

PHYSICAL FITNESS AND PERFORMANCE

Effect of oxygen breathing following submaximal and maximal exercise on recovery and performance

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ABSTRACT

ROBBINS, M. K., K. GLEESON, and C. W. ZWILLICH. Effect of oxygen breathing following submaximal and maximal exercise on recovery and performance. *Med. Sci. Sports Exerc.*, Vol. 24, No. 6, pp. 720–725, 1992. To determine whether supplemental oxygen following exercise hastens recovery or enhances subsequent performance we evaluated its effectiveness in 13 male athletes. The exercise periods consisted of two 5-min submaximal efforts on a treadmill ergometer followed by a single bout to exhaustion. Intervals of exercise were separated by a 4-min recovery period during which the subject breathed either 1) room air, 2) 100% oxygen, or 3) 2 min of 100% oxygen followed by 2 min of room air on three nonconsecutive days. We found that breathing 100% oxygen produced no significant difference on the recovery kinetics of minute ventilation or heart rate, or improvement in subsequent performance as measured by duration of exercise (3.33 ± 0.04 min, air vs 3.46 ± 0.03 , oxygen) and peak $\dot{V}O_2$ (59.9 ± 2.2 ml·kg⁻¹·min⁻¹, air vs 54.5 ± 2.2 , oxygen). In addition, the perceived magnitude of exertion estimated by the Borg scale was no different during oxygen breathing. These findings offer no support for the use of supplemental oxygen in athletic events requiring short intervals of submaximal or maximal exertion.

PULMONARY VENTILATION, OXYGEN CONSUMPTION,
BORG SCALE

Supplemental oxygen is used by athletes during recovery from vigorous exercise in the belief that it hastens recovery or enhances subsequent performance. Most previous efforts to determine the efficacy of this practice have been flawed by study designs that neither simulate intermittent maximal exercise (3,8,9) nor control for possible placebo effects (7,9). As a result, there have been surprisingly few well-controlled studies evaluating the effect of supplemental oxygen following vigorous exercise upon objective and subjective measures of recovery and subsequent exercise performance.

Accordingly, we hypothesized that the administration

of 100% oxygen immediately following intermittent submaximal and maximal exertion would result in a more rapid recovery from exercise-induced tachycardia and hyperventilation, enhanced subsequent performance as measured by increased maximal oxygen uptake and duration of exercise, and a reduction in the perceived magnitude of exertion. Unlike previous studies, we used multiple episodes of exertion and intermittent rest periods sometimes observed in sports where supplemental oxygen is often used. Heart rate, minute ventilation, oxygen uptake, subjective responses, and duration of performance were evaluated in a single-blinded fashion.

METHODS

Subjects. Thirteen male athletes skilled in treadmill running and conditioned in exhaustive effort were studied. Most subjects were serious avocational runners or cyclists: one was a professional triathlete. Informed consent was obtained using a protocol approved by the institution's Clinical Investigation Committee.

Equipment. Progressive exercise was performed on a Quinton treadmill model 18–60 employing a 2700 series Hans-Rudolf nonrebreathing valve and mouthpiece with a two-way valve. The inspiratory limb of the mouthpiece was connected to a 100-l Douglas bag by 80 cm of 3.3-cm diameter corrugated tubing with a valve that directed either room air or 100% oxygen into the bag without the knowledge of the subject. Inflation was maintained by connection to a high flow wall device. A 210-cm length of 3.3-cm tubing connected the expiratory limb of the Hans-Rudolf valve to the recording transducers. Ventilation was measured with a dry rolling seal spirometer. Expired air was sampled for O₂ using a paramagnetic oxygen analyzer (Cybron-

Taylor) and CO₂ using an infrared absorption analyzer (Beckman Instruments). These instruments were calibrated with a known gas mixture and calibration syringe prior to each trial. All signals were entered into a Gould 9000 Pulmonary computer, which calculated oxygen uptake ($\dot{V}O_2$), peak oxygen consumption and minute ventilation in real time. To verify the calibrations of these instruments under the dynamic experimental circumstances, we compared the value of minute ventilation and oxygen consumption as calculated by the computer to those simultaneously determined by gas calibration technique. To accomplish this, we tested three subjects during steady state exercise using the techniques described above and simultaneously collecting expired gas for 1 min in a 100-l balloon. With the use of a 120-l Collins gasometer, the expired minute ventilation was calculated. A sample of expired gas was withdrawn and the oxygen content was measured. The oxygen consumption was then calculated. There was no significant difference between the measured and calculated values for minute ventilation and oxygen consumption.

Protocol. Each subject was exercised on three non-consecutive days in randomized order in a single-blind fashion. All subjects reported to the laboratory having rested and fasted for at least 4 h, and having been instructed to limit exercise and to maintain their activities as constant as possible on each study day. After arrival in the laboratory, ECG leads and a Hans-Rudolf valve mouthpiece with headgear were applied. Each subject walked on the treadmill for 10–15 min for light warm-up and familiarization with the apparatus. The protocol for all three study days is graphically represented in Figure 1. During the first exercise period each subject ran at approximately 70% of predicted peak $\dot{V}O_2$ at a constant grade and speed while breathing

room air through the mouthpiece. The first two exercise periods were 5 min in duration, and each was followed by a recovery period during which the subject walked slowly for 4 min and breathed either 1) air from a Douglas bag for 4 min, 2) 100% oxygen from an identical Douglas bag for 4 min, or 3) oxygen for 2 min followed by air for 2 min (combination). This sequence of supplemental oxygen followed by room air was used in an attempt to isolate, for the subsequent exercise period, the effect of supplemental oxygen upon recovery without the confounding effect of antecedent hyperoxia. The three different inspired gas mixtures were randomly selected for the three different days, but on a single testing day the same gases were used during each recovery period. During the third exercise period (Ex3) each subject began at the same grade and speed as at the end of Ex2. Every 30 s the grade was increased 2% until the subject reached exhaustion, indicated by a prearranged hand signal. No verbal encouragement was offered. The treadmill was then lowered and slowed. The subject then walked for 6 min during the third recovery period (R₃). During R₃ the inspired gas mixture was the same as the first two recovery periods, except it was administered for 6 min. For the third combination the subject breathed 100% oxygen for 2 min, then room air for 4 min. Heart rate and expired ventilation were recorded every 20 s. During each exercise period the subject was asked to rate his overall exertion using the Borg scale (Table 2) of perceived exertion every 1 min (2). Oxygen uptake was calculated by the computer in the metabolic cart. When the F_IO₂ = 1.0 no calculation of $\dot{V}O_2$ was attempted, although minute ventilation and pulse were recorded. The peak $\dot{V}O_2$ was determined by choosing the highest $\dot{V}O_2$ recorded during the final (maximal) exercise period for each condition.

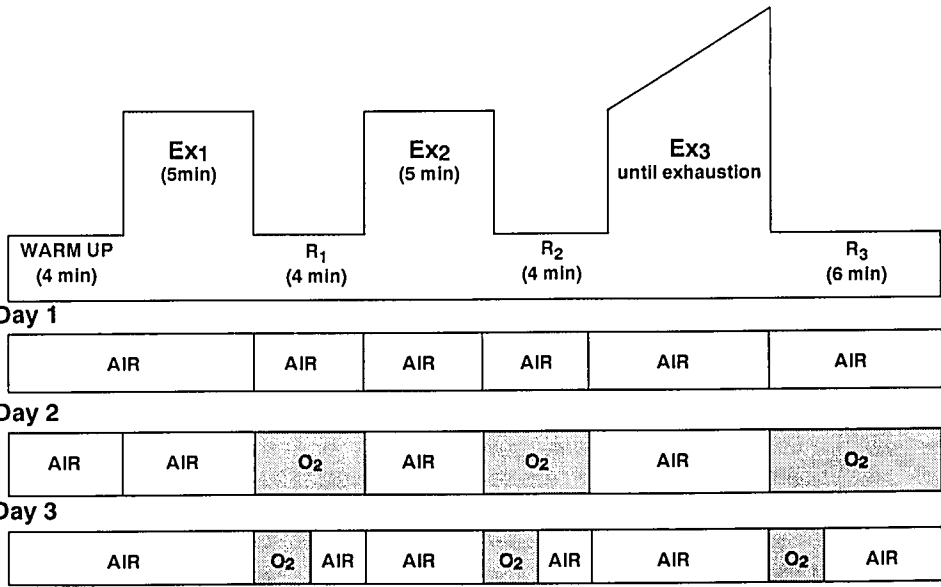


Figure 1—Study protocol for the three study days. The top panel shows the duration of warm-up, exercise and rest for the two submaximal periods (Ex1, Ex2) and the maximal exercise period (Ex3). The three gas mixtures (air, oxygen, and combination) are shown in the three panels below each panel representing one study day. The sequence of the three days was randomized.

Statistics. The individual and aggregate data compared heart rate, minute ventilation, peak $\dot{V}O_2$, and perceived exertion score during room air, oxygen, and O_2 -air combination using two-way analysis of variance (SPSS, Statistical Program for the Social Sciences, Microsoft). Two-way analyses of variance (ANOVA) of repeated pairs compared the following pairs: 1) air vs oxygen, 2) air vs combination, and 3) oxygen vs combination. Recovery from exercise was assessed by comparing heart rate and minute ventilation at 20-s intervals following the exercise period for the three different inspired gas mixtures using two-way analysis of variance. A *P* value less than 0.05 was considered significant. Results are reported as mean values $\pm$ standard error of mean.

RESULTS

The mean age, height, weight, resting and maximum values for heartrate and minute ventilation, and peak $\dot{V}O_2$ measured during the room air trial for each subject are shown in Table 1. The group exhibited a high mean peak $\dot{V}O_2$ ($59.9 \pm 2.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), mean maximal heart rate ($192 \pm 2.4 \text{ bpm}$), and mean maximal minute ventilation ($158 \pm 5.4 \text{ l}\cdot\text{min}^{-1}$).

The effect of supplemental oxygen on recovery from exercise is shown in Figures 2 and 3, which demonstrate the recovery curves for the group as a whole for heart rate and minute ventilation after maximal exercise breathing room air, oxygen, and the gas combination,

respectively. No significant difference could be found for any variable after the two submaximal periods. Each individual's recovery curves following each gas were also compared, and no significant differences were found.

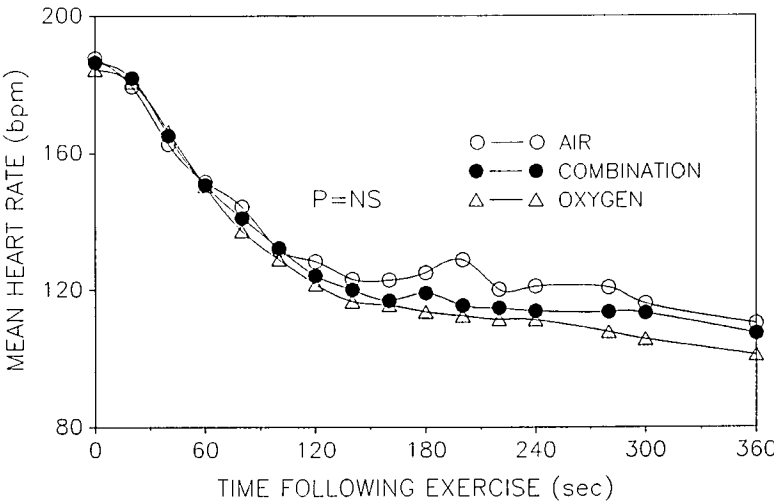
The mean heart rate and minute ventilation for the final 20 s of each exercise period (Ex_1 , Ex_2 , Ex_3) are shown in Figures 4 and 5. During the third exercise period the maximal heart rates were $187.7 \pm 2.6 \text{ bpm}$, 184.4 ± 3.8 , and 186.5 ± 4.1 for air, oxygen, and combination, respectively ($P = \text{NS}$). During the same period the mean expired ventilation was $148.6 \pm 8.0 \text{ l}\cdot\text{min}^{-1}$, 138.9 ± 5.6 , and 141.0 ± 6.6 for air, oxygen, and combination, respectively ($P = \text{NS}$). In addition, during the final 20 s of the preceding two bouts of submaximal exercise expired ventilation and heart rate were not significantly different between the three trials. The peak $\dot{V}O_2$ during exercise period 3 was $59.9 \pm 2.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, 54.5 ± 2.2 , and 58.5 ± 2.4 following air, oxygen, and combination, respectively, as shown in Figure 6, with no statistically significant differences being present. In addition no difference was seen in oxygen consumption during submaximal exercise for the three trials. The times to exhaustion during Ex_3 were $3.33 \pm 0.04 \text{ min}$, 3.46 ± 0.03 , and 3.40 ± 0.03 for air, oxygen, and combination, respectively ($P = \text{NS}$). To assess for possible learning effects, the time to exhaustion in the first trial and the final trial for each subject was compared. The mean time to exhaustion was $3.50 \pm 0.04 \text{ min}$ and 3.67 ± 0.03 , respectively, a statistically insignificant difference. Because the mean

TABLE 1. Subject characteristics and room air cardiorespiratory parameters.

	Age	Height (cm)	Weight (kg)	Rest HR	Max HR	Rest $\dot{V}E$	Max $\dot{V}E$	$\dot{V}O_{2max}$
Mean	28	179	76.3	66	192	12.5	158	59.9
SEM	2.0	1.8	2.1	3.3	2.4	0.8	5.4	2.2
Range	22-47	168-191	61.8-88.6	52-88	180-206	8.1-17.5	128-193	51.0-78.6

Rest HR = resting heart rate (bpm), Max HR = maximal heart rate (bpm), Rest $\dot{V}E$ = resting minute ventilation (liters/minute), Max $\dot{V}E$ = maximal minute ventilation ($\text{l}\cdot\text{min}^{-1}$), $\dot{V}O_{2max}$ = peak oxygen consumption ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), SEM = standard error of mean.

Figure 2—Mean heart rate following maximal exertion when breathing air, oxygen, or a combination of gases. Time 0 indicates the end of exercise period 3 and the beginning of the last recovery period. *P* = NS represents a nonsignificant difference ($P > 0.05$).



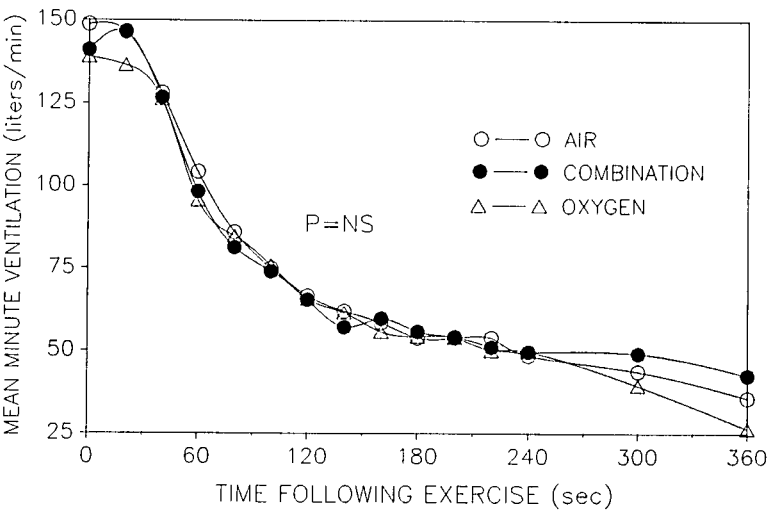


Figure 3—Mean minute ventilation following maximal exertion when breathing air, oxygen, and combination of gases. Time 0 indicates the end of exercise period 3 and the beginning of the last recovery period. *P* = NS represents a nonsignificant difference (*P* > 0.05).

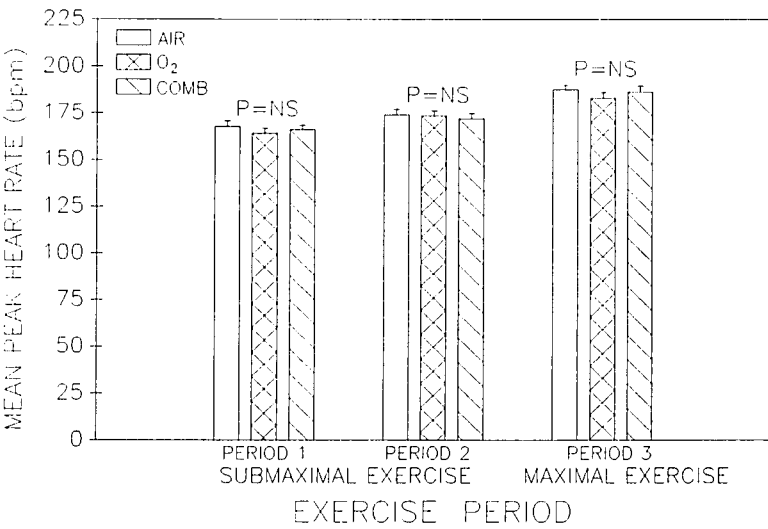


Figure 4—Mean maximal heart rate during the final 20 s of each exercise period. Error bars represent the standard error of mean. *P* = NS represents a nonsignificant difference (*P* > 0.05).

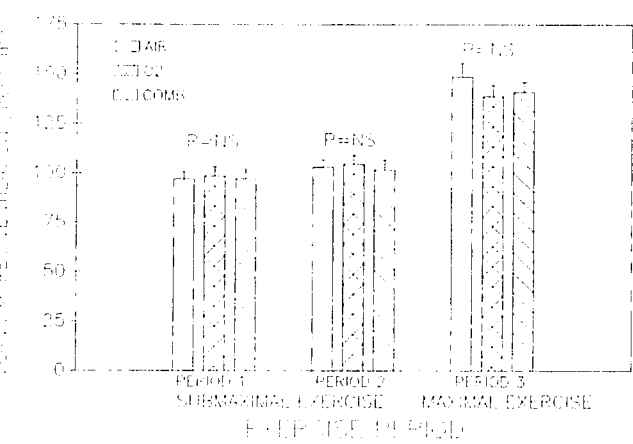


Figure 5—Mean minute ventilation ($\pm$ SEM) during the final 20 s of each exercise period.

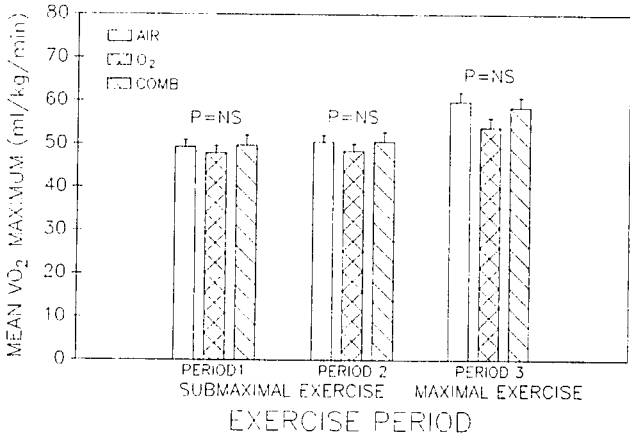


Figure 6—Mean peak $\dot{V}O_2$ (oxygen uptake) during the final 20 s of each exercise period.

peak $\dot{V}O_2$ of the first and third trials was also similar (55.7 ± 2.1 vs 57.7 ± 3.1 ml $\cdot$ kg⁻¹ $\cdot$ min⁻¹), we believe no learning effect was seen.

Subjective responses of perceived exertion (Table 2) also demonstrated no change with oxygen. During sub-

maximal exertion the mean perceived degree of exertion according to the Borg scale was 11.2 ± 0.3 for room air and 12.0 ± 0.3 for supplemental oxygen. This was also true during maximal exertion where the perceived exertion scores were 18.1 ± 0.2 and 17.0 ± 0.3

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TABLE 2. Borg scale of perceived exertion.

6
7 Very, very light
8
9 Very light
10
11 Fairly light
12
13 Somewhat hard
14
15 Hard
16
17 Very hard
18
19 Very, very hard
20

for room air and supplemental oxygen, respectively. When questioned at the study's completion, the subjects were unable to discern which gas mixture was used.

DISCUSSION

In this study we have shown that supplemental oxygen following short intervals of submaximal or maximal exercise has no discernible effect on the rate of recovery of minute ventilation or heart rate. In addition, we were unable to demonstrate that supplemental oxygen prior to vigorous exercise has any influence on subsequent performance as measured by exercise duration or maximal oxygen uptake. Finally, supplemental oxygen breathing did not alter the perception of the magnitude of exertion as determined by the Borg scale. The subjects were unable to discern when oxygen was in use.

Although the use of oxygen during exertion appears beneficial in prolonging endurance and easing dyspnea (1,6,9,10), its effect when administered during recovery alone is controversial (3,7–9,11). Most previous studies demonstrate conflicting results, which may reflect methodological differences or lack of appropriate controls. Miller found supplemental oxygen to have no effect on recovery of minute ventilation or heart rate when administered following submaximal or maximal treadmill exercise in a cohort of athletes (8). However, Eibel et al. (3) found that following submaximal treadmill running subjects breathing 100% oxygen had a lower heart rate and a higher respiratory rate than the same subjects breathing room air. In addition, following 6 min of submaximal exercise on a cycle ergometer, Garner et al. (4) found that breathing supplemental oxygen during the recovery period did not alter ventilation or heart rate compared with breathing room air. Finally, Winter et al. (11) recently demonstrated that following exhaustive exertion, breathing supplemental oxygen had no effect on recovery or serum lactate levels. Accordingly, the available evidence fails to convincingly demonstrate an effect of hyperoxia on heart rate

or ventilation during recovery from submaximal or maximal exercise.

On the other hand, several studies suggest heightened exercise capacity following a period of hyperoxia prior to performance. Hill and Flack (5) found that trained runners had improved performance with less dyspnea and lower heart rates during recovery when oxygen was used for 5 min prior to exertion. In addition, oxygen administered to members of the 1932 Japanese Olympic swimming team resulted in several world records when given within 1 min of the exercise (7). The effect was most notable in events such as the 100- and 200-yard swim, which lasted only 2–3 min. Each of these cited studies lacked both suitable controls and a failure to blind the participants. It is therefore difficult to draw firm conclusions based on such data. In summary, supplemental oxygen may be of benefit in improving subsequent exercise performance when administered for several minutes immediately prior to exertion of less than 2 min duration, but because of flaws in experimental design these findings are inconclusive. Our data fail to confirm any effect of hyperoxia on measures of recovery or subsequent performance. The time to exhaustion following supplemental O₂ breathing (3.46 ± 0.03 min) tended to be longer compared with room air breathing (3.33 ± 0.04 min) but did not reach statistical significance ($P > 0.05$). Whether this difference represents inherent variability in this physiologic measure or a real effect of hyperoxia on subsequent performance is a question a larger study could address. However, this small or absent effect is in accord with a recent report where no beneficial effect of supplemental oxygen on subsequent performance was found in a randomized blinded study (11). A lack of effect of supplemental oxygen on subsequent performance might be expected based upon the relatively small increase in arterial O₂ content it produces in normal subjects, which would become rapidly depleted at the onset of exercise.

Similarly, we did find ventilation at maximal exercise to be lower, although not significantly so, when oxygen was administered prior to exercise (Fig. 5). The effect of pre-exercise hyperoxia probably does not explain this difference because the result was similar following the combination of gases (oxygen followed by air) during which room air was inspired for the 2 min immediately preceding this maximal exercise period. Other studies have shown that hyperoxia during exercise reduces ventilation (9), but no study has shown that recovery oxygen effects maximal ventilation during subsequent exertion. It is likely that the nonsignificant difference of $10 \text{ l} \cdot \text{min}^{-1}$ may merely represent physiologic variability seen in performance on separate days. Interpretation of our results is limited, however, by our failure to employ multiple periods of *maximal* exercise, which may more accurately reflect the intensity and duration

of exertion often required in sports such as basketball or football. Conceivably, our findings may have been different had we done so.

In summary, supplemental oxygen during the recovery period of intermittent maximal activity failed to have any effect on physiological variables. Performance was not enhanced nor was any subjective relief demonstrated. We therefore can offer no scientific basis for the use of supplemental oxygen in speeding recovery or improving subsequent performance in athletic events

where exertion comparable to our experimental conditions is commonly used.

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REFERENCES

1. ADAMS, R. P. and H. G. WELCH. Oxygen uptake, acid-base status, and performance with varied inspired oxygen fractions. *J. Appl. Physiol.* 44:863-868, 1980.
2. BORG, G. Perceived exertion as an indicator of somatic stress. *Scand. J. Rehabil. Med.* 2-3:92-98, 1970.
3. EIBEL, E., D. ORMAND, and D. CLOSE. Some effects of breathing oxygen before and after exercise. *J. Appl. Physiol.* 16:48-52, 1961.
4. GARNER, R. P., S. K. POWERS, and G. CHURCH. Effects of hypoxia and hyperoxia on ventilatory kinetic during recovery from exercise. *Aviat. Space Environ. Med.* 57:1165-1169, 1986.
5. HILL, L. and M. FLACK. The influence of oxygen on athletes (Proceedings). *J. Physiol.* 38:xxviii-xxxvi, 1909.
6. HOGAN, M. C. and H. G. WELCH. Effect of varied lactate levels on bicycle ergometer performance. *J. Appl. Physiol.* 57:507-513, 1984.
7. KARPOVICH, P. V. The effect of oxygen on swimming performance. *Res. Q. Am. Assoc. Health, Phys. Educ. Recreat.* 5:24, 1934.
8. MILLER, A. T. JR. Influence of oxygen administration on cardiovascular function during exercise and recovery. *J. Appl. Physiol.* 5:165-168, 1952.
9. WELCH, H. G. Hyperoxia and human performance: a brief review. *Med. Sci. Sports Exerc.* 14:253-262, 1982.
10. WELTMAN, A., V. KATCH, and S. SADY. Effects of increasing oxygen availability on bicycle ergometer endurance performance. *Ergonomics* 21:247-238, 1978.
11. WINTER, F. D., P. G. SNELL, and J. STRAY-GUNDERSON. Effects of 100% oxygen on performance of professional soccer players. *J.A.M.A.* 262:227-229, 1989.