A New Whole Room Indirect Calorimeter for Measurement of the Energetics of Exercise

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ABSTRACT

Rising R, Whyte K, Albu J, Pi-Sunyer X. A New Whole Room Indirect Calorimeter for Measurement of the Energetics of Exercise. JEPonline 19(6):156-169. The purpose of this study was to compare the accuracy of exercise energy expenditure (EXEE) measurements from a metabolic cart (HG_MC) to that obtained with a new exercise whole room indirect calorimeter (EX_WRIC). First, the HG_MC and the EX_WRIC were subjected to 10, 30-min ethanol (99.8% purity) and propane (99.5% purity) combustion validations, respectively, for EE, ventilation rates (liters) of oxygen (VO₂), carbon dioxide (VCO₂), and the respiratory quotient (RQ; VCO₂/VO₂). Then, 15 healthy adults (13 men and 2 women) cycled at 65% age predicted heart rate max for random determination of their EXEE, VO₂, VCO₂ and RQ after a 12-hr fast with both the HG-MC and EX_WRIC. Comparing stoichiometry to combustion, the HG_MC underestimated heart rate max for random determination of their EXEE, VO₂, VCO₂ and RQ after a 12-hr fast with both the HG-MC and EX_WRIC. Comparing stoichiometry to combustion, the HG_MC underestimated EE (P<0.05), VO₂ (P<0.05), VCO₂ (P<0.05), and RQ (P<0.05) while no differences were found for the EX_WRIC. The EXEE and VO₂ were lower (P<0.05) while RQ was greater (P<0.05) when measured with the HG_MC versus the EX_WRIC. The EX_WRIC was more accurate than the HG_MC without the related tethered connections.

Key Words: Energy Expenditure, Metabolic Cart, Head Gear
INTRODUCTION

At the present time, there is no accurate methodology for measuring the energetic costs of various exercise activities that is comfortable for the subjects. The energetics of exercise is currently measured utilizing various types of head gear connected to a metabolic cart (HG_MC). Furthermore, the systems that are currently used, such as the Vmax 2900 series metabolic cart is frequently acknowledged as the gold standard for validating various new consumer technologies for calculating the energetics of specific physical activities (21). For example, the amount of energy expended (EE) calculated by the Walk4Life Elite pedometer was compared to that measured by the HG_MC during treadmill walking (11). Moreover, EE calculated by the Suunto Heart Rate System was compared to that measured by the HG_MC in elite athletes during treadmill running (10). Finally, a new application available for the iPhone® and I-Pod® Touch for calculating EE during treadmill walking was tested using the HG_MC (12).

In an attempt to eliminate the restrictions to movement when using the HG_MC system, several new portable metabolic systems have been developed (3,5,16). These systems have eliminated the need for the subject to be limited to exercise testing via a treadmill or a cycle ergometer in a laboratory. For example the Cosmed K4b2 is a portable dual module 0.75 kg metabolic system that the exercising subject wears on his or her back. It has been validated against the HG_MC. However, there is still the need for a face mask and tubular connections leading to the module on the back (5). Moreover, there is still the recurring issue of possible discomfort for subjects and the added weight of the analytical modules used to calculate the energetic costs of exercise, especially if the process involves long distance running or other physical activities over a long duration of time.

Another portable metabolic cart recently validated against the Douglas bag method is the CareFusion Oxycon Mobile metabolic system (16). It consists of two modules worn on the chest with a weight of 1 kg. The system is connected via a rubber face mask and related tubing. Also, there is the Medgrahics VO2000 portable metabolic system that was recently validated against the Douglas bag method (3). It consists of just a single module weighing 0.75 kg. The system also requires the use of a face mask and related tubing for connection to the electronics.

To eliminate the aforementioned problems associated with the exercise energy expenditure (EXEE) measurements with currently used HG_MC’s or portable metabolic systems, a new exercise whole room indirect calorimeter (EX_WRIC) was designed and built specific for these types of measurements. The main advantage of the new EX_WRIC is the elimination of any tethered connections to the instrumentation as well as the added weight of the module on the back or chest. The new EX_WRIC provides unrestricted movements for subjects during just about any type of exercise over any length of time. The purpose of this study was to evaluate the performance of the new EX_WRIC regarding the measurement of the energetic costs of cycling exercise as compared to the current gold standard, the HG_MC (21).

METHODS

Description of the EX_WRIC

The EX_WRIC at the New York Obesity Nutrition Research Center in Manhattan, NY is a 2.4 x 2.4 x 2.5 m climate controlled room with a volume of 10,000 Liters. Any type of exercise
equipment that will fit in the space can be used for EXEE measurements (Figure 1). A large window and an intercom system are available for observation and communication with the subject during exercise testing. The EX_WRIC improves the subject comfort by eliminating the need for a head apparatus, tethered connections to instrumentation, and the weight of back or chest worn electronics. The oxygen ($O_2$) and carbon dioxide ($CO_2$) concentrations (%) are measured by the Promethion (Model GA-06/FG-01) integrated instrumentation (Sable Systems International, Las Vegas, NV) as previously described (14, 17).

![Figure 1. Photo of the New Exercise Whole Room Indirect Calorimeter.](image)

The major advantage of the new EX_WRIC over that of all other WRICs where sub-maximal exercise testing has been done is the new technology in regards to the instrumentation. The most notable benefit is the elimination of desiccants necessary for drying sample gases prior to analysis by the instrumentation (9). This is a major improvement since exercising subjects generate a lot of moisture that could lead to errors in the final determination of EXEE. Moreover, this is the most sensitive WRIC of its kind with resolutions for the determination of oxygen and carbon dioxide concentrations to 0.001% (9). This enables the EX_WRIC to measure the energetic costs of very low level exercises (such as slow walking that was not possible with prior WRICs) as well as that of extreme intensity exercises.

**Validations**

Ten ethanol and propane combustion tests were performed for the HG_MC (Vmax Encore 2900, Carefusion Inc, San Diego, CA) and EX_WRIC, respectively, as described previously (14). Ethanol (2) and propane (13) combustion are accepted gold standards for validating the HG_MC and whole room indirect calorimeters, respectively, no matter whether future subject testing involves the energetics of exercise or resting metabolic rate. Furthermore, both of these validation techniques are recommended by the respective instrument manufacturers operating manuals as the ultimate check for accuracy and precision. This is due mainly by
the fact that they best emulate a human subject by oxidizing source elements and producing carbon dioxide and water (2,13). Finally, the magnitude of the results from both validation techniques are less than that with human subjects during exercise, however, it is assumed that they are linear (2,13). The metabolic results from each combustion test for 30-min, representing the “exercise” period, was then compared to that calculated from the respective stoichiometries. Metabolic data consisted of the expired ventilation (VE) rates (liters/30-min) of oxygen (VO₂) and carbon dioxide (VCO₂) as well as the respiratory quotient (VCO₂/VO₂) and EE (kcal·30-min). These data were calculated by multiplying by 30 each respective parameters minute-by-minute means.

**Human Subjects**

Fifteen healthy non-smoking adult subjects (13 males and 2 females, weight = 77.0 ± 14.0 kg, BMI = 25.1 ± 3.9, age = 28.3 ± 10.8 yrs) were recruited locally to participate in this study. Medical histories were obtained by physicians familiar with the study. Exclusion criteria were age <18 yrs old, recent or prescribed medications affecting metabolism, any current or past injury that would not allow exercise and pregnancy in the women as verified by an on-site HCG urine test.

After the informed consent was obtained, the subjects were instructed to fast for 12-hrs and refrain from caffeine, strenuous exercise and alcohol for one day prior to exercise testing. Anthropometrics were obtained upon arrival to the laboratory. Thereafter, the subjects were instructed on how to perform the cycling exercise protocol with each methodology (HG_MC or EX_WRIC). For the EX_WRIC, subjects were allowed a 15-min stretching and warm-up period while sitting on the cycle ergometer (Monark Cardio Care 927E, Monark Exercise AB, Vansbro Sweden) within the room, set to their comfort, until instructed to begin the exercise protocol.

During the 30-min exercise portion, subjects cycled at 65% of age predicted heart rate max (beats·min⁻¹), as calculated by the Karvonen formula (7), at a cadence of 60 rev·min⁻¹. Heart rate was monitored continuously during exercise using a Polar monitor (Model# POLAR FT1, Polar Electro Inc. Lake Success, NY). The subjects’ exercise heart rates were maintained within 2 beats·min⁻¹ of that calculated by the subjects by adjusting the resistance on the cycle ergometer themselves while maintaining cadence. This moderate exercise intensity was chosen in order to be below the lactic acid threshold (8). However, any error that might be attributed to this would be canceled out since the exercise intensity for each subject was the same for both methodologies, conducted on the same day, and within a half-hour of one another.

When the subjects had cycling EXEE measured by the HG_MC, it was necessary that a harness was placed and secured to their head with elastic strips. This contained the flow sensor and related tubing necessary for connection to the metabolic cart. Thereafter, they were allowed a similar warm-up period prior to performing the prescribed exercise protocol using the same model cycle ergometer as described for the EX_WRIC. Since the exercise intensity was maintained according to that calculated by the Karvonen formula (7), any minor differences in the cycle ergometers used would be canceled out. The temperature of the EX_WRIC room and the laboratory housing the HG_MC were maintained at 24 ± 1°C at ~30% relative humidity. Finally, after each testing procedure the subjects perceived level of comfort was recorded.
Two different technologies were utilized to measure the air flow rates during exercise testing. The EX_WRIC utilized a single fresh air flow setting of 100 L·min⁻¹ throughout the exercise protocol (14). The HG_MC, however, utilized a thermo-flow sensor that measured each inhalation and exhalation (breath-by-breath), which is the current procedure as recommended by the manufacturer of the HG_MC for exercise testing. The O₂ and CO₂ volume of the exhalations, as well as the related respiratory exchange, were used for the exercise metabolic calculations. The procedure is similar to a prior study where by the VmaxSt portable metabolic analyzer, utilizing the breath-by-breath procedure, was compared to a metabolic cart set in dilution mode in subjects exercising at 60% heart rate max (1).

The subjects were randomized as to which method (HG_MC or EX_WRIC) was used first. The HG_MC and EX_WRIC are located in two different laboratories on the same floor within 10 m of each other. After the first exercise metabolic test was completed, the subjects were escorted to the next laboratory, where they rested for 30-min prior to repeating the testing procedure. Prior to the start of each exercise test, respective instrumentations were calibrated as previously described (14). Metabolic data for the subjects were calculated by each respective method’s instrumentation (HG_MC and EX_WRIC) software as described previously (14). The EXEE was calculated by both methodologies utilizing the Weir equation (19).

In the present study, there was no comparison to the American College of Sports Medicine (ACSM) equations. This was due to the two similar cycle ergometers used (Monark Cardio Care 927E) not providing an output for the amount of work (Watts) that was performed during exercise. Similarly, other studies validating new techniques for measuring EXEE did not include comparison to the ACSM equations (3,5,16). The study procedures were approved by the Institutional Review Boards of St. Luke’s-Roosevelt Hospital and Columbia University.

**Statistical Analysis**

Statistical analysis was performed using SPSS (Version 23, Chicago, IL). Independent t-tests (P<0.05) were used to determine any effects of which method was used first for EXEE measurements. Paired t-tests (P<0.05) were utilized to determine any differences in all metabolic parameters between ethanol or propane stoichiometry and that obtained from actual combustion. A similar analysis was performed to determine any differences between both methodologies for all 30-min exercise metabolic parameters measured in the subjects. The number of subjects used for our protocol was similar and deemed appropriate, based on prior exercise equipment validation studies (3,5,16). Pearson Correlations were used to determine the statistical relationships between all metabolic parameters obtained from both methodologies.

The Bland-Altman (6) limit analysis was applied first to the ethanol and propane data to determine agreement between related stoichiometry and actual combustion in regards to EE, RQ, VO₂ and VCO₂ for both the HG_MC and EX_WRIC. A similar analysis was applied to the subject data to determine the magnitude of agreement for the same metabolic parameters. Proportional bias (P<0.05) was determined by regressing mean differences for combustion (ethanol or propane) for each the HG_MC and the EX_WRIC for EE, VO₂ and VCO₂ on mean values obtained by both methods. A similar proportional bias was also performed for the human subject metabolic data.
RESULTS
Validations
All descriptive statistics for EE, RQ, VO₂ and VCO₂ calculated from ethanol and propane stoichiometry and that obtained by combustion for each methodology are shown in Table 1. The HG_MC underestimated (P<0.05) EE, RQ, VO₂ and VCO₂ in comparison to the stoichiometric values for ethanol. In contrast, there were no differences in EE, RQ and VO₂ between the EX_WRIC and the respective stoichiometric values of propane. However, VCO₂ from combustion for the EX_WRIC was lower (P<0.05) than the stoichiometric value of propane.

Table 1. Descriptive Statistics for all Metabolic Variables Measured with Each Technique.

<table>
<thead>
<tr>
<th></th>
<th>HG_MC</th>
<th>EX_WRIC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calculated from ethanol stoichiometry</td>
<td>Derived from ethanol combustion</td>
</tr>
<tr>
<td>Burn rate (g·min)</td>
<td>0.193 0.106 0.272 0.054 0.017</td>
<td>----- ----- ----- ----- -----</td>
</tr>
<tr>
<td>EE (kcal·30-min)</td>
<td>40.4 22.3 57.1 11.4 3.6 34.4 20.8 45.3 8.5 2.7</td>
<td></td>
</tr>
<tr>
<td>RQ (VO₂/VCO₂)</td>
<td>0.67 0.67 0.67 0.00 0.00 0.66 0.65 0.67 0.01 0.00</td>
<td></td>
</tr>
<tr>
<td>VO₂ (L·30-min)</td>
<td>8.44 4.65 11.92 2.38 0.75 7.61 4.59 10.02 1.89 0.60</td>
<td></td>
</tr>
<tr>
<td>VCO₂ (L·30-min)</td>
<td>5.63 3.10 7.95 1.58 0.50 5.03 2.98 6.62 1.27 0.40</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Derived from propane stoichiometry</th>
<th>Derived from propane combustion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burn rate (g·min)</td>
<td>0.168 .112 .232 .033 .01</td>
<td>----- ----- ----- ----- -----</td>
</tr>
<tr>
<td>EE (kcal·30-min)</td>
<td>60.0 40.5 83.0 11.7 3.7 59.8 39.4 83.2 11.5 3.6</td>
<td></td>
</tr>
<tr>
<td>RQ (VO₂/VCO₂)</td>
<td>0.60 0.60 0.60 0.00 0.00 0.60 0.55 0.63 0.03 0.01</td>
<td></td>
</tr>
<tr>
<td>VO₂ (L·30-min )</td>
<td>12.81 8.55 17.72 2.50 0.79 12.99 8.61 18.06 2.48 0.79</td>
<td></td>
</tr>
<tr>
<td>VCO₂ (L·30-min )</td>
<td>7.68 5.13 10.63 1.50 0.48 7.84 4.99 10.89 1.60 0.51</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Measured by HG_MC</th>
<th>Measured by EX_WRIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXEE</td>
<td>216.7 85.6 305.9 71.5 18.5 266.6 139.9 316.8 56.2 14.5</td>
<td></td>
</tr>
<tr>
<td>RQ</td>
<td>0.92 0.83 1.02 0.05 0.01 0.85 0.75 0.93 0.05 0.01</td>
<td></td>
</tr>
<tr>
<td>VO₂</td>
<td>43.0 21.1 61.2 12.4 3.2 49.9 22.5 64.7 13.6 3.5</td>
<td></td>
</tr>
<tr>
<td>VCO₂</td>
<td>41.6 20.3 63.2 14.2 3.7 44.8 26.4 56.0 9.0 2.3</td>
<td></td>
</tr>
</tbody>
</table>

Difference (P<0.05) between stoichiometry and combustion by paired t-test for above table.

Exercise period EE, calculated from both ethanol and propane stoichiometries, were correlated (P<0.01) to that obtained from actual combustion for the HG_MC (Figure 2A) and the EX_WRIC (Figure 2B).
Figure 2. Relationships between energy expenditure (EE; kcal·30-min) calculated from ethanol and propane stoichiometry's and that obtained from combustion for head gear connected to the metabolic cart (HG_MC; plot A) and for the whole room indirect calorimeter specific for measuring the energetics of exercise (EX_WRIC; plot B).
The related comparisons in terms of the Bland-Altman limit analysis are presented in Table 2. The magnitude of the differences were greater (P<0.05) for EE, VO$_2$ and VCO$_2$ between ethanol stoichiometry and that obtained from actual combustion for the HG_MC. This was also reflected in a much greater bias and 95% confidence intervals (Table 2). The magnitude of the differences between propane stoichiometry and combustion for EE, VO$_2$ and VCO$_2$ obtained from the EX_WRIC were of smaller magnitude as reflected by the much tighter limits of agreement (Table 2). In regards to the RQ the limits of agreement were slightly greater for the EX_WRIC during propane versus the HG_MC with ethanol combustion, respectively (Table 2). However, there was significant proportional bias for EE, VO$_2$ and VCO$_2$ for the HG_MC while none existed for these values for the EX_WRIC, thus suggesting greater disagreements will occur with larger average values when using the HG_MC for metabolic measurements.

### Table 2. Bland-Altman Limit Analysis Between the HG_MC and the EX_WRIC for Validations and Subject Cycling Exercise.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Parameter</th>
<th>Bias</th>
<th>95% CI</th>
<th>Limits of Agreement</th>
<th>Proportional Bias (P&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol vs. HG_MC</td>
<td>EE (kcal·30-min)</td>
<td>6.01±3.61</td>
<td>3.77-8.25</td>
<td>-1.22-13.24</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>RQ (VO$_2$/VCO$_2$)</td>
<td>0.01±0.01</td>
<td>0.00-0.01</td>
<td>0.00-0.02</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>VO$_2^6$ (L·30-min)</td>
<td>0.83±0.68</td>
<td>0.41-1.26</td>
<td>-0.53-2.20</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>VCO$_2^6$ (L·30-min)</td>
<td>0.59±0.46</td>
<td>0.31-0.88</td>
<td>-0.33-1.52</td>
<td>0.03</td>
</tr>
<tr>
<td>Propane vs. EX_WRIC</td>
<td>EE (kcal·30-min)</td>
<td>0.12±1.86</td>
<td>-1.03-1.27</td>
<td>-3.60-3.84</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>RQ (VO$_2$/VCO$_2$)</td>
<td>0.00±0.03</td>
<td>-0.02-0.02</td>
<td>-0.06-0.06</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>VO$_2$ (L·30-min)</td>
<td>-0.18±0.48</td>
<td>-0.48-0.11</td>
<td>-1.13-0.77</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>VCO$_2$ (L·30-min)</td>
<td>-0.15±0.20</td>
<td>-0.28-0.03</td>
<td>-0.55-0.24</td>
<td>0.15</td>
</tr>
<tr>
<td>HG_MC vs. EX_WRIC</td>
<td>EXEE (kcal·30-min)</td>
<td>49.95±46.05</td>
<td>26.65-73.26</td>
<td>-42.15-142.05</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>RQ (VO$_2$/VCO$_2$)</td>
<td>-0.07±0.07</td>
<td>-0.11-0.04</td>
<td>-0.21-0.06</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>VO$_2$ (L·30-min)</td>
<td>6.95±12.77</td>
<td>0.48-13.41</td>
<td>-18.60-32.49</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>VCO$_2$ (L·30-min)</td>
<td>3.22±12.27</td>
<td>-2.98-9.43</td>
<td>-21.32-27.76</td>
<td>0.70</td>
</tr>
</tbody>
</table>

**Human Subjects**

The 65% age-predicted heart rate for exercise intensity was 146 ± 7 beats·min$^{-1}$ (range 127-152) for the subjects that ranged in age from 18 to 57 yrs old. The methodology sequence had no effect upon any of the metabolic measurements (P=0.94). Exercise EE measured by both methodologies (Figure 3) were correlated (P<0.05). Moreover, all the subjects reported much greater comfort in regards to EXEE measurements within the EX_WRIC as compared to that with the HG_MC. In comparison to the EX_WRIC, the HG_MC underestimated EXEE,
VO\textsubscript{2} and VCO\textsubscript{2} by 31.4 ± 33.1, 22.5 ± 39.3, and 17.1 ± 37.9%, respectively. However, the EX_WRIC underestimated the RQ by 7.7 ± 6.9% in comparison to the HG_MC. This is further reflected in terms of the Bland-Altman limit analysis (Table 2).

Figure 3. Relationship between Cycling Exercise Energy Expenditure (EXEE; kcal·30-min) Measured in 15 Healthy Adult Non-Smoking Human Subjects by Both Head Gear Connected to the Metabolic Cart (HG_MC) and the Whole Room Indirect Calorimeter Specific for Measuring the Energetics of Exercise (EX_WRIC).
Furthermore, the Bland-Altman limit of agreement plot clearly shows how EXEE is underestimated by the HG_MC in comparison to the EX_WRIC (Figure 4). Moreover, there was significant proportional bias (P<0.05) only for the \( \text{VO}_2 \) suggesting that greater values will lead to larger disagreements between the two methods in the subjects (Table 2).

![Bland-Altman Limits of Agreement](image)

**Figure 4.** Bland-Altman Limits of Agreement Analysis for Cycling Exercise Energy Expenditure (EXEE; kcal·30-min) Between Head Gear Connected to the Metabolic Cart (HG_MC) and the Whole Room Indirect Calorimeter Specific for Measuring the Energetics of Exercise (EX_WRIC) for the 15 Healthy Adult Non-Smoking Human Subjects.

**DISCUSSION**

**Validations**

When compared to ethanol stoichiometry, there was greater variation with the HG_MC versus that compared with propane stoichiometry for the EX_WRIC. The static nature of both the ethanol and propane combustion tests may be a limitation. To date, there is no validated international gold standard that would truly simulate an exercise condition for validating both the HG_MC and the EX_WRIC.

**Human Subjects**

With regard to the comparison between the two methods for the subjects, all exercise metabolic measurements, except the RQ, were greater for the EX_WRIC. Even though there was a relationship between the two methods in terms of EXEE, the values obtained from the subjects by the EX_WRIC tended to be 30% greater than that from the HG_MC. However, the HG_MC showed an almost 8% over estimate in the RQ versus the EX_WRIC. Finally, the subjects reported much greater comfort with exercise testing within the EX_WRIC.
The lower values obtained by the HG_MC in the subjects is in contrast to that expected. The elimination of the head gear (15) along with a more comfortable environment of the EX_WRIC room suggests that EXEE would be lower with this technique. However, the unexpected lower values for EXEE with the HG_MC might be partly explained by the technological differences between the two methods. For example, the air flow rates utilized for the EX_WRIC is a fixed 100 L·min$^{-1}$ (14). This is in contrast to the HG_MC where only the exhalation flow rate is measured as part of a breath-by-breath procedure and then calculated with a software algorithm. Moreover, exhalations are nearly 100% saturated with moisture generated by the exercising subject. The sample gas moisture extracted from the flow sensor via the Naphion tubing is supposed to equilibrate to that within the laboratory prior to analysis by the metabolic carts electronics. However, it is possible that the sample gas is not fully equilibrated by the time it reaches the oxygen and carbon dioxide sensors. In the breath-by-breath mode, the oxygen and carbon dioxide concentrations are measured directly by the sensors without prior mixing or further moisture removal. Moreover, there are two additional external loops of Naphion tubing on the inlet ports of the sensor electronics that is supposed to provide additional equilibration when the instrument is set in breath-by-breath mode. However, unaccounted for moisture in the sample gas stream could possibly lead to an over correction in the VO$_2$ that would explain the higher RQ and the lower EXEE obtained despite the possible discomfort of the head gear.

A similar relationship has been found previously during the validation of the new whole room indirect calorimeter specific for measurement of resting metabolic rates against a HG_MC (14). Moreover, if the headgear is not fitted properly, it is possible that sweat from the subjects head leaked into the face mask and contaminated the thermal electrodes of the flow sensor that further contributes to errors. Similar problems have arisen in a prior study during validation of the Aerosport TEEM 100 Portable Metabolic Measurement System for the measurement of EXEE where moisture from the exercising subject would be drawn directly into the sensor electronics, thus causing errors in the metabolic results (20). Moreover, VO$_2$ was also lower in comparison to that measured by the HG_MC set in dilution mode (20). Therefore, problems with the head gear as well as erroneous moisture correction by the HG_MC set in breath-by-breath mode may translate into a greater magnitude of errors found in both the RQ and EXEE. This is further verified by the significant proportional bias found in VO$_2$ for the HG_MC.

Both methods utilize the Weir equation (19) for calculation of EXEE. Moreover, both methodologies also rely on the fuel cell oxygen sensors to provide the VO$_2$ data. The VO$_2$ has a threefold greater influence than VCO$_2$ on the outcome for EXEE with regard to the Weir equation (19). Thus, any moisture not accounted for prior to analysis by the oxygen sensor will lead to large underestimates of the VO$_2$ thereby significantly reducing EXEE. These effects would explain the much greater RQs found in the subjects when EXEE was measured with the HG_MC. This is further verified by the greater variability in all of the metabolic parameters measured by the HG_MC by ethanol versus that found for the EX_WRIC by propane combustion. All of these potential problems with the HG_MC are eliminated when EXEE is measured within the new EX_WRIC. The EX_WRIC instrumentation does not require desiccants (9) to dry sample gases prior to analysis during metabolic testing. Sample gas moisture is measured continuously by water vapor pressure sensors and the resultant data utilized to correct all the metabolic parameters (9).
There have been prior attempts to measure the energetics of other types of exercise activities, but usually they involved some form of indirect measure of the actual EE. For example, pre-exercise VO$_2$ max testing was used to determine the cardiovascular fitness of yoga practitioners (18) and EXEE was measured during a boxing bout using a Cosmed K4b$^2$ portable metabolic cart (4). Both of these exercise EXEE measurements still required a HG_MC (20) or the added weight of the portable metabolic system (4), thus contributing to potential inaccuracies in EXEE.

The advantage of the EX_WRIC is that it allows the energetics of just about any exercise activity to be determined with great sensitivity. For example, EXEE (kcal·30-min) during yoga (243), shadow boxing (267), playing of musical instruments such as the guitar (81) or the flute (61) has been determined in the EX_WRIC (unpublished observations).

**CONCLUSIONS**

This clearly shows the versatility of the EX_WRIC in accurate measurements of EXEE of various physical activities while providing greater comfort for the subjects. This could lead to improvements in the determination of the energetic costs of various exercise activities that were previously unavailable or estimated by prediction equations. Finally, this could possibly lead to greater success rates for weight loss programs requiring exercise prescriptions as well as precise caloric determinations for elite athletes in training.

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