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ORIGINAL ARTICLE

Different methods for monitoring intensity during water-based aerobic exercises

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Abstract The aim of this study was to compare different measurement techniques (indirect calorimetry, IC; heart rate monitoring, HR; an activity monitoring system, AH; rates of perceived exertion, RPE) to estimate physical activity intensity (light, moderate, vigorous) during water-based aerobic exercises (WE). Twelve healthy young women performed five common WE of 10-min duration at three frequencies in an indoor swimming pool. Data recorded from the 5th to 9th minute of exercise were averaged to obtain mean $\dot{V}O_2$ (IC), HR and AH values; RPE was recorded at the end of each WE. Oxygen uptake was also estimated from HR data using three different $\dot{V}O_2$ versus HR regression equation models. Significant correlations ($p < 0.001$) were found for the indirect methods that used HR, RPE and AH data regressed as a function of $\dot{V}O_2$ (IC); the highest correlations were found between the measured values of $\dot{V}O_2$ (IC) and those estimated from the three $\dot{V}O_2$ versus HR equations ($R > 0.7$ in all cases). An ANOVA test showed no significant differences between all predicted and measured $\dot{V}O_2$ values; however, when the Bland & Altman analysis was considered, AH data showed the larger explained variances (95% CI) and the larger standard errors. These data indicate that the most accurate way to estimate physical activity intensity during WE is based on HR measurements.

Keywords Head out aquatic exercises · Physical activity · Exercise intensity · Water-based activities

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Introduction

The assessment of exercise intensity is deeply related with physical activity responses in relation to risk stratification and with dose–response principles (ACSM 1998, 2007, 2009). Even if a strong relationship between regular physical activity and health has been clearly established (Pate et al. 1995; US Department of Health and Human Services 1996; Haskell et al. 2007), the selection of an appropriate physical activity (in terms of exercise intensity, mode, frequency and duration) is essential in order to obtain actual training effects, to avoid injuries and to ensure exercise adherence. Exercise of at least moderate intensity is recommended as the minimum exercise stimulus for healthy adults, while a combination of moderate and vigorous intensity exercise is ideal to achieve improvements in physical fitness in most adults (Haskell et al. 2007). Exercise intensity can be defined in different ways (e.g. as % $\dot{V}O_{2max}$, % HR_{max}, METs) and can be assessed by different measurement techniques (e.g. indirect calorimetry, heart rate monitoring, activity monitoring and rates of perceived exertion). Their advantages and limitations have to be evaluated on the basis of specific aims as well as on the basis of the feasibility–validity relationship. Indirect calorimetry can be considered as the "gold standard" but requires expensive equipment, so it is mainly utilized for research purposes. Heart rate monitoring can provide detailed information about the amount of time spent in different heart rate intervals and is less expensive than indirect calorimetry, so it is more frequently used in field settings (e.g. in a gym or a swimming pool). Activity monitoring systems that combine heart rate recordings and accelerometry data for the prediction of physical activity intensity during free-living conditions are also used in field settings (Westerterp 2009). Finally, a system frequently utilized in field settings to estimate and to prescribe exercise intensity is based on the rates of perceived exertion (RPE, Borg Scale, Borg 1982).

Water-based activities (WA), in recent years, have gained popularity and are considered as one of the possible alternatives among the traditional physical activities (in terms of "exercise mode") for well-being and health (e.g. Takeshima et al. 2002; Campbell et al. 2003; Colado et al. 2008, 2009b; Barbosa et al. 2009; Raffaelli et al. 2010).

Even if the physiological and training effects of WA have been investigated by several authors (e.g. Cassady and Nielsen 1992; Chu and Rhodes 2001; D'Acquisto et al. 2001; Takeshima et al. 2002; Poyhonen et al. 2002; Campbell et al. 2003; Robinson et al. 2004; Martel et al. 2005; Broman et al. 2006; Gappmaier et al. 2006; Tsourlou et al. 2006; Barbosa et al. 2007; Colado et al. 2009a, b; Triplett et al. 2009; Raffaelli et al. 2010), monitoring intensity in field settings (during water-based classes) remains difficult, particularly for aquagym, aquaerobics or callisthenics exercises (generally utilized in water fitness programs) as compared to walk, run or aqua-bike which are more easy to standardize.

Recently, Raffaelli et al. (2010) showed that it is possible to standardize the most common water-based aerobic exercises (WE) in terms of amplitude and frequency of movement and that the metabolic intensity of exercise can be controlled by changing the type of exercise and/or the frequency of the music track. By measuring exercise intensity by means of indirect calorimetry, these authors were able to classify the most common water-based aerobic exercises on the basis of ACSM criteria (ACSM 1998, 2007), thus allowing to set, in a given population (e.g. young adult healthy women), the intensity level of an aquatic fitness lesson and/or of a training program. Indirect calorimetry is, however, a method not commonly used in the field, while it is still unclear which could be the most accurate "field method" that a WA trainer could utilize to estimate exercise intensity during his/her water-based classes.

This study is a follow up of the work of Raffaelli et al. (2010) and it is based on additional data (assessed by means of an activity monitoring system, see below) and on a more recent classification of the exercises intensity (ACSM 2009 vs. ACSM 2007). More specifically, the aim of this study was to compare different measurement techniques to estimate physical activity intensity during water-based aerobic activities. The methods taken into consideration were: indirect calorimetry (utilized as "gold standard"), heart rate monitoring, an activity monitoring system and the rates of perceived exertion. Among the available activity monitoring systems, we decided to utilize the Actiheart (Cambridge Neurotechnology, UK), a combined sensor of heart rate and accelerometry.

To our knowledge, no studies so far were conducted to assess the validity of this system to estimate exercise intensity in the water environment even if the Actiheart was validated in walking and running (Brage et al. 2005) as well as in a wide range of land activities in a field setting (Crouter et al. 2008). Even if the integration of HR and accelerometer data can, theoretically, improve the estimation of physical activity intensity (Strath et al. 2005), we could hypothesize that, in water, this system would not be as accurate as on land due to the physical characteristics of the medium (we refer here mainly to the effects of buoyancy, hydrostatic pressure and hydrodynamic resistance) that are likely to affect determination of exercise load when based on movement counts.

Materials and methods

Twelve physically active college female students took part in the study (26.0 ± 2.9 years of age; 1.65 ± 0.03 m of stature; 53.6 ± 3.3 kg of body mass; 19.7 ± 1.6 kg m^{-2} of body mass index). The inclusion criteria of the study are reported in the paper of Raffaelli et al. (2010) to which the reader is referred for further details.

Different measurement techniques have been used to quantify the intensity of the proposed physical activity. Oxygen consumption (indirect calorimetry, IC) was measured by means of a portable metabolic system ($K4b^2$, Cosmed, Italy). These data have been used as "gold standard" and compared with data obtained with:

- a heart rate monitor (T31, Polar, Finland);
- an activity monitoring system (Actiheart, Cambridge Neurotechnology, UK), which was applied, after skin preparation, with ECG electrodes on the left side of the chest and in the lower position (as indicated by Brage et al. 2006). The Actiheart was protected with a special waterproof wide-area fixation dressing;
- the Borg's 6-20 scale (RPE, Borg 1982); the subjects were asked to rate this scale immediately after each trial.

While RPE and HR measurement techniques do not require a specific calibration, the gas analyzers and the flowmeter of the metabolimeter were calibrated before each test following the indications of the producers. The

Actiheart requires a more complex calibration, which will be described in detail in the following paragraphs.

Physical activity intensity can be estimated by the Actiheart using a group calibration or an individual calibration. As indicated by Rennie et al. (2000), the individual calibration is the more accurate procedure. To obtain the data required for the Actiheart individual calibration, during the first week of the 2-week study period, as indicated by Brage et al. (2007), we measured the resting metabolic rate (RMR) and the sleeping heart rate (SHR) of our subjects (two “non-exercise-based individual calibrations”); we also asked our subjects to perform a maximal test to exhaustion (to assess $\dot{V}O_{2max}$ and HR_{max}) and a step test during which the individual $\dot{V}O_2$ versus HR relationship was determined (two “exercise-based individual calibrations”). All these tests were performed on land but the step test was performed in water (see below).

RMR was assessed by means of indirect calorimetry during a test lasting 15 min; the average of the values collected between the 5th and the 10th minute was used to calculate RMR. This test was performed in the early morning, while the subjects were lying quietly on a bed.

SHR was determined, by means of the Actiheart, during a free-living observation period of three (consecutive) days. The instrument was configured to record data with a 1-min epoch interval and SHR was derived as the average of the highest values of the 30 lowest minute-by-minute HR readings during the 72-h period (Melzer et al. 2009).

Each participant performed an incremental test to exhaustion on a treadmill (Run-Race, Technogym, Italy) to determine maximal oxygen uptake ($\dot{V}O_{2max}$) and maximal heart rate (HR_{max}). Following a warm-up of 2 min at 6 km h^{-1}, the running speed was increased to 0.5 km h^{-1} for each minute. Each participant reached a plateau of oxygen consumption at the end of the test and $\dot{V}O_{2max}$ was calculated as the average of the data collected during the last step (1-min duration). HR_{max} was accounted for as the highest value attained at the end of the exhaustive treadmill test.

The $\dot{V}O_2$ versus HR relationship was assessed by means of a step test that was performed in water (water depth: 1.2 m; water temperature: 28°C; humidity: 70%); during this test, breath-by-breath oxygen consumption ($\dot{V}O_2$, ml min^{-1} kg^{-1}) and heart rate (HR, bpm) were measured continuously by means of a portable metabolic system ($K4b^2$, Cosmed, Italy); during the test, the participants were also wearing the Actiheart. The ramped step test involved 8 min of stepping up and down, followed by 2 min of recovery. Participants were instructed to progressively increase their stepping frequency, dictated by a drum rhythm included in the Actiheart software, to facilitate time synchronization. The height of the step was 20 cm and the stepping frequency increased linearly from 15 cycles per minute (1 cycle: ‘up, up, down, down’) to 33 cycles per minute. All participants were able to complete this test.

The experimental protocol

A repeated measures within-subjects design was used to compare exercise intensity (estimated by different measurement techniques) during a series of exercises in water. Five typical water-based aerobic exercises (WE) were utilized in this study: “running on the spot raising the knees high” (S), “jumping on the spot moving the legs sideways (in the frontal plane)” (SJ), “jumping on the spot moving the legs backward and forward (in the sagittal plane)” (FJ), “alternate forward kicks (in the sagittal plane)” (FK) and “alternate sideways kicks (in the frontal plane)” (SK). Each activity was performed at three frequencies, corresponding to three different movement speeds (f1 = 1.8–2 Hz, f2 = 2–2.17 Hz and f3 = 2.17–2.33 Hz). These exercises, commonly utilized during aerobic water fitness activities, were described in detail by Raffaelli et al. (2010).

Experiments were conducted in an indoor swimming pool (water depth: 1.2 m, up to the chest; water temperature: 28°C; humidity: 70%) in three separate days at the same time of the day. Each trial (a given exercise at a given frequency) lasted 10 min with a 5-min break between trials. Each subject completed 15 trials (5 exercises × 3 frequencies) and was monitored by means of: (a) a portable metabolic system ($K4b^2$, Cosmed, Italy); (b) a heart rate monitor (T31, Polar, Finland) and (c) the Actiheart (Cambridge Neurotechnology, UK). Data recorded at steady state (from the 5th to the 9th minute) were averaged to obtain mean $\dot{V}O_2$ (ml min^{-1} kg^{-1}), HR (bpm) and Actiheart (METs) values. Finally, (d) the rates of perceived exertion (RPE, 6-20 Borg scale) were collected at the end of each single trial. The subjects were familiarized with this scale before the experiments.

Data analysis

In order to compare data obtained with different measurement techniques, gross energy expenditure was expressed in ml min^{-1} kg^{-1} for all devices, as for oxygen uptake ($\dot{V}O_2$).

As far as data of HR are regarded, we “estimated oxygen consumption” using different $\dot{V}O_2$ versus HR regression equation models previously studied on land (ACSM 1998) and in water (Brown et al. 1998) as well as using the $\dot{V}O_2$ versus HR relationship experimentally assessed in our study (12 subjects, 5 WE at 3 frequencies, $n = 180$): $\dot{V}O_2 = 0.25HR - 8.19$ (see “Results”).

The ACSM equation was chosen because it is the most utilized to estimate $\dot{V}O_2$ from HR data (even if it refers to land exercise); the Brown et al. (1998) equation was obtained for deep water running (a different movement type compared to the exercises involved in this study and at a different water level), but, to our knowledge, it is the only equation reported in the literature for "water-based aerobic activities".

As far as the Actiheart data are regarded, this instrument gives the possibility to estimate energy expenditure using only HR data, only accelerometer data or by combining them according to a so-called "Branched Model" (Brage et al. 2004). This model was used in this study (Branched model, Actiheart Software, version 2.2) after having entered the individual calibrations. Gross energy expenditure, with this instrument, is expressed in METs, these values were thus multiplied by 3.5 to convert them in ml min^{-1} kg^{-1}.

As far as data of RPE are regarded, we "estimated oxygen consumption" from the RPE versus $\dot{V}O_2$ regression equation experimentally assessed in our study (12 subjects, 5 WE at 3 frequencies, $n = 180$): $\dot{V}O_2 = 1.18\text{RPE} + 6.92$ (see "Results").

Data have been analyzed by considering all exercises types at all frequencies or by dividing the exercises for relative intensity (light, moderate and vigorous) according to the most recent ACSM's classification (ACSM 2009; see Table 1).

Statistical analysis

Data analysis was performed using Stat View (version 5.0). Descriptive statistics were computed for all variables. Data are presented as mean ± standard deviation (SD). The alpha level was set at 0.05. Pearson's correlation coefficients were used to determine the relationships between actual (IC) and calculated $\dot{V}O_2$ values (ml min^{-1} kg^{-1}) based on measures of HR, AH and RPE. Fisher's r to z transformation was carried out to locate significant differences. A one-way repeated measures ANOVA was performed to assess absolute differences in energy expenditure. Different measurement techniques were considered within-subject factors in the repeated measures ANOVA. In addition, simple effects were analyzed when a significant integration effect was present, using pairwise comparisons with Bonferroni adjustments.

When different measurement methods are to be compared, neither the correlation coefficient nor the regression analysis is "completely appropriate". The more utilized statistical test to assess the agreement between a new measurement technique and a "gold standard" is the Bland & Altman analysis (Bland and Altman 1986, 1999). This analysis was used to show the variability in the individual error scores (data have not been adjusted for by subtracting the mean difference from the new method). For each trial, the error scores were computed by subtracting the estimate (HR, AH, RPE) from criterion (IC). Systematic differences were assessed by calculating the correlation coefficients between the difference of the methods (criterion − estimate) and the average of the methods (criterion and estimate) in the Bland & Altman plots. The same analysis was performed for data classified by intensity.

Results

During the preliminary tests conducted to perform the *individual calibrations* of the Actiheart, the following data were obtained: RMR, 1,284 ± 222 kcal day^{-1}; SHR, 52.3 ± 6.3 bpm; maximal oxygen consumption ($\dot{V}O_{2max}$), 46.1 ± 10.6 ml min^{-1} kg^{-1}; maximal heart rate (HR_{max}),

Table 1 The exercise classification (for healthy young active women, ACSM 2009) of the water-based exercises (WE) utilized in this study. In the third column, the METs values are expressed in equivalent $\dot{V}O_2$ values (ml kg^{-1} min^{-1}). Maximal oxygen consumption according to this classification (12 METs = 42 ml kg^{-1} min^{-1}) is close to the $\dot{V}O_{2max}$ actually measured in our sample (46.1 ± 10.6 ml kg^{-1} min^{-1}). See text for details

Relative intensity	ACSM criteria (METs)	$\dot{V}O_2$ equivalents (ml kg^{-1} min^{-1})	WE
Very light	<3.2	<11.2	–
Light	3.2–5.3	11.2–18.5	S–f1, SJ–f1, SJ–f2, SJ–f3, FJ–f1, FJ–f2
Moderate	5.4–7.5	18.9–26.2	S–f2, S–f3, FJ–f3, FK–f1, SK–f1, SK–f2
Hard (vigorous)	7.6–10.2	26.6–35.7	FK–f2, FK–f3, SK–f3
Very hard	≥10.3	≥36.05	–
Maximal	12	42	–

S "running on the spot raising the knees high", *SJ* "jumping on the spot moving the legs sideways (in the frontal plane)", *FJ* "jumping on the spot moving the legs backward and forward (in the sagittal plane)", *FK* "alternate forward kicks (in the sagittal plane)", *SK* "alternate sideways kicks (in the frontal plane)"; f1 = 1.8–2 Hz, f2 = 2–2.17 Hz and f3 = 2.17–2.33 Hz

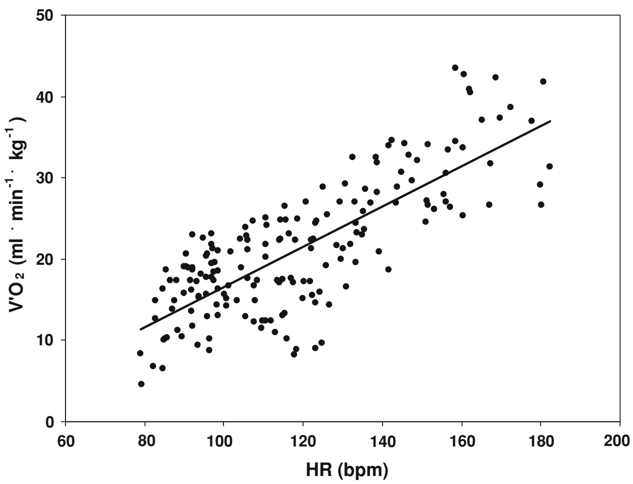

Fig. 1 The relationship between $\dot{V}O_2$ (ml min^{-1} kg^{-1}) and HR (bpm) as obtained in this study during water-based exercise (12 subjects, 5 WE at 3 movement frequencies): $\dot{V}O_2 = 0.25\text{HR} - 8.19$, $n = 180$, $R = 0.782$, $p < 0.001$

186 ± 11 bpm. During the step test in water, the following $\dot{V}O_2$ versus HR relationship was determined: $\dot{V}O_2 = 0.20\text{HR} - 10.54$, $R = 0.931$ (average for all subjects), this relationship being similar to that obtained during WE (see "Materials and methods"; Fig. 1).

As far as the data collected during the experiments in water are concerned (12 subjects, 5 WE at 3 frequencies), in Table 2, the average values of $\dot{V}O_2$, HR and AH (as measured from the 5th to the 9th minute of each exercise) as well as the RPE data (as measured at the end of each WE) grouped for relative intensity (light, moderate and vigorous) according to the most recent ACSM's classification are reported (ACSM 2009).

The $\dot{V}O_2$ versus $\text{HR}_{(\text{GroupCal})}$, $\dot{V}O_2$ versus RPE and $\dot{V}O_2$ versus AH regressions, as experimentally determined in this study, are reported in Figs. 1, 2 and 3, respectively.

In Table 3, the grand averages for measured (IC, indirect calorimetry) and predicted $\dot{V}O_2$ values (ml kg^{-1} min^{-1}, as estimated based on AH, HR and RPE data) are reported; in the same table, these data are also reported for the three intensity levels (light, moderate and vigorous exercise).

No significant differences (repeated measures ANOVA) were observed among the $\dot{V}O_2$ values determined with the "gold standard" (IC) and the indirect methods (except for $\text{HR}_{(\text{Brown})}$ at light intensity which was found to be significantly lower compared with IC, $p < 0.0001$).

Data reported in Table 3, when compared to data reported in Table 1, indicate that: (a) for light exercises the average estimated $\dot{V}O_2$ based on AH, $\text{HR}_{(\text{Brown})}$ and $\text{HR}_{(\text{GroupCal})}$ allowed a correct classification of the exercise intensity, while for $\text{HR}_{(\text{ACSM})}$ and RPE the average estimated $\dot{V}O_2$ overestimates the actual exercise intensity; (b) for moderate exercises only AH underestimates exercise intensity, while the other measurement techniques allowed a correct intensity classification when compared with the actual values; (c) for vigorous exercises, the $\text{HR}_{(\text{ACSM})}$, $\text{HR}_{(\text{Brown})}$ and $\text{HR}_{(\text{GroupCal})}$ allowed a correct classification of the exercise intensity while RPE and especially AH regression equations underestimate the actual exercise intensity.

Significant correlations ($p < 0.001$) were found between the $\dot{V}O_2$ data assessed by means of indirect calorimetry (IC) and the $\dot{V}O_2$ data obtained by means of all the "indirect methods" we utilized to assess energy expenditure (see Table 4). Data reported in Table 4 indicate that the IC versus RPE and the IC versus AH correlations, although significant, are less strong than the IC versus HR correlations. This holds true also when data are analyzed according to the intensity classification (see Table 4, $p < 0.001$) except for AH (light and vigorous) and RPE (light, moderate and vigorous). In all these cases: (a) the highest correlation coefficients were found for the IC versus $\text{HR}_{(\text{ACSM})}$, IC versus $\text{HR}_{(\text{Brown})}$ and IC versus $\text{HR}_{(\text{GroupCal})}$ regressions; and (b) the correlation coefficients are higher for moderate and vigorous exercises compared to light exercises.

As indicated by the Bland & Altman analysis (all data at all intensity levels), the IC versus $\text{HR}_{(\text{Brown})}$ and IC versus RPE equations underestimate the energy expenditure, whereas the IC versus $\text{HR}_{(\text{ACSM})}$ and IC versus $\text{HR}_{(\text{GroupCal})}$ equations overestimate metabolic requirement (see mean differences in Table 5); the greater explained variances (range of error: 95% CI) were found for AH. The analysis of standard errors (SEE), which allows to detect how precise are the estimates, showed that the more accurate equations are $\text{HR}_{(\text{ACSM})}$, $\text{HR}_{(\text{Brown})}$, $\text{HR}_{(\text{GroupCal})}$ and RPE (see SEE in Table 5). When the Bland & Altman plots are

Table 2 Average (±SD) values of $\dot{V}O_2$, HR and RPE grouped per intensity categories (light, moderate and vigorous exercise). In the last row, the data obtained by means of the Actiheart (AH) are reported. See text for details

	All data ($n = 180$)	Light intensity ($n = 72$)	Moderate intensity ($n = 72$)	Vigorous intensity ($n = 36$)
$\dot{V}O_2$ (ml kg^{-1} min^{-1})	21.5 ± 6.4	16.6 ± 5.1	22.7 ± 6.7	28.7 ± 8.8
HR (bpm)	119 ± 18	104 ± 14	120 ± 19	145 ± 23
RPE	12.1 ± 1.5	10.1 ± 1.9	12.3 ± 1.5	15.9 ± 0.9
AH (METs)	4.7 ± 3.7	3.9 ± 2.3	5.2 ± 4.2	5.3 ± 4.9

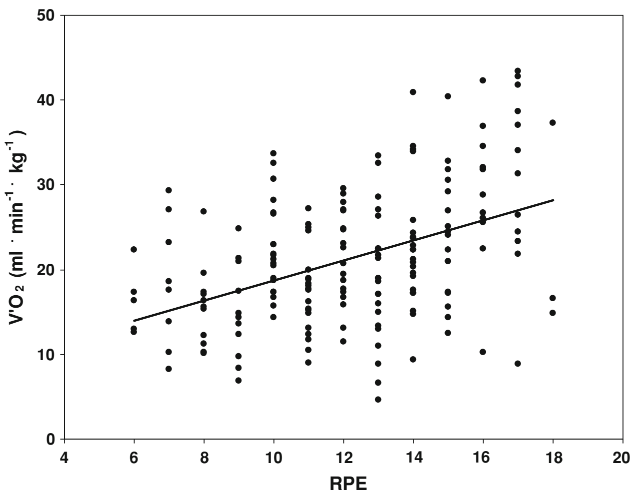

Fig. 2 The relationship between $\dot{V}O_2$ (ml min^{-1} kg^{-1}) and rates of perceived exertion (RPE) as obtained in this study during water-based exercise (12 subjects, 5 WE at 3 movement frequencies): $\dot{V}O_2 = 1.18RPE + 6.92$, $n = 180$, $R = 0.436$, $p < 0.001$

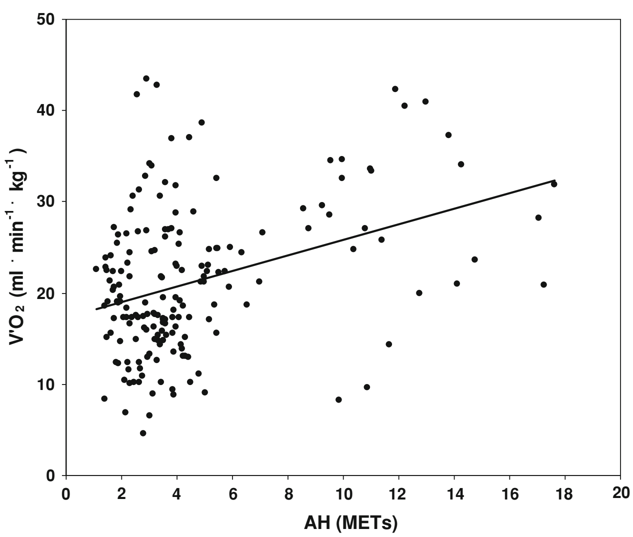

Fig. 3 The relationship between $\dot{V}O_2$ (ml min^{-1} kg^{-1}) and Actiheart data (AH, METs) as obtained in this study during water-based exercise (12 subjects, 5 WE at 3 movement frequencies): $\dot{V}O_2 = 0.85AH + 17.28$, $n = 180$, $R = 0.358$, $p < 0.001$

considered, a case of proportional error is depicted: differences are positive for small values and negative for large values for AH, $HR_{(ACSM)}$ and $HR_{(Brown)}$; on the contrary, differences are negative for small values and positive for large values for $HR_{(GroupCal)}$ and RPE. A significant inverse correlation was observed between the difference of the methods and the mean of the methods for AH, $HR_{(ACSM)}$ and $HR_{(Brown)}$ equations when compared with the gold standard. On the contrary, a significant and positive correlation was observed between $HR_{(GroupCal)}$ and RPE equations and the gold standard.

Data reported in Table 5 also refer to exercises divided by intensity classes. The average mean difference increases with increasing intensity only for the AH equation; on the contrary, the average mean difference decreases with intensity for the $HR_{(Brown)}$ equation. For the other equations, the average mean difference remains almost constant. The greater explained variances (95% CI) increase with intensity for the AH and the RPE equations; for the other equations, they remain almost constant. From the analysis of standard errors (SEE), the analysis carried out at the different intensities underlines that the more accurate regression equations are the $HR_{(GroupCal)}$ and RPE. When the plots of AH, $HR_{(ACSM)}$, $HR_{(Brown)}$, $HR_{(GroupCal)}$ and RPE are considered at each of the three intensities, the observed differences in predicted $\dot{V}O_2$ between equations remained similar (a case of proportional error is still depicted). A significant inverse correlation was observed between the difference of the methods and the mean of the methods for AH, $HR_{(ACSM)}$ and $HR_{(Brown)}$; on the contrary, a significant and positive correlation was observed for $HR_{(GroupCal)}$ and RPE, for all the different intensities considered.

Discussion

In the last 10 years, many studies (e.g. Pate et al. 1995; US Department of Health and Human Services 1996) underlined the health-related benefits of regular physical activity (PA), according to the dose–response relationship between PA and health. These publications have affected the development of the actual guidelines on the correct amount and intensity of PA (Haskell et al. 2007). According to risk stratification, moderate (3–6 METs) or vigorous (>6 METs) exercises can be performed with or without medical examination and clearance (ACSM 2009). In order to know if participants to water-based aerobic activities (WA) fulfill physical activity and public health guidelines for healthy adults and to determine when a medical examination is recommended, it is, therefore, important to accurately assess intensity during these activities.

In our previous study (Raffaelli et al. 2010), we showed that it is possible to standardize the most common water-based aerobic exercises in terms of amplitude and frequency of movement and that the metabolic intensity of exercise can be controlled by changing the type of exercise and/or the frequency of the music track. In that study, however, we also underlined how: "in group activities the standardization of movement is often not sufficient to elicit a similar response even in a homogeneous group of subjects". Hence, the need to address the question of which "indirect method" can be utilized to "individually" estimate exercise intensity in field setting (during water-based

Table 3 Average values for measured (IC: indirect calorimetry) and predicted $\dot{V}O_2$ values (ml min^{-1} kg^{-1}) grouped per intensity categories. In the last two rows, the power and the statistical significance (ANOVA) are also reported

	All data (n = 180)	Light intensity (n = 72)	Moderate intensity (n = 72)	Vigorous intensity (n = 36)
IC	21.5 ± 6.4	16.6 ± 5.1	22.7 ± 6.7	28.7 ± 8.8
AH	13.5 ± 13.1	13.6 ± 7.9	18.2 ± 14.6	18.6 ± 17.0
$HR_{(ACSM)}$	24.8 ± 9.5	20.2 ± 7.0	25.7 ± 8.7	32.3 ± 10.4
$HR_{(Brown)}$	17.8 ± 11.0	11.7 ± 7.7	19.0 ± 9.6	27.7 ± 11.4
$HR_{(GroupCal)}$	21.3 ± 6.3	17.6 ± 4.3	21.9 ± 5.5	27.4 ± 6.1
RPE	21.2 ± 3.5	18.8 ± 3.0	21.5 ± 2.4	25.6 ± 1.5
ANOVA data				
p value	<0.001	<0.0001	NS	<0.0001
Power	0.991	1.000	0.696	0.999

AH $\dot{V}O_2$ values as obtained with the Actiheart (METs × 3.5 ml min^{-1} kg^{-1}), $HR_{(ACSM)}$ $\dot{V}O_2$ values as obtained from the $HR_{(ACSM)}$ regression equation, $HR_{(Brown)}$ $\dot{V}O_2$ values as obtained from the $HR_{(Brown)}$ regression equation, $HR_{(GroupCal)}$ $\dot{V}O_2$ values as obtained from the $\dot{V}O_2$ versus HR regression equation determined in our subjects, *RPE* $\dot{V}O_2$ values as obtained from the $\dot{V}O_2$ versus RPE regression equation

Table 4 Correlation coefficients (R) of the regression equations relating the $\dot{V}O_2$ values (ml kg^{-1} min^{-1}) experimentally determined by means of indirect calorimetry (IC) and those estimated by means of the other "indirect measurement techniques". See text for details

	All data (n = 180)	Light intensity (n = 72)	Moderate intensity (n = 72)	Vigorous intensity (n = 36)
IC vs. AH	0.358*	0.126	0.455*	0.243
IC vs. $HR_{(ACSM)}$	0.830*	0.674*	0.786*	0.846*
IC vs. $HR_{(Brown)}$	0.831*	0.618*	0.772*	0.860*
IC vs. $HR_{(GroupCal)}$	0.782*	0.541*	0.693*	0.741*
IC vs. RPE	0.436*	0.024	0.046	0.176

AH $\dot{V}O_2$ values as obtained with the Actiheart (METs × 3.5 ml min^{-1} kg^{-1}), $HR_{(ACSM)}$ $\dot{V}O_2$ values as obtained from the $HR_{(ACSM)}$ regression equation, $HR_{(Brown)}$ $\dot{V}O_2$ values as obtained from the $HR_{(Brown)}$ regression equation, $HR_{(GroupCal)}$ $\dot{V}O_2$ values as obtained from the $\dot{V}O_2$ versus HR regression equation determined in our subjects, *RPE* $\dot{V}O_2$ values as obtained from the $\dot{V}O_2$ versus RPE regression equation

* $p < 0.001$, significantly correlated with model (IC)

classes) when measurements of indirect calorimetry are not available. The three "feasible" methods to estimate exercise intensity in water we decided to analyze in this study were: heart rate monitoring, an activity monitoring system and the rates of perceived exertion.

Since heart rate and oxygen consumption are linearly related (and since some HR measuring systems are waterproof), recordings of HR can be used to estimate oxygen consumption. In this paper, two well-known group $\dot{V}O_2$ versus HR equations have been utilized: the first (which refers to land exercise) was proposed by ACSM (1998) and is largely utilized to estimate $\dot{V}O_2$ from HR data; the second was proposed by Brown et al. (1998) and was determined during deep water running. Even if this equation was obtained during a different movement type (water running vs. WA) and at a different water level, (deep vs. chest level) to our knowledge, this is the only equation reported in the literature that refers to water-based aerobic exercises. Furthermore, we utilized the group $\dot{V}O_2$ versus HR relationship determined in this study.

Predicting $\dot{V}O_2$ data based on a group $\dot{V}O_2$ versus HR regression equation is less accurate than when an individual $\dot{V}O_2$ versus HR regression equation is experimentally determined. However, the latter might be impractical and/or unfeasible for the trainers on the field. Moreover, in order to know if participants to water-based activities fulfill physical activity and public health guidelines, it is sufficient to predict, accurately, the intensity levels (light, moderate, vigorous) of the proposed exercises (even if the estimation of energy expenditure is not accurate).

Data reported in this study indicate that, among the investigated indirect methods, the three group equations (IC vs. $HR_{(ACSM)}$, IC vs. $HR_{(Brown)}$, IC vs. $HR_{(GroupCal)}$) do indeed estimate IC with the better accuracy ($r > 0.7$). Moreover, these equations showed no mean bias against IC (Bland & Altman analysis) and seem to reflect average physical activity intensity with reasonable validity on a group level .

In this study, IC data were also compared with measures obtained with the Actiheart, a waterproof activity

Table 5 Agreement between the values assessed by means of indirect calorimetry (IC) and those obtained by means of the other "measurement techniques". For this comparison, all data were expressed in oxygen uptake equivalents (ml kg^{-1} min^{-1}). In the last two columns, the *R* and *p* values as obtained from the analysis of the systematic differences are reported (*R* = correlation coefficients between the difference of the methods and the mean of the methods in the Bland & Altman plots). See text for details

Measurement techniques	Mean difference	95% limits of agreement	SEE	*R*	*p*
All data					
AH	4.7 ± 12.7	−20.8; 30.2	7.8	−0.466	<0.0001
$HR_{(ACSM)}$	−3.7 ± 5.3	−14.31; 7	8.1	−0.277	<0.001
$HR_{(Brown)}$	3.4 ± 6.2	−9.0; 15.8	8.0	−0.482	<0.0001
$HR_{(GroupCal)}$	−0.1 ± 5.2	−10.4; 10.2	6.3	0.375	<0.0001
RPE	0.1 ± 7.4	−14.8; 14.6	3.5	0.718	<0.0001
Light intensity					
AH	2.7 ± 8.9	−15.1; 20.4	4.6	−0.392	<0.001
$HR_{(ACSM)}$	−3.9 ± 5.2	−14.3; 6.5	5.2	−0.375	<0.01
$HR_{(Brown)}$	4.6 ± 6.1	−7.6; 16.8	5.2	−0.457	<0.0001
$HR_{(GroupCal)}$	1.3 ± 4.6	−10.6; 8.0	4.1	0.218	NS
RPE	−2.5 ± 6.0	−14.4; 9.4	2.6	0.508	<0.0001
Moderate intensity					
AH	4.2 ± 13.0	−21.8; 30.1	7.2	−0.654	<0.0001
$HR_{(ACSM)}$	−3.3 ± 5.4	−14.1; 7.5	7.2	−0.299	<0.05
$HR_{(Brown)}$	3.4 ± 6.1	−8.8; 15.6	7.2	−0.417	<0.001
$HR_{(GroupCal)}$	0.5 ± 5.2	−9.9; 10.9	5.5	0.358	<0.01
RPE	−0.9 ± 7.4	−14.0; 15.8	2.3	0.806	<0.0001
Vigorous intensity					
AH	9.9 ± 17.0	−24.2; 43.9	8.3	−0.616	<0.0001
$HR_{(ACSM)}$	−3.9 ± 5.6	−15.1; 7.2	8.5	−0.359	<0.05
$HR_{(Brown)}$	0.8 ± 6.0	−11.1; 12.7	8.3	−0.511	<0.01
$HR_{(GroupCal)}$	1.0 ± 5.7	−10.3; 12.4	6.2	0.446	<0.01
RPE	2.8 ± 8.3	−13.8; 19.4	1.5	0.939	<0.0001

AH $\dot{V}O_2$ values as obtained with the Actiheart (METs × 3.5 ml min^{-1} kg^{-1}), $HR_{(ACSM)}$ $\dot{V}O_2$ values as obtained from the $HR_{(ACSM)}$ regression equation, $HR_{(Brown)}$ $\dot{V}O_2$ values as obtained from the $HR_{(Brown)}$ regression equation, $HR_{(GroupCal)}$ $\dot{V}O_2$ values as obtained from the $\dot{V}O_2$ versus HR regression equation determined in our subjects, *RPE* $\dot{V}O_2$ values as obtained from the $\dot{V}O_2$ versus RPE regression equation

monitoring system that combines measurements of HR with accelerometer data. This combination has been shown to be more accurate in the classification of PA than measurement of HR or accelerometer data alone on land (e.g. Freedson and Miller 2000; Strath et al. 2001). However, to our knowledge, no studies attempted so far to validate the use of this instrument in water. We included this instrument in our analysis with the hypothesis that in water this system would not be as accurate as on land due to the physical characteristics of the medium that are likely to affect the correct determination of exercise load when based on accelerometer data. To calibrate the Actiheart system as accurately as possible, the HR/$\dot{V}O_2$ relationship (e.g. the step test) was obtained (performed) in water in line with previous works (Cassady and Nielsen 1992; Darby and Yaekle 2000) that found that the HR/$\dot{V}O_2$ relationship is shifted to the right during water exercises compared to dry land. Even though we attempted to calibrate the system as accurately as possible, data reported in this study indicated that the $\dot{V}O_2$ values as estimated based on AH data tend to underestimate systematically PA intensity (AH would classify all the exercises as of light intensity).

Of course, HR data could not be the reason of this underestimation: indeed, where the data calculated based on HR values only, the estimated energy expenditure values would have been the same as those obtained from the $\dot{V}O_2$ versus HR relationship alone. By the way, it would have been useless to use the Actiheart in this way since a HR measuring system would have been sufficient. So, the accelerometer data should be held responsible for these differences. In line with our hypothesis, this is not surprising since, at least in water, the displacement, speed and acceleration of the body segments are necessarily different than on land due to the buoyancy, the hydrostatic pressure and the hydrodynamic resistance. The use of AH in water had certainly other limitations: (a) special attention has to be paid in the electrodes choice and (b) the quality of the HR signal is affected by the movements performed in and out of the water (as was the case in our study). These limitations seem to affect the ability of this instrument to accurately predict exercise intensity in these environmental conditions.

Finally, IC data were also compared with measures obtained by means of the RPE (6-20) Borg scale. This is a simple and cheap measurement technique to estimate exercise intensity on field setting, especially when physical activities are performed in group. In the literature, a strong relationship between RPE and HR was established (Borg 1982); moreover, recent studies, concerning the prediction of maximal oxygen uptake from sub-maximal rating of perceived exertion and heart rate (Faulkner et al. 2007; Lambrick et al. 2009) or from rating of perceived exertion and work rate during exercises performed on land (Okura and Tanaka 2001), have been published. Recently, Alberton et al. (2010) founded a high and significant correlation between rates of perceived exertion and physiological variables (HR, $\dot{V}O_2$ and V'_E) during stationary water running.

Our results indicated that the data obtained from RPE scores, even if significantly related ($R = 0.4$, $p < 0.001$) to IC and not significantly different from the "gold standard", do not allow a correct intensity classification of exercises since, with this method, all exercises are considered as "moderate".

Conclusions

When WA trainers need to assess accurately intensity during WA activities, and when indirect calorimetry (the "gold standard") could not be utilized, HR measurements should be performed. Indeed, the $\dot{V}O_2$ versus $HR_{(ACSM)}$, $\dot{V}O_2$ versus $HR_{(Brown)}$ and $\dot{V}O_2$ versus $HR_{(GroupCal)}$ regression equations are accurate in predicting the intensity of the exercises (light, moderate, vigorous) and, as demonstrated by the Bland & Altman analysis, in all these cases the range of error is acceptable. On the contrary, the analysis of the Actiheart data failed to confirm that, at least in our experimental conditions (e.g. during head out water-based aerobic exercises), the simultaneous measurement of HR and movement counts increase the accuracy of energy expenditure estimation when compared to HR data alone (with this instrument all exercises would be considered of light intensity). As far as the RPE scores are considered, our data suggest that this method has to be used only if HR monitors are not available (with this instrument all exercises would be considered as of moderate intensity). These findings could help WA trainers to better control the intensity of water-based aerobic exercises and to better plan a training program for healthy fit women.

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