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ORIGINAL ARTICLE

Comparison of gas exchange data using the Aquatrainer® system and the facemask with Cosmed K4b2 during exercise in healthy subjects

Mathieu Gayda · Laurent Bosquet · Martin Juneau · Thibaut Guiraud · Jean Lambert · Anil Nigam

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Abstract The aim of this study was to determine the level of agreement between the new Aquatrainer® system and the facemask in the assessment of submaximal and maximal cardiopulmonary responses during exercise performed on ergocycle. Twenty-six physically active healthy subjects (mean age: 41 ± 14 years) performed a submaximal constant work test followed by maximal incremental exercise test on ergocycle, one with cardiopulmonary responses measured using the Cosmed K4b2 facemask, the other using the Cosmed K4b2 Aquatrainer®. Using the Aquatrainer®, the gas exchange variables at 100 W were significantly lower for VO_2 (1,483 ± 203 vs. 1,876 ± 204 ml min^{-1}, $P < 0.0001$), VCO_2 (1,442 ± 263 vs. 1,749 ± 231 ml min^{-1}, $P < 0.0001$), VE (38 ± 5 vs. 44 ± 6 l min^{-1}, $P < 0.0001$), and VT (1.92 ± 0.47 vs. 2.18 ± 0.41 l, $P < 0.0001$) relative to facemask. The bias ±95% limits of agreement (LOA) for VO_2 was 393 ± 507 ml min^{-1} for the submaximal constant work test at 100 W and 495 ± 727 ml min^{-1} for VO_{2max}. At maximal intensity, cardiopulmonary responses measured with the Aquatrainer® system were significantly lower for: VO_2 (2,799 ± 751 vs. 3,294 ± 821 ml min^{-1}, $P < 0.0001$), VCO_2 (3,426 ± 836 vs. 3,641 ± 946 ml min^{-1}, $P = 0.012$), VE (98 ± 21 vs. 108 ± 26 l min^{-1}, $P = 0.0009$) relative to facemask. A non-constant measurement error [interaction effect: (facemask or aquatrainer) × power] was noted from 60 to 270 W for VO_2 (ml min^{-1}), VCO_2 (ml min^{-1}), ventilation (l min^{-1}) ($P < 0.0001$) and VT (l, $P = 0.0001$). Additional studies are required to detect the main sources of error that could be physical and/or physiological in nature. Due to the significant measurement error, the new Aquatrainer® system should be used with extreme caution in filed testing conditions of swimmers.

Keywords Comparison · Oxygen uptake · Ventilation · Gas exchange analysis · Respiratory valve · Facemask · Aquatrainer · Cosmed K4b2

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M. Gayda (✉) · M. Juneau · T. Guiraud · A. Nigam
Montreal Heart Institute Cardiovascular and Prevention Center (Centre ÉPIC), Université de Montréal, 5055 St-Zotique Street East, Montreal, QC H1T 1N6, Canada
e-mail: mathieu.gayda@icm-mhi.org

M. Gayda · M. Juneau · T. Guiraud · J. Lambert · A. Nigam
Research Center, Montreal Heart Institute,
Université de Montréal, Montreal, QC, Canada

L. Bosquet
Department of Kinesiology, Université de Montréal,
Montreal, QC, Canada

J. Lambert
Department of Social and Preventive Medicine,
Faculty of Medicine, Université de Montréal,
Montreal, Canada

L. Bosquet
Faculty of Sport Sciences, Université de Poitiers, Poitiers,
France

Introduction

The assessment of maximal oxygen uptake (VO_{2max}) is widely accepted as the gold standard method to evaluate maximal aerobic capacity in healthy subjects, in athletes or in patients with different pathologies (cardiovascular, pulmonary or metabolic) (ATS/ACCP 2003; Meyer et al. 2005a, Meyer et al. 2005b). The assessment of VO_{2max} and associated exercise performance parameters including

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maximal heart rate, maximal aerobic power and maximal aerobic speed is fundamental for evaluation purposes, exercise training prescription and to follow cardiopulmonary adaptations after training, in both athletes and in the general population (Meyer et al. 2005b; American College of Sports Med Position Stand 1998). In endurance athletes, swimmers in particular, cardiopulmonary exercise responses should be assessed ideally under field conditions (in the swimming pool for example) to obtain responses that most optimally reflects real-life conditions and which can differ substantially from exercise responses obtained in the exercise laboratory (Meyer et al. 2005a; Fernandes et al. 2003, Roels et al. 2005).

In free swimming, the environment has reduced in the past, the possibility of measuring continuous cardiopulmonary responses in a breath-by-breath mode. Prior to the 1990s, the assessment of VO_2 uptake during swimming was performed in a flume or with a pulley system, using a Douglas bag technique or a mixing chamber analyzer (Di Prampero et al. 1974, Holmer 1972; Holmer and Astrand 1972) or using a backward extrapolation method (Lavoie and Montpetit 1986). Toussaint et al. (1987) developed a valid respiratory valve system with low drag, allowing continuous VO_2 uptake measurement during free swimming. In the early 1990s, a portable gas analyzer was developed by Cosmed (K2) composed of a facemask, a flow meter, an O_2 gas analyzer and a telemetric receiver. This system was found to be valid for measuring cardiopulmonary responses compared to the Douglas bag technique (Kawakami et al. 1992) and the conventional stationary gas analyzer (Crandall et al. 1994; Gayda et al. 2003; Lucia et al. 1993; Peel and Utsey 1993). Newer versions of the Cosmed portable gas analyzer (Cosmed K4 and K4b2), equipped with a CO_2 analyzer and allowing breath by breath measurement (Cosmed K4b2) have also shown their accuracy in the assessment of cardiopulmonary responses for various exercise intensities (Doyon et al. 2001; Duffield et al. 2004; Hausswirth et al. 1997; McLaughlin et al. 2001). In 2003, the valve system of Toussaint et al. (1987) was rebuilt and a respiratory and snorkel system adapted for the Cosmed K4b2 was proposed (Keskinen et al. 2003); this modified system was found to a valid tool for measuring cardiopulmonary responses relative to the traditional facemask during submaximal steady-state exercise on ergocycle (Keskinen et al. 2003). With this system, VO_2 uptake is measured using inspiratory and expiratory flows through the respiratory-snorkel system, and the inspiratory and expiratory tubes are connected before the turbine (Fig. 1a). The same authors reported for ergocycle exercise intensities from 100 to 200 W (4 min stage), an approximate 5% underestimation for ventilation, VO_2 and VCO_2 measured by the respiratory and snorkel system compared to the facemask values (Keskinen et al. 2003).

The most recent version of the Cosmed Aquatrainer®, however, is very different from the respiratory and snorkel system developed by Keskinen et al. (2003) (Fig. 1b). This new system only uses the expiratory flow (only the expiratory tube is connected before the turbine), and calculates gas exchange from an algorithm developed by Cosmed Ltd. (2005) (hardware configuration: in/ex software). Recently, several studies were published in which the respiratory and snorkel system developed by Keskinen was used to assess submaximal and maximal VO_2 uptake during free swimming (Barbosa et al. 2006, 2005a, b; Libicz et al. 2005). However, the latest version of the Aquatrainer® system has never been compared with the facemask in the assessment of cardiopulmonary exercise test responses either for submaximal or maximal exercise intensities. Therefore, the purpose of this work was to determine the level of agreement between this new Aquatrainer® system and the facemask in the assessment of submaximal and maximal cardiopulmonary responses during exercise performed on ergocycle.

Methods

Twenty-six healthy physically active subjects (21 men and 5 women, age: 18–65 years) were recruited at the cardiovascular prevention centre of the Montreal Heart Institute. The condition of being healthy men and women with age $\geq$ 18 years was necessary for study inclusion. Exclusion criteria consisted of documented cardiovascular, pulmonary, or metabolic pathology, or inability to perform a maximal cardiopulmonary exercise test. Participants regularly performed physical activity approximately 2–3 times per week in our centre (Gayda et al. 2008). Informed consent was obtained from all patients and the protocol was approved by the Montreal Heart Institute ethics committee. Anthropometric data of the 26 subjects are presented in Table 1.

Study procedures

On the first visit, subjects were evaluated with measurement of body mass, height, resting blood pressure (manual sphygmomanometer, WelchAllyn, USA) and resting ECG (Quark T12, Cosmed, Italy). Subjects were instructed to refrain from smoking, or consuming alcohol or caffeine 48 h prior to exercise testing and to refrain from strenuous exercise >12 h prior to exercise testing. In random order, subjects then underwent 2 exercise tests on ergocycle: one with cardiopulmonary responses measured with the Cosmed K4b2 facemask (Cosmed Ltd., Rome, Italy), the other with the Cosmed K4b2 Aquatrainer® system (Fig. 1b). Each exercise test (facemask or Aquatrainer® system) consisted of a submaximal followed by a maximal component (see below). Exercise tests were separated by 2–3 days.

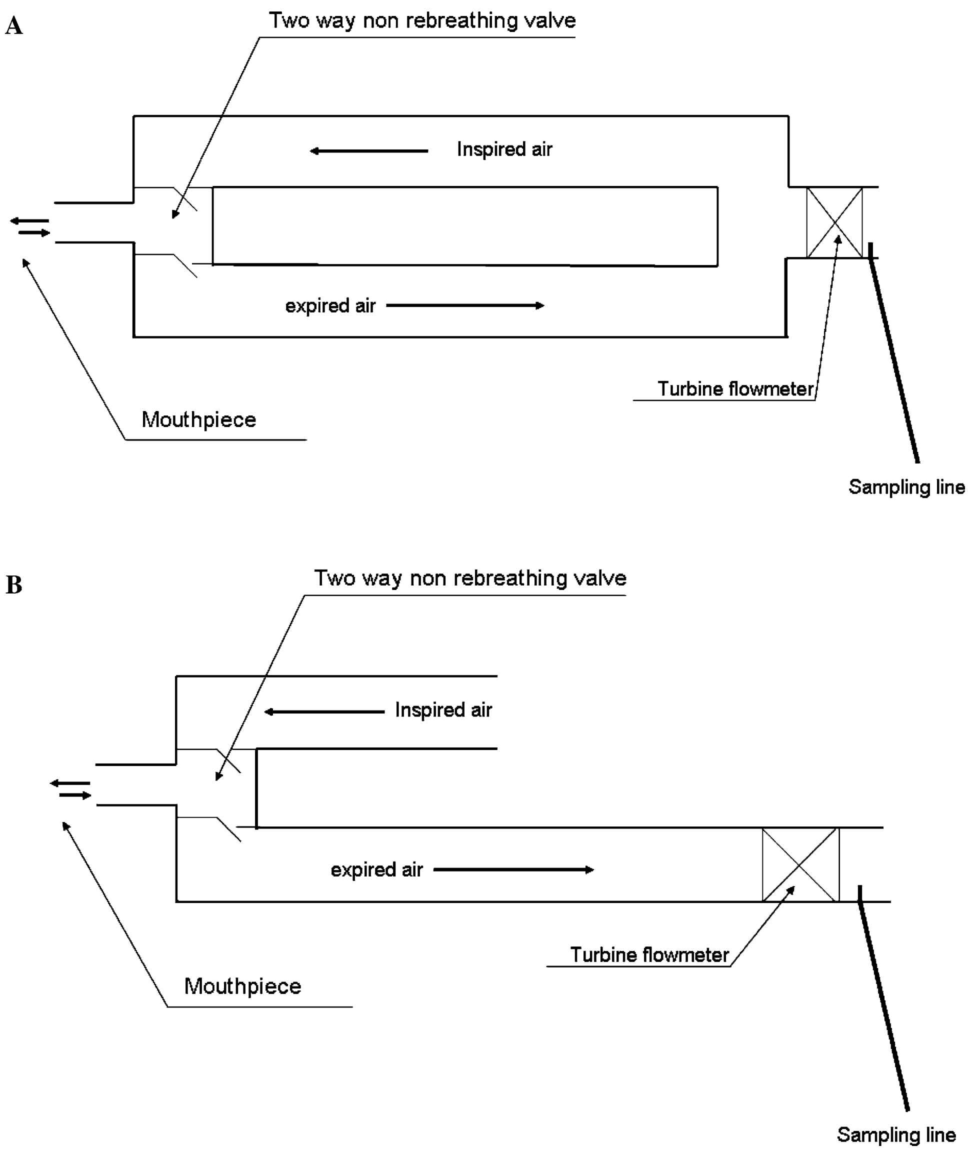


Fig. 1 **a** Schematic drawing of the Aquatrainer module developed by Keskinen et al. (2003); **b** schematic drawing of the new Aquatrainer® module (Cosmed Ltd. 2005)

Table 1 Anthropometric data of the subjects ($N = 26$)

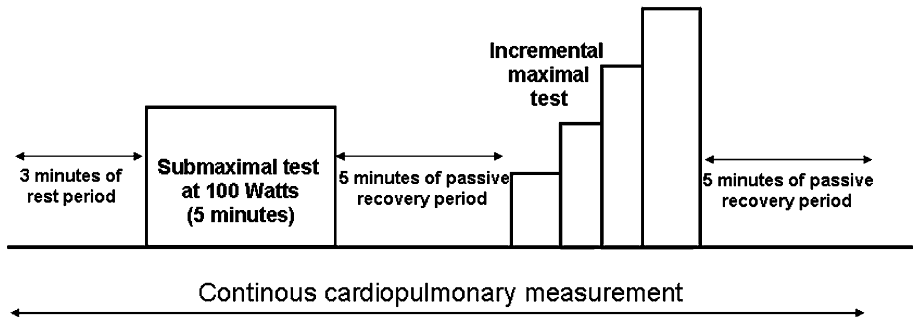
Parameters	Mean ± SD
Age (years)	41 ± 14
Total body mass (kg)	77 ± 16
Height (cm)	174 ± 9
Sex (*n*, male/female)	Males 21/5 females
BMI (kg m^{-2})	25.6 ± 4.9

BMI body mass index

Cardiopulmonary exercise responses measured with the facemask

Before the start of the test, calibration of the flow module was accomplished by introducing a calibrated volume of air at several flow rates with a 3-l pump. Each gas analyzer was calibrated before each test using a standard certified commercial gas preparation (O_2: 16%, CO_2: 5%) (Cosmed Ltd. 2004). The hardware configuration was set on in/ex hardware for facemask use (Cosmed Ltd. 2004, 2005). Each subjects accommodated the ergocycle dimensions to their anthropometrical dimension and body posture was the same for both tests. Respiratory gas exchange data were measured with a portable telemetric gas analyzer (Cosmed K4b2, Cosmed, Italy) continuously during 3 min at rest, 5 min during the submaximal exercise phase at 100 W on an ergocycle (Ergoline 800S, Bitz, Germany) at a regular cycling cadency of 60 rpm, 5 min during recovery and during the maximal incremental test (see Fig. 2). Data were measured breath by breath during testing, and then averaged every 15 s for minute ventilation (VE, l min^{-1}, BTPS), O_2 uptake (VO_2, l min^{-1}, STPD), CO_2 production (VCO_2, l min^{-1} STPD),

Fig. 2 Schematic drawing of the exercise testing procedure



and respiratory frequency (Rf). Exercise ECG was performed with a telemetric ECG system (Quark T12, Cosmed, Italy). After the submaximal test 5 min recovery period, the maximal incremental test was performed on the same ergocycle with an initial power of 60 W that was then increased by 30 W each 2 min with a regular cycling cadency of 60 rpm. The maximal exercise test lasted until attainment of a VO_2 plateau or the attainment of at least 2 of the 3 additional criteria: (1) a plateau of heart rate despite an increased power, (2) inability to maintain the cycling cadency, or (3) exercise cessation due to substantial fatigue. VO_2 plateau was defined as an increase in $VO_2 \leq 50$ ml min^{-1} during the last 30 s (Yoon et al. 2007) despite increased power. The highest VO_2 values reached during the exercise phase of the incremental test were considered as the maximal VO_2 uptake.

Cardiopulmonary exercise responses measured with the new Aquatrainer® system

Before the start of the test, the same calibration procedure used for facemask tests was performed on the same Cosmed K4b2 analyzer used for the facemask measurement (Cosmed Ltd. 2004). Subsequently, the hardware configuration was set on in/ex software, and the expiratory tube was maintained as tight as possible according to the manufacturer's recommendations (Cosmed Ltd. 2005). The Aquatrainer® system was installed on subjects and cardiopulmonary responses were measured according to the same methodology described previously using the same Cosmed K4b2 analyzer.

Statistical analysis

All data were analyzed using Statview software (SAS. USA, version 5.0) and are presented as mean ± standard deviation except where otherwise indicated. A one-way ANOVA with repeated measure (test) was performed to compare submaximal and maximal cardiopulmonary responses obtained with the facemask and with the Aquatrainer® system for all subjects ($n = 26$). A one-way ANOVA with repeated measure was performed to compare cardiopulmonary responses obtained with the facemask and with the Aquatrainer® system for each same power output. In addition, a Bland and Altman (1986) analysis was performed to assess the agreement between facemask and Aquatrainer VO_2 uptake measured at 100 W and maximal effort. In the Bland and Altman analysis on the constant work rate test at 100 W, the last 2 min of the exercise phase was analyzed (8 data point of 15 s average breath by breath value), whereas, for maximal exercise testing, the higher values (one data point 15 s average breath by breath value) was analyzed. Comparisons of maximal cardiopulmonary exercise responses were done for the same exercise time and power output. A P level < 0.05 was considered statistically significant.

Results

Cardiopulmonary exercise testing data during submaximal test performed at 100 W

Cardiopulmonary exercise test data for the 26 subjects performed during submaximal steady state at 100 W are presented in Table 2. Compared with the facemask, cardiopulmonary data measured with the Aquatrainer® system were significantly lower for the main cardiopulmonary data (VO_2, VCO_2, VE, O_2 pulse and VT) and these variables differed by −12 to −21% ($P < 0.0001$). The bias ±95% limits of agreement (LOA) for VO_2 was 393 ± 507 ml min^{-1} (Fig. 3).

Maximal cardiopulmonary exercise data measured during incremental test

Maximal cardiopulmonary exercise responses for the 26 subjects performed during incremental test on ergocycle are presented in Table 3. Compared with the facemask, maximal cardiopulmonary testing data measured with the Aquatrainer® system were significantly lower for VO_2 (2,799 ± 751

Table 2 Comparison of submaximal cardiopulmonary data in 26 subjects measured with the facemask and with the new Aquatrainer® system during submaximal steady state exercise performed at 100 W on the ergocycle

Parameters	Facemask	Aquatrainer®	ANOVA *P* value	*r* and Bias (95% LOA)
VO_2 (ml min^{-1})	1,876 ± 204	1,483 ± 203	<0.0001	0.22, −269 (281)
VCO_2 (ml min^{-1})	1,749 ± 231	1,442 ± 263	<0.0001	0.43, −210 (280)
VE (l min^{-1})	44 ± 6	38 ± 5	<0.0001	0.34, −4.33 (6.68)
VT (l)	2.18 ± 0.41	1.92 ± 0.47	<0.0001	0.53, −0.17 (0.38)
Rf (cycles min^{-1})	21 ± 5	20 ± 5	0.29	0.65, −0.19 (3.56)

Values are mean ± SD. *VE* ventilation, *HR* heart rate, *VT* tidal volume, *Rf* respiratory frequency. Data were compared at 100 W during the last 2 min of the 5 min-exercise phase. Data presented are mean of the 2 last minutes of the exercise phase. *$p < 0.001$. *LOA* limits of agreement

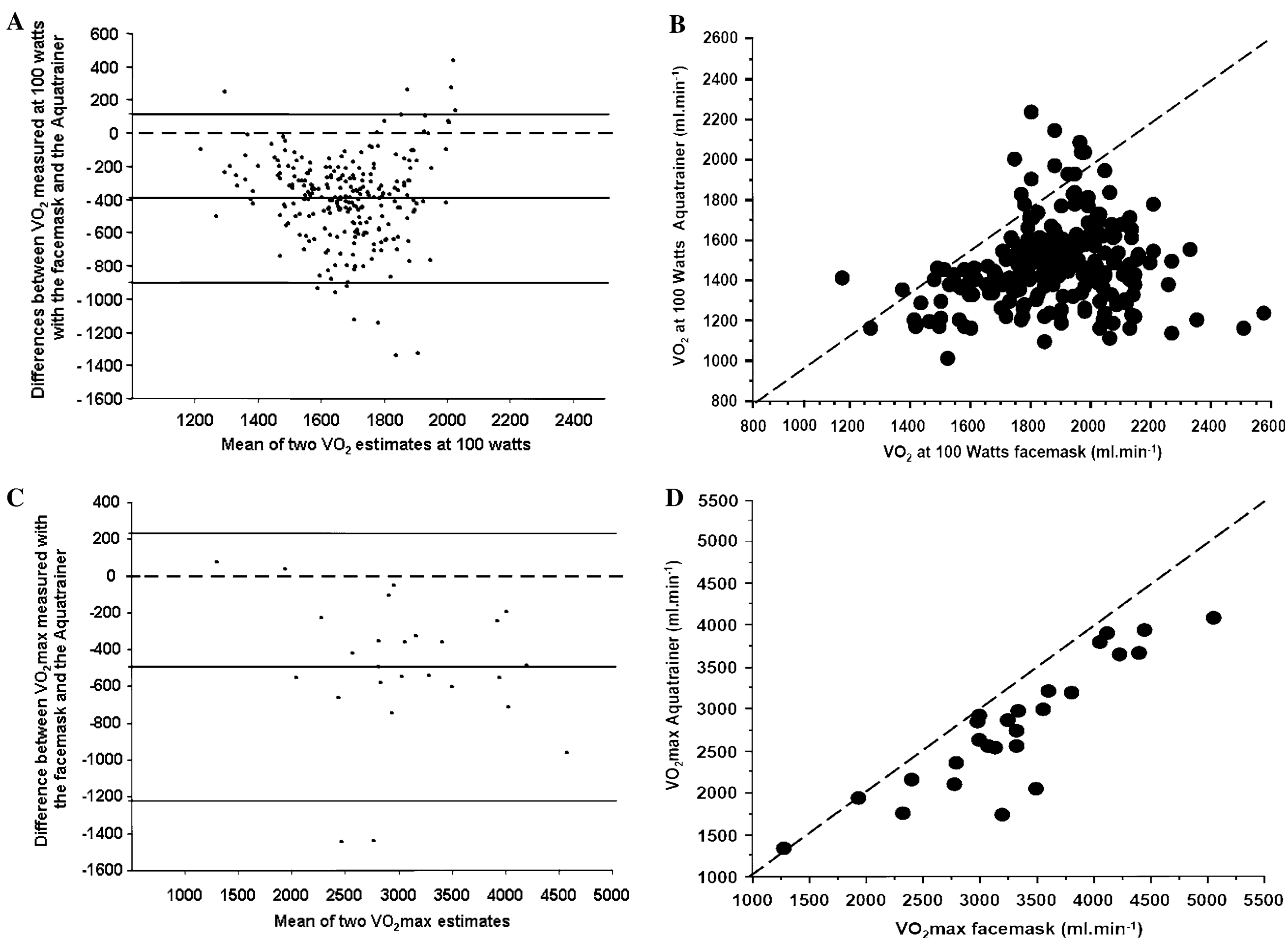


Fig. 3 **a**, **c** Bland and Altman plots of comparison between both estimates for VO_2 uptake at 100 W (**a**) and maximal effort (**c**). Association between VO_2 uptake in (ml min^{-1}) measured with the facemask and the Aquatrainer at 100 W (**b**) and maximal effort (**d**). The *dashed line* is the line of identity. *Thick lines* in **a** and **d** are the bias

vs. 3,294 ± 821 ml min^{-1}, $P < 0.0001$), VCO_2 (3,426 ± 836 vs. 3,641 ± 946 ml min^{-1}, $P = 0.012$) and *VE* (98 ± 21 vs. 108 ± 26 l min^{-1}, $P = 0.0009$) (Table 3). These variables were lower by approximately −6 to −16% with the Aquatrainer® system. The bias ±95% limits of agreement (LOA) for VO_{2max} was 495 ± 727 ml min^{-1} (Fig. 3).

Cardiopulmonary exercise testing data from 60 to 270 W

Main cardiopulmonary exercise test data measured from 60 to 270 W are presented in Fig. 4. Compared with the facemask, cardiopulmonary responses (VO_2, VCO_2) measured with the Aquatrainer® system were systematically

Table 3 Comparison of maximal cardiopulmonary data in 26 subjects measured with the facemask men and with the new Aquatrainer® system

Maximal parameters	Facemask	Aquatrainer®	ANOVA *P* value	*r* and Bias (95% LOA)
VO_2 (ml min^{-1})	3,294 ± 821	2,799 ± 751	<0.0001	0.89, −36.2 (162.4)
VCO_2 (ml min^{-1})	3,641 ± 946	3,426 ± 836	0.012	0.90, −15.2 (121.7)
VE (l min^{-1})	108 ± 26	98 ± 21	0.0009	0.86, −0.73 (4.43)
VT (l)	3.10 ± 0.77	3.05 ± 0.76	0.50	0.91, −0.00 (0.08)
Rf (cycles min^{-1})	34 ± 6	32 ± 5	0.06	0.36, −0.19 (2.03)

Values are means ± SD. *VE* ventilation, *VT* tidal volume, *Rf* respiratory frequency. Data were compared for the same maximal exercise time and power on ergocycle. Mean values reported are maximal values measured during the exercise phase (averaged for 15 s). *LOA* limits of agreement

lower for the entire power output range (Fig. 4). Compared to facemask data, ventilation measured by the Aquatrainer® system was systematically lower from 60 to 240 W, as was *VT* from 60 to 210 W (Fig. 4). Compared to the facemask data, FeO_2 measured with the Aquatrainer® system were systematically higher from 60 to 270 W ($P < 0.001$ at 60 and 270 W, $P < 0.0001$ from 90 to 240 W) (Fig. 4). Compared to the facemask data, $FeCO_2$ measured with the Aquatrainer® system were systematically lower at 60 ($P < 0.001$), 150 and 270 W ($P < 0.05$) (Fig. 4). ANOVA revealed a significant interaction effect [modality (facemask or aquatrainer) × power] for VO_2 (ml min^{-1}, $P < 0.0001$), VCO_2 (ml min^{-1}, $P < 0.0001$), ventilation (l min^{-1}, $P < 0.0001$), *VT* (l, $P = 0.0001$).

Discussion

The main finding of our study was the poor level of agreement between measures obtained from the new Aquatrainer® system and the classical facemask system, evidenced by large systematic differences and wide 95% limits of agreement. All relevant maximal cardiopulmonary responses, including VO_2, VCO_2, *VT* and *VE* were systematically lower when measured with the Aquatrainer® system, no matter exercise intensity. FeO_2% measured with the Aquatrainer® system was found significantly higher irrespective of exercise mode or intensity level. We also found that the error difference was not constant during increasing exercise intensity (60–270 W) particularly with respect to VO_2, VCO_2, ventilation and *VT*. To our knowledge, no previous studies have compared the new Aquatrainer® system and the facemask for measuring cardiopulmonary responses during submaximal and maximal exercise. Actually, from a practical point, the utility and use of the new Aquatrainer® system is not acceptable for field-testing, particularly in swimming conditions. For example, in the study of Perini et al. (1996), the VO_{2max} of young swimmers (measured with a facemask) was improved by 12% after 5 months of training. In this study, the Aquatrainer system could not be used to assess the VO_{2max} of those swimmers and has no utility because of the too large error measurement compared to facemask.

Cardiopulmonary exercise testing data during submaximal test performed at 100 W

It should be noted however that the mean VO_2 measured by the Aquatrainer® (1,483 ± 203 ml min^{-1}) was closer to expected values (1,487 ± 123 ml min^{-1} according to the ACSM formula) than that measured by the facemask (1,876 ± 204 vs. 1,591 ± 124 ml min^{-1} according to the ACSM formula). The tendancy of the Cosmed K4b^2 (i.e. with the facemask) to overestimate VO_2 at submaximal workloads has occasionally been reported in the literature (McLaughlin et al. 2001), but the difference we found in our study (~15%) was larger than the 3–9% difference with the Douglas bag method observed by McLaughlin et al. (2001). Some factors including the calibration procedure, the accuracy of the expected VO_2 estimation, differences between systems of the same model and many others can be put forward to explain this discrepancy. Its main implication is probably that facemask measures, although they have been shown to be valid (Doyon et al. 2001; Duffield et al. 2004; Hausswirth et al. 1997; McLaughlin et al. 2001), cannot necessarily be considered as criterion measures. It would therefore be scientifically more accurate to consider that both systems provided an estimation of true VO_2, and that this value was an unknown parameter of this study. Our results then suggest that the level of agreement between the Aquatrainer® system and the classical facemask was rather weak, since their respective VO_2 measures were poorly associated ($r = 0.22$) and displayed wide 95% LOA (17% of the average VO_2), but cannot determine which measure was closer to the true VO_2.

Cardiopulmonary responses during incremental exercise from 60 to 270 W

We did perform an additional comparative analysis of cardiopulmonary responses between the Aquatrainer® and

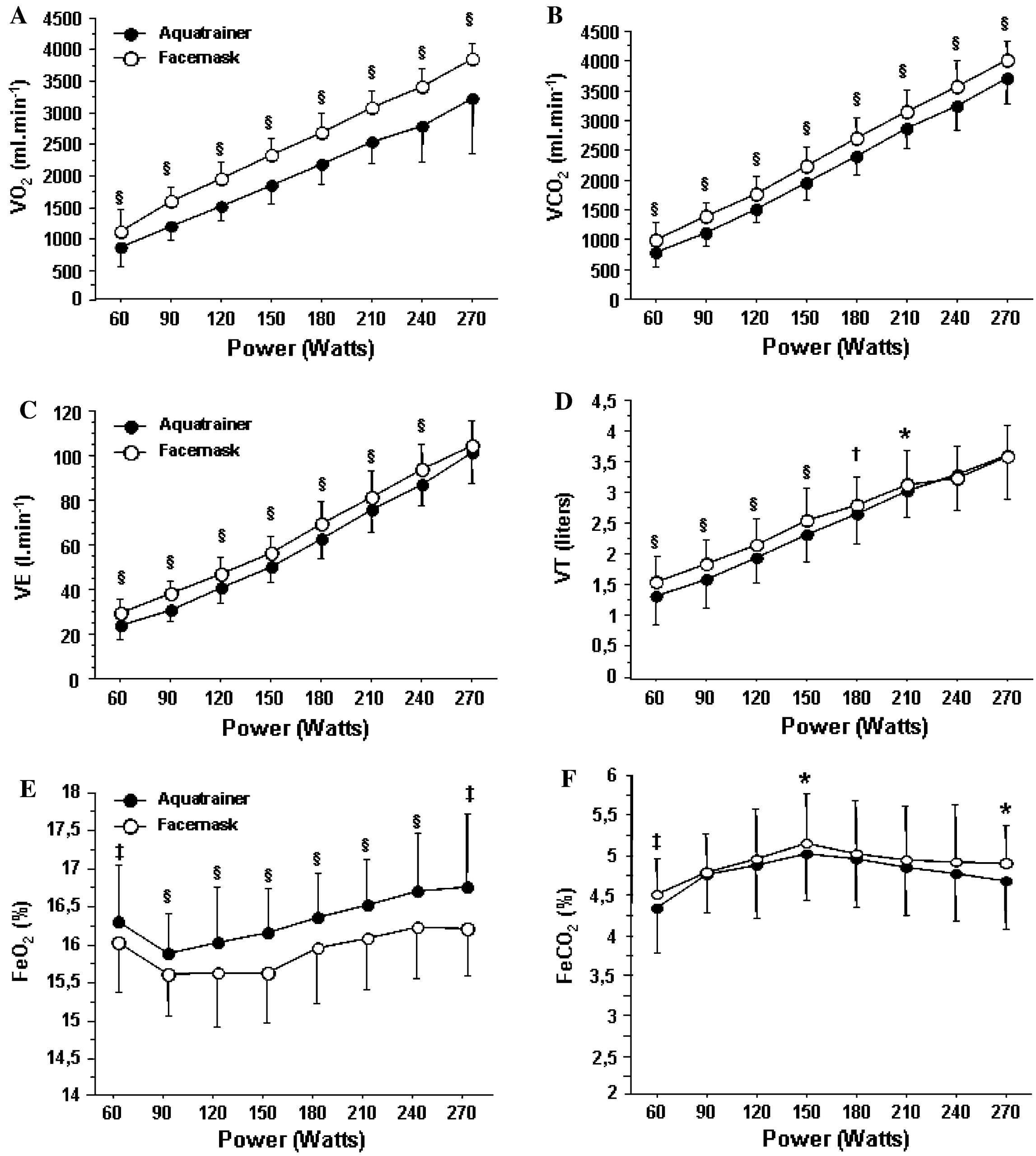


Fig. 4 Comparison of main cardiopulmonary responses (VO_2, VCO_2, *V*E, *V*T, FeO_2 and $FeCO_2$) measured during incremental exercise testing on ergocycle with the facemask and the Aquatrainer system. Each mean (±SD) is the mean of the 2-min stage presented on power ranging from 60 to 270 W. *$P < 0.05$, †$P < 0.01$, ‡$P < 0.001$, §$P < 0.0001$, *V*E ventilation, *V*T tidal volume

the facemask to document at which exercise intensity the cardiopulmonary responses began to differ, and more importantly, whether measurement error would remain constant throughout the range of exercise intensities. Surprisingly, our data revealed that from 60 W, the Aquatrainer® and the facemask measurement started to differ with respect to all main cardiopulmonary responses. Measurement error was not constant, with an interaction effect noted for VO_2, VCO_2, ventilation, and *V*T. However, measurement error remained relatively constant for other variables at all exercise intensities studied (60–270 W).

We should mention that our results faced two validation problems that cannot be resolved in our study: first, the physical validation of the system (Aquatrainer® system itself), the second, is the influence of the system on several physiological variables. Additional studies are required in the future, particularly a physical study of the system with a metabolic simulator. However, several hypotheses can be put forward to explain the discrepant results between the two systems used in this study. First, the hardware configuration is not the same between the facemask and the Aquatrainer® system, a second important difference might pertain to the two systems (facemask and Aquatrainer) themselves. Additional studies will be required to know where the potential sources of errors are. (physical and/or physiological influences). In the Aquatrainer® documentation (Cosmed Ltd. 2005), it is specified that the air of one single expiration does mix along the tube, but than it goes out of the tube pushed by the expired breath of the next breath, so that the mixing of two breath is minimized. However, how important is the gas mixing of several breaths remain to be determined during exercise, but our results showed a potential effect concerning the concentration measurement. As noted previously, the Aquatrainer® system only uses the expiratory flow (Fig. 1b) whereas the facemask uses both the inspiratory and the expiratory flows for calculation of gas exchange data. Therefore, calculation of cardiopulmonary gas exchange variables with the Aquatrainer® model is performed in a different manner (hardware configuration: in/ex software, Cosmed Ltd. 2005) compared with the facemask. Concerning ventilatory variables (*V*E, *V*T and Rf) the measurement are performed breath by breath, whereas, the gas concentration for O_2 and CO_2 are more close to mixing chamber mode (Cosmed Ltd. 2005). Due to the length of the expiratory tube and to this particular mode, there may be a delay between the flow signal and the concentration signals, it is assumed that this delay is accounted in the software/hardware configuration, but this information is not available in the operator manual (Cosmed Ltd. 2005). It is also stated that the expired air makes the turbine spin in one direction only, therefore, to know when expiration ends, the analyzer cannot read the direction of the turbine, but they consider an ended expiration when the turbine turns below a threshold velocity (Cosmed Ltd. 2005). It is possible that compression and decompression occurs during expiration over this long tube, affecting the flow and its measurement. This may cause an under spin of the turbine leading to volume measurement error. When using the facemask, because of the short distance between the mouth and the flowmeter, the air temperature is assumed 34°C (Cosmed Ltd. 2005). However, the long expiratory tube of the Aquatrainer® system also results in a lower air temperature. With the Aquatrainer, the temperature is measured in the turbine (Cosmed Ltd. 2005) and the flow is corrected with ambient temperature. However, this might influence calculation of ventilation, VO_2 and VCO_2. Another possible factor influencing *V*E could be the respiratory resistance associated with the Aquatrainer module, than can lower the ventilation as demonstrated (Demedts and Anthonisen 1973). This may increase its resistance that could be higher to the inspiratory one, whereas, is it stated in the Aquatrainer brochure that both tube resistance are the same (9 cmH_2O at 100 l min^{-1}) (Aquatrainer brochure. http://www.ardsport.com/adminakort/pdf/K4b2_Acquatrainer_option.pdf).

Ventilation and *V*T are both underestimated from 60 to 240 W but Rf is not affected by the Aquatrainer® use. This would indicate that *V*E and *V*T are implicated in part in the difference of gas exchange measurements (VO_2 and CO_2). Because both FeO_2 and $FeCO_2$ are involved in the calculation of VO_2 and VCO_2 (ATS/ACCP 2003), we should know if those two expiratory gas fraction are correctly measured by the Aquatrainer®. FeO_2 is systematically overestimated from 60 to 270 W with the Aquatrainer®, whereas, for $FeCO_2$ (less influenced by the Aquatrainer®), less important and frequent underestimations are observed at 60, 150 and 270 W ($P < 0.001$ and 0.05). Cardiopulmonary testing with the two systems, although performed in random order, occurred on different days. Nevertheless, a large body of evidence has demonstrated the high reproducibility of cardiopulmonary exercise testing in health and disease (ATS/ACCP, 2003) with coefficients of variation ranging from 3 to 9% for VO_2max, 5 to 9% for VCO_2max and 5 to 12% for ventilation depending on the population tested.

Conclusions

Principal cardiopulmonary exercise testing data differed when measured with the Aquatrainer® system during exercise compared to the facemask. Additional studies, involving physical validation (metabolic simulator) are required in order to detect the sources of error in the Aquatrainer system. The potential errors could involve: (1) the Aquatrainer® algorithm (hardware configuration), (2) the long corrugated tubing of the Aquatrainer® system might lead to (a) prolonged gas mixing time and (b) elevated resistance leading to unexpected physiological effects, and (3) to a lesser degree, the role of the within-subject variability. Actually, the utility and use of the new Aquatrainer® system is not acceptable for field-testing, particularly for swimming.

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Conflict of interest statement The authors declare that they have no conflict of interest.

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