P.W. ILTIS, and M.W. GIVENS. Validation Of The CALTRAC™ Accelerometer During Simulated Multi-Geared Cycling At Different Work Rates. JEPonline, 3(2):21-27, 2000. Nineteen male and ten female subjects, 21.6±6.8 years old participated in a study to determine the validity of the CALTRAC accelerometer in its cycling mode of operation during electronically braked cycling ergometry. Warm-up cycling at 25 Watts was followed by four minute duration exercise trials at 75, 100 and 123 Watts. Pedal rate was voluntary in order to simulate elective gearing during each load. Caloric expenditure from the CALTRAC (CTCALS) during the last two minutes of each stage was compared to metabolically determined caloric expenditure (METCALS) during the same time period. Repeated measures ANOVA revealed significant (p<0.001) main effects for both measurement method (METHOD) and work rate (LOAD) with CALTRAC underestimating caloric cost at every load. A significant (p<0.001) METHOD by LOAD interaction was also found suggesting that CALTRAC underestimation was greater as work rate increased. The results suggest that CALTRAC is inaccurate for assessing the caloric cost of cycling when pedal rate is voluntarily chosen.

Key Words: accelerometer, energy expenditure, oxygen uptake, cycling

INTRODUCTION

Quantification of caloric expenditure during human activity has importance for several reasons. First, it allows the exerciser to monitor their effort with respect to a variable which relates directly to weight control. Second, estimates of energy expenditure during physical activity are of paramount importance to exercise science professionals interested in obtaining descriptive data about different populations (1-3). Additionally, studies assessing the relationship of physical activity to risk factors associated with disease often rely on caloric monitoring (4-7).

The CALTRAC accelerometer has been developed to provide a simple, objective method of estimating caloric expenditure (8). In general, accelerometers consist of a transducer body, a constant seismic mass, and a measuring element. Displacement of the transducer body causes a force to act on the mass, and this is monitored by the measuring element. This force is proportional to the acceleration as described by Newton's first law: F =
An electrical charge is generated by the measuring element which is proportional to this force and hence, acceleration. The CALTRAC records and integrates this information when worn by human participants. It is designed to be placed at the hip and to measure vertical acceleration. Readings from the device were used to predict oxygen consumption and net caloric expenditure during exercise by Montoye et al (8). The current CALTRAC design uses derived prediction equations to calculate caloric expenditure and the value is displayed on a small screen. In addition, the CALTRAC allows the user to enter information concerning gender, age, height, and weight in order to provide a means of estimating the resting component of energy expenditure as well. Thus, the device allows the prediction of both gross and net energy expenditure, depending on the mode which is selected. Its use brings a dimension of objectivity to the assessment of physical activity in field studies.

Questions concerning the accuracy of the CALTRAC have often been addressed in the literature (9-11). In particular, the fact that it is a uniaxial accelerometer limits its usefulness to those activities in which vertical acceleration of the body takes place. In order for the CALTRAC to accurately respond to increases in caloric output of the wearer, there must be measurable increases in vertical acceleration with increases in work rate. This could occur through increases in vertical displacement at the same frequency of movement, through increases in the frequency of movement through a given vertical displacement, or with some combination of these two variables.

Cycling is a form of recreational activity that presents a unique challenge for the CALTRAC. When worn at the hip as instructed by the manufacturer, the amount of vertical displacement with each pedal revolution might be assumed to be rather constant, and thus any differences in vertical acceleration would primarily be a function of increased pedal rates associated with increased riding speeds. Only one cycling study has been conducted to investigate the validity of the CALTRAC at different riding speeds (12). In that study, the cyclists were required to pedal in the cycles highest gear and speeds were altered by changing pedal rate. By this method, a high validity coefficient for the CALTRAC was determined for riding at four different speeds.

However, these findings may be misleading. Cycling at higher speeds requires greater power output in humans, and this in turn requires greater rates of energy expenditure. Higher power output can be accomplished by pedaling at a faster rate against the same resistance, by pedaling at the same rate against greater resistance, or by some combination of these factors. Keeping pedal rate the same while increasing resistance to increase speed is generally accomplished through shifting to higher gears in road riding. Because of the mechanism by which the CALTRAC monitors activity, it would seem doubtful that this device would be capable of detecting increased metabolic work during cycling at higher speeds unless those higher speeds involved faster pedal rates. The CALTRAC simply would not be capable of detecting the greater forces required when riding in higher gears.

Simulating conditions of increased riding speed in the laboratory on traditional mechanically braked cycle ergometers is difficult. These ergometers allow the resistance to pedaling to be increased by means of a tension belt positioned around the circumference of a heavy flywheel. Thus, if pedaling rate is kept constant, one can simulate increases in speed by simply tightening the resistance and thus increasing the work performed. Alternatively, increases in speed can be simulated by keeping the resistance on the flywheel constant and by pedaling faster. This is similar to the previously mentioned study when the bicycles used were kept in their highest gear.

In fact, neither method is particularly satisfactory. Cyclists may choose to increase pedal rate, shift to a higher gear, or some combination of both to achieve faster riding speeds. Hence, the mechanically braked ergometer proves to be an unsuitable exercise mode to study the question of CALTRAC validity. On the other hand, electronically braked ergometers have the capability to adjust pedal resistance according to pedal rate in order to maintain a constant power output. Thus, if one of these devices were set to several different power
outputs, thus simulating several different speeds, participants could be allowed to choose whichever method they wanted to achieve that new power output as they normally would during road riding. Indirect calorimetry would verify increases in caloric expenditure at each power output, and the CALTRAC could be used to concurrently estimate energy expenditure. If the CALTRAC is truly sensitive to changes in caloric output at different riding speeds, then its readings should mirror those found by indirect calorimetry. Therefore, the purpose of the current investigation was to determine the validity of the CALTRAC accelerometer in monitoring caloric expenditure during cycling at 75, 100, and 125 Watts (W) using an electronically braked cycle ergometer.

**METHODS**

**Subjects**

After reading a description of the study, completing a brief medical history and completing an informed consent, ten women and nineteen men volunteered as participants in the study. Both men and women were used in an effort to assess the accuracy of CALTRAC regardless of gender; no effort was made to assess gender differences as a between subjects main effect. The participants were apparently healthy as defined by the American College of Sports Medicine (ACSM), and could best be described as recreational cyclists as all were familiar with the mode of exercise, but did not use it as a method for training. Table 2 provides additional pertinent information about the subjects with regard to age, weight, body mass index and predicted aerobic capacity.

**CALTRAC Selection**

Prior to subject testing, three CALTRAC accelerometers (Muscle Dynamics, Torrance, CA) were tested in the cycling mode for agreement by simultaneously mounting them on a variable amplitude, variable frequency mechanical oscillator (General Radio Co., Cambridge, MA) set at 30°/sweep at 80 Hz. Readings were taken every two minutes for a total of 10 minutes. This test indicated that one of the CALTRACs was unsuitable for use as its cumulative calorie count differed by the other two by 7.5 Kcals over the ten minute period. Of the remaining two, one was randomly selected for use in the study. This accelerometer was subjected to reliability testing again at 30°/sweep at 80 Hz, and the intraclass correlation coefficient was subsequently calculated (13) and found to be 0.85.

**Testing Protocol**

The testing protocol consisted of a brief warm-up period of cycling at 25 W followed by three bouts of exercise, each four minutes in duration at work rates of 75, 100 and 125 W to simulate riding at speeds ranging from ~3.53 -6.7 m/s (~8-15 mph). All rides were conducted on an electronically braked ergometer (SensorMedics Ergo 2000, Yorba Linda, CA). The participants were instructed to cycle at any pedal rate they felt comfortable with for the entire test while expired air was continuously analyzed by a metabolic cart (SensorMedics VMax 29, Yorba Linda, CA) to determine steady-state oxygen consumption at each work rate. The criteria for establishing steady state were oxygen consumption in mL/kg/min (±10%), respiratory exchange ratio (±5%), and heart rate (±5 beats/min) for two consecutive minutes (14).

During testing, heart rates were monitored by a heart rate monitor worn at the chest (Polar, Woodbury, NY), and a CALTRAC was worn at the hip. The device was attached to a stiff belt worn at the waist, and was positioned at the height of the iliac crest along the mid-axillary line. The CALTRAC was set to monitor calories used during exercise in the cycling mode according to the manufacturer's instructions, and was zeroed after the first two minutes at each stage. Thus, reading of Kcals used was obtained during the last two minutes of each stage, and this was subsequently converted to kcal/min. These CALTRAC estimates of caloric expenditure (CTCALS) were compared to metabolically determined caloric expenditure measurements (METCALS) obtained from indirect calorimetric techniques involving measured steady-state oxygen consumption values (mL/min) and respiratory exchange ratios during the same time period. In addition, measurements of pedal rates (rev/m) were obtained from the SensorMedics system. Finally, for descriptive purposes, maximal oxygen consumption (VO\textsubscript{2}max) was predicted from the regression of steady-state heart rate and oxygen uptake values during testing using the convention...
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220-age to predict maximal heart rate. While this procedure obviously lacks the accuracy of a true maximal test, it did not appear crucial to the investigators to subject the participants to full maximal testing. The focus of the study was upon the accuracy of CALTRAC, which should, in theory, be independent of fitness level.

Statistics
A repeated measures ANOVA was conducted to compare the caloric expenditure rates (kcal/min) in a design consisting of two within participants main effects: measurement method (METHOD) and work rate (LOAD). There were two levels of METHOD (CTCALS and METCALS) and three levels of LOAD (75, 100 and 125 W). Each level of LOAD was nested within each level of METHOD (see Table 1). Where significant main effects were found, Tukey’s honestly significant difference test was employed to determine where the differences were. In addition, the Bland-Altman technique (15) was used as a second method to assess the validity of CALTRAC. Finally, a repeated measures ANOVA was also employed to assess differences in the pedaling frequency (RPM) of the participants.

RESULTS
The reliability of the CALTRAC used in this study as assessed by the intraclass correlation technique was 0.85. Descriptive data for the study participants are presented in Table 2. As can be seen, these subjects possessed predicted VO$_2$max values that were slightly above average for college-aged subjects.

The mean values for CTCALS were consistently lower than the METCALS values as can be seen in Figure 1. Significant METHOD by LOAD interactions were found, (F = 226.1, p<0.001) as well as significant main effects differences for both METHOD (F = 1315.4, p<0.001) and LOAD (F = 384.9, p<0.001). The METHOD main effect showed CTCALS to be significantly lower than METCALS for all loads, combined, and the LOAD main effect showed significantly increased caloric expenditure at each work rate. The significant METHOD by LOAD interaction can be seen in the diverging lines depicted in Figure 1 suggesting that the severity of CALTRAC underestimation of caloric expenditure is increased with increasing work rates.

Table 1. Design of the repeated measures study: two levels of METHOD (CTCALS and METCALS) with three levels of LOAD (75, 100 and 125 W) nested within each level of METHOD.

<table>
<thead>
<tr>
<th>INTENSITY</th>
<th>METHOD</th>
<th>CALTRAC</th>
<th>CALORIMETRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>75 Watts</td>
<td>n=29</td>
<td>n=29</td>
<td></td>
</tr>
<tr>
<td>100 Watts</td>
<td>n=29</td>
<td>n=29</td>
<td></td>
</tr>
<tr>
<td>125 Watts</td>
<td>n=29</td>
<td>n=29</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Descriptive characteristics of the subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean±SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21.6±6.8</td>
<td>18-51</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>74.0±12.7</td>
<td>54.1-101.8</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>23.6±2.4</td>
<td>19.2-27.4</td>
</tr>
<tr>
<td>VO$_2$max (mL/kg/min)*</td>
<td>45.3±10.5</td>
<td>27.1-68.8</td>
</tr>
</tbody>
</table>

* predicted values, (n=29)

Figure 1. Caloric cost of cycling as determined by CALTRAC and METCALS at three work rates. Significant METHOD and LOAD main effects as well as METHOD X LOAD interactions were found (p < .001).

The Bland-Altman analysis is presented in Figure 2. The line of identity is signified by the zero position on the Y axis, and it can be seen that the METCAL values are consistently above this line. The 95% confidence limits for the estimated bias of CALTRAC from these data were calculated to be...
5.9±2.3 Kcal/min below metabolically determined Kcal/min values. Further, the spread of data appears greater at the higher values which is supportive of the observed interaction previously described.

**Figure 2.** Bland-Altman analysis of the caloric data. The consistent positive difference between METCALS and CTCALS shows the underestimation by CALTRAC.

**DISCUSSION**

Three primary considerations arise from the data generated by the current investigation. First, it is apparent that CALTRAC was indeed able to monitor changes in work rates in 25 W increments within the range studied. This can readily be observed in Figure 1 in which a positive slope can be observed for the line depicting CTCALS as a function of work rate. Second, there is a great deal of disparity between caloric expenditure determined by CALTRAC and that determined by indirect calorimetric methods (CTCALS vs. METCALS). Third, it is apparent from casual observation of Figure 1 that the slopes of the lines depicting CTCALS and METCALS with respect to time are not the same. The data suggest that the degree of discrepancy between the two methods of caloric estimation becomes greater at higher simulated riding speeds.

With respect to the first observation, it was somewhat puzzling to observe that CALTRAC was able to detect incremental changes in work rate. Since the CALTRAC monitors changes in vertical acceleration of the hip when worn in that area, these data suggest that this variable must have been increasing to some degree during each successive load. As mentioned earlier, this could occur through pedaling at faster pedal rates while keeping the amplitude of hip displacement constant, through pedaling at constant pedal rates while increasing the amplitude of hip displacement, or through some combination of these two variables. In the original study by Hunter et al, (12), power output was increased primarily by increasing pedal rate while keeping the bicycle in a single gear. In the current study, the participants were free to choose how they adjusted to increased work rates. This is analogous to a rider being allowed to choose to shift to a higher gear to increase speed, a practice common to both recreational and trained cyclists. The participants in the current study clearly preferred to maintain a constant pedal rate while tolerating greater effort with each pedal stroke at the higher work rates. Figure 2 presents the data pertaining to pedal frequency as a function of work rate, and from that illustration it can be seen that pedal rate was kept constant across subjects at ~59 revolutions per minute (58.9, 59.1, and 59.7 RPM at each...
successive work rate). Despite the fact that these small differences failed to reach statistical significance, the CALTRAC seemed to respond to each successive work rate (see Figure 1). Thus, it is likely that some factor other than pedal rate was influencing the CALTRAC, and a likely candidate is the degree of vertical displacement of the device at each load.

In support of this hypothesis, some comment about the nature of the participants appears warranted. The subjects were recreational cyclists rather than habitually cycle trained individuals. It was informally observed that at higher work rates, several of the participants appeared to alter the mechanics somewhat by employing greater lateral hip rocking during pedaling. Such a change would have increased the amplitude of vertical displacement of the CALTRAC worn at the hip. Thus, despite no statistically different change in the pedaling frequency, the CALTRAC unit could have detected greater acceleration at successive loads. These mechanical changes might not have occurred had the participants been habitually trained cyclists. This idea is supported from pilot data obtained on a well-trained competitive cyclist where the subject was required to perform the same test at a constant 60 rev/min. In this case, CTCALS held constant at each load suggesting a more mechanically consistent riding style.

Perhaps of greater concern is the observation of significant differences between estimates of caloric expenditure by CALTRAC and measured steady-state caloric expenditure. CALTRAC significantly underestimated the actual caloric cost of exercise by 4.2, 5.6, and 6.7 Kcals/min at 75, 100 and 125 W, respectively (see Figure 1). Further, the finding of significant METHOD by LOAD interaction, as depicted in Figure 1, shows an increasing level of discrepancy at higher work rates. This suggests that the algorithms used to calculate caloric expenditure from vertical acceleration data are simply not applicable to the participants studied in the current investigation. The manufacturer recommends programming the CALTRAC in a more sensitive cycling mode for use in monitoring this mode of exercise, and yet despite having made this adjustment, actual caloric expenditure was underestimated.

Other studies which have examined the validity of the CALTRAC have shown varying results. Several studies have reported that CALTRAC provided overestimates of metabolically determined caloric expenditure during walking or running (10,16,17). In contrast, there have been studies which have shown CALTRAC to underestimate actual caloric expenditure during elective activity during a 24 hour period (2) and still others which report quite satisfactory validity (8,18). Further, the degree of accuracy seems to vary with whether one measures net or gross caloric expenditure (11,19). In the current study, it was assumed that the typical user would be most interested in knowing their gross caloric expenditure during exercise since most activity tables make their estimates based upon this measure. Thus, in the current study, the CALTRAC was used in the CALS USED mode during testing, a mode which superimposes the effect of exercise on estimates of resting metabolism. Haymes has suggested that estimating gross energy expenditure might increase the accuracy of the CALTRAC because of the high degree of relationship between CTCALS and resting metabolic rate (11). Despite these observations by other investigators, the current study clearly shows that a high degree of error persists when using the CALTRAC to estimate the caloric cost of cycling at the selected work rates.

Finally, regardless of the apparent weaknesses of the CALTRAC in accurately monitoring the energetics of cycling exercise, it must be noted that this device has proven itself as a fairly good objective instrument for assessing general activity in a variety of populations (2,20,21). That it lacks validity for very specific activities such as cycling does not suggest that it should not be used for monitoring more general and varied types of physical activity. In conclusion, the results of this investigation suggest that although the CALTRAC accelerometer appears somewhat responsive to changes in simulated riding speeds during simulated multi-gear cycling, it consistently underestimated the actual caloric cost of this form of exercise. Further, the degree of underestimation is exacerbated as work rate increases.
REFERENCES


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