VersaClimbing elicits higher $\dot{V}O_{2max}$ than does treadmill running or rowing ergometry

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ABSTRACT

BRAHLER, C. J. and S. E. BLANK. VersaClimbing elicits higher $\dot{V}O_{2max}$ than does treadmill running or rowing ergometry. *Med. Sci. Sports Exerc.*, Vol. 27, No. 2, pp. 249–254, 1995. Collegiate varsity oarswomen and coxswain (N = 11) completed maximal aerobic exercise tests on a treadmill, a rowing ergometer, and a simulated climbing machine. Successful completion of each test was evidenced by a plateau in oxygen consumption in response to increasing work rates. $\dot{V}O_{2max}$ ($l \cdot min^{-1}$), and minute ventilation ($\dot{V}_E$, $l \cdot min^{-1}$) at $\dot{V}O_{2max}$ were significantly greater ($P < 0.05$) during simulated climbing compared to treadmill running and rowing ergometry. Maximal heart rate ($beats \cdot min^{-1}$) was significantly greater ($P < 0.05$) during climbing and running than during rowing. Findings indicate that progressive, incremental, whole-body climbing exercise elicits significantly greater $\dot{V}O_{2max}$ values for collegiate oarswomen and coxswain than does graded treadmill running or progressive rowing ergometry.

ROWING ERGOMETER, WHOLE-BODY EXERCISE, FEMALE ATHLETES, CRITERION $\dot{V}O_{2max}$

Every individual has a maximal rate of oxygen consumption that determines the capacity for aerobic energy transfer (24). This variable can be assessed during maximal exercise, but its rate varies for the same individual during different types of exercise (2,5,18,26). There is discrepancy in the literature regarding the mode of exercise that yields an individual's highest maximal oxygen uptake (5,13,18,19,26,32).

The amount of actively contracting skeletal muscle has a direct effect on $\dot{V}O_{2max}$ (17–19,26). For example, treadmill running on a grade elicits higher maximal oxygen uptake than does cycle ergometry (3,8,18,20,23,30), simultaneous arm and leg cranking exercise occasionally yields $\dot{V}O_{2max}$ values that are higher than treadmill values (5,13,32), and cross-country ski exercise by trained skiers often exceeds treadmill values (5,13,17,26,32). However, a critical muscle mass may be reached, beyond which $\dot{V}O_{2max}$ is independent (13,17,25,26,28,30), as may be evidenced when $\dot{V}O_{2max}$ values during simultaneous arm and leg exercise do not exceed those achieved during leg exercise only (3,25,28).

$\dot{V}O_{2max}$ can be negatively impacted if the mass of active muscle is too small, such as during arm work (2,6,22). When the work rate per square area of muscle is excessive, peripheral circulation may be impaired; local muscular fatigue may ensue (12,24). Upper-body-trained individuals may be able to complete more arm work compared to individuals who are not upper-body trained, which may enable them to achieve higher $\dot{V}O_{2max}$ during whole-body exercise compared to treadmill running (13,27).

For the present investigation, trained collegiate oarswomen and coxswain were selected to complete maximal exercise during rowing ergometry, simulated climbing, and treadmill running because 1) treadmill running is traditionally considered the activity that elicits the highest $\dot{V}O_{2max}$, 2) climbing and rowing are whole-body activities that allow subjects to employ greater amounts of upper-body involvement compared to treadmill running, and 3) the subjects were specifically trained to row. Subjects were selected because they comprised a group of female athletes that were engaged in the same training regimen. The hypothesis of the study was that maximal oxygen uptake would be greater during simulated climbing than during treadmill running or rowing ergometry.

METHODS

Subjects

Subjects gave written, informed consent, in accordance with the policy statements of the American College of Sports Medicine, prior to participation in this project. Subjects included members of the Washington State University women's varsity crew (N = 10, ages 21 ± 2.7 yr (mean ± SD)) and coxswain (N = 1, age 19 yr). Physical characteristics for the coxswain were greater than 2.0 SD from the mean values for crew, and are presented

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separately: height, 174.9 ± 5.58 cm, 154.3 cm; weight, 75.41 ± 7.59 kg, 50.47 kg for crew and coxswain, respectively. All subjects were whole-body trained athletes.

Practice Sessions and Test Procedures

Subjects completed five practice sessions to acclimate to laboratory procedures, equipment, and environment. Subjects were randomly assigned to six tests (replicates on the three exercise devices). Oxygen uptake values were averaged if two criterion $\dot{V}O_{2max}$ were achieved on one exercise device. Scores were not averaged if subjects failed to achieve criterion $\dot{V}O_{2max}$ in replicate; only criterion $\dot{V}O_{2max}$ values were used in the statistical analyses. Nine subjects achieved criterion $\dot{V}O_{2max}$ during running, rowing, and climbing exercise. One subject was unable to achieve criterion $\dot{V}O_{2max}$ during treadmill running, and one was unable to achieve criterion $\dot{V}O_{2max}$ during rowing ergometry. Tests were administered during a 1-month period of time to avoid a change in training status. Subjects completed a 15-min warm-up on a cycle ergometer or treadmill immediately prior to each test.

Simulated Climbing Tests

The CL-108PS Model VersaClimber (Heart Rate, Inc.) was used for climbing exercise; tests were conducted on the least-resistance setting (3,20). Continuous digital output was monitored for climbing speed (0–73.12 vertical $m \cdot min^{-1}$), total accumulated feet climbed, step height, and total accumulated exercise time. The handles of the climber were positioned at a level just below shoulder height to accommodate a recovery position during the descent phase of each arm stroke. Footstraps were fitted snugly to facilitate lower-body work. Subjects were advised to: 1) maintain a very loose hand grip, 2) allow the arms to relax at the lower phase of each stroke, 3) avoid a static ''squatting'' position during climbing, 4) complete full range-of-motion strokes on the VersaClimber (0.508 $m \cdot step^{-1}$), 5) avoid "hanging" on the arms, and 6) maintain full use of the lower body throughout the climbing bout.

VersaClimber exercise was conducted according to an original protocol, developed exclusively for the present study. It was continuous and consisted of 2-min work stages of 30.48, 36.58, 42.68, 48.77, and 54.87 $m \cdot min^{-1}$, followed by a 2-min supramaximal effort. Subjects completed the work stage that they perceived as very difficult (85–95% $\dot{V}O_{2max}$) and then progressed to a final climbing rate that was at least 3.048 $m \cdot min^{-1}$ greater than the immediately preceding climbing rate. The climbing rate for this final segment was self-determined by the athlete, who was instructed that the climbing rate should represent a supramaximal effort that may be sustained to $\dot{V}O_{2max}$. Subjects were verbally encouraged to maintain this rate for the final 2-min segment or until a plateau in oxygen uptake was achieved.

Treadmill and Rowing Exercise

Treadmill exercise was on a Quinton Model 18–60 treadmill, according to the Bruce Treadmill Protocol (5). Rowing exercise was conducted on a Concept II rowing ergometer, set on the small sprocket with vents in the closed position. The rowing protocol was original and was developed exclusively for the present study. It consisted of continuous, 2-min work stages at 100, 136, 194, 220, 250, and 290 W. Subjects completed the work stage that they perceived as very difficult (85–95% $\dot{V}O_{2max}$) and then progressed to a supramaximal work rate, which was self-determined and perceived as supramaximal. Rowers were verbally encouraged to maintain this rate for the entire 2-min segment or until a plateau in oxygen uptake was achieved. Watts were converted to 500-m-split times using the Concept II conversion calculator (10.0-, 9.0-, 8.0-, 7.67-, 7.33-, and 7.0-min-splits) and displayed with watts during testing for the subject's benefit.

The climbing and rowing protocols were appropriate for crew athletes because crew sport requires a supramaximal effort for the final 500 m of a high-intensity, 2000-m race. The Bruce Treadmill Protocol was appropriate because the women incorporate running hills and stairs into their workout program. Subjects were coached throughout the tests to maintain proper exercise form.

Heart Rates and Metabolic Data

Heart rates were monitored during exercise tests with chest electrodes in a CM5 arrangement. Digital display was provided by wrist monitors during running and rowing (Polar Pacer, Inc.) and modular display during climbing (Heart Rate, Inc.).

Metabolic determinations were made via open-circuit spirometry. Metabolic variables were calculated (Vista^{CX} Desktop Metabolic Measurement System and TurboFit software program (Vacumetrics, Inc.)), and displayed every 30 s (386e-S25 P.C. Partner XL (Leading Technology Inc.)). Calculated values for each test included oxygen consumption ($\dot{V}O_2$, $l \cdot min^{-1}$ and $ml \cdot kg^{-1} \cdot min^{-1}$), minute ventilation ($\dot{V}_E$, $l \cdot min^{-1}$), carbon dioxide production ($\dot{V}CO_2$, $l \cdot min^{-1}$), respiratory exchange ratio (RER), and ventilatory equivalent ($\dot{V}_E/\dot{V}O_2$).

Data Analyses

Statistical analyses were conducted using SAS/STAT (SAS Institute, Inc., Cary, NC). Mean differences for calculated values at $\dot{V}O_{2max}$ during climbing, running, and rowing exercises were compared using a randomized incomplete block design (block by subject, incomplete design because two subjects were not able to achieve criterion $\dot{V}O_{2max}$ on one exercise device each). Statistical significance was set at the $P < 0.05$ level. *Post hoc* tests

TABLE 1. Selected Physiological Variables at $\dot{V}O_{2max}$.

	VersaClimber	Treadmill	Rowing Ergometer
Heart rate (beats·min^{-1})	196 ± 0.9	195 ± 0.9	193 ± 0.9*
V_E (l·min^{-1})	153.70 ± 2.89	141.28 ± 3.11*	143.23 ± 3.11*
$\dot{V}CO_2$ (l·min^{-1})	3.89 ± 0.04	3.75 ± 0.04	3.60 ± 0.04
RER	1.03 ± 0.01	1.04 ± 0.02	1.02 ± 0.02

Values represent least square means ± SE.
* Significantly less than VersaClimber ($P < 0.05$).

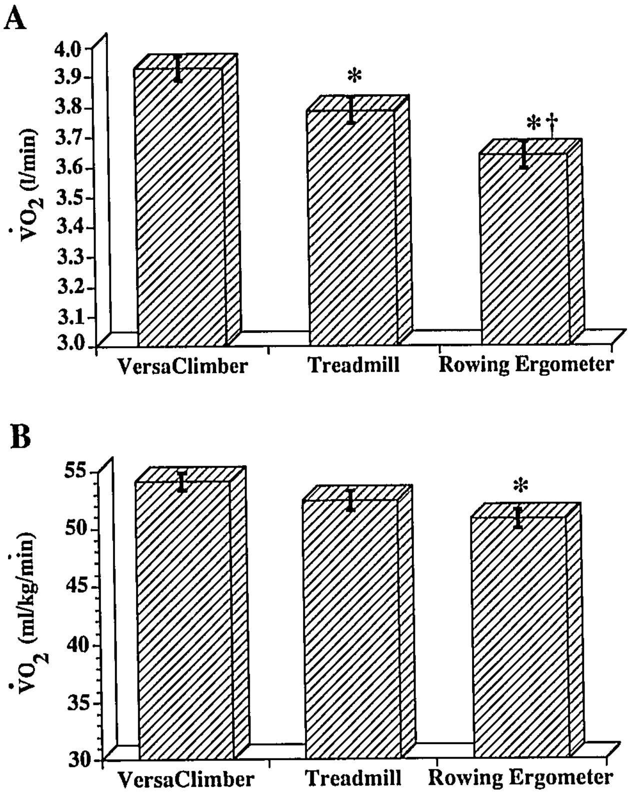

Figure 1—Maximal oxygen consumption during climbing *versus* treadmill exercise and rowing ergometry. Values represent means ± SEM. *Significantly less than VersaClimber ($P < 0.05$).

consisted of least square means (LSM), which is comparable to least square differences (LSD) but is for an incomplete dataset. The relation between subject body weights and various climbing rates during climbing exercise was determined by regression analysis.

RESULTS

Physiological variables measured at $\dot{V}O_{2max}$ were similar for crew and coxswain and are presented in Table 1. No significant differences existed between respiratory exchange ratio and $\dot{V}CO_2$ values that coincided with $\dot{V}O_{2max}$. LSM revealed that minute ventilation recorded at $\dot{V}O_{2max}$ was significantly greater during climbing than during running ($P = 0.009$), and during climbing than during rowing ($P = 0.0239$); maximal heart rate was

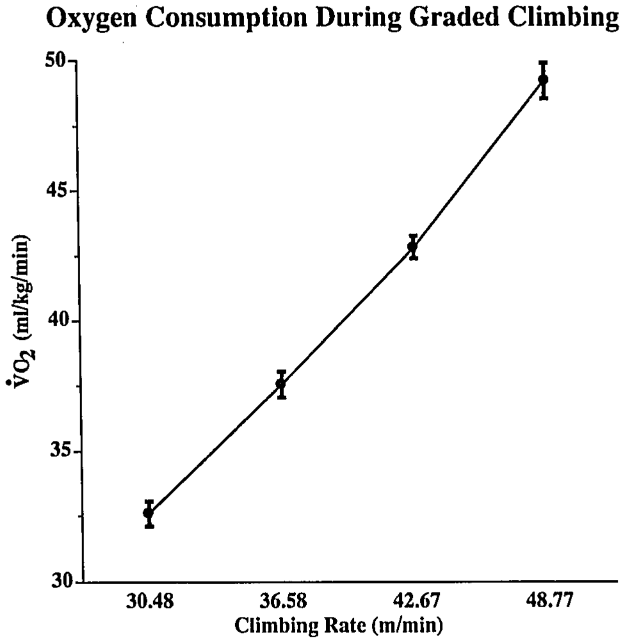

Figure 2—Oxygen consumption at progressive climbing rates. Values represent means ± SEM. ($r = 0.90$).

significantly greater at $\dot{V}O_{2max}$ during climbing compared to rowing ($P = 0.0121$).

Maximal oxygen consumption (l·min^{-1}) was significantly greater during climbing compared to running ($P = 0.0312$) and rowing exercises ($P = 0.0001$), and during running compared to rowing ($P = 0.0289$) (Fig. 1). $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1}) was significantly greater during climbing compared to rowing ($P = 0.0077$) but was not significantly different between climbing and running ($P = 0.1421$) or running and rowing ($P = 0.1752$). Oxygen consumption increased linearly with climbing rate and proportionally with the subject's body weight (Fig. 2). The O_2 cost (ml·kg^{-1}·min^{-1}) of climbing at a given rate was similar for all subjects ($r = 0.90$), which supports previous reports that simulated climbing exercise is a weight-dependent activity (4,24). A prediction equation was generated for energy expenditure during climbing exercise: $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) = (0.9086 × m climbed·min^{-1} + 5.3245); 2.52, standard error of the estimate ($P < 0.0001$).

DISCUSSION

The principal finding of this study was that $\dot{V}O_{2max}$ (l·min^{-1}) values were significantly greater during VersaClimber exercise compared to treadmill running or rowing ergometry. Treadmill running on a grade is generally accepted as the exercise that elicits an individual's highest maximal oxygen uptake (3,8,18,20,23,30). However, the addition of ski-poling to maximal uphill running elicits significantly greater $\dot{V}O_{2max}$ values compared to uphill running only (17). The level of skill required during exercise is an important factor that can influence $\dot{V}O_{2max}$ values, and although maximal cross-country skiing exercise may enable skilled skiers to attain higher $\dot{V}O_{2max}$ values compared to treadmill exercise, its application for $\dot{V}O_{2max}$ testing may be confined to skilled skiers. Simulated climbing, however, does not require a high degree of skill, and it is possible that optimal $\dot{V}O_{2max}$ values may be achieved by well-conditioned individuals during climbing exercise.

Although not selected specifically for their whole-body-trained status, the present subjects were trained collegiate oarswomen and coxswain, which is a factor that warrants consideration. VersaClimbing employs a greater amount of upper-body involvement during exercise compared to running only, which may prove advantageous for upper-body-trained oarswomen and coxswain during climbing exercise. However, it is reasonable to assume that if upper-body training were the only reason subjects generated greater $\dot{V}O_{2max}$ values during climbing compared to running, $\dot{V}O_{2max}$ values should have been greater during rowing exercise as well, because rowing relies heavily upon upper-body strength. Trained male rowers generate $\dot{V}O_{2max}$ values during rowing ergometry that are 100–115% of treadmill $\dot{V}O_{2max}$ values (2). However, an individual may require significant upper-body strength to exceed treadmill $\dot{V}O_{2max}$ values during rowing ergometry (15). A known physiological difference between males and females is that males can, on the average, develop greater upper-body strength compared to females (33). Women rowers do not develop as much upper-body strength as men rowers (16), and trained women rowers generate significantly lower $\dot{V}O_{2max}$ values during rowing ergometry than during cycle ergometry (21).

Because upper-body strength may not solely account for the higher $\dot{V}O_{2max}$ values during climbing, compared to running or rowing, several additional explanations can be advanced. It is assumed that muscle mass recruitment during climbing exercise was maximized because the maximal stepping height on the VersaClimber is 0.508 m and was fully executed. Another advantage of a 0.508-m stepping height is that it facilitates a reduced climbing frequency (cycles per minute, cpm) for a given climbing rate. During cycle ergometry, a pedaling frequency of 60 revolutions$\cdot$min^{-1} is optimal for $\dot{V}O_{2max}$ testing (18). It is interesting to note that subjects reached $\dot{V}O_{2max}$ at climbing rates between 54.87 and 60.96 m$\cdot$min^{-1}, which equates to climbing frequencies from 54 to 60 cpm. This range may be optimal for measuring $\dot{V}O_{2max}$ during climbing exercise. In support of this postulate, others have observed an inverse relation between stepping frequency and $\dot{V}O_{2max}$ during laddermill climbing (19) and bench-stepping exercise (29). It is possible that weight bearing could contribute to the differences in oxygen uptake between rowing and the other two exercises; however, this cannot explain the higher $\dot{V}O_{2max}$ values during VersaClimbing exercise compared to treadmill running. Full range-of-motion climbing exercise, via maximal step height, may have optimized $\dot{V}O_{2max}$ by increasing active muscle mass (17–19,26) and optimizing climbing frequency.

Optimal time to assess $\dot{V}O_{2max}$ is 8–10 min (3,8), partly because severe exercise is difficult to sustain during conditions of metabolic acidosis that may ensue (11,12,14). The climbing rate used increased by 6.1 m every 2 min to a climbing rate that the subject perceived as very difficult. The subject then proceeded to a final climbing rate that was self-determined to be supramaximal but could be sustained to $\dot{V}O_{2max}$. The final work rate was an average of 3.048–6.096 m$\cdot$min^{-1} greater than the immediately preceding work rate. Subjects achieved $\dot{V}O_{2max}$ in an average of 8.25 ± 0.32 min. The rapidly progressing $\dot{V}O_{2max}$ protocols used in the present study presumably enabled subjects to elicit $\dot{V}O_{2max}$ before local muscle fatigue limited exercise.

In the only published report, by Ballor et al. (4), comparing physiological responses to VersaClimbing exercise, treadmill running, and cycle ergometry, young male subjects achieved significantly greater $\dot{V}O_{2max}$ values during treadmill running compared to cycle ergometry and VersaClimbing (4). Numerous differences between the previous and present studies may explain the discrepant results. The male subjects maintained a 0.381-m stepping height, which may have limited the mass of actively contracting muscle compared to a 0.508-m stepping height, and which may equate to a faster stepping frequency than is optimal for maximal climbing exercise. The Ballor protocol required incremental increases of 9.144 m$\cdot$min^{-1} during exercise (4), and average exercise time to volitional exhaustion was approximately 15–18 min. It is possible that these factors diminished the subject's ability to elicit $\dot{V}O_{2max}$ values during climbing exercise that were higher than values achieved during treadmill running or cycle ergometry. Whether gender affects $\dot{V}O_{2max}$ during climbing exercise remains speculative and cannot be determined until males follow a protocol similar to the one described here.

$\dot{V}O_{2max}$ (ml$\cdot$kg$^{-1}\cdot$min^{-1}) was not significantly different between VersaClimbing and treadmill running, or rowing ergometry and treadmill running. Assessment of $\dot{V}O_{2max}$ (ml$\cdot$kg$^{-1}\cdot$min^{-1}) inherently introduces the variability of a ratio ($\dot{V}O_{2max}$(ml$\cdot$min^{-1})/body weight (kg)) into the statistical analysis. Because the variability in the ratio (denominator term) was larger than the variability in $\dot{V}O_{2max}$ (l$\cdot$min^{-1}) (numerator term), the power of the test comparing treatment means was smaller for $\dot{V}O_{2max}$ (ml$\cdot$kg$^{-1}\cdot$min^{-1}) compared to $\dot{V}O_{2max}$ (l$\cdot$min^{-1}) for all exercise modes (10). Statistical significance was protected when the variability in $\dot{V}O_{2max}$ (l$\cdot$min^{-1}) was large enough to compensate for the variability in the ratio

($\dot{V}O_{2max}$(ml·min^{-1})/body weight (kg)) and explains the ability to preserve statistical significance between climbing and rowing, but not between rowing and running, and climbing and running exercises. Similar results were obtained with or without the inclusion of data obtained from the coxswain.

Other physiological variables recorded at $\dot{V}O_{2max}$ included minute ventilation and heart rate response. Average $\dot{V}_E$ (l·min^{-1}) was significantly greater during climbing exercise compared to treadmill running and rowing exercise. The lower ventilatory rates associated with rowing$_{max}$ may indicate a specific training response for the trained rowers (1,19), and minute ventilation may be limited during rowing by the cramped body position assumed during the activity (15,21). Mean heart rate was significantly greater during climbing and running compared to rowing. Heart rate must increase to enhance blood flow and perfusion of arm muscles held overhead against the force of gravity (3) during climbing exercise. Higher heart rates and minute ventilation during maximal climbing exercise may reflect the significantly greater maximal oxygen uptakes achieved during that activity.

In summary, the present climbing protocol is the first to optimize a climbing technique that enables the completion of maximal climbing exercise in trained female rowers and coxswain athletes. It is possible that the greater $\dot{V}O_{2max}$ values achieved during climbing compared to running were influenced by selecting whole-body-trained subjects. However, this selective training did not enable the athletes to achieve superior $\dot{V}O_{2max}$ values during rowing ergometry. Maximal oxygen uptake was greater during climbing exercise than during treadmill running and rowing ergometry, which may reflect a combination of good climbing technique and a well-designed climbing protocol that achieves an optimal counterbalance between stepping frequency and stepping height during progressive climbing exercise. Thus, using the protocol described herein, VersaClimber exercise elicits higher $\dot{V}O_{2max}$ values in oarswomen and coxswain compared to treadmill running or rowing ergometry.

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