Journal of Strength and Conditioning Research, 2004, 18(4), 810–815

Comparison of the Wingate and Bosco Anaerobic Tests

William A. Sands,[1] Jeni R. McNeal,[2] Marshall T. Ochi,[2] Terri L. Urbanek,[3] Monem Jemni,[4] and Michael H. Stone[1]

[1]U.S. Olympic Committee, Colorado Springs, Colorado 80909; [2]Department of Physical Education, Health, & Recreation, Eastern Washington University, Cheney, Washington 99004; [3]Lake Placid Olympic Training Center, Lake Placid, New York 12946; [4]School of Education and Professional Development, Leeds Metropolitan University, Leeds, United Kingdom.

Abstract. Sands, W.A., J.R. McNeal, M.T. Ochi, T.L. Urbanek, N. Jemni, and M.H. Stone. Comparison of the Wingate and Bosco anaerobic tests. *J. Strength Cond. Res. 18(4):000–000. 2004.*—The purpose of this study was to compare the Wingate cycling and Bosco repeated jumps anaerobic tests. Eleven men (21.36 ± 1.6 years; 179.1 ± 9.3 cm; 78.7 ± 11.0 kg) and 9 women (21.89 ± 3.66 years; 171.8 ± 10.0 cm; 75.9 ± 21.4 kg), all university athletes, volunteered to participate. Subjects performed each test in random order. The tests consisted of a 30-second Wingate test and a 60-second Bosco test. The Wingate test was conducted using a Monark cycle ergometer and the Bosco test was conducted on a force platform. Following the performance of each test, peak lactate concentrations were determined. Average and peak power values were statistically greater in men and on the Bosco test. Peak lactate values were statistically greater in men but did not differ based on test. Correlations between peak lactate concentrations between tests and lactate values with peak or average power were not statistically significant. The relationship between peak power between tests was statistically significant among men, but not women. The results of the study indicated that the Bosco and Wingate tests, which both measure anaerobic characteristics, appear to measure different aspects of anaerobic power and capacity. The Bosco test also may be inappropriate for athletes who are not well trained in jumping.

Key Words. Wingate, repeated jump test, anaerobic

Introduction

Tests of anaerobic power and capacity are important to modern sport. However, a consensus "gold standard" test of anaerobic power and capacity has eluded sport science (1, 21). The Wingate and Bosco tests are considered tests of anaerobic metabolism (1, 4, 7, 17, 28). However, within the conceptual structure of anaerobic metabolic processes are several interacting components. These subcomponents have been described as power, capacity, and duration (9, 13, 40). Duration characteristics of anaerobic tests have been divided somewhat arbitrarily into short-term (lasting about 10 seconds), intermediate-term (lasting about 30 seconds), and long-term (lasting about 90 seconds) (9). Within this framework, a number of tests have targeted different aspects of relatively short duration and relatively high intensity activities. Investigators have shown, via factor analysis and other methods, that different anaerobic tests appear to measure different characteristics within the concept of anaerobic power and capacity (24, 25).

Anaerobic power and capacity tests have been dominated largely by the Wingate test (17), various short-duration power tests such as vertical jump tests (14, 36, 37) and the Margaria test (26, 40, 41). In 1983, Bosco and colleagues (6–8) reported a new test of anaerobic power that involved repeated jumping from a surface with a timing interface that recorded time in the air for each jump. The uniqueness of the Bosco test lies in the test's relatively large involvement of the stretch-shortening cycle (SSC) action of the lower extremity, repeated over a relatively long duration. Although single effort vertical jump tests and the Margaria test involve SSC actions, these tests do not include a duration component beyond 2–3 seconds. The Wingate test can assess short-term fatigue on power production due to its 30-second duration; the Wingate test, however, is dominated by concentric actions of the lower extremity muscles. "The Wingate cycle ergometer test is a widely used test of sustained muscular power. A limitation of the test is the lack of development and retrieval of stored elastic energy due to a lack of an eccentric phase" (22).

The Bosco test is attractive for activities that involve repeated use of the stretch-shortening cycle in jumping motions of the lower extremity. For example, the Bosco test was a sensitive measure of anaerobic power and capacity changes during the 7 months leading to the women's Olympic Gymnastics Trials and was a predictive factor in the team that was selected participate in the Sydney Olympic Games (31, 33, 34).

The Bosco test has not received the same degree of scientific scrutiny as the Wingate test. "The Wingate test has been evaluated more extensively than any other anaerobic performance test, in both able-bodied participants and disabled populations, and found to be highly reliable and valid" (2). Due to the Bosco test's attractiveness for SSC-type sports, the Bosco test merits detailed analyses in a variety of settings, with participants of varying backgrounds and training histories. The purpose of this study was to compare and contrast the Wingate and Bosco anaerobic tests among a group of university athletes.

Methods

Experimental Approach to the Problem

This study attempted to compare the Wingate and Bosco anaerobic power and capacity tests using a convenience sample of university athletes. Because the Wingate test is a widely accepted test of anaerobic characteristics, one measure of the validity of the Bosco test as a measure of anaerobic power and capacity is to compare it with the Wingate test. Peak and average power were compared to determine if the tests were measuring similar characteristics of anaerobic performance. Peak blood lactates, as a blood-borne product of anaerobic energy processes, were compared to determine if the tests resulted in similar anaerobic energy demands. Correlations were also calculated to determine if someone who performed well on one test, also performed well on the other test. We hypothesized that: (a) the Bosco test would be superior in power expression, due in part to the Bosco test's use of the SSC; (b) the tests would not differ in peak lactates, because the tests would both tax anaerobic energy processes; and (c) the tests would be only modestly correlated, because the 2 tests share similar anaerobic energy production, but do not share the same muscle tension dominance or mechanical characteristics. Finally, validation is a process rather than an outcome. This study is one of very few comparing the Bosco test with another anaerobic test. As such, the results of this study merely add to the convergence of evidence that will ultimately lend confidence to judgments regarding the anaerobic nature of the Bosco test.

Subjects

Nine women (21.89 $\pm$ 3.66 years; 171.8 $\pm$ 10.0 cm; 75.9 $\pm$ 21.4 kg) and eleven men (21.36 $\pm$ 1.6 years; 179.1 $\pm$ 9.3 cm; 78.7 $\pm$ 11.0 kg) volunteered to participate in this study. Research was conducted with approval of the Institutional Review Board of Eastern Washington University. The subjects who volunteered were predominantly from track and field. Their individual training histories included mostly sprinters and middle-distance runners among the men, and field event jumpers and throwers among the women. The study was conducted over the summer, and the athletes were in an off-season training period.

Instrumentation

The Wingate test was performed on a Monark cycle ergometer (Model 818E, Varberg, Sweden). Flywheel revolutions were measured using an optical sensor detecting 16 evenly spaced reflective markers. The optical sensor was interfaced to a computer using SportsMedicine Industries software (SMI, St. Cloud, MN, v.3.02). Jumping performance of the Bosco test was conducted on a 1-dimensional force platform (23). The force platform (67.5 cm $\times$ 67.5 cm) was surrounded by a wood platform of equal height with 20.3-cm width for safety in the event of a fall or misstep during jumping. The force platform was interfaced to a laptop computer via analog to digital conversion and Noraxon Myosoft Software (Version 1.06.1, Scottsdale, AZ), sampling at 500 Hz. Lactate measurements were performed using the Accusport Portable Lactate Analyzer (Sports Resource Group, Boehringer Mannheim, Indianapolis, IN), following the instructions of the manufacturer.

Procedures

Participants were randomly assigned to 1 of 2 test groups based on the order of tests (Wingate vs. Bosco). All tests were conducted with a minimum of 24 hours between tests. Upon arrival for testing, participants read, discussed, and signed the experimental protocol human consent form. Then participants were queried for age and measured for mass and height. Following initial measurements, a resting blood sample was taken to determine resting lactate levels. Following the initial blood sample, the participants performed a self-selected warm up of at least 10 minutes that would prepare them for maximal effort. All participants were university athletes and familiar with their preferred warm-up exercises and sequence. Following the warm-up, participants prepared for the specific tests.

The 30-second Wingate test was performed according to procedures described earlier (1, 3). The Wingate test was administered for 30 seconds and resistance was set at 7.5% of body mass (1). Participants were seated on the Monark ergometer and adjustments to the ergometer were made to ensure an optimal riding position. The conduct of the test was partially controlled by software with a 10-second countdown prior to test initiation and subsequent data collection. Rapid adjustment of flywheel tension was performed by one of the investigators such that required tension was achieved at the start of the 30-second test. Participants were encouraged to pedal as fast as they could prior to the application of resistance. Following application of resistance, the participants attempted to pedal at maximum speed throughout the remaining 30 seconds. Verbal encouragement was provided by the investigators. Software recorded the effort of the participant each second of the exercise task. Test-retest reliability values (r) for the Wingate test have varied from 0.89 to 0.99 (17).

The Bosco test was conducted on a large, square, 1-dimensional force platform (23). Participants were instructed to perform continuous rapid jumps of maximum effort for the entire 60-second duration of the test. Participants were instructed to lower to approximately 90° of knee flexion during the transition from one jump to the next. Participants were placed in the knee-flexed position prior to testing to familiarize them with the squat-depth required. During the test, an investigator watched the knee angle and instructed the athlete to increase or decrease the depth of knee flexion as the test effort proceeded. Participants were required to keep their hands on their waists throughout the test to minimize contribution of the upper body to the test performance. Verbal encouragement was provided by the investigators. The 60-second duration for the Bosco test was chosen based on previous experience which showed that total ground contact time was approximately 30 seconds, roughly approximating the duration of muscle tension in the Wingate test (31–33, 35). Reliability of the Bosco test has been reported at $r = 0.95$ (7). In a previous unrelated study (31), test-retest reliability of Bosco tests performed 1 month apart among athletes preparing for the Sydney Olympic Games resulted in an intraclass correlation of $\alpha = 0.87$.

Finger-prick blood samples were obtained from each participant following the Wingate and Bosco tests to obtain a peak lactate concentration. Samples were taken until a reduction in lactate concentration was observed when compared with a previous sample. Samples were taken following exercise at 3, 5, 7, 9, and 11 minutes, as needed, to obtain the peak lactate concentration (11, 13, 29).

Statistical Analyses

Participants were randomly assigned to an initial test group. Data were then analyzed via descriptive statistics, 2×2 and $2 \times 2 \times 6$ ANOVAs (sex by test, and sex by test by exercise interval) with repeated measures on test

TABLE 1. Average power values for each test and sex.

	Bosco test		Wingate test	
	Women ($n = 9$)	Men ($n = 11$)	Women ($n = 9$)	Men ($n = 11$)
W·kg^{-1}	12.19	17.81	7.93	8.86
SD	2.39	2.73	1.59	1.09
Watts	922.53	1,383.99	531.11	690.27
SD	339.42	172.45	116.47	77.28
Allometric	50.23	74.76	29.38	37.22
SD	11.06	9.58	2.66	3.75

TABLE 2. Peak power values for each test and sex.

	Bosco test		Wingate test	
	Female ($n = 9$)	Male ($n = 11$)	Female ($n = 9$)	Male ($n = 11$)
W·kg^{-1}	19.21	23.65	9.03	12.62
SD	6.87	3.08	1.57	1.61
Watts	1,531.76	1,845.71	746.67	984.82
SD	1,001.73	249.09	220.36	133.05
Allometric	80.80	99.42	40.72	53.04
SD	35.91	11.30	5.57	6.11

and exercise interval, and Pearson product moment correlation coefficients. Analysis of exercise intervals was performed by dividing the entire duration of the test into 6 exercise intervals of 5 seconds in the Wingate test and 10 seconds in the Bosco test (1, 6, 7, 17). Type I error was estimated by the Dunn-Sidak method (30, 38), and statistical significance was set at $p \leq 0.01$. All ANOVA calculations showed statistically significant Mauchly's Test of Sphericity. As a result, the Greenhouse-Geisser adjustments provided by the SPSS (Statistical Program for the Social Sciences, Version 10.0.1, SPSS, Inc., Chicago, IL) were used to interpret the results of the statistical analyses (16, 39). Statistical effect size estimates (η^2) and statistical power values (P_s) were obtained from the SPSS statistics software (Version 10.0.1, Chicago, IL), and via Cohen (10). Power data were analyzed in absolute, relative to body mass (W·kg^{-1}), and via allometric scaling of body mass (W·kg$^{-0.67}$) (19).

RESULTS

Power Assessments

The results of this study (Table 1) showed that average power (W·kg^{-1}) was statistically different by sex ($p < 0.001$, $\eta^2 = 0.53$, $P_s = 1.0$), test type ($p < 0.001$, $\eta^2 = 0.89$, $P_s = 1.0$), and the sex by test type interaction ($p < 0.001$, $\eta^2 = 0.50$, $P_s = 0.98$). Average absolute power (W) analysis showed a similar pattern (sex: $p = 0.001$, $\eta^2 = 0.97$, $P_s = 0.97$; test: $p < 0.001$, $\eta^2 = 0.91$, $P_s = 1.0$; sex × test: $p = 0.002$, $\eta^2 = 0.42$, $P_s = 0.93$), as did average allometrically scaled power (sex: $p < 0.001$, $\eta^2 = 0.64$, $P_s = 1.0$; test: $p < 0.001$, $\eta^2 = 0.93$, $P_s = 1.0$; sex × test: $p < 0.001$, $\eta^2 = 0.52$, $P_s = 0.99$) Peak power values were calculated from values obtained over 5-second intervals in the Wingate test and 10-second intervals in the Bosco test (Table 2). The average power (W·kg^{-1}) results showed statistically significant differences by sex ($p = 0.008$, $\eta^2 = 0.33$, $P_s = 0.80$) and by test ($p < 0.001$, $\eta^2 = 0.85$, $P_s = 1.0$). The test by sex interaction did not reach statistical significance ($p = 0.17$, $\eta^2 = 0.01$, $P_s = 0.07$). A similar pattern was observed for absolute peak power (sex: $p = 0.008$, $\eta^2 = 0.33$, $P_s = 0.80$; test: $p < 0.001$, $\eta^2 = 0.85$, $P_s = 1.0$; sex × test: $p < 0.684$, $\eta^2 = 0.01$, $P_s = 0.07$). Analysis of the allometrically scaled peak power showed a different pattern, with sex and the sex by test interaction failing to reach statistical significance, although test remained statistically different (sex: $p = 0.025$, $\eta^2 = 0.25$, $P_s = 0.64$; test: $p < 0.001$, $\eta^2 = 0.79$, $P_s = 1.0$; sex × test: $p < 0.562$, $\eta^2 = 0.02$, $P_s = 0.09$). This information supported our first hypothesis, that the tests would differ in average and peak power. Allometric scaling resulted in a different relationship in peak power due to sex.

TABLE 3. Work interval power values for each work interval, test, and sex.

		Bosco test		Wingate test	
	Exercise interval	Women ($n = 9$)	Men ($n = 11$)	Women ($n = 9$)	Men ($n = 11$)
W·kg^{-1}	1	18.79	22.87	9.81	12.54
		7.23	3.85	0.99	1.78
	2	16.08	21.42	8.33	10.82
		2.29	3.87	0.95	1.62
	3	13.44	19.57	7.19	9.01
		2.51	3.29	1.11	1.34
	4	11.63	17.07	6.37	7.71
		2.84	3.43	0.95	0.97
	5	9.75	14.46	5.79	6.90
		1.75	3.02	0.93	0.80
	6	7.67	11.08	5.33	6.18
		1.75	1.94	1.03	0.67
Watts	1	1,498.39	1,783.30	745.82	976.82
		1,017.71	303.10	221.12	136.69
	2	1,222.43	1,666.33	624.91	844.60
		411.40	286.83	161.69	129.82
	3	993.54	1,520.59	532.67	701.51
		235.57	213.55	119.63	92.35
	4	853.88	1,326.92	468.84	600.33
		219.45	244.42	85.32	61.47
	5	716.31	1,121.20	425.04	536.64
		144.08	191.80	75.41	47.09
	6	552.45	858.61	388.78	481.40
		69.71	107.98	67.10	45.05
Allometric	1	73.03	96.09	40.67	52.67
		37.15	14.80	5.63	6.76
	2	66.62	89.94	34.36	45.48
		11.60	14.78	4.05	6.23
	3	55.19	82.13	29.55	37.84
		9.09	11.78	3.71	4.80
	4	47.64	71.66	26.12	32.40
		9.98	13.12	2.55	3.16
	5	39.95	60.66	23.72	28.97
		5.31	11.27	2.55	2.40
	6	31.25	46.48	21.80	25.97
		5.10	6.80	3.04	2.08

The Wingate and Bosco tests' relative power values were averaged across 5- and 10-second intervals to examine power production over shorter and regular intervals of the tests, respectively. The results of the exercise intervals data reductions are shown in Table 3. Work interval power values (W·kg^{-1}) analyses resulted in statistical differences due to sex ($p < 0.001$, $\eta^2 = 0.52$, $P_s = 0.97$), test ($p < 0.001$, $\eta^2 = 0.93$, $P_s = 1.0$), exercise interval ($p < 0.001$, $\eta^2 = 0.86$, $P_s = 1.0$), test by sex interaction ($p = 0.004$, $\eta^2 = 0.38$, $P_s = 0.86$), and test by exercise interval interaction ($p < 0.001$, $\eta^2 = 0.49$, $P_s = 0.98$). The exercise interval by sex, and test by exercise interval by

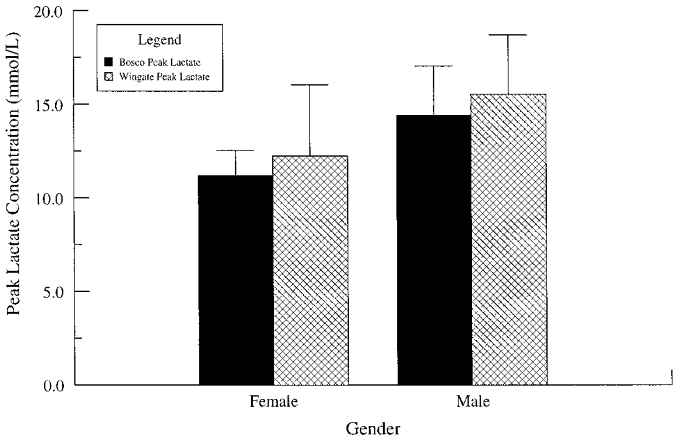

FIGURE 1. Peak lactate values for each test and sex.

sex interactions did not reach statistical significance (all $p > 0.05$). Work interval absolute power values (Watts) analyses resulted in statistical differences due to sex ($p < 0.002$, $\eta^2 = 0.43$, $P_s = 0.94$), test ($p < 0.001$, $\eta^2 = 0.91$, $P_s = 1.0$), exercise interval ($p < 0.001$, $\eta^2 = 0.75$, $P_s = 1.0$), and the test by time interaction ($p < 0.002$, $\eta^2 = 0.38$, $P_s = 0.93$). The test by sex interaction narrowly missed statistical significance ($p < 0.01$, $\eta^2 = 0.32$, $P_s = 0.78$). The exercise interval by sex and the test by time by sex interaction failed to reach statistical significance (all $p > 0.05$). The allometrically scaled work interval power values analyses resulted in statistical differences due to sex ($p < 0.001$, $\eta^2 = 0.60$, $P_s = 0.99$), test ($p = 0.003$, $\eta^2 = 0.93$, $P_s = 1.0$), exercise interval ($p < 0.001$, $\eta^2 = 0.83$, $P_s = 1.0$), test by sex interaction ($p = 0.003$, $\eta^2 = 0.39$, $P_s = 0.89$), and test by exercise interval interaction ($p < 0.001$, $\eta^2 = 0.45$, $P_s = 0.99$). The test by exercise interval by sex interaction did not reach statistical significance ($p > 0.05$).

The results shown in Table 3 also supported our first hypothesis: the tests will differ in peak and average power. The analysis of shorter exercise intervals over the duration of the tests also showed that the overall pattern of power production was similar.

Peak Lactate

Postexercise peak lactate values were statistically different by sex ($p = 0.008$, $\eta^2 = 0.33$, $P_s = 0.81$), but not by test type ($p = 0.13$, $\eta^2 = 0.12$, $P_s = 0.32$) or the sex by test type interaction ($p = 0.99$, $\eta^2 = 0.00$, $P_s = 0.05$) (Figure 1). Our second hypothesis, that peak lactate values would not differ, was supported by the data.

Relationships Between Average Power, Peak Power, and Peak Lactate Concentrations

Due to initial sex differences in peak lactate values, Pearson product-moment correlation coefficients were calculated on each sex separately. This procedure was followed to avoid calculating an inflated correlation coefficient due to a sex-based increased range of scores (15). Correlations between tests of the peak lactate concentrations did not reach statistical significance (men: $r(9) = 0.46$, $p = 0.16$, $P_s \approx 0.13$; women: $r(7) = 0.49$, $p = 0.18$, $P_s \approx 0.10$).

Relative Power Correlations ($W \cdot kg^{-1}$)

Correlations between lactate values and average and peak power values from both tests did not reach statistical significance among men or women (all $p > 0.05$). Men who participated in this study showed statistically significant relationships between Bosco average power and Wingate average power ($r(9) = 0.89$, $p < 0.001$, $P_s \approx 0.96$). The correlation between average power values for women was not statistically significant and negative ($r(7) = -0.18$, $p = 0.65$, $P_s \approx 0.24$). The relationship between peak power between tests among men was not statistically significant ($r(9) = 0.69$, $p = 0.02$, $P_s \approx 0.46$). Among women, the correlation between peak power values was not statistically significant either ($r(7) = 0.40$, $p = 0.28$, $P_s \approx 0.06$).

Absolute Power Correlations (Watts)

Correlations between lactate values and average and peak power values from both tests did not reach statistical significance among men or women (all $p > 0.05$). When average power was expressed in absolute terms, the women showed a significant correlation between Bosco and Wingate tests ($r(7) = 0.88$, $p = 0.002$, $P_s \approx 0.88$). The correlation between peak power values among the women did not reach statistical significance ($r(7) = 0.73$, $p = 0.024$, $P_s \approx 0.33$). Among men, correlations between tests of average and peak power both reached statistical significance ($r(9) = 0.82$, $p = 0.002$, $P_s \approx 0.74$; $r(9) = 0.88$, $p < 0.001$, $P_s \approx 0.95$, respectively).

Allometrically Scaled Power Correlations ($W \cdot kg^{-0.67}$)

Correlations between lactate values and average and peak power values did not reach statistical significance (all $p > 0.05$). Among women, none of the correlations between tests of peak and average power were statistically significant (all $p > 0.05$). Among men, the correlation between tests of average power reached statistical significance ($r(9) = 0.84$, $p = 0.001$, $P_s \approx 0.84$). Peak power among men did not reach statistical significance ($r(9) = 0.72$, $p = 0.013$, $P_s \approx 0.48$).

The correlational analyses of the test data resulted in partially supporting our third hypothesis: the tests would be only modestly correlated. The men showed a strong correlation between average power on both tests, whereas the women showed somewhat paradoxical results depending on how average and peak power were expressed.

DISCUSSION

The results of this study indicate that the Bosco test and the Wingate test differ in the expression of peak and average power, regardless of how these values are expressed (i.e., absolute, relative to mass, or allometrically scaled) (25). Bosco and colleagues indicated that the Wingate and Margaria tests measured "chemo-mechanical" (7) (p. 273) conversion while a rebound-jump series also measured an "elastic" muscular component (7, 13). Therefore, the Bosco and Wingate tests should be correlated, with at least some of any unexplained variance likely due in part to the SSC prevalent in the Bosco test. The Bosco 60-second test showed an average power correlation of $r = 0.87$ with the Wingate 30-second test, and a correlation of $r = 0.84$ with a 60-m dash (7). A previous comparison of a 30-second Wingate and a 30-second Bosco test showed that peak power for the modified Bosco test was 21.29 ($\pm$5.77 $W \cdot kg^{-1}$) and average power was 18.3 ($\pm$5.28 $W \cdot kg^{-1}$), whereas the Wingate test showed mean peak power 11.69 ($\pm$1.98 $W \cdot kg^{-1}$) and average power was 6.86 ($\pm$1.21 $W \cdot kg^{-1}$) (12). In an earlier study of 12 men by Bosco and colleagues, the Bosco test resulted in an average power of 20 W·kg^{-1}, whereas the Wingate test elicited average power of 7 W·kg^{-1} (7). These values compare well with those obtained in this study (Table 1).

Although the peak and average power values of both tests may provide useful estimates of anaerobic power and capacity relative to the 2 tests, a higher resolution analysis of the test performance is often helpful. Dividing the Wingate and Bosco tests into smaller performance segments based on time permits a higher resolution view of test performance. Analysis of smaller duration segments with the Wingate test has been more common (1, 12, 17, 20, 21) than with the Bosco test (6, 7). Table 3 shows that the basic trends of the dissected power values are similar, with higher power values demonstrated during the Bosco test. The η^2 values indicate that the dominant factors in the analysis belonged to the type of test and the test intervals, whereas sex and sex-associated interactions were of lesser influence. Although the 2 tests may be assessing different aspects of anaerobic performance, the overall pattern of performance is similar. The Bosco test demonstrates higher power values which may be indicative of the addition of the SSC to the constellation of factors that contribute to anaerobic performance.

Our second hypothesis was supported by the lack of statistical differences in the peak lactate values between the 2 tests. However, evidence of the anaerobic nature of the 2 tests has been supported by the magnitude of the peak lactate values in this study. Evidence of the validity of the Wingate test in measuring anaerobic components has been confined largely to comparisons with other seemingly accepted anaerobic tests or tasks. Correlations between the Wingate test and other tests or tasks having an assumed or measured anaerobic component have ranged from $r = 0.32$ to $r = 0.92$ (1). Wingate peak lactate values have been shown to exceed peak lactate values from the Bosco test among basketball players (15.4 ± 2.1 mmol·L^{-1} vs. 8.1 ± 0.9 mmol·L^{-1}, respectively) (7). Peak lactate values from Wingate tests have ranged from 11.2–14.8 mmol·L^{-1} (5, 18, 27). This study compares well with these peak lactate values. However, in contrast to previous studies, lactate values obtained in this study were not statistically different, showing a closer lactate correspondence between the 2 tests. The trend for higher peak lactate values obtained in the Wingate test has been preserved. In an earlier study, the correlation between the peak lactate values and average power values in the Wingate test was modest ($r = 0.60$) (1). This study did not show statistically significant correlations between average or peak power and lactate concentrations for men or women. This may have been due to the training backgrounds of the participants and potential differences in dominant fiber type distributions.

Our third hypothesis was partially supported in that correlations were largely modest. The magnitude of the correlations, however, appeared to depend on the method of power expression. This study appears to be somewhat underpowered for correlational analyses, which should lead to cautious interpretation. In this study, using relative power values (W·kg^{-1}), the women's performances resulted in a statistically nonsignificant correlation between the tests. Paradoxically, it also showed a negative relationship, albeit very small, indicating that high performance on the Wingate test was paired with relatively lower performance on the Bosco test. This paradox may be due to the athletic backgrounds of the women who participated in this study. Approximately half of the women in this study came from track and field throwing events. As such, several of these participants were not trained in jumping and had some difficulty completing the Bosco test; they were able to perform the supported/seated Wingate test with less difficulty. When power was expressed in absolute terms (Watts), both men and women showed more statistically significant correlations between tests. This supports the idea that size and mode of performance may have considerable influence on the results of both the Wingate and Bosco tests, and may partially explain why the women's power relationships between tests in this study were somewhat paradoxical. Comparisons between a weight-supported test (such as the Wingate) with a weight-bearing test (such as the Bosco test) may suffer when comparisons are made relative to body mass and allometrically scaled body mass.

The results of this study indicate that the Wingate and Bosco tests, though both anaerobic in nature, are measuring somewhat different aspects of anaerobic performance. Moreover, the Bosco test may be more suitable for jump-trained athletes.

In conclusion, our 3 hypotheses were generally supported by the data. Based on the results of this study, the Bosco test appears to be a worthy test of anaerobic power and capacity when compared with the Wingate test. However, the Bosco test may be a weaker indicator of anaerobic metabolism when the participants are not trained in jumping. In contrast, this weakness can also be regarded as a primary strength when the athletes are trained in jumping. Correlational analyses showed some paradoxical results, particularly with regard to women. Anaerobic tests, such as the Bosco and Wingate, still merit validity and reliability assessments due to remaining questions as to how these tests apply to specific athletic backgrounds, sports, effort durations, and effort intensities.

PRACTICAL APPLICATIONS

The Bosco test is an attractive jumping test that may be a more specific measure of anaerobic power and capacity among jump-trained athletes than the Wingate test. Gymnastics, track and field, basketball, volleyball, and other similar sports may benefit from a test of anaerobic power that invokes the stretch-shortening muscle tension cycle rather than a test of predominantly concentric tension. The Bosco test can be used to acquire roughly the same information that has traditionally been acquired from the Wingate test while employing a jump-specific exercise task.

REFERENCES

1. BAR-OR, O. The Wingate anaerobic test: An update on methodology, reliability, and validity. *Sports Med.* 4:381–394. 1987.
2. BAR-OR, O. Anaerobic performance. In: *Measurement in Pediatric Exercise Science.* D. Docherty, ed. Champaign, IL: Human Kinetics, 1996. pp. 161–182.
3. BAR-OR, O., R. DOTAN, AND O. INBAR. A 30 second all-out ergometer test—its reliability and validity for anaerobic capacity. *Israel J. Med. Sci.* 13:126–130. 1977.
4. BAR-OR, O., R. DOTAN, O. INBAR, A. ROTHSTEIN, J. KARLSSON, AND P. TESCH. Anaerobic capacity and muscle fiber type distribution in man. *Int. J. Sports Med.* 1:82–85. 1980.
5. BENEKE, R., C. POLLMANN, I. BLEIF, R. M. LEITHAUSER, AND M. HUTLER. How anaerobic is the Wingate Anaerobic Test for humans? *Eur. J. Appl. Physiol.* 87:388–392. 2002.

6. BOSCO, C., P.V. KOMI, J. TIHANYI, G. FEKETE, AND P. APOR. Mechanical power test and fiber composition of human leg extensor muscles. *Eur. J. Appl. Physiol.* 51:129–135. 1983.
7. BOSCO, C., P. LUHTANEN, AND P.V. KOMI. A simple method for measurement of mechanical power in jumping. *Eur. J. Appl. Physiol.* 50:273–282. 1983.
8. BOSCO, C., P. MOGNONI, AND P. LUHTANEN. Relationship between isokinetic performance and ballistic movement. *Eur. J. Appl. Physiol.* 51:357–364. 1983.
9. BOUCHARD, C., A.W. TAYLOR, J. SIMONEAU, AND S. DULAC. Testing anaerobic power and capacity. In: *Physiological Testing of the High-Performance Athlete.* Duncan MacDougall, J., H.A. Wenger, and H.J. Green, eds. Champaign, IL: Human Kinetics, 1991. pp. 175–221.
10. COHEN, J. *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.
11. EMMERT, J. Analytical requirements for the measurement of lactate. In: *Workshop Report Accusport.* E. Ramstetter, ed. Mannheim, Germany: Boehringer Mannheim GmbH, 1995. pp. 26–28.
12. FABIAN, N. M., K.J. ADAMS, M.P. DURHAM, R.L. KIPP, J.M. BERNING, A.W. SWANK, AND B.A. STAMFORD. Comparison of power production between the Bosco and Wingate 30-second power tests. *Med. Sci. Sports Exer.* 33(5):S25. 2001.
13. FOSTER, C., L.L. HECTOR, K.S. MCDONALD, AND A.C. SNYDER. Measurement of anaerobic power and capacity. In: *Physiological Assessment of Human Fitness.* Maud, P. J. and C. Foster, eds. Champaign, IL: Human Kinetics, 1995. pp. 73–85.
14. GRAY, R.K., K.B. START, AND D.J. GLENCROSS. A test of leg power. *Res. Q.* 33(1):44–50. 1962.
15. HAYS, W. L. *Statistics*. New York: Holt, Rinehart, and Wilson, Inc., 1994.
16. HEDDERSON, J. *SPSS/PC+ Made Simple.* Belmont, CA: Wadsworth Publishing, 1991.
17. INBAR, O., O. BAR-OR, AND J.S. SKINNER. *The Wingate Anaerobic Test.* Champaign, IL: Human Kinetics, 1996.
18. JACOB, C., H. ZOUHAL, S. VINCENT, A. GRATAS-DELAMARCHE, P. M. BERTHON, D. BENTUE-FERRER, AND P. DELAMARCHE. Training status (endurance or sprint) and catecholamine response to the Wingate-test in women. *Int. J. Sports Med.* 23: 342–347. 2002.
19. JARIC, S. Role of body size in the relation between muscle strength and movement performance. *Exerc. Sport Sci. Rev.* 31: 8–12. 2003.
20. JASTRZEBSKI, Z. Selected aspects of the assessment of anaerobic capacity by applying the Wingate test. *Biol. Sport* 12:131–135. 1995.
21. KATCH, V., A. WELTMAN, R. MARTIN, AND L. GRAY. Optimal test characteristics for maximal anaerobic work on the bicycle ergometer. *Res. Q.* 48(2):319–327. 1978.
22. KIRKENDALL, D.T., AND G.M. STREET. Mechanical jumping power in athletes. *Br. J. Sports Med.* 20(4):163–164. 1986.
23. MAJOR, J.A., W.A. SANDS, J.R. MCNEAL, D.D. PAINE, AND R. KIPP. Design, construction, and validation of a portable one-dimensional force platform. *J. Strength Cond. Res.* 12(1):37–41. 1998.
24. MANNING, J. M., C. DOOLY-MANNING, AND D.H. PERRIN. Factor analysis of various anaerobic power tests. *J. Sports Med. Phys. Fitness* 28:138–144. 1988.
25. MAUD, P.J. AND B.B. SHULTZ. Gender comparisons in anaerobic power and anaerobic capacity tests. *Br. J. Sports Med.* 20(2): 51–54. 1986.
26. MAYHEW, J. L., L.M. PRATHER, K. MCGUIRE, T.E. BALL, AND J.C. BOWEN. Validation of gender difference in the Margaria-Kalamen Anaerobic Power Test. *J. Hum. Move. Stud.* 36:289–301. 1999.
27. NUMMELA, A., M. ALBERTS, R.P. RIJNTJES, P. LUHTANEN, AND H. RUSKO. Reliability and validity of the maximal anaerobic running test. *Int. J. Sports Med.* 17(Suppl 2):S97–S102. 1996.
28. PATTON, J. F., AND A. DUGGAN. An evaluation of tests of anaerobic power. *Aviat. Space Environ. Med.* 58:237–242. 1987.
29. ROBKOPF, P., W. LAMPRECHT, AND H. LIESEN. The Accusport analyzer and its operation. In: *Workshop Report Accusport.* E. Ramstetter, C. Zieres-Nauth, and M. Mack, eds. Mannheim, Germany: Boehringer Mannheim GmbH, 1995. pp. 33–36.
30. RYAN, T.A. Multiple comparisons in psychological research. *Psychol. Bul.* 56(1):26–47. 1959.
31. SANDS, W.A. Olympic Preparation Camps 2000 Physical Abilities Testing. *Technique* 20(10):6–19. 2000.
32. SANDS, W.A. Physiological aspects of gymnastics. In: *Actes des 2émes Journées Internationales d'Etudes de l'A.F.R.A.G.A.* B.G. Bardy, T. Pozzo, P. Nouillot, N. Tordi, P. Delemarche, C. Ferrand, Y. Léziart, D. Hauw, J. Aubert, M. Loquet, A. Durny, and J.F. Robin, eds. Université de Rennes, Rennes, France, L'Association Française de Recherche en Activités Gymniques et Acrobatiques (A.F.R.A.G.A.), 2000. pp. 68–71.
33. SANDS, W.A., J.R. MCNEAL, AND M. JEMNI. Anaerobic power profile. *Technique* 21(5):5–9. 2001.
34. SANDS, W.A., J.R. MCNEAL, AND M. JEMNI. Fitness profile comparisons: USA Women's Junior, Senior, and Olympic Gymnastics Teams. *J. Strength Cond. Res.* 15(3):398. 2001.
35. SANDS, W.A., J.R. MCNEAL, AND M. JEMNI. Does average jumping power keep pace with increasing age and size in U.S. National Team female gymnasts. *Med. Sci. Sports Exer.* 34(5): S143. 2002.
36. SARGENT, D.A. The physical test of a man. *Amer. Phys. Ed. Rev.* 26:188–194. 1921.
37. SEMENICK, D. The vertical jump. *Natl. Strength Cond. Assoc. J.* 12(3):68–69. 1990.
38. SOKAL, R.R. AND F. JAMES ROHLF. *Biometry*. New York: W.H. Freeman, 1969.
39. SPSS. *SPSS Base 10.0 Applications Guide.* Chicago: SPSS, 1999.
40. VAN PRAAGH, E. Testing anaerobic performance. In: *The Child and Adolescent Athlete.* O. Bar-Or, ed. Oxford, England: Blackwell Science, Ltd., 1996. pp. 602–616.
41. VANDEWALLE, H., G. PERES, AND H. MONOD. Standard anaerobic exercise tests. *Sports Med.* 4:268–289. 1987.

Address correspondence to William A. Sands, bill.sands@usoc.org.