Effects of Resistance Exercise on Selected Physiological Parameters During Subsequent Aerobic Exercise

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Reference Data

ABSTRACT
The effects of weight training (WT) on the responses to aerobic exercise (AE) were studied in 11 subjects in a counterbalanced, repeated measures design. In the control sessions, subjects engaged in 20 min of AE on a cycle ergometer at 60% of their VO2 max. Heart rate, blood pressure, RPE, and core temperature were assessed 10 min into the exercise and again during the final 30 sec. Mean blood pressure (MBP) and rate-pressure product (RPP) were calculated later. In the experimental sessions, subjects undertook a standard 50-min WT program working all major muscle groups; after 15 min of recovery, data were obtained from an AE bout identical to that used in the control session. At 10 min, HR, MBP, and RPP were significantly higher when AE was preceded by WT. When measured during the last 30 sec of exercise, HR, RPE, and RPP differed significantly. The inclusion of WT shortly before AE apparently affected subject responses to AE, possibly causing a shift in the slope of the HR-VO2 relationship.

Key Words: weight training, cross-training

Introduction
Over the years numerous studies have sought the optimal methods for prescribing various modes of exercise during a single exercise session, and the acute and chronic effects of these modes on humans. The American College of Sports Medicine (1) has an extensive position statement summarizing the research and discussing the proper methods for developing and maintaining muscular and aerobic fitness. In almost all cases, the researchers looked exclusively at exercise sessions with one bout of one mode (e.g., weight training or endurance training), with no consideration given to other possible modes in the same session.

A few studies have examined the effects of aerobic exercise on a subsequent bout of the same aerobic exercise and found significant elevations in heart rate (HR) (7-9) and decreases in stroke volume (8, 9). On the other hand, the effects of sequential training of different modes during the same exercise session have received scant attention. We know of only one study (6) that examined the effects of resistance exercise on subsequent aerobic exercise. Although that study concluded there was but a slight effect on HR measured 5 min into the exercise, only several sets of one isolated exercise movement were used. Pollock and Wilmore (13), in a widely used textbook on exercise prescription, noted this lack of information, stating, "whether participants complete their muscular conditioning program or aerobic program first . . . is not important. No data suggest that one sequence is better than the other" (p. 436).

However, even if equal long-term aerobic training effects were experienced at the same power output regardless of mode order, factors such as myocardial oxygen consumption or perceived exertion might be altered enough to cause concern in populations requiring precise exercise prescription, for example cardiac patients, exercising diabetics, and so on. Hence, if there are physiological alterations in the expected response of humans to specific modes when used in sequence with differing modes, this would be of interest to those who prescribe aerobic exercise in sessions using multiple modes. It is known that weight training differs substantially from aerobic exercise in the relationship between heart rate and oxygen uptake (3). If the physiological sequelae associated with resistance exercise alter normal body homeostasis for a long enough time, many assumptions about the acute effects of aerobic exercise (if performed soon after weight training) may not be completely valid.

The purpose of this study was to examine the effects of a bout of standardly prescribed weight training on exercise HR, ratings of perceived exertion (RPE), core temperature (Tcore), mean blood pressure (MBP), and rate-pressure product (RPP) during a subsequent bout of aerobic exercise in the same exercise session. These parameters were chosen because of their relevance to exercise prescription.

Materials and Methods
Eleven men, average age 26 yrs (±5.3 yrs), took part in a repeated measures, counterbalanced design after appropriate medical screening. All were recreational weight trainers who had been placed on a weight training program duplicating the exercise to be used in the study for at least 8 weeks preceding data collection.
In the first session each subject was tested for maximal aerobic power on a Monark cycle ergometer with open-circuit spirometry. Ametek CO₂ (Model CD3A) and O₂ (Model S-3A) analyzers with a Model R-2 flow control pump were used along with a Kozak turbine compensator and a K-520 flow transducer for gas volumes. These devices were interfaced with a computer for data collection and an OCM-2 program for analysis. Testing was terminated at the point of volitional fatigue and considered valid if an RPE of at least 19 and an RER of at least 1.1 was obtained. Exactly 1 week after max testing, either the control (cycle ergometry alone) or the experimental session (weight training followed by cycle ergometry) was conducted. Testing order was random.

In the control trials, subjects underwent 20 min of continuous cycle ergometry at about 60% of their measured VO₂max, as quantified by the cycle resistance and pedaling rate (60 rpm) monitored by a metronome cadence. Approximately 10 min into the exercise, HR was determined by ECG (CM-5 configuration), blood pressure by auscultation, RPE through the Borg Scale (4), and Tₚmax by a disposable YSI rectal probe attached to a YSI tele-thermometer (The Borg Scale was discussed in detail and placed within view.) The same data were again collected during the last 30 sec of the exercise bout.

The experimental trials began with a typical bout of weight training (approx. 50 min) that included 9 exercises chosen to work all major muscle groups in the following order: leg press, leg extension, leg curl, standing planter flexions, bench press, seated military press, lat pulls, seated arm curls, and curl-ups (only 1 set of curl-ups to volitional fatigue). All leg exercises were done first to allow a longer rest for these muscles, since they are also integrally involved in cycle ergometry. Nautilus and Universal type machines were used, and subjects performed three 8- to 12-RM sets at each station with precisely 90 sec rest between sets. In addition, 90 sec of rest were allowed between each station.

After the resistance exercise, subjects were taken to the laboratory and fitted with ECG electrodes, a blood pressure cuff, a rectal probe, and were placed on a preadjusted Monark cycle ergometer. After the monitoring devices were fitted and 15 min had passed since the end of the last weight training exercise (curl-ups), each subject performed precisely the same workload on the cycle for the same duration as the one in the control session. Data were collected during the same time intervals as in the control trials.

Subsequent to data collection, the MBP and RPP were calculated for each subject. Dependent t tests were used to check for significant differences between test conditions in the factors examined. Specifically, HR, RPE, Tₚmax, MBP, and RPP were analyzed. A nonparametric method, the Wilcoxon Signed-Rank Test, was used for RPE data. Finally, effect sizes were calculated for all comparisons except RPE.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>10 min Control vs. exper.</th>
<th>20 min Control vs. exper.</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>130 ±15.4</td>
<td>133 ±15.5</td>
</tr>
<tr>
<td></td>
<td>144±5.6</td>
<td>147±5.6</td>
</tr>
<tr>
<td></td>
<td>20886 ±2904</td>
<td>23593 ±3126</td>
</tr>
<tr>
<td></td>
<td>37.6 ±0.45</td>
<td>37.8 ±0.76</td>
</tr>
<tr>
<td>RPP</td>
<td>19008 ±21854±</td>
<td></td>
</tr>
<tr>
<td></td>
<td>106.8±5.0</td>
<td>109.5±7.8</td>
</tr>
<tr>
<td></td>
<td>12 ±4.0</td>
<td>13.8 ±4.8</td>
</tr>
<tr>
<td></td>
<td>12.7±5.0</td>
<td>14.8±5.0</td>
</tr>
</tbody>
</table>

Note. RPE calculated with a nonparametric version of a t test.
*p < 0.05; **p < 0.02; ***p < 0.01; ****p < 0.002; *****p < 0.001.

Results

In the initial testing all subjects attained the criteria listed above as definitive of the true VO₂ max. Mean maximal oxygen consumption was 43.1 ml · kg⁻¹ · min⁻¹ (SD ± 5.6).

As can be seen in Table 1 (alpha at p < 0.05), HR differed significantly at both 10 min (p < 0.001) and 20 min (p < 0.001). In a similar manner, RPP differed significantly between conditions at both 10 min (p < 0.002) and 20 min (p < 0.01). MBP differed significantly at 10 min (p < 0.05) but not at 20 min. RPE, which was analyzed through nonparametric methods, was significant at both 10 min (p < 0.01) and 20 min (p < 0.01). While MBP differed significantly at 10 min (p < 0.05), the difference was not significant at 20 min.

A growing trend in the published research is to include an additional measure of the meaningfulness of a relationship beyond simply reporting means, standard deviations, and p values, such as either statistical power or the effect size (5, 15). This is seen as a prudent caution since, according to Thomas et al. (15), "small differences can be declared significant based on some combination of small variances and large Ns, or the reverse can occur—large differences can be declared nonsignificant due to large variances and small Ns" (p. 334). Furthermore, "reporting effect sizes offers valid standards of comparison with past and future research and indicates important characteristics to guide subsequent research" (p. 334). Indeed, Cohen (5) has even suggested that the calculated effect size is more important than p values for interpreting research results. In view of this, effect sizes were calculated (Table 2).

As might have been anticipated from the significance levels, the effect of prior weight training on HR during aerobic exercise was large at both time intervals. Core temperature as reflected by rectal temperature showed little evidence of an effect. For MBP, effect size added to the probability level results. While the experimental means were greater at both time intervals, only the 10-min differences were significant (p < 0.05). On the
On the other hand, we know of only one study that used resistance exercise as the prior exercise mode (6); no overall effect on heart rate was found, but that study did not use a full weight training program. Three sets of leg extensions (i.e., 3 sets for the left leg and 3 sets for the right leg) were performed at 30° per second in some trials and 240° per second in other trials in order to vary the resistance between high and low, respectively. These two dynamometer velocities were then crossed with 20 min of cycle ergometry at 63 and 73%, respectively, of the subjects’ VO₂ max.

A significant difference was found only at 5 min for HR during the more intense bouts when isokinetic speed was set for the higher intensity contractions, followed by the more intense cycle exercise. This difference was not apparent at the 20-min mark. In the present study, although the p values are slightly greater for HR at 10 min than at 20 min, the effect sizes were slightly greater at 20 min than at 10 min. Hence it seems likely that there was no substantial difference in HR between 10 and 20 min. The reason for the differences between the present study and that of Crawford et al. (6) can only be speculated upon, but it would seem reasonable to conclude that the isokinetic workload in that study was not enough to elicit the full effect. Crawford et al. acknowledged the limitation, stating, “it is not possible to generalize the findings to upper body exercises or a complete weight training workout” (p. 508).

The large statistical effects associated with RPP are in line with the large HR effects, since RPP is a product of systolic blood pressure and HR. On the other hand, p values for MBP were only significant at 10 min. Once again though, effect size values (Table 2) indicated a large effect at 10 min and a medium effect at 20 min. Apparently both HR and blood pressure were being affected by the experimental treatment, resulting in pronounced effects on RPP.

The RPP results could be of clinical importance. It is generally agreed that RPP is a rough indicator of myocardial oxygen use, and in patients with coronary artery disease or angina, the onset of angina or ST segment depression tends to be rather closely correlated with a set RPP (14). On the other hand, the more exaggerated diastolic BP response associated with weight training leads to greater blood perfusion of the coronary arteries and results in a higher ischemic threshold than found with aerobic exercise (11). It is for this reason that resistance exercise has become more accepted in cardiac rehabilitation settings. At the same time, there is evidence that if some form of static exercise is integrated into dynamic aerobic exercise bouts, the diastolic effect of the isometric-like contractions may lead to better overall exercise tolerance (2, 11). However, the present research suggests that if weight training is followed by aerobic exercise (with no isometric component), the individual might have to employ a lesser aerobic exercise workload in order to remain below a given RPP.

Table 2

Effect Sizes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>10 min</th>
<th>20 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>0.91***</td>
<td>1.14***</td>
</tr>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>0.22*</td>
<td>0.3*</td>
</tr>
<tr>
<td>MBP</td>
<td>0.98***</td>
<td>0.47**</td>
</tr>
<tr>
<td>RPP</td>
<td>1.2***</td>
<td>1.1***</td>
</tr>
<tr>
<td>Small*</td>
<td>Medium**</td>
<td>Large***</td>
</tr>
<tr>
<td>&lt; 0.41</td>
<td>0.41-0.70</td>
<td>&gt;0.70</td>
</tr>
</tbody>
</table>

other hand, there was an effect deemed large at 10 min and medium at 20 min, suggesting that reliance on probability level alone could be misleading. RPP effect size results were as clear-cut and dramatic as those associated with HR, with large effect sizes at both time intervals.

Discussion

This study presents evidence that the order of exercise mode (weight training vs. cycle ergometry) may make a difference with respect to the variables measured. After approximately 50 min of WT using movements for all major muscle groups, HR, RPE, MBP, and RPP were all significantly affected at some point during the subsequent exercise on the cycle. As noted in the Results, the effect sizes also indicated that in the case of HR (both time intervals), RPP (both time intervals), and MBP (at 10 min), the effects were not only statistically significant but could be rated as large (15).

Assuming that p values must be analyzed in conjunction with some indication of statistical power and/or effect size (5, 15), the interpretation of the present results would be slightly modified. The influence of prior weight training on aerobic exercise was emphasized by the effect-size findings with respect to HR, a crucial factor in the prescription of aerobic exercise. In another case, MBP at 20 min, a classical analysis would have labeled the differences between these means as not significant and probably stopped at that point. However, the finding of a medium effect size would seem to follow the general overall trend seen in the p values.

Contrasting the present results with the literature is difficult given the little research on this topic. Past studies have indicated a possible effect on HR and stroke volume when aerobic exercise precedes aerobic exercise (8, 9). While stroke volume was not assessed here, HR findings were in general agreement with the earlier studies even though the mode (weight training) differed. Grimby et al. (7) used 30 min of cycle ergometry at either 600 or 900 kpm per min, followed by a 2-hr rest period and concluding with a 30-min work bout identical to the first. HR was significantly higher for both workloads, elevated by an average of 9 and 10 bpm, respectively. Hence if the exercise is viewed simply as a prior metabolic load, the present study at least partially reflects past research, especially since all subjects used workloads within this same 600- to 900-kpm range.
Perceived exertion, while not as affected as HR or RPP, was also clearly influenced. Since RPE is assumed to be fairly stable under a variety of conditions, if the workload is at the same relative VO₂, (13), this was notable. Crawford et al. (6) also found a significantly elevated RPE at 20 min associated with the most intense trials (slow-speed isokinetics followed by the higher cycle workload). If RPE is affected by exercise sequencing, the usual assumptions concerning RPE and exercise intensity (4) may not be completely accurate. If aerobic exercise is a prime component in an exercise program, there is the possibility that an elevated RPE (due to prior weight training) could lead to reduced adherence at a given workload.

The mechanisms responsible for the altered values found during aerobic exercise when preceded by weight training can only be speculated upon at this point. It seems obvious that WT induced some type of alteration in the body's normal homeostasis that could not be normalized by the time AE began. Any number of metabolites are elevated during weight training including various stress hormones (epinephrine, norepinephrine, cortisol, etc.), lactate (10), and so on. This could have resulted in raising levels enough above baseline at the beginning of AE to influence the exercise response to differ significantly from what might have been expected. Cardiac output and stroke volume were not measured in this study. However, if stroke volume decreased, as has been found in sequential aerobic exercise (8, 9), the increased HR could have been an attempt to maintain cardiac output at the same level for the aerobic exercise.

The degree to which any research can be generalized beyond the specific conditions of the study (external validity) is always open to debate. In their conclusions section, Crawford et al. (6) state, “it is important to understand that there was no clinically significant alteration in the HR-VO₂ relationship following the strength exercise of this study as there is with high intensity endurance activity prior to further endurance exercise” (p. 509). Since the same amount of work should have approximately the same energy costs for the same person measured at different times (3), the results of the present study suggest there may well be clinically relevant alterations in this relationship following a weight training session as well. Given that endurance and isometric-like exercise stimulate quite different acute physiological responses, further research is needed to clarify the mechanisms responsible for the effect.

**Practical Applications**

When both resistance and aerobic exercise are to be prescribed and the aerobic portion is deemed the more important of the two, it might be prudent to either prescribe aerobic exercise first and weight training second, or aerobic exercise and weight training on alternate days. This could be the case in weight management programs, cardiac rehabilitation programs, or even in programs for health related fitness.

While the degree to which weight training provides some of the same health benefits as aerobic exercise is still a matter of debate, some of the latest research suggests that the positive changes in blood triglycerides and cholesterol levels are maximized during aerobic exercise. Kokkinos et al. (12), for example, actually found no significant changes in lipid and cholesterol profiles, lipoprotein lipase activity, or VO₂ max after 20 weeks of weight training. On the other hand, upper body strength increased by 50% while lower body strength increased 37%. Hence there was a substantial increase in strength and no increase in those factors that are often associated with better long-term health. It would therefore seem most prudent to consider the factors that might influence the training heart rate during aerobic exercise.

**References**