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The oxygen uptake-heart rate relationship in trained female wheelchair athletes

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Abstract—We examined the relationship between the percentage of peak heart rate (HR) and the percentage of peak oxygen uptake ($\dot{V}O_2$) during steady-rate incremental wheelchair propulsion in 10 trained female wheelchair athletes (WAs) to determine the appropriateness of using American College of Sports Medicine (ACSM) target HRs for training prescription. Oxygen uptake was calculated during each submaximal exercise stage, and HR was monitored continuously. Peak $\dot{V}O_2$ was determined with the use of a separate protocol. Linear regression equations of percentage of peak HR versus percentage of peak $\dot{V}O_2$ were measured for each participant. Subsequently, we calculated the percentage of peak HR values corresponding with 40%, 60%, 80%, and 85% peak $\dot{V}O_2$. The linear regression formula (derived as the group mean of the slope and intercept terms determined from each individual participant) was % peak HR = 0.652 × % peak $\dot{V}O_2$ + 35.2 (standard error of the estimate [SEE] 3.41). The group mean of the individual correlation coefficients for the $\dot{V}O_2$-HR relationship was $r = 0.973$. The percentage peaks of HRs for the WAs were slightly, though not significantly, greater than those suggested by the ACSM across the exercise intensity continuum. These findings suggest that training programs prescribed on the basis of ACSM target HR guidelines need not be altered for trained female WAs with lesions of T6 and below. Notably, the discrepancy between the WA values and the population norm (ACSM) decreased from 6% at 40% peak $\dot{V}O_2$ (i.e., 61% vs. 55%) to <1% at 85% peak $\dot{V}O_2$ (i.e., 90.6% vs. 90.0%). This discrepancy indicates a tendency for the use of percentage of HR peak at the lower exercise intensities to slightly underestimate the relative exercise intensity (i.e., percentage of peak $\dot{V}O_2$) in the WA population.

Key words: training prescription, wheelchair ergometry.

INTRODUCTION

During the last decade, heart rate (HR) monitors have become a widely used training aid for a variety of paralympic sports, and HR data based upon lactate and/or ventilatory threshold have become available within this population [1,2]. Although the training principles may be similar across many wheelchair sports, those employed by the able-bodied (AB) athlete may not be directly transferable to the wheelchair athlete (WA) [3,4]. WAs have a unique physiological response during upper-limb exercise, as a function of vascular insufficiency of the lower limbs and adrenergic dysfunction [4]. Consequently, it would not be surprising if coaches, who were unaware of the specific details of these physiological limitations, prescribed training programs based on HR that may not be entirely appropriate for some paralympic athletes.

Abbreviations: AB = able-bodied, ACSM = American College of Sports Medicine, HR = heart rate, RER = respiratory exchange ratio, SD = standard deviation, SEE = standard error of the estimate, SPSS = service provisioning system software, $\dot{V}O_2$ = oxygen uptake, WA = wheelchair athlete, WERG = wheelchair ergometer, WR = wheelchair racer.

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Previously, a comparison of regression slopes of percentage of peak heart rate (% peak HR) versus percentage of peak oxygen uptake (% peak $\dot{V}O_2$) between paraplegic and AB individuals revealed no differences [5]. These authors suggested that exercise training prescription guidelines recommended by the American College of Sports Medicine [6] could be adopted by paraplegics without modification. Whether or not this recommendation is applicable to male elite wheelchair racers (WRs) has been questioned [3]. The participants in Hooker's study were all considered to be either sedentary or minimally active, and not upper-body aerobically trained [5]. Furthermore, the test protocol was based on arm-crank ergometry with increases in intensity every minute. It is unlikely that the participants would have demonstrated anything even close to a physiological steady state in these short exercise stages, and it is doubtful whether the mode of exercise would reflect the physiological responses seen during wheelchair exercise.

We have recently reported that when WRs use the percentage of peak HR, training below 85 percent peak $\dot{V}O_2$ may not be at the intensity the ACSM general exercise guidelines suggest [3]. This finding is in contrast to Hooker et al. [5], who recommend that the ACSM guidelines are appropriate across the exercise intensity continuum for arm-crank exercise. Apparently, using the ACSM [6] guidelines below 85 percent peak HR might slightly underestimate the relative exercise intensity (% peak $\dot{V}O_2$) in this WR population. However, at the upper end of the exercise intensity continuum (i.e., 85% peak $\dot{V}O_2$), the continued use of percentage of peak HR as a proxy measure for percentage of peak $\dot{V}O_2$, as originally endorsed by the ACSM, was recommended in elite-level WRs.

Limited exercise prescription guidelines have been established for persons who perform wheelchair exercise, and the most recent work involving athletes was restricted to males [3]. To date, the relationship between HR and $\dot{V}O_2$ has not been evaluated in female WAs. Comparisons between male and female trained athletes with paraplegia indicate that the latter group has a lower peak $\dot{V}O_2$ [7]. These lower values may be due to a lower trained status prior to the injury and/or the lower percentage of lean body mass in females limiting the attainable peak $\dot{V}O_2$ [7]. Given the importance of training prescription and the increased popularity of females entering paralympic sports, it is important that we examine the HR-$\dot{V}O_2$ relationship in female trained athletes. Therefore in this study, we examined the HR-$\dot{V}O_2$ relationship in a group of trained female WAs to compare the percentage of peak $\dot{V}O_2$ and the percentage of peak HR values to those suggested by the ACSM [6].

METHODS

Participants

Ten trained female WAs (3 tennis, 5 racing, 1 basketball, and 1 water skiing) volunteered to participate in the study. All participants gave written informed consent prior to any involvement in the study. Approval for the study procedures was obtained from the University Research Ethics Committee. All the participants were considered trained if they competed regularly at a national level and were part of Great Britain squads in their respective sports. The participant disability and descriptive characteristics are presented in **Table 1**. The participants attended the laboratory regularly, which involved using a computerized wheelchair ergometer (WERG), and were familiar with the testing procedures used in this study. Body mass was measured to the nearest 0.1 kg with the use of a seated beam balance scale (Seca, Germany).

Instrumentation

We performed the testing using a WERG (Bromking, England, UK). The calibration procedure included a "deceleration test" performed when the participants were in an intermediate inclined position, as suggested by Theisen et al. [8]. The deceleration test ensured that the friction between the ergometer and the wheelchair tires simulated the resistance level of propulsion developed by the wheelchair manufacturers (Bromking, England, UK) and software manufacturers (KingCycle, England, UK). The WERG system allowed each participant to be tested in her own sports wheelchair.

The WERG consisted of a single cylinder (length, 1.17 m; circumference, 0.48 m). A flywheel sensor was linked to the roller and interfaced with a personal computer, which recorded the speed of the roller and calculated the power output. The participants' speed was determined by an electronic speedometer, which had been calibrated based on the diameter of the rear wheel. Continuous feedback from the speedometer and the power output display allowed the participants to maintain a constant speed at each successive exercise stage.

Table 1.
Participant disability and physiological characteristics (mean ± SD).

Participant	Disability	Sport/Classification	Age (yr)	Body Mass (kg)	Peak $\dot{V}O_2$ (L/min^1)	Peak HR (BPM^{-1})	Peak RER
1	T10 (inc)	Tennis-Open	22	43.0	1.10	190	1.29
2	T6 (inc)	Tennis-Open	31	59.8	1.92	191	1.24
3	L-1 (inc)	Tennis-Open	33	50.1	1.98	179	1.31
4	SB	Racing-PRC3	27	45.7	1.68	187	1.23
5	SB	Racing-PRC4	18	43.0	1.55	192	1.18
6	Amputee*	Racing-PRC4	31	68.6	2.52	169	1.17
7	SB	Racing-PRC3	30	37.6	1.20	182	1.16
8	L-4 (inc)	Racing-PRC4	39	67.5	1.90	175	1.29
9	T-9 (com)	Basketball-IWBF1.5	22	60.0	1.56	189	1.31
10	PMD	Water skiing-MP3	38	55.9	1.40	170	1.12
—	—	Mean	29	53.1	1.68	183	1.23
—	—	SD	7	10.8	0.40	9	0.10

*Single-leg above-knee amputee
BPM = beats per minute, com = complete, HR = heart rate, inc = incomplete, IWBF = International Wheelchair Basketball Federation, MP = motor potential, PMD = postmyelitis dystomia, PRC = Paralympic Racing Classification, RER = respiratory exchange ratio, SB = spina bifida, SD = standard deviation, T = thoracic, $\dot{V}O_2$ = oxygen uptake

Submaximal Exercise Protocol

Participants completed five to seven steady-state, submaximal exercise stages, each lasting 4 minutes on the WERG. Push speed was increased by 0.50 m/s^{-1} at the end of each submaximal exercise stage. The initial speed ranged from 1.8 m/s^{-1} to 3.8 m/s^{-1} based on each participant's performance in previous WERG tests performed in the same laboratory. The starting speed was slow in order to obtain a low relative exercise intensity (mean ± standard deviation [SD] starting intensity 32% ± 7% peak $\dot{V}O_2$) that could be used with the subsequent exercise stages to determine the $\dot{V}O_2$-HR relationship. Throughout the test, HR was monitored using short-range radio telemetry (PE4000 Polar Sport Tester, Kempele, Finland). Expired air was collected into Douglas bags during the final minute of each exercise stage. The concentration of oxygen and carbon dioxide in the expired air samples was determined with a paramagnetic oxygen analyzer (Series 1400, Servomex Ltd., Sussex, UK) and an infrared carbon dioxide analyzer (Series 1400, Servomex Ltd., Sussex, UK). Expired air volumes were measured with the use of a dry gas meter (Harvard Apparatus, Kent, UK) and corrected to standard temperature and pressure (dry). $\dot{V}O_2$, carbon dioxide output ($\dot{V}CO_2$), expired minute ventilation, and respiratory exchange ratio (RER) were calculated for each Douglas bag. The analyzers were calibrated with gases of known concentration before each test, and the linearity of the gas meter was checked using a 3 L calibration syringe.

Peak Oxygen Uptake (Peak $\dot{V}O_2$)

A 5-minute active recovery period followed the last submaximal exercise stage, and then peak $\dot{V}O_2$ was determined for each participant with the use of a continuous WERG test with 0.5 m/s^{-1} increments every minute until volitional exhaustion. The initial speed for each participant was based on the previous submaximal protocol and ranged from 3.13 m/s^{-1} to 7.15 m/s^{-1}. The mean (SD) time to complete this test was 9 min ± 1 min. HR was monitored continuously with the use of radio telemetry, and expired air samples were collected and analyzed with the use of the Douglas bag technique over the last two consecutive stages of the test. Peak HR was defined as the highest value recorded during this test. The criteria for a valid peak $\dot{V}O_2$ were a maximal RER value 1.10 and/or a peak HR 95 percent of age-predicted maximum (200 beats per minute^{-1} [BPM] – chronological age; [9]). All the participants satisfied these criteria.

Data Analyses

We obtained standard descriptive statistics (mean ± SD) for all variables measured using service provisioning system software (SPSS) 11.0 for Windows (SPSS, Chicago, IL). The $\dot{V}O_2$ and HR data at the end of the peak

$\dot{V}O_2$ test and each submaximal steady-state stage were expressed as percentages of their respective peak values. For each participant, we conducted a linear regression using the paired data points of percentage of peak $\dot{V}O_2$ and percentage of peak HR values. Data obtained at each completed submaximal exercise stage and peak values were included in the analyses. The percentage of peak $\dot{V}O_2$ values was included in the analyses as the independent variable. The data for the whole group were not pooled together for a single linear regression equation, because this would obscure statistically the individual relationships [10]. The mean (± SD) values for the intercept, slope, standard error of the estimate (SEE), and Pearson's *r* correlation are presented in **Table 2**. Using the individual linear regressions, we determined the peak HR corresponding to 40, 60, 80, and 85 percent of peak $\dot{V}O_2$ were determined for each of the WAs (**Table 2**). The mean percentage of peak HR data were then compared to those previously used by the ACSM (e.g., 55%, 70%, 85%, and 90%, respectively) with the use of a one-sample Student's *t*-test, with the ACSM value as the designated population norm (see **Figure**). The a priori significant alpha level chosen for all statistical tests was 0.05.

RESULTS

The means (± SD) of the 10 individual linear regression equations were used for the following prediction equation: % peak HR = (0.652 × % peak $\dot{V}O_2$) + 35.3. The group mean (± SD), Pearson product moment correlation coefficient of 0.973 (± 0.022), and the SEE of 3.409 (± 1.4) suggests that there was a strong linear fit between percentage of peak HR and percentage of peak $\dot{V}O_2$. The percentage of peak HRs for the WAs was higher, though not significantly, than those suggested by the ACSM across the exercise intensity continuum (**Figure**). The discrepancy between the WA values and the population norm (ACSM) decreased from 6 percentage points at 40 percent peak $\dot{V}O_2$ (61% vs. 55%) to less than 1 percentage point at 85 percent peak $\dot{V}O_2$ (90.6% vs. 90.1%). The small differences between the WA values and ACSM [6] guidelines tend to suggest that below 80 percent peak HR, the relative exercise intensity (% peak $\dot{V}O_2$) is slightly underestimated, with a better agreement of the percentage of HR attained by the WA above 80 percent peak HR. The individual alpha values are shown in the **Figure**.

DISCUSSION

We gleaned from this study that the $\dot{V}O_2$-HR relationship recommended by ACSM [6] for general (e.g., nonspecific exercise limb) exercise prescription does not need not to be altered for female WAs. However, despite the lack of significant findings, trends in the data do suggest that female WAs exercising below 80 percent peak $\dot{V}O_2$ would not be training at the specific intensity the ACSM general exercise guidelines suggest (see **Figure**).

Table 2.
Individual linear regression characteristics of wheelchair athletes (mean ± SD).

Participant	Slope	Intercept	SEE	Pearson's *r*	$\%HR_{peak}$ at 40% $\dot{V}O_2$	$\%HR_{peak}$ at 60% $\dot{V}O_2$	$\%HR_{peak}$ at 80% $\dot{V}O_2$	$\%HR_{peak}$ at 85% $\dot{V}O_2$
1	0.584	41.680	0.863	0.998	65.04	76.72	88.40	91.32
2	0.717	26.388	2.994	0.982	55.07	69.41	83.75	87.33
3	0.437	57.764	4.593	0.919	75.24	83.98	92.72	94.91
4	0.651	40.542	5.106	0.955	66.58	79.60	92.62	95.88
5	0.689	31.154	3.091	0.981	58.71	72.49	86.27	89.72
6	0.851	10.620	3.369	0.981	44.66	61.68	78.70	82.96
7	0.786	22.401	2.609	0.986	53.84	69.56	85.28	89.21
8	0.584	42.045	4.432	0.965	65.41	77.09	88.77	91.69
9	0.739	28.204	5.125	0.974	57.76	72.54	87.32	91.02
10	0.478	51.676	1.905	0.986	70.80	80.36	89.92	92.31
Mean	0.652	35.247	3.409	0.973	61.31	74.34	87.38	90.64
SD	0.132	14.177	1.412	0.022	9.03	6.53	4.21	3.70

HR = heart rate; SD = standard deviation; SEE = standard error of the estimate; $\dot{V}O_2$ = oxygen uptake

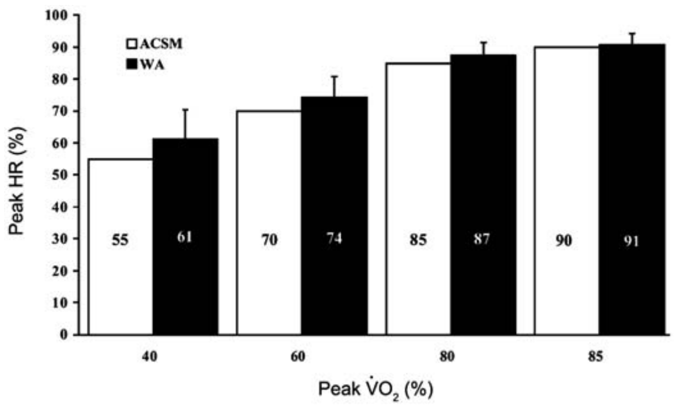

Figure.
Percentages of peak heart rate (HR) attained by wheelchair athletes (WAs) at indicated percentages of peak oxygen uptake ($\dot{V}O_2$).

This finding is in agreement with Tolfrey et al. [3], where the ACSM guidelines were found to be inappropriate for elite male WRs exercising below 85 percent peak $\dot{V}O_2$ for wheelchair propulsion exercise. According to the results of this study and our previous work [3], the $\dot{V}O_2$-HR relationship within trained participants competing in wheelchair sports is not influenced by sex.

The results of the current study indicate that the discrepancy between the WA values reported and the ACSM recommendation is still quite small, even below 80 percent peak $\dot{V}O_2$ (ranging from a 6% peak HR discrepancy at 40% peak $\dot{V}O_2$ to <1% at 85% peak $\dot{V}O_2$). Whether differences of this magnitude are meaningful for female WAs preparing for competition has to be carefully considered by athletes and coaches alike [3]. The participants in this study had a mean peak $\dot{V}O_2$ of 1.68 ± 0.40 L/min^{-1}, which ranged from 1.10 to 2.52 L/min^{-1}, demonstrating that these athletes were well conditioned [11–13]. However, the large within-group variance for aerobic conditioning may have influenced the results.

The average female WA peak $\dot{V}O_2$ was found to be lower than that of the elite male WR performing wheelchair propulsion (2.45 L/min^{-1}) in the study where direct comparisons of the slope between HR and $\dot{V}O_2$ can be made [3]. However for both studies, all the athletes satisfied the peak $\dot{V}O_2$ testing criteria by reaching a peak HR 95 percent of age-predicted maximum (200 BPM^{-1} – chronological age; [9]). In fact, the female WA group mean (± SD) peak HR of 183.0 ± 9.0 BPM^{-1} would suggest that HR was not impaired by abnormal autonomic cardiac regulation secondary to the nature of the disability [14], and that the peak HRs were comparable to those of AB runners at exhaustion [15], this was also evident for their male WR counterparts [3].

As implied by Tolfrey and coworkers [3], some authors have suggested that even in WAs where there is full sympathetic innervation of the heart, a lower-stroke volume is compensated for by a higher HR. This leads to a similar cardiac output for a given $\dot{V}O_2$ as AB participants [16,17]. It is possible that this statement, used to explain the elite male WR data, is also pertinent to help explain the female $\dot{V}O_2$-HR relationship, whether or not it pertains to exercise intensities below 85 percent or 80 percent peak $\dot{V}O_2$. It is possible that venous blood pooling may have been present at the lower exercise intensities and may have resulted in higher submaximal $\dot{V}O_2$-HR ratios for the paraplegics (male and females) when compared to the former AB guidelines [6].

CONCLUSION

In summary, the group of WAs in the present study exhibited physiological responses representative of a well-trained female population. The current study using female WAs and a previous study using male elite WRs [3] have found that use of the ACSM [6] guidelines below 80 percent peak HR for females (p = 0.07) and 85 percent peak HR for males ($p < 0.05$) may underestimate slightly the relative exercise intensity (% peak $\dot{V}O_2$). However, the current study found no significant differences between the regression slopes between the female WAs and the nonimpaired healthy subjects [6]. This may be due to the relatively high-functioning subjects with low lesions. Based on this evidence, coaches can continue to use the percentage of peak HR as a proxy measure for the percentage of peak $\dot{V}O_2$, as originally endorsed by the ACSM, to prescribe training for trained female WAs with lesion levels of T6 and below.

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