Inaccuracy of the HR Reserve vs. $\dot{V}O_2$ Reserve Relationship during Prone Arm-paddling Exercise in Surfboard Riders

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Abstract Previous studies have demonstrated that during lower-body exercise the percentage of heart rate reserve (%HRR) is equivalent to the percentage of the oxygen consumption reserve (%$\dot{V}O_{2R}$) but not to a percentage of the peak oxygen consumption (%$\dot{V}O_{2peak}$). The current study examined these relationships in trained surfboard riders (surfers) during upper-body exercise. Thirteen well-trained competitive surfers performed a stepwise, incremental, prone arm-paddling exercise test to exhaustion. For each subject, data obtained at the end of each stage (i.e., HR and $\dot{V}O_2$ values) were expressed as a percentage of HRR, $\dot{V}O_{2peak}$, and $\dot{V}O_{2R}$ respectively and used to determine the individual %HRR-%$\dot{V}O_{2peak}$ and %HRR-%$\dot{V}O_{2R}$ relationships. Mean slope and intercept were calculated and compared with the line of identity (slope=1, intercept=0). The %HRR versus %$\dot{V}O_{2R}$ regression mean slope (0.88 ± 0.06) and intercept (20.82 ± 4.57) were significantly different ($p<0.05$) from 1 and 0, respectively. Similarly, the regression of %HRR versus %$\dot{V}O_{2peak}$ resulted in a line that differed in the slope ($p<0.05$) but not in the intercept ($p=0.94$) from the line of identity. Predicted values of %HRR were significantly higher ($p<0.05$) from indicated values of %$\dot{V}O_{2R}$ for all the intensities ranging from 35% to 95% $\dot{V}O_{2R}$. Unlike results found for lower-body exercise, a given %HRR during prone upper-body exercise was not equivalent to its corresponding %$\dot{V}O_{2R}$. Thus, to ensure more targeted exercise intensity during arm-paddling exercise, individual HR-$\dot{V}O_2$ equations should be used. *J Physiol Anthropol 29(6): 189–195, 2010* http://www.jstage.jst.go.jp/browse/jpa2
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Introduction

Surfboard riding (surfing) is a highly competitive professional sport. The increases in competition standards and sponsorship contracts have resulted in the need for new coaching expertise and training techniques to help improve surfing performance and prevent injuries (Mendez-Villanueva and Bishop, 2005). During surfing practice, surfboard riders (surfers) are frequently involved in extensive periods of arm-paddling exercise as surfboard paddling takes up the largest percentage (44–50%) of total surfing time (Mendez-Villanueva et al., 2006). In addition, Mendez-Villanueva et al. (Mendez-Villanueva et al., 2006) reported that surfers can spend up to 25% of their total time in the water at intensities above 90% of their maximal heart rate. Accordingly, despite the fact that paddling has no influence on the judge's scores, arm-paddling aerobic fitness is an important physiological trait of competitive surfboard riders (Mendez-Villanueva et al., 2006). Indeed, arm paddling is always necessary prior to catching a wave, which represents the essence of surfing. As training intensity (in combination with training volume and frequency) is an important factor influencing adaptations in physiological parameters, achievement of optimal upper-body aerobic fitness levels in highly-trained surfers requires individually tuned training programs in which workload intensities are precisely define and monitored.

Based on the linear relationship between heart rate (HR), work rate, and oxygen uptake ($\dot{V}O_2$), a percentage of peak heart rate (HR$_{peak}$) (%HR$_{peak}$) to elicit a predetermined percentage of peak oxygen uptake (%$\dot{V}O_{2peak}$) has often been used for assessing exercise intensity. Recent investigations, conducted with different populations, have found that the values obtained for estimated values of %HR$_{peak}$ to predict %$\dot{V}O_{2peak}$ were not accurate (Swain et al., 1994). Different approaches in the utilization of HR for prescribing exercise intensity have been

proposed. One such method is HR reserve (%HRR), that is, the percentage of the difference between resting and maximal heart rate. Although this method provides a more precise estimation of %$\dot{V}$O$_{2peak}$, research conducted by Swain and colleagues has demonstrated that the values of %HRR do not correspond to the equivalent values of %$\dot{V}$O$_{2peak}$, for both cycling and running exercise (Swain and Leutholtz, 1997; Swain et al., 1998). Rather, Swain and colleagues (Swain and Leutholtz, 1997; Swain et al., 1998) showed that %HRR values are more closely related to the values of %$\dot{V}$O$_2$ reserve (%$\dot{V}$O$_{2R}$), i.e., to a percentage of the difference between resting and peak oxygen uptake. Similar conclusions have been reached in recent studies with obese subjects (Byrne and Hills, 2002), heart disease patients (Brawner et al., 2002), diabetic individuals (Colberg et al., 2003), and elite road cyclists (Lounana et al., 2007).

While research has demonstrated that HR is a valid tool to prescribe exercise intensity for lower-body exercise, very few studies have investigated the HR-$\dot{V}$O$_2$ relationship for upper-body exercise. In fact, to the best of our knowledge, only one previous study has investigated the relationship between %HRR and %$\dot{V}$O$_{2R}$ during upper-body exercise (Rotstein and Meckel, 2000). Their results showed that predictions of %$\dot{V}$O$_{2R}$ from %HRR obtained during seated arm-cycling exercise were overestimated. This result placed in doubt the accuracy of %HRR as an estimate of exercise intensity during upper-body exercise. However, no previous study has examined the HR-$\dot{V}$O$_2$ relationship in the upper-body during prone exercise. In this regard, while the hemodynamic differences between the legs and arms during maximal and submaximal exercise are well-known (Pendergast, 1989; Sawka, 1986), most of these studies have employed seated arm cranking as the chosen arm exercise. However, the body position adopted during exercise has been reported to alter the hemodynamic and performance parameters during exercise (Pendergast et al., 1979). For example, %$\dot{V}$O$_{2peak}$ values during arm exercise have been found to be consistently lower in the horizontal (prone or supine) than in the erect (sitting and or upright) posture (Pendergast et al., 1979). In addition, a relatively higher HR at given $\dot{V}$O$_2$ during horizontal arm exercise in comparison with seated arm exercise has been reported (Bevegard et al., 1966; Stenberg et al., 1967). Thus, the HR-$\dot{V}$O$_2$ relationships during prone arm exercise may have specific characteristics.

Despite the fact that HR is the only physiological parameter recordable during in-water surfing sessions, it is not known whether HR accurately reflects $\dot{V}$O$_2$ demands during arm-paddling exercise and the validity of prescribing arm-paddling intensities with HR is also presently unknown. Therefore the aims of the present study were: a) to evaluate the %$\dot{V}$O$_{2peak}$-%HR$_{peak}$ relationship in well-trained athletes during prone, upper-body exercise; b) to determine whether %HRR was equivalent to %$\dot{V}$O$_{2peak}$ or %$\dot{V}$O$_{2R}$ in a sample of well-trained competitive surfers during prone upper-body exercise.

Methods

Subjects

Thirteen well-trained, competitive surfers volunteered to participate in this study. Surfers were of regional and national elite standard and the group contained regional, national, and European championship participants. The exercise protocol and all possible risks and benefits associated with participation in the study were explained to each subject. Each subject provided written informed consent prior to participating in the study. The testing procedures were approved by the Institutional Research Ethics Committee. All subjects underwent a physical examination, including resting electrocardiograms and medical history, prior to testing.

Study Design

The data for this study was collected from 13 highly trained, male competitive surfers. In this investigation, an observational, descriptive-correlation design was used to examine the relationship between the %HR$_{peak}$, %HRR, %$\dot{V}$O$_{2R}$, and %$\dot{V}$O$_{2peak}$. All subjects completed an incremental exercise test to determine the individual relationship between HR and $\dot{V}$O$_2$.

Equipment

A modified, calibrated, wind-braked kayak ergometer (Modest, Odense, Denmark), that has been previously described (Larsson et al., 1988), was used to carry out the testing. The kayak bench was replaced by a surfboard that was fitted and fixed at the rails. Likewise, the kayak paddle was removed and two hand paddles were attached. These modifications allowed subjects to adopt a prone position which resembled their actual surfing paddling position and to perform a simulated surfboard arm-paddling exercise by pulling alternately on the hand paddles. Power output for each stroke was continuously fed back to the surfer via a calibrated digital display and therefore the surfer could achieve the target power output by freely chosen alterations in stroke force, length, or frequency.

Incremental Test

Before testing, all surfers were allowed to become accustomed to the laboratory environment, equipment, and testing procedures. All tests were conducted at the same time of the day, between 09:00 and 13:00 h. The subjects were asked to follow their normal diet and refrain from any form of intense physical activity for the 24 h prior to testing. After 5 min of prone rest, a continuous incremental exercise test was performed for each surfer to determine $\dot{V}$O$_{2peak}$ (Mendez-Villanueva et al., 2005). Subjects commenced a 5-min warm-up at a self-selected intensity. The incremental test commenced at an initial workload of 30 W and was increased by 15 W every 3 min. Exercise continued until subjects were no longer able to maintain the required power output. Each subject was verbally encouraged to continue for as long as possible.

$\dot{V}O_{2peak}$ was determined to be the highest $\dot{V}O_2$ measured during 15 s.

Gas and heart rate measurement

Expired air was continuously measured breath-by-breath with a Vmax 29 gas analyzer (SensorMedics, Yorba Linda, CA, USA). The system was calibrated with known gases before each test following the standard calibration procedures, according to the manufacturer's manual. Throughout the test, HR was monitored and recorded at 5-s intervals using a short-range telemetry system (Polar 4000 Sport Tester, Polar Electro, Kempele, Finland).

Data analysis

$\dot{V}O_{2peak}$ and HR_{peak} were defined as the highest values attained during the incremental test. The lowest values of HR and $\dot{V}O_2$ recorded over the prone rest were considered to be the resting values (Swain and Leutholtz, 1997). HRR and $\dot{V}O_{2R}$ were calculated by subtracting the value at rest from the respective maximum value of each parameter. HR and $\dot{V}O_2$ values from the 3rd minute of each stage were expressed as a percentage of HR_{peak}, HRR, $\dot{V}O_{2peak}$, and $\dot{V}O_{2R}$. For each individual, data obtained at rest, at the last minute of each stage, and at maximum workload were used to perform three types of linear regression (%HR_{peak} vs. %$\dot{V}O_{2peak}$, %HRR vs. %$\dot{V}O_{2peak}$, and %HRR vs. %$\dot{V}O_{2R}$) and to calculate the respective slopes, intercepts, and squared correlation coefficients. Mean slope and intercept were then calculated for the entire group. In addition, using each individual's equation for %HRR vs. %$\dot{V}O_{2peak}$, and %HRR vs. %$\dot{V}O_{2R}$, we calculated the mean %HRR values that would result from intensities prescribed at 35%, 45%, 55%, 65%, 75%, 85%, and 95% of %$\dot{V}O_{2peak}$ and %$\dot{V}O_{2R}$, respectively.

Statistical analysis

Data are presented as mean±standard deviation (SD) in the text and mean±standard error (SE) in the figures, unless otherwise stated. Paired samples t-tests were employed to determine whether the mean values for intercepts and slopes of the linear regressions of %HRR-%$\dot{V}O_{2peak}$ and %HRR-%$\dot{V}O_{2R}$ differed from 0 and 1, respectively (reflecting a difference from the line of identity). Also, paired t-tests were used to determine whether mean predicted values of %HRR were significantly different from the corresponding %$\dot{V}O_{2peak}$ and %$\dot{V}O_{2R}$ values. A p-level less than 0.05 was considered significant.

Results

A summary of the physical characteristics and physiological data of the subjects is shown in Table 1. Figure 1 illustrates the $\dot{V}O_2$ and HR responses during the continuous incremental exercise test for one subject.

The mean (±SD) values for intercept, slope, and Pearson's r correlation of the 13 %HR_{peak} versus %$\dot{V}O_{2peak}$ individual linear regressions and for the percentage of HR_{peak} obtained for

Table 1 Subjects' characteristics and physiological parameters obtained during the laboratory test (n=13).

Variables	Mean±SD
Age (yr)	24.9±3.6
Body mass (kg)	69.3±4.0
Height (cm)	172.9±5.0
Sum of 6 skinfolds (mm)*	47.1±11.2
$\dot{V}O_{2peak}$ (L·min^{-1})	3.4±0.3
$\dot{V}O_{2peak}$ (L·min^{-1}·kg^{-1})	49.0±5.3
HR_{max} (bpm)	179±12

* Sum of abdominal, suprailiac, triceps, subscapular, thigh, and medial calf skinfolds.
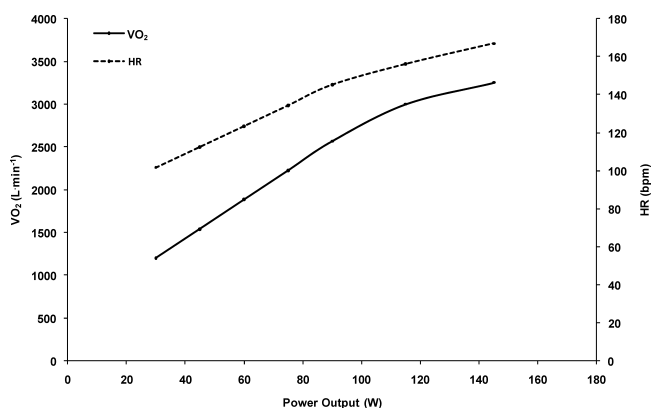

Fig. 1 Representative oxygen uptake ($\dot{V}O_2$) and heart rate (HR) data during the continuous incremental exercise test for one subject.

each subject at each selected percentage of $\dot{V}O_{2peak}$ are presented in Table 2. The %HR_{peak}-%$\dot{V}O_{2peak}$ HR_{peak}-$\dot{V}O_{2peak}$ relationship yielded the following equation: %HR_{peak}=0.65 (±0.11) %$\dot{V}O_{2peak}$+35.5 (±9.0); r=0.97 (±0.02).

The results of the regression equations of %HRR versus %$\dot{V}O_{2peak}$ and %HRR versus %$\dot{V}O_{2R}$ are shown in Table 3. Neither the regression for %HRR predicted from %$\dot{V}O_{2peak}$ nor the regression for %HRR predicted from %$\dot{V}O_{2R}$ coincides with the line of identity. The mean value of both equations' slope was significantly different from one ($p<0.05$), reflecting a difference with the line of identity. Further, the mean value of the intercept differed significantly from 0 ($p<0.001$) for the %HRR-%$\dot{V}O_{2R}$ regression but not for the %HRR-%$\dot{V}O_{2peak}$ regression ($p=0.94$). The resulting regression lines for the relationship between %HRR versus %$\dot{V}O_{2peak}$ and %HRR versus %$\dot{V}O_{2R}$ are displayed in Figs. 2 and 3 respectively. Average lines were calculated from the intercepts and slopes of each individual regression line.

Figure 4 shows the resultant (i.e., average of all subjects) %HRR based on exercise intensities computed at 35%, 45%, 55%, 65%, 75%, 85%, and 95% of %$\dot{V}O_{2peak}$ and %$\dot{V}O_{2R}$, respectively. Predicted values of %HRR were significantly higher ($p<0.05$) than the corresponding value for %$\dot{V}O_{2R}$ for all the intensities ranging from 35% to 95% of $\dot{V}O_{2R}$. On the other hand, predicted values of %HRR were significantly

Table 2 Linear regression equations (%HR$_{peak}$ versus %$\dot{V}$O$_{2peak}$) and predicted HR values at 35%, 45%, 55%, 65%, 75%, 85%, and 95% of %$\dot{V}$O$_{2peak}$ for each individual. $\dot{V}$O$_{2peak}$: peak oxygen uptake; HR$_{peak}$: peak exercise heart rate.

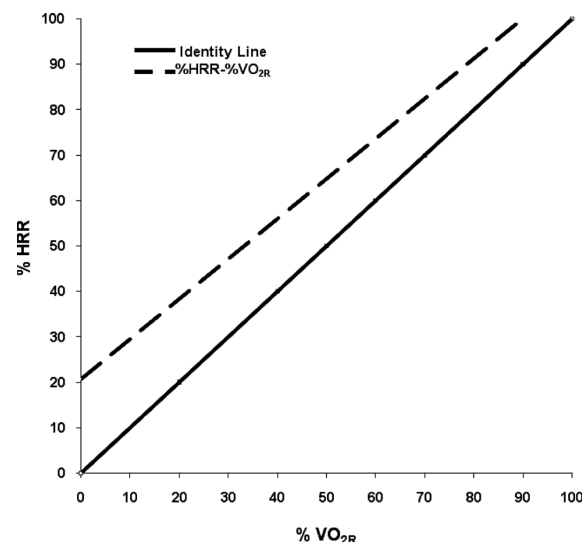| Participant	Intercept	Slope	Pearson's r	%HR$_{peak}$ at 35%$\dot{V}$O$_{2peak}$	%HR$_{peak}$ at 45%$\dot{V}$O$_{2peak}$	%HR$_{peak}$ at 55%$\dot{V}$O$_{2peak}$	%HR$_{peak}$ at 65%$\dot{V}$O$_{2peak}$	%HR$_{peak}$ at 75%$\dot{V}$O$_{2peak}$	%HR$_{peak}$ at 85%$\dot{V}$O$_{2peak}$	%HR$_{peak}$ at 95%$\dot{V}$O$_{2peak}$
1	24.6	0.81	0.90	53.1	61.2	69.3	77.4	85.6	93.7	101.8
2	38.3	0.59	0.91	58.8	64.6	70.5	76.4	82.2	88.1	93.9
3	37.5	0.67	0.96	61.1	67.9	74.6	81.4	88.1	94.9	101.6
4	27.5	0.80	0.97	55.4	63.3	71.3	79.2	87.2	95.2	103.1
5	48.7	0.47	0.97	65.2	69.9	74.6	79.4	84.1	88.8	93.5
6	39.8	0.59	0.99	60.5	66.4	72.3	78.2	84.1	90.0	95.9
7	38.2	0.65	0.96	60.9	67.4	73.9	80.4	86.9	93.4	99.9
8	21.2	0.80	0.99	49.1	57.1	65.1	73.1	81.0	89.0	97.0
9	39.3	0.63	0.99	61.3	67.6	73.8	80.1	86.4	92.7	99.0
10	31.9	0.67	0.99	55.4	62.1	68.8	75.5	82.3	89.0	95.7
11	24.8	0.75	0.96	51.0	58.5	66.0	73.5	81.0	88.4	95.9
12	40.3	0.59	0.99	60.9	66.8	72.7	78.6	84.5	90.4	96.3
13	49.8	0.51	0.99	67.5	72.6	77.7	82.8	87.8	92.9	98.0
Mean	35.5	0.65	0.97	58.5	65.0	71.6	78.1	84.7	91.3	97.8
SD	9.0	0.11	0.02	5.4	4.5	3.6	2.9	2.5	2.6	3.1

Table 3 Intercepts, slopes, and correlation coefficients of linear regression analyses for %HRR predicted from %$\dot{V}$O$_{2peak}$ and for %HRR predicted from %$\dot{V}$O$_{2R}$.

	Intercept	Slope	Correlation coefficient
%HRR vs. %$\dot{V}$O$_{2peak}$	-0.37 ± 5.56	1.09 ± 0.07**	0.97 ± 0.01
%HRR vs. %$\dot{V}$O$_{2R}$	20.82 ± 4.57*	0.88 ± 0.06**	0.97 ± 0.01

* Differs significantly from 0 ($p<0.05$) ** Differs significantly from 1 ($p<0.05$)
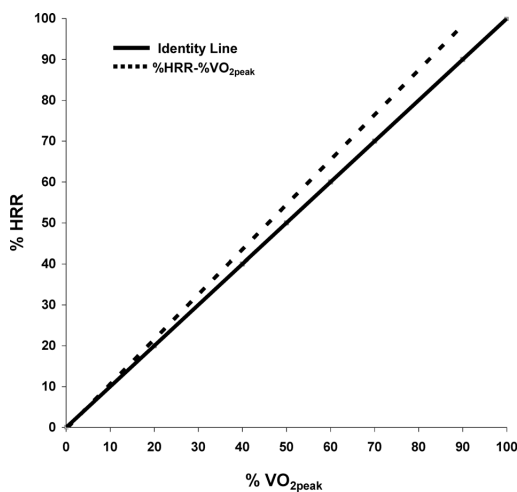
Fig. 2 Regression line illustrating the relationship between %HRR and %$\dot{V}$O$_{2peak}$. The regression line was the average of individual regression lines obtained from surfers during the incremental arm-paddling exercise test (n=13).

Fig. 3 Regression line illustrating the relationship between %HRR and %$\dot{V}$O$_{2R}$. The regression line was the average of individual regression lines obtained from surfers during the incremental arm-paddling exercise test (n=13).

Discussion

To the best of our knowledge, this is the first study to specifically test the relationship between %HRR, %$\dot{V}$O$_{2peak}$, and %$\dot{V}$O$_{2R}$ during prone upper-body exercise. The primary finding of the present investigation was that during arm-paddling exercise in well-trained competitive surfers the prediction of target %$\dot{V}$O$_2$ from %HRR was not accurate using either %$\dot{V}$O$_{2R}$ or %$\dot{V}$O$_{2peak}$. This finding is important because exercise intensities while paddling on the water are difficult to assess and HR monitoring might prove useful in this regard.

Previous studies examining the relationship between %HRR and %$\dot{V}$O$_{2R}$ have employed exercise protocols involving lower-
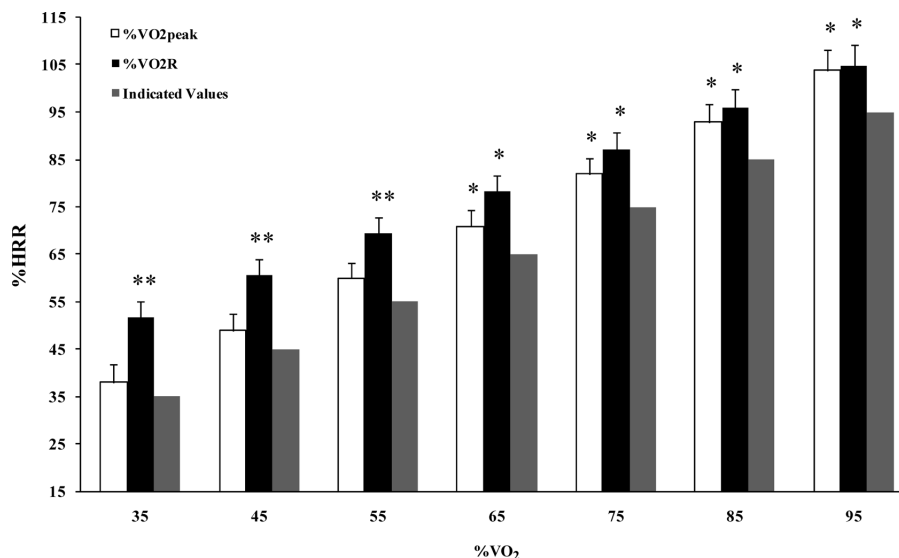
higher ($p<0.05$) than indicated values of %$\dot{V}$O$_{2peak}$ from 65 to 95% of %$\dot{V}$O$_{2peak}$. The disparity between %HRR and %$\dot{V}$O$_{2peak}$ was not significant at 35%, 45%, and 55% of $\dot{V}$O$_{2peak}$.

Fig. 4 Values of %HRR corresponding with indicated values of $\%\dot{V}O_{2R}$ and $\%\dot{V}O_{2peak}$. Significant differences between %HRR and the corresponding $\%\dot{V}O_{2R}$ or $\%\dot{V}O_{2peak}$ value: * $p < 0.05$; ** $p < 0.001$.

body, large muscle groups, such as cycling (Swain and Leutholtz, 1997) and running (Swain et al., 1998), in apparently healthy men and women, diabetic individuals (Colberg et al., 2003), elite cyclists (Lounana et al., 2007), obese subjects (Byrne and Hills, 2002), and heart-disease patients (Brawner et al., 2002). All demonstrated an equivalency between %HRR and $\%\dot{V}O_{2R}$ values. Therefore, this relationship has been recommended for exercise intensity prescription. However, Rotstein and Meckel (Rotstein and Meckel, 2000) found that the prediction of $\%\dot{V}O_{2R}$ from %HRR obtained during seated arm exercise was overestimated in untrained subjects. While this suggests a difference between upper- and lower-body exercise, it is important to note that the approach undertaken by Rotstein and Meckel (Rotstein and Meckel, 2000) to analyse the data may have led to some erroneous conclusions. In their study, regression analyses were performed using the %HRR as the independent variable. Subsequent prediction of the %HRR at given percentages of $\dot{V}O_{2R}$ using this regression equation is mathematically unsound. As with previous studies, using lower-body exercise modes (Brawner et al., 2002; Byrne and Hills, 2002; Swain and Leutholtz, 1997; Swain et al., 1998) we took the %HRR as the dependent variable with which to perform the linear regression analyses. Therefore, this is the first study investigating whether %HRR is equivalent to $\%\dot{V}O_{2peak}$ or $\%\dot{V}O_{2R}$ during upper-body exercise using this mathematical approach.

Our results showed that exercise intensity in terms of $\dot{V}O_2$ is underestimated using either the %HRR-$\%\dot{V}O_{2peak}$ or %HRR-$\%\dot{V}O_{2R}$ relationship obtained in trained surfers during prone arm-paddling exercise. Thus, our results demonstrate a discrepancy between %HRR and $\%\dot{V}O_{2R}$. The equivalency between %HRR and $\%\dot{V}O_{2R}$ was established by individual regression analysis, with the result that the %HRR-$\%\dot{V}O_{2R}$

relationship was significantly different than the line of identity in terms of slope and intercept. The discrepancy between the %HRR and $\%\dot{V}O_{2R}$ was also confirmed by the significantly higher predicted %HRR values resulting from exercise intensities prescribed at intensities ranging from 35% to 95% of $\%\dot{V}O_{2R}$ (see Fig. 4). These results are in agreement with other studies conducted with youth (Hui and Chan, 2006) and chronic heart failure patients (Mezzani et al., 2007), which also failed to demonstrate the equivalency of %HRR and $\%\dot{V}O_{2R}$. Thus, although the established guidelines support the use of %HRR in relation to $\%\dot{V}O_{2R}$, some exceptions with particular populations (Hui and Chan, 2006; Mezzani et al., 2007) and/or exercise modes need to be considered.

It has consistently been reported that the %HR at a given $\%\dot{V}O_2$ is higher during upper-body exercise than for lower-body exercise (Pendergast, 1989). At any given $\dot{V}O_2$, HR is approximately 20% higher during arm work than during leg exercise (Pendergast, 1989). Similarly, in the present study %HR$_{peak}$ was substantially higher than $\%\dot{V}O_{2peak}$ (see Table 2). Therefore, inaccuracy of exercise intensity prescription, based on either $\%\dot{V}O_{2peak}$ or $\%\dot{V}O_{2R}$, during arm exercise in the present study is likely to reflect the uniqueness in the hemodynamic responses, particularly HR kinetics, of this mode of exercise. In addition, higher levels of cardiovascular fitness in our subjects might also contribute to the disproportioned %HR-$\%\dot{V}O_2$ relationship. Well-trained individuals must attain a higher %HR$_{peak}$ to achieve a given $\%\dot{V}O_{2peak}$ as compared with untrained individuals (Franklin, 1989; Swain et al., 1994). This leftward shift in the %HR$_{peak}$-$\%\dot{V}O_{2peak}$ regression equation results in a higher %HR$_{peak}$ at a given $\%\dot{V}O_{2peak}$ in more conditioned subjects (Franklin, 1989; Swain et al., 1994). Therefore, both the nature of our exercise protocol (upper-body exercise) and the characteristics of our subjects (well-trained competitive surfers) are likely candidates

to impact the %HR$_{peak}$-%$\dot{V}O_{2peak}$ relationship, although previous studies have reached similar conclusions using lower-body exercise (i.e., cycling or running) with untrained populations (Pendergast, 1989; Swain et al., 1994).

One unique aspect of this study was that subjects carried out an incremental test adopting the prone position, while performing alternating arm-paddling exercise. This is an exercise mode that resembles the posture and arm actions of surfboard riding. There are few published data for prone arm exercise (Gergley et al., 1984; Swaine and Winter, 1999). Most studies have compared exercise responses using seated or standing arm cranking with a supine posture (Stenberg et al., 1967). Body position has been reported to alter hemodynamic and performance parameters in both arm and leg exercise (Pendergast et al., 1979; Stenberg et al., 1967). $\dot{V}O_{2peak}$ values during upper- and lower-body exercise have been found to be consistently lower in the horizontal posture (prone or supine) than in the erect (sitting or upright) posture (Holmer and Astrand, 1972; Pendergast et al., 1979). This occurs despite the fact that cardiac output is reported to be higher in the horizontal than in the erect posture for a given submaximal workload (Bevegard et al., 1966). During erect arm exercise (i.e., seated or standing up), stroke volume increases only slightly or not at all with $\dot{V}O_2$, contrary to the findings observed during leg exercise (Miles et al., 1989). Consequently, an increase in HR is expected to compensate for the smaller stroke volume to maintain the required cardiac output (Gonzalez-Alonso et al., 1999). However, in the horizontal posture (supine) no differences in the increase in stroke volume have been observed between different exercise types (i.e., arms vs. legs) (Bevegard et al., 1966). Thus, it is unlikely that an increase in HR is necessary to compensate for the smaller stroke volume required to maintain the desired cardiac output during the prone exercise mode employed in our study, as has been suggested to occur during seated/upright arm-cranking exercise (Sawka, 1986). Despite these findings, a steeper increase of HR and, therefore, a relatively higher HR at given $\dot{V}O_2$ during arm-horizontal exercise have been reported (Bevegard et al., 1966; Stenberg et al., 1967). This would suggest a unique HR kinetics during arm exercise regardless of posture, with higher HR values for arm exercise than for leg exercise at a given $\dot{V}O_2$.

Some possible additional mechanisms previously reported to induce elevated HR values during seated submaximal arm exercise are also likely to contribute to the higher HR values obtained in the present study using a prone arm-paddling exercise mode. Higher muscle tensions associated with exercise using a small muscle mass are likely to induce higher HR. Body position on the board and the specific limited-movement patterns of the arm and shoulders during arm-paddling exercise appear to solicit a smaller active muscle mass compared with leg exercise (Gergley et al., 1984). Intramuscular tension is also likely to be higher, and closer to mode-specific maximal isometric tensions, during arm exercise (Sawka et al., 1983). High muscle forces might lead to

restriction of muscle blood flow because the intramuscular pressure rises above perfusion pressure (Foster et al., 1999; Radegran, 1997). In fact, the blood flow would be constricted even at quite low force levels (10–15% of maximal dynamic force) and contractions of 70% of maximal voluntary force might cause a complete shutdown of the capillaries (Shephard et al., 1988). This in turn might induce a disproportionately higher HR at any given $\dot{V}O_2$ and, therefore, explain in part the overestimation in the prediction of %$\dot{V}O_{2R}$ and %$\dot{V}O_{2peak}$ from %HRR in the present study. Additionally, or alternatively, Cornett et al. (Cornett et al., 2000) found that the exercise pressor reflex (i.e., increase in blood pressure and HR) was heavily influenced by work intensity (% of maximal voluntary contraction) with greater arterial pressures and HR responses at higher tensions than at lower tensions; this effect was independent of blood flow. This may explain Fig. 2, where the %HRR-%$\dot{V}O_{2peak}$ regression line is represented. The values obtained for %HRR are higher than %$\dot{V}O_{2peak}$ at any exercise intensity but these differences increase as exercise intensity increases. Thus, high intramuscular tensions associated with our exercise protocol would have the potential for muscular ischemia and might lead to a disproportionate increase in HR relative to $\dot{V}O_2$ (Foster et al., 1999) and explain the discrepancies between %HRR and %$\dot{V}O_{2R}$ in the present study.

Another likely candidate to explain the somewhat high HR values for any given $\dot{V}O_2$ in the present study is the suggested great additional isometric component of neck, scapula, and high and low back area muscles to allow effective arm-stroke action during prone arm-paddling exercise. This additional isometric exercise component, carried out by trunk muscle, allowing body stabilization, is likely to be greater during arm exercise than during leg exercise (Sawka, 1986). Sustained static exercise has also been reported to elevate sympathetic activity (Kilbom and Persson, 1981). Moreover, a higher sympathetic outflow has been observed to occur with arm exercise (Bevegard et al., 1966). All these findings provide a rationale for the observation of a disproportionately HR compared to $\dot{V}O_2$ during prone arm-paddling exercise and, therefore, support the present study's findings reporting no equivalency between %HRR and %$\dot{V}O_{2R}$.

In conclusion, previous findings using lower-body exercise modes, in a variety of populations, have shown that %HRR is equivalent to %$\dot{V}O_{2R}$ and not to %$\dot{V}O_{2peak}$. However, the relationships of %HRR versus %$\dot{V}O_{2R}$ during prone upper-body exercise had not been described. Unlike results found for lower-body exercise, this study showed that the prediction of target %$\dot{V}O_2$ was not accurate using either %$\dot{V}O_{2peak}$ or %$\dot{V}O_{2R}$. These findings seem to reflect the well-known differences in the hemodynamic responses, particularly HR kinetics, between leg and arm exercise.

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