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**Research article**

# Validation of a new portable metabolic system during an incremental running test

**Víctor Díaz [1], Pedro José Benito [1], Ana Belén Peinado [1], María Álvarez [1], Carlos Martín [1], Valter Di Salvo [2], Fabio Pigozzi [2], Nicola Maffulli [3]✉ and Fracisco Javier Calderón[1]**
[1] Laboratory of Exercise Physiology, Faculty of Physical Activity and Sports Science (INEF), Technical University of Madrid, [2] Department of Health Sciences, Rome University of Movement and Science, Italy, [3] Department of Trauma and Orthopaedic Surgery, Keele University Medical School, Store On Trent, England

**Abstract**

We tested a new portable metabolic system, the Jaeger Oxycon Mobile (OM) at a range of running speeds. Six subjects carried out, in random order, two incremental tests on a treadmill, one of them using the OM, and the other using the Jaeger Oxycon Pro (OP). There are systematic errors in the measurements of oxygen consumption ($VO_2$) and respiratory exchange ratio (RER) with the OM. Production of $CO_2$ ($VCO_2$) tends to be overestimated by the OM, although the differences are not significant. Ventilation ($V_E$) showed very similar values in both analyzers. Data of $VO_2$ and RER were corrected with a regression equation which minimised the differences among the devices. The portable metabolic system OM makes systematic errors in measurements of $VO_2$ and RER which can be adjusted with a regression analysis to obtain data comparable to those obtained by fixed systems.

**Key words:** Portable metabolic chart, accuracy, consistency, running, oxygen consumption.

## Introduction

Portable metabolic systems are frequently used to explore various physiological ventilatory variables in field tests (Crouter et al., 2006; King et al., 1999; Lampard et al., 2000; McLaughlin et al., 1999; 2001; Parr et al., 2001; Hodges et al., 2005; Macfarlane, 2001), collecting the same volume of data of the best automated metabolic systems (Macfarlane, 2001).

The results of validation of the Jaeger Oxycon Mobile (OM) are controversial (Perret and Mueller, 2006; Rosdahl and Gullstrand, 2004). We therefore compared the OM to the automated metabolic system Jaeger Oxycon Pro (OP) (Carter and Jeukendrup, 2002; Foss and Hallen, 2005; Rietjens et al., 2001). We also developed an equation which allows to correct the results of the OM to reduce the systematic differences between both analyzers.

## Methods

### Subjects

Six moderately trained subjects (age 25.5 ± 7.8 years; weight 69.6 ± 4.3 kg; height 1.72 ± 0.06 m) volunteered to participate in the study. All were informed of the risks of the study, and signed an informed consent according to the recommendations of the declaration of Helsinki for investigation with human subjects (World Medical Association 2004). The Local Ethics Committee approved the study.

### Expired gas analysis

The gas analyzer OP (Erich Jaeger, Viasys Healthcare, Germany) is an automated metabolic system that measures $O_2$ by the differential paramagnetic principle, and $CO_2$ by infrared absorption method. This analyzer has been compared with the Douglas' bag technique (Foss and Hallen, 2005; Pedersen et al., 2002; Rietjens et al., 2001). Volumes are measured using a Triple turbine V® with low resistance and dead space (Miller et al., 2005; Quanjer et al., 1993).

The portable metabolic system OM (Erich Jaeger, Viasys Healthcare, Germany) measures air volumes and air composition in a breath-by-breath fashion. It is composed of two small modules that can be attached to the subject's chest or back using a harness, for a total weight of less than two kilograms. $O_2$ and the $CO_2$ are derived from an electrochemical cell and from thermal conductivity, respectively. Air volume is measured in the same way as in the OP system.

### Experimental procedure

Each subject performed two incremental tests on a treadmill (H/P Cosmos Pulsar, H/P/COSMOS 3P 4.0 ®, H/P/COSMOS Sports & Medical, Nussdorf-Traunstein, Germany) using one or the other metabolic system in a random order. After a warm up of 3 min at 9 $Km \cdot h^{-1}$, the speed increased to 11 $Km \cdot h^{-1}$. Thereafter, speed increased 1 $Km \cdot h^{-1}$ every 2 minutes until exhaustion. The tests were performed with one rest day between each other, at the same hour of the day. During the experimental phase subjects, did not compete and did not undertake any physical training. At each speed, $VO_2$, $VCO_2$, VE and RER data were averaged every 15 seconds for later analysis.

### Statistical analysis

The differences in the measures for the $VO_2$, $VCO_2$, VE and RER were analyses with a *t*-Student test for related samples. To check the validity of the OM, graphics were drawn for bias, following the procedure described by Bland and Altman (1986). Lastly, an analysis of linear regression following the steps method was used to correct the values obtained by the OM. The coefficient of determination ($R^2$), and the values of the *t* coefficients were

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**Table. 1.** Mean (±SD) [95% interval confidence] values measured by Jaeger Oxycon Pro (OP) and Jaeger Oxycon Mobile (OM).

| Speed ($Km·h^{-1}$) | Device | $VO_2$ ($ml·min^{-1}$) | $VCO_2$($ml·min^{-1}$) | VE ($L·min^{-1}$) | RER |
|---|---|---|---|---|---|
| 11 | OP | 2939 (491) [2424 - 3454] | 2498 (553) [1917 – 3078] | 71.3 (14.9) [55.7 – 87.0] | .84 (.06) [.78 - .90] |
| | OM | 2616 (220) [2386 -2847] | 2327 (223) [2093 -2561] | 66.4 (6.1) [60.0 – 72.9] | .89 (.03) [.86 - .92] |
| 12 | OP | 3256 (429) * [2806 - 3706] | 2748 (413) [2315 – 3181] | 80 (12) [68 – 92] | 0.84 (0.04) * [0.81 – 0.88] |
| | OM | 2935 (244) [2679 – 3192] | 2755 (254) [2489 – 3022] | 78 (8.0) [69 – 86] | 0.94 (0.03) [0.91 – 0.97] |
| 13 | OP | 3537 (442) * [3074 – 4001] | 3023 (427) [2575 – 3472] | 89.0 (14.7) [73.5 - 104.5] | 0.85 (0.04) * [0.81 - 0.90] |
| | OM | 3175 (214) [2950 – 3399] | 3102 (223) [2868 – 3337] | 89.7 (9.0) [80.3 - 99.1 ] | 0.98 (0.03) [0.94 – 1.01] |
| 14 | OP | 3832 (439) * [3371 – 4293] | 3340 (443) [2875 – 3805] | 99.3 (18.0) [80.4 – 118.3] | 0.87 (0.04)* [0.83 – 0.91] |
| | OM | 3400 (234) [3154 – 3646] | 3424 (265) [3146 – 3703] | 101.5 (12.6) [88.3 - 114.7] | 1.01 (0.03) [0.97 – 1.04] |
| 15 | OP | 4195 (392)* [3783 – 4606] | 3575 (416) [3322 - 4194] | 112.5 (19.1) [92.4 – 132.6] | 0.90 (0.05)* [0.85 – 0.94] |
| | OM | 3656 (254) [3390 - 3923] | 3794 (358) [3418 - 4170] | 112.2 (18.5) [94.8 -129.5 ] | 1.04 (0.04) [0.99 – 1.09] |
| 16 | OP | 4429 (385)* [4025 – 4833] | 4128 (422) [3685 -4570 ] | 124.5 (20.9) [102.6 – 146.4] | 0.93 (0.05) [0.88 – 0.99] |
| | OM | 3892 (296) [3581 - 4202] | 4180 (467) [3689 - 4670] | 123.3 (20.9) [101.4 – 145.3] | 1.07 (0.07) [0.99 – 1.15] |
| 17 | OP | 4580 (376)* [4113 – 5048] | 4435 (485) [3833 – 5037] | 136.2 (22.4) [108.4 – 164.0] | 0.97 (0.06)* [0.89 – 1.04] |
| | OM | 3966 (272) [3268 - 4304] | 4497 (394) [4008 - 4986] | 141.8 (16.5) [121.3 – 162.3] | 1.14 (0.05) [1.08 – 1.20] |

$VO_2$ = oxygen consumption, $VCO_2$ = Production of $CO_2$, $V_E$ = ventilation volume, RER = respiratory exchange ratio
* significant differences ($p < 0.05$).

used to check the viability of the pattern in the regression equation proposed. The residuals of this regression were analyzed to demonstrate the feasibility of the procedure. Statistical analysis was performed using SPSS 12.0 for Windows (SPSS Worldwide Headquarters, Chicago, IL). Significance level was fixed at $p < 0.05$.

## Results

All subjects reached a maximum speed of 17 $Km·h^{-1}$ in both tests. There were significant differences in the values of $VO_2$ at 12 $Km·h^{-1}$ and 17 $Km·h^{-1}$, but no statistical significance ($p = 0.09$) at 9 $Km·h^{-1}$ and 11 $Km·h^{-1}$. Significant differences were observed for RER in all the speeds except at 11 $Km·h^{-1}$. $VCO_2$ showed a tendency to be overestimated by OM, but no significant differences were observed. Likewise, $V_E$ did not show significant differences at any speed (Table 1).

Figure 1 shows Bland and Altman plots for the variables studied at the various speeds. The bias for $VO_2$ was of 411.65 ± 267.5 $ml·min^{-1}$, while for RER it was of -0.12 ± 0.06, a mean error of 8.9 and 12% respectively.

Using linear regression analysis, the equation 1 explained 94% of the variance for $VO_2$. Equation 2 explained 65% of the variance for RER.

**Eq. [1]** $$VO_2(OP) = - 508.639 + 1.281\ VO_2(OM) \quad R^2 = 94.0\%$$

**Eq. [2]** $$RER(OP) = 0.315 + 0.564\ RER(OM) \quad R^2 = 65.0\%$$

When the proposed regression equations were applied to the values for $VO_2$ and RER, the significant differences disappeared, and systematic errors were reduced to -0.89 ± 204.4 $ml·min^{-1}$ for $VO_2$ and 0.00015 ± 0.04 for RER. In practice, the mean errors decreased to 0.02% for $VO_2$ and 0.01% for RER (Figure 2).

## Discussion

This study showed a systematic error of OM in the measurement of $VO_2$ and RER. When the values were corrected with the proposed equations, the data from both analyzers were comparable, although the OM overestimated the $VCO_2$ in a constant, not statistically significant way.

Previous studies have shown errors in $VO_2$ measurement with portable metabolic systems. Some studies show relatively large errors for $VO_2$ (McLaughlin et al., 2001; Wideman et al., 1996), others smaller values (Crandall et al., 1994; Lothian et al., 1993; Peel and Utsey, 1993), and other investigations still report similar results between fixed and portable metabolic systems (Hausswirth et al., 1997; Schulz et al., 1997). Since $V_E$ did not show significant differences, it appears that the Triple V® is capable of valid and reliable measures, and the differences found in the measurements of $VO_2$ could be related to the different procedures used in the two devices (electrochemical in OM vs paramagnetic in OP) (Perret and Mueller, 2006).

The results of this study agree with previous investigations (Perret and Mueller, 2006) showing significantly

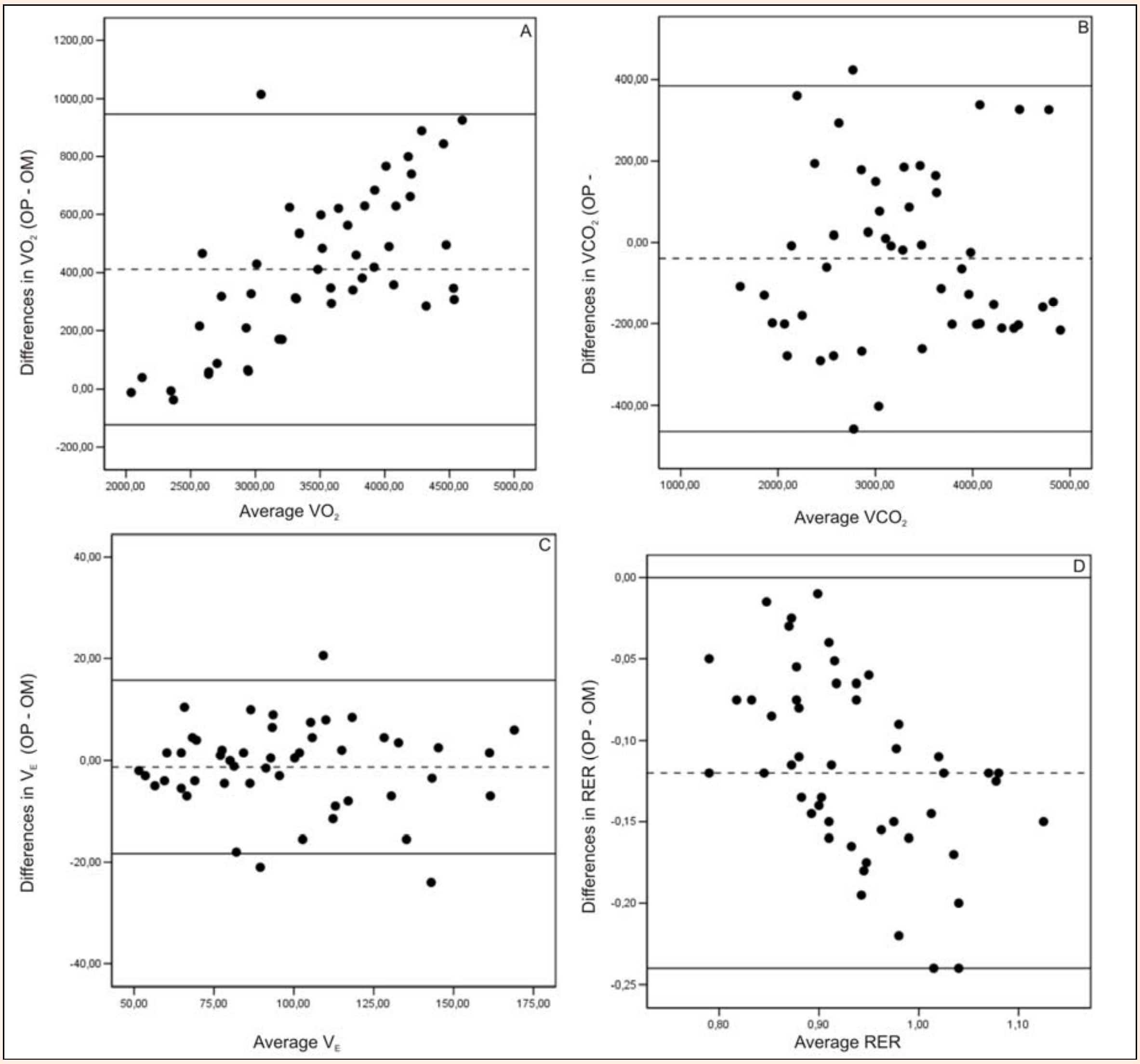


**Figure 1. Bland and Altman plots depicting absolute differences in values between OM and OP. (A) $VO_2$ (ml· min$^{-1}$); (B) $VCO_2$ (ml·min$^{-1}$); (C) $V_E$ (L·min$^{-1}$); (D) RER.**

lower values for $VO_2$. However, the systematic errors are different: Perret and Mueller (2006) report a value of -110 ± 127 ml·min$^{-1}$ (OM - OP), while in our study the value increases to 411.65 ± 267.5 ml·min$^{-1}$ (OP - OM). This difference can arise from the differences in the ergometer used: we used a treadmill instead of a cyclergometer.

$VCO_2$ showed a tendency to be overestimated by the OM. Again, this is in agreement with previous data (Perret and Mueller, 2006). As a consequence of the systematic errors in $VO_2$ and $VCO_2$ measurement, RER is overestimated by the OM, and, although the systematic errors are slightly larger in our study compared with that of Perret and Mueller (2006) (-0.12 ± 0.06 vs 0.05 ± 0.03), the results are similar. Therefore, presumably by correcting $VO_2$ values, the differences in RER would be reduced.

When the regression equations were applied to our data, the systematic error decreased significantly for $VO_2$ (411.65 ± 267.5 ml·min$^{-1}$ vs -0.89 ± 204.4 ml·min$^{-1}$) and RER (-0.12 ± 0.06 vs 0.00015 ± 0.04).

## Conclusion

The OM produces systematic errors when measuring $VO_2$ and RER. These errors that can be corrected with simple equations, making this portable metabolic system easy to use, and a valid measurement tool for metabolic expenditure in athletes. Given the lack of manufacturers´ information about the procedures used to measure the different variables calculated (Hodges, Brodie et al., 2005), we recommend to use regression equations to obtain comparable data between portable and automated metabolic systems.

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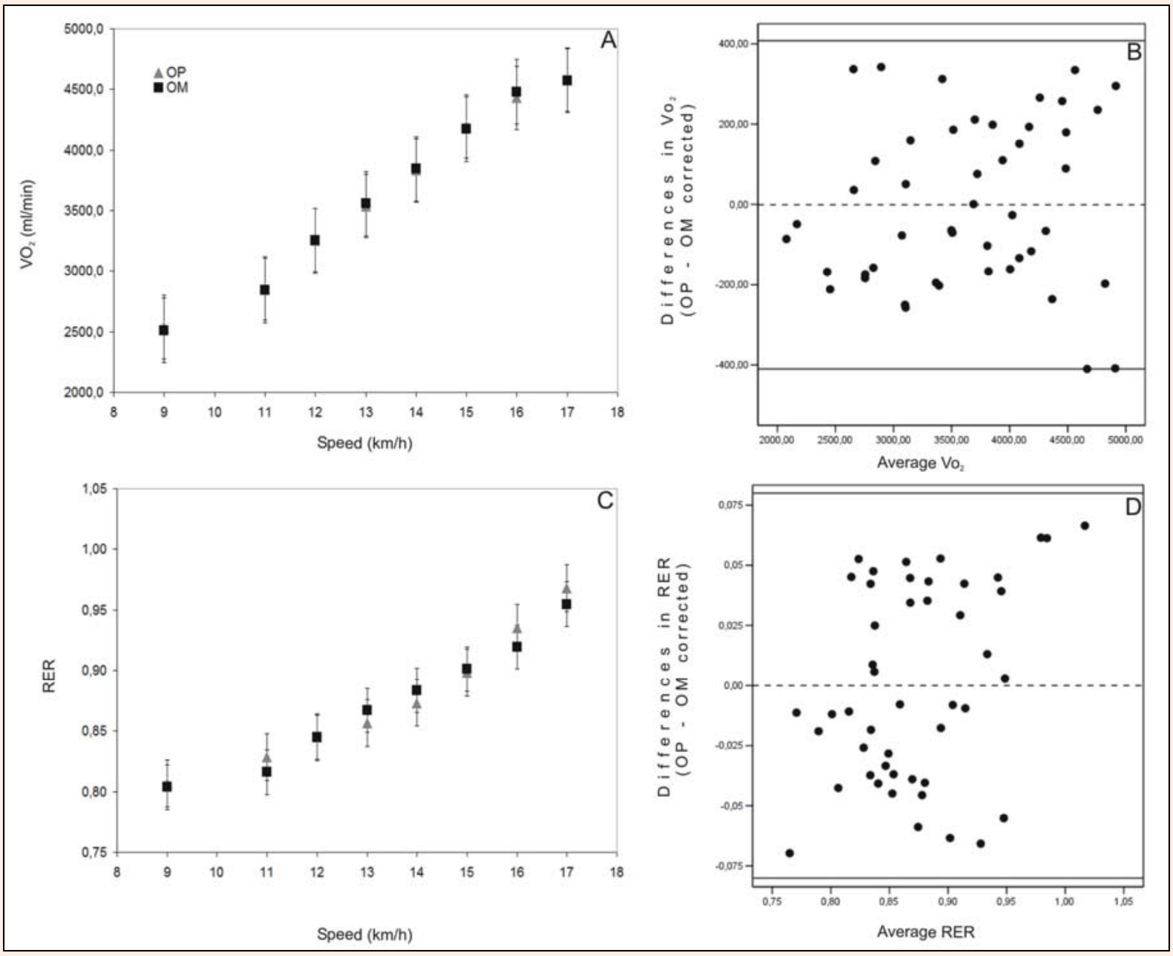


**Figure 2. Left panels show mean and standard deviation values measured by OP or OM. Right panels show Bland and Altman plots depicting absolute differences in values between OM and OP corrected with proposed ecuation. (A) $VO_2$; (B) RER.**


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## Key points

- Portable metabolic systems are frequently used to explore various physiological ventilatory variables in field tests
- There are systematic errors in the measurements of oxygen consumption ($VO_2$) and respiratory exchange ratio (RER) with the Jaeger Oxycon Mobile (OM) portable metabolic system
- Production of $CO_2$ ($VCO_2$) tends to be overestimated by the OM
- Data of $VO_2$ and RER can be corrected with a regression equation
- The portable metabolic system OM makes systematic errors in measurements of $VO_2$ and RER which can be adjusted with a regression analysis to obtain data comparable to those obtained by fixed systems.

## AUTHORS BIOGRAPHY

**Víctor DÍAZ**
**Employment**
Technical University of Madrid.
**Degree**
PhD
**Research interests**
Exercise physiology.
**E-mail:** victordiazmolina@gmail.com

**Pedro José BENITO**
**Employment**
Technical University of Madrid
**Degree**
PhD
**Research interests**
Exercise physiology.
**E-mail:** pedroj.benito@upm.es

**Ana Belén PEINADO**
**Employment**
Technical University of Madrid.
**Degree**
PhD
**Research interests**
Exercise physiology.
**E-mail:** anabelen.peinado@upm.es

**María ÁLVAREZ**
**Employment**
Technical University of Madrid
**Degree**
PhD
**Research interests**
Exercise physiology.
**E-mail:** marialavarezsanchez@gmail.com

**Carlos MARTÍN**
**Employment**
Technical University of Madrid.
**Degree**
PhD
**Research interests**
Exercise physiology.
**E-mail:** c.martincaro@gmail.com

**Valter Di SALVO**
**Employment**
Rome University of Movement and Science
**Degrees**
PhD
**Research interests**
Traning sScience, exercise physiology.
**E-mail:** valterdisalvo@hotmail.com

**Fabio PIGOZZI**
**Employment**
Rome University of Movement and Science.
**Degree**
MD
**Research interests**
Sports cardiology, exercise physiology.
**E-mail:** fabio.pigozzi@iusm.it

**Nicola MAFFULLI**
**Employment**
Keele University Medical School.
**Degrees**
MD, MS, PhF, FRCS(Orth)
**Research interests**
Sports traumatology, anaerobic threshold.
**E-mail:** n.maffulli@keele.ac.uk

**Fracisco Javier CALDERÓN**
**Employment**
Technical University of Madrid.
**Degree**
PhD
**Research interests**
Exercise physiology.
**E-mail:** franciscojavier.calderon@upm.es

✉ **Nicola Maffulli**
Department of Trauma and Orthopaedic Surgery, Keele University Medical School, Store On Trent, England.