©Journal of Sports Science and Medicine (2008) **7**, 532-536
http://www.jssm.org

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

Received: 11 September 2008 / Accepted: 21 October 2008 / Published (online): 01 December 2008

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

Speed ($Km{\cdot}h^{-1}$)	Device	VO_2 ($ml{\cdot}min^{-1}$)	VCO_2($ml{\cdot}min^{-1}$)	VE ($L{\cdot}min^{-1}$)	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 $Km{\cdot}h^{-1}$ in both tests. There were significant differences in the values of VO_2 at 12 $Km{\cdot}h^{-1}$ and 17 $Km{\cdot}h^{-1}$, but no statistical significance ($p = 0.09$) at 9 $Km{\cdot}h^{-1}$ and 11 $Km{\cdot}h^{-1}$. Significant differences were observed for RER in all the speeds except at 11 $Km{\cdot}h^{-1}$. 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 $ml{\cdot}min^{-1}$, 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] $VO_2(OP) = - 508.639 + 1.281\ VO_2(OM)$
$R^2 = 94.0\%$

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

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 $ml{\cdot}min^{-1}$ 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

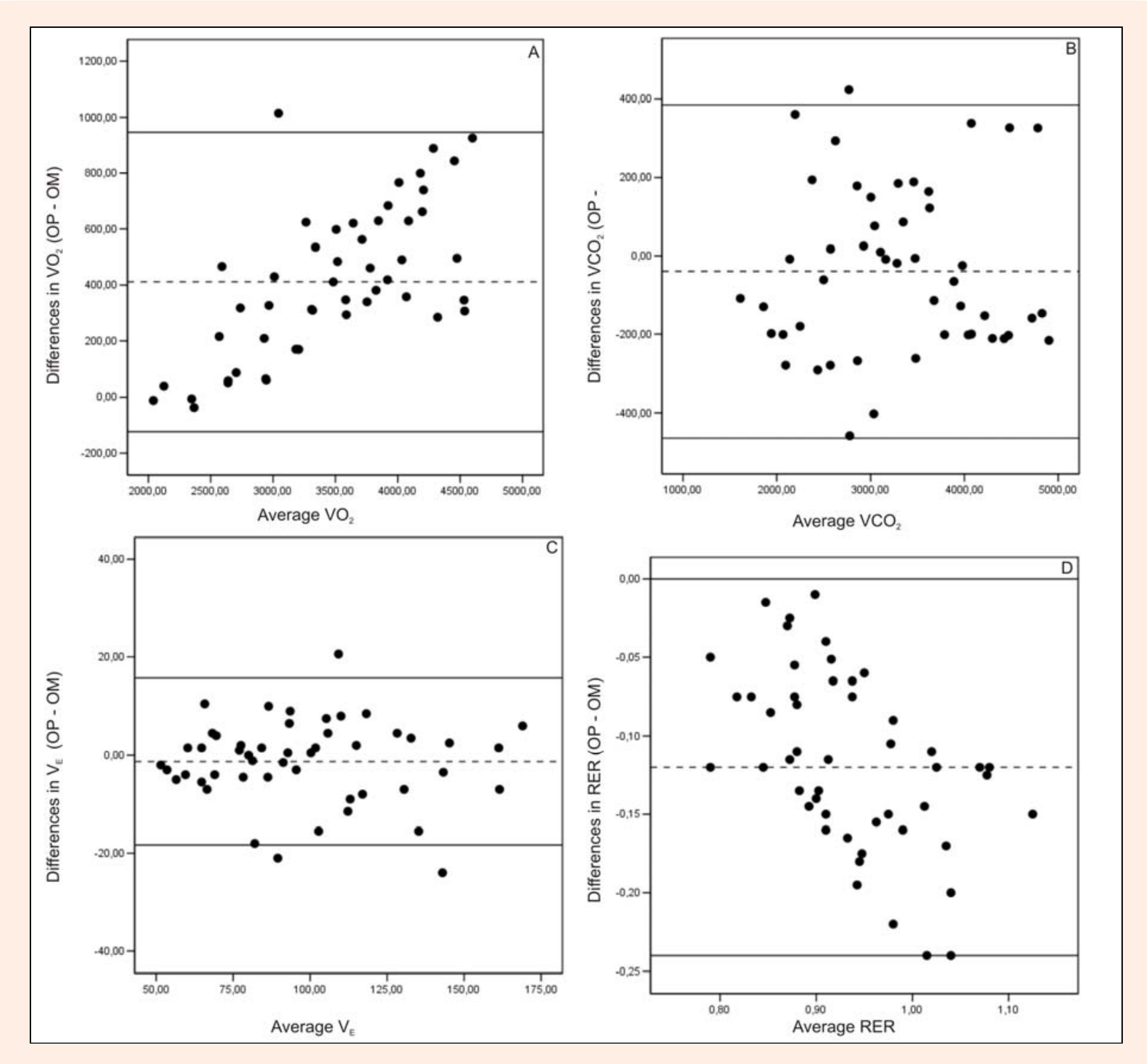

Figure 1. Bland and Altman plots depicting absolute differences in values between OM and OP. (A) VO_2 (ml· min^{-1}); (B) VCO_2 (ml·min^{-1}); (C) V_E (L·min^{-1}); (D) RER.

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.

References

Bland, J.M. and Altman, D.G. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* **1(8476),** 307-310.

Carter, J. and Jeukendrup, A.E. (2002). Validity and reliability of three commercially available breath-by-breath respiratory systems. *European Journal of Applied Physiology* **86(5),** 435-441.

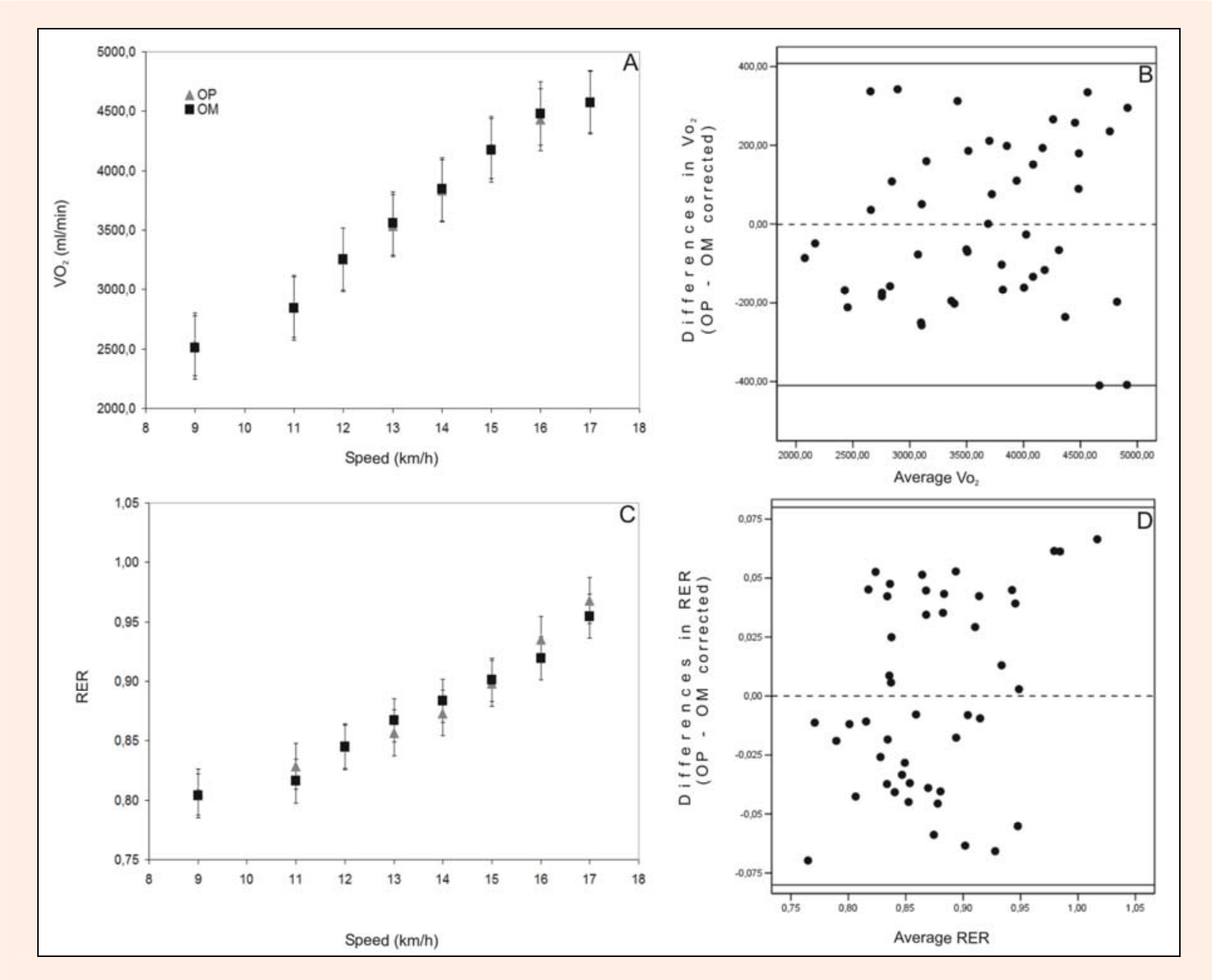

Figure 2. Left panels show mean and standard deviation values measured by OP or OM. Right panels show Bland and Altman plots depicting absolute differences in values between OM and OP corrected with proposed ecuation. (A) VO_2; (B) RER.

Crandall, C.G., Taylor, S.L. and Raven, P.B. (1994) Evaluation of the Cosmed K2 portable telemetric oxygen uptake analyzer. *Medicine and Science in Sports and Exercise* **26(1),** 108-111.

Crouter, S.E., Antczak, A., Hudak, J.R., DellaValle, D.M. and Haas, J.D. (2006) Accuracy and reliability of the ParvoMedics TrueOne 2400 and MedGraphics VO2000 metabolic systems. *European Journal of Applied Physiology* **98(2),** 139-151.

Foss, O. and Hallen, J. (2005) Validity and stability of a computerized metabolic system with mixing chamber. *International Journal of Sports Medicine* **26(7),** 569-575.

Hausswirth, C., Bigard, A.X. and Le Chevalier, J.M. (1997) The Cosmed K4 telemetry system as an accurate device for oxygen uptake measurements during exercise. *International Journal of Sports Medicine* **18(6),** 449-453.

Hodges, L.D., Brodie, D.A. and Bromley, P.D. (2005) Validity and reliability of selected commercially available metabolic analyzer systems. *Scandinavian Journal of Medicine and Science in Sports* **15(5),** 271-279.

King, G.A., McLaughlin, J.E., Howley, E.T., Bassett D.R. Jr., and Ainsworth, B.E. (1999) Validation of Aerosport KB1-C portable metabolic system. *International Journal of Sports Medicine* **20(5)**, 304-308.

Lampard, H.A., Nethery, V.M. and D'Acquisto, L.J.D. (2000) Assesment of the Aerosport KB1-C and its associated telemetry system [abstract no. 1597]. *Medicine and Science in Sports and Exercise* **32(Suppl. 5),** S319.

Lothian, F., Farrally, M.R. and Mahoney, C. (1993) Validity and reliability of the Cosmed K2 to measure oxygen uptake. *Canadian Journal of Applied Physiology* **18(2),** 197-206.

Macfarlane, D.J. (2001) Automated metabolic gas analysis systems: a review. *Sports Medicine* **31(12),** 841-861.

McLaughlin, J.E., King, G.A. and Howley, E.T. (1999) Assesment of the Cosmed K4b2 portable metabolic system [abstract no. 1411]. *Medicine and Science in Sports and Exercise* **31(Suppl. 5),** S285.

McLaughlin, J. E., King, G.A. and. (2001) Validation of the COSMED K4 b2 portable metabolic system. *International Journal of Sports Medicine* **22(4),** 280-284.

Miller, M.R., Hankinson, J., Brusasco, V., Burgos, F., Casaburi, R., Coates, A., Crapo, R., Enright, P., van der Grinten, C.P., Gustafsson, P., Jensen, R., Johnson, D.C., MacIntyre, N., McKay, R., Navajas, D., Pedersen, O.F., Pellegrino, R., Viegi, G., Wanger, J. and ATS/ERS Task Force. (2005) Standardisation of spirometry. *European Respiratory Journal Supplement* **26(2),** 319-338.

Parr, B. B., Strath, S.J., and Bassett, D.R. (2001) Validation of the Cosmed K4b2 portable metabolic measurement system [abstract no. 1961]. *Medicine and Science in Sports and Exercise* **33(Suppl. 5),** S300.

Pedersen, P.K., Kjaer, K. and Magnusson, K. (2002) Limits of agreement for VO_2 and VCO_2 with the Oxicon Pro System vs the Douglas Bag. In: *Abstract Book of 7th Annual Congress of the College of Sport Science, Athens, Greece, 24-28 July 2002*. 83

Peel, C. and Utsey, C. (1993) Oxygen consumption using the K2 telemetry system and a metabolic cart. *Medicine and Science in Sports and Exercise* **25(3),** 396-400.

Perret, C. and Mueller G. (2006) Validation of a new portable ergospirometric device (Oxycon Mobile) during exercise. *International Journal of Sports Medicine* **27(5)**, 363-367.

Quanjer, P.H., Tammeling, G.J. Cotes, J.E., Pedersen, O.F., Peslin, R., and Yernault, J.C. (1993) Lung volumes and forced ventilatory flows. Report Working Party Standardization of Lung Function Tests, European Community for Steel and Coal. Official State-

ment of the European Respiratory Society. *European Respiratory Journal Supplement* **16,** 5-40.
Rietjens, G.J., Kuipers, H., Kester A.D. and Keizer H.A. (2001) Validation of a computerized metabolic measurement system (Oxycon-Pro) during low and high intensity exercise. *International Journal of Sports Medicine* **22(4),** 291-294.
Rosdahl, H. and Gullstrand L. (2004) Validity and reproducibility of the Oxycon Mobile portable BBB metabolic system as compared to the Douglas bag technique. In: *Abstract Book of 9th Annual Congress of European College of Sport Science, Clermont-Ferrand (France), 3-6 July 2004.* 119.
Schulz, H., Helle, S. and Heck, H.. (1997) The validity of the telemetric system CORTEX X1 in the ventilatory and gas exchange measurement during exercise. *International Journal of Sports Medicine* **18(6),** 454-457.
Wideman, L. and Stoudemire, N.M. (1996) Assessment of the aerosport TEEM 100 portable metabolic measurement system. *Medicine and Science in Sports and Exercise* **28(4),** 509-515.
World Medical Association. (2004) Declaration of Helsinki. Aviable from URL: http://www.wma.net/e/ethicsunit/helsinki.htm [01/05/01].

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.