Indexes of power and aerobic capacity obtained in cycle ergometry and treadmill running: comparisons between sedentary, runners, cyclists and triathletes*

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ABSTRACT

The objectives of this study were: a) to determine, in a cross-sectional manner, the effect of aerobic training on the peak oxygen uptake (VO₂peak), the intensity at VO₂peak (IVO₂peak) and the anaerobic threshold (AnT) during running and cycling; and b) to verify if the transference of the training effects are dependent on the analyzed type of exercise or physiological index. Eleven untrained males (UN), nine endurance cyclists (EC), seven endurance runners (ER), and nine triathletes (TR) were submitted, on separate days, to incremental tests until voluntary exhaustion on a mechanical braked cycle ergometer and on a treadmill. The values of VO₂peak (ml.kg⁻¹.min⁻¹) obtained in running and cycle ergometer (ER = 68.8 ± 6.3 and 62.0 ± 5.0; EC = 60.5 ± 8.0 and 67.6 ± 7.6; TR = 64.5 ± 4.8 and 61.0 ± 4.1; UN = 43.5 ± 7.0 and 36.7 ± 5.6; respectively) were higher in the group that presented specific training in the modality. The UN group presented the lower values of VO₂peak regardless of the type of exercise. This same behavior was observed for the AnT (ml.kg⁻¹.min⁻¹) determined in running and cycle ergometer (ER = 56.8 ± 6.9 and 44.8 ± 5.7; EC = 51.2 ± 5.2 and 57.6 ± 7.1; TR = 56.5 ± 5.1 and 49.0 ± 4.8; UN = 33.2 ± 4.2 and 22.6 ± 3.7; respectively). It can be concluded that the transference of the training effects seems to be only partial, independently of the index (VO₂peak, IVO₂peak or AnT) or exercise type (running or cycling). In relation to the indices, the specificity of training seems to be less present in the VO₂peak than in the IVO₂peak and the AnT.

Key words: Specificity. Maximal oxygen uptake. Anaerobic threshold. Running. Cycling.

INTRODUCTION

The effects of training on the body depend on the interaction of at least three factors: initial fitness level; applied overload (intensity, duration, and weekly frequency); and type of exercise (movement specificity).

The possible transference of the training effects from one type of exercise to another has been broadly investigated. This model of study is rather interesting, as it allows one to assess the physiologic mechanisms accountable for and/or limit body adjustments to training. Moreover, such data also interest the professionals in charge of assessment and training multiple-sports athletes (biathlon and triathlon), or injured athletes who need, for a period of time, to replace the type of movement they perform in their training.

Most of the studies that investigated the transference of the effects from aerobic training between different body segments (arm-leg or leg-arm) found that adjustments were limited to the trained segment¹⁻³. Studies that assessed such transference among the same body segments, but using different exercises (cycling-running or running-cycling), have collected data one may consider conflicting. In these studies, it has been noted that cycling-running and running-cycling may be similar⁴, higher from cycling to running⁵ or from running to cycling⁶. Such contraposition may be explained, in part, by lack of control and/or difference in the initial fitness status of the subjects in the previously mentioned studies. So, it has been suggested that transferences would be lower and lower, with the enhancement of the initial fitness status and, conversely, with sensitivity decrease of the training effects. However,
er, very recent data collected from triathletes have shown that effects from cycling were transferred to running performance (longer distance covered in 30 minutes), which shows that, even in athletes, transference (at least for the performance) from cycling effects to running could exist.

Another less investigated aspect is that the magnitude of the training effects transference between running and cycling could depend on the physiologic indices used to determine training effects. As the peak oxygen uptake (VO2peak) found in a maximum exertion test has been considered the golden standard to determine functional fitness of the cardiorespiratory system during physical activity, a number of studies used it alone to assess possible transferences from training effects. However, this may not be the most suitable index, as a number of studies found, in moderately or highly trained subjects, that there may little or even no change in VO2peak even though some adjustments and improvement of aerobic performance may occur with training. To confirm this, studies have found that short- (2-5 min), medium- (5-30 min), or long-term (> 30 min) performance does not depend on VO2peak alone. This happens because, in trained subjects, VO2peak seems to be limited by the central oxygen supply (maximum cardiac output), which, from a specific fitness level upward, does not change due to training. For the exercise intensity corresponding to VO2peak (IVO2peak), which is the best index to reflect the association between maximum aerobic power and economy of movement, the aspects previously discussed do not seem to occur. IVO2peak has shown to be a good aerobic performance predictor, and it is also sensitive to the effects of training in athletes, even when VO2peak does not change, as there may be an improvement in the economy of movement. The same seems to take place with lactate response to incremental exercises (known in general terms as anaerobic threshold – AnT), which, as depending more of peripheral adaptations (muscular oxidative capability), is highly sensitive to training effects, and also presents high correlation with aerobic performance in medium- and long-duration events. Notwithstanding, few studies have used AnT and, as far as we know, no study so far has investigated IVO2peak to determine training effects transferences among different types of exercise.

The studies that make a longitudinal assessment of training effects may be considered, at first, the best investigative models. In these models, possible influences of the genetic load on the investigated indices are potentially best controlled. On the other hand, almost all these longitudinal studies covered somewhat small periods of time (4 to 24 weeks), which makes the collection of information on adjustments that may occur over the longer term with training (1 to 2 years) more difficult to obtain.

Thus, the purposes of this investigation were: a) to determine, in a cross-sectional way, training effects on VO2peak, IVO2peak and AnT during running and cycling; and b) to check if the transference of training effects depends on the type of exercise or the physiological index investigated.

**MATERIAL AND METHODS**

**Subjects**

Seven runners (ER: 25.8 ± 6.0 years, 60.4 ± 4.1 kg, 172.1 ± 6.9 cm), 9 cyclists (EC: 22.6 ± 2.1 years, 62.8 ± 5.4 kg, 173.8 ± 5.9 cm), and 9 triathletes (TR: 21.4 ± 4.1 years; 66.2 ± 7.0 kg; 174.2 ± 8.4 cm) well trained in endurance tests, and 11 untrained individuals (UN: 26.8 ± 4.1 years, 74.9 ± 14.3 kg, 175.1 ± 5.1 cm), all males, took part in the study. The athletes had, at least, two years practice in their specific modality. Each volunteer was informed on the investigation procedures and their implications, and signed an informed consent form to take part in the study. The protocol was approved by the Research Ethics Committee of the Biosciences Institute – Unesp – Rio Claro.

**Experimental procedures**

Each volunteer took part in two experimental sessions, which were randomly carried out, with intervals of 5 to 7 days between the sessions. The subjects were advised to come to the tests rested, fed, and hydrated, and not having done heavy exertion over the past 48 hours. Each volunteer attended both sessions at the same place and time of day (± 2 hours).

The running tests were performed on a treadmill (Inbramed Millenium Super ATL) at an inclination of 1%. Cycling tests were performed on a braked cycle ergometer, with constant rotation of 70 rpm throughout the test. Respiratory variables were measured by a gas analyzer (Cosmed K4, Rome, Italy), collecting data breath-by-breath and calculating an average at every 15 seconds. Blood samples were analyzed by a lactate electrochemical analyzer (YSL 2300 STAT), and heart rate was monitored through a frequency-meter (Polar X – Trainer plus).

**Determining ÎVO2peak, ÎVO2peak and AnT**

The initial speed of the incremental test performed on the treadmill was 14 km.h-1 for runners and triathletes, and 9 km.h-1 for the other subjects, with 1 km.h-1 increments at every 3 minutes until voluntary exhaustion. At the end of each stage, there was a 30-second pause, when heart rate (HR) was measured and 25 ml of blood from the ear lobe were collected.

For the progressive and continuous cycle ergometer test, the initial load was of 105 W for cyclists and triathletes, and 70 W for the other subjects, with increments of 35 W
at every 3 min until voluntary exhaustion. At the end of each stage, HR was measured and 25 ml of blood from the ear lobe was collected, with no pause.

The highest VO\(_2\) measured within 15 seconds was considered VO\(_{2\text{peak}}\). \(\text{IVO}_{2\text{peak}}\) was the lowest speed or power VO\(_{2\text{peak}}\) measurement. If the intensity of the measured VO\(_{2\text{peak}}\) was not sustained for at least 1 minute, the intensity of the previous stage was considered \(\text{IVO}_{2\text{peak}}\). \(\text{AnT}\) was calculated through linear interpolation, assuming a fixed lactate concentration of 3.5 mM.\(^{16}\)

**Statistical analysis**

All data are expressed as means ± SD. Values for VO\(_{2\text{peak}}\), maximum heart rate (HR\(_{\text{max}}\)), peak lactate, \(\text{AnT}\) in absolute figures (\(\text{VO}_{2\text{AnT}}\)) and as a proportion of VO\(_{2\text{peak}}\) (\(\text{AnT}\%\text{VO}_{2\text{peak}}\)), \(\text{AnT}\)-related heart rate (HR\(_{\text{AnT}}\)), and HR\(_{\text{AnT}}\) in relation to HR\(_{\text{max}}\) (\(\text{AnT}\%\text{HR}_{\text{max}}\)) were assessed with the use of an ANOVA two-way (group vs. modality), complemented by Scheffé’s test. \(\text{IVO}_{2\text{peak}}\) comparison was done with the use of an ANOVA one-way, complemented by Scheffé’s test. In all tests a significance level of \(p < 0.05\) was adopted.

**RESULTS**

VO\(_{2\text{peak}}\) values are presented in figure 1 and in table 1. VO\(_{2\text{peak}}\) was significantly higher in running than cycling for ER and UN groups. For the TR group there was no difference between the exercises, and for the EC group, VO\(_{2\text{peak}}\) was higher in cycling. UN group presented a VO\(_{2\text{peak}}\) lower than the other groups, for both types of exercise. Comparison of ER and EC groups showed that VO\(_{2\text{peak}}\) was higher for those where athletes had specific training. Group TR had a VO\(_{2\text{peak}}\) lower than group EC for cycling, and it was statistically similar for running. As for ER group, VO\(_{2\text{peak}}\) values of the TR groups were not different for both types of exercise.

Figures 2 and 3 show \(\text{IVO}_{2\text{peak}}\) from running and cycling, respectively. \(\text{IVO}_{2\text{peak}}\) of the UM group was lower than the other groups, for both types of exercise. For running, ER group showed \(\text{IVO}_{2\text{peak}}\) higher than the one from CL group, whereas for cycling, EC group had \(\text{IVO}_{2\text{peak}}\) higher than the one from the ER group. \(\text{IVO}_{2\text{peak}}\) of the TR group was not different from the one of the EC group, and significantly

![Fig. 1 – Mean peak oxygen uptake values (\(\text{VO}_{2\text{peak}}\)) from treadmill and cycle ergometer for untrained (UN), runners (ER), cyclists (EC) and triathletes (TR) groups](image-url)

### TABLE 1

Mean values ± SD of peak oxygen uptake (\(\text{VO}_{2\text{peak}}\)), of the intensity corresponding to \(\text{VO}_{2\text{peak}}\) (\(\text{IVO}_{2\text{peak}}\)), of maximum heart rate (HR\(_{\text{max}}\)) and of peak lactate (LAC\(_{\text{peak}}\)) from cycle ergometer and treadmill for untrained (UN), runners (ER), cyclists (EC) and triathletes (TR) groups

<table>
<thead>
<tr>
<th>Variables</th>
<th>Ergometer</th>
<th>UN (n = 11)</th>
<th>ER (n = 7)</th>
<th>EC (n = 9)</th>
<th>TR (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{VO}_{2\text{peak}}) (ml.kg(^{-1}).min(^{-1}))</td>
<td>Treadmill</td>
<td>43.5 ± 7.0(^a)</td>
<td>68.8 ± 6.3(^c)</td>
<td>60.5 ± 8.0(^b)</td>
<td>64.5 ± 4.8</td>
</tr>
<tr>
<td></td>
<td>Cycle</td>
<td>36.7 ± 5.6(^ab)</td>
<td>62.0 ± 5.0(^bc)</td>
<td>67.6 ± 7.6</td>
<td>61.0 ± 4.1(^c)</td>
</tr>
<tr>
<td>(\text{IVO}_{2\text{peak}})</td>
<td>Treadmill*</td>
<td>12.8 ± 1.0(^a)</td>
<td>19.7 ± 1.7</td>
<td>16.4 ± 1.2(^a)</td>
<td>19.2 ± 1.2</td>
</tr>
<tr>
<td></td>
<td>Cycle**</td>
<td>200.3 ± 36.2(^a)</td>
<td>267.4 ± 35.9(^a)</td>
<td>332.2 ± 41.3</td>
<td>328.5 ± 47.1</td>
</tr>
<tr>
<td>HR(_{\text{max}}) (bpm)</td>
<td>Treadmill</td>
<td>199.1 ± 7.1</td>
<td>195.4 ± 5.7</td>
<td>194.8 ± 10.6</td>
<td>193.0 ± 11.2</td>
</tr>
<tr>
<td></td>
<td>Cycle</td>
<td>186.2 ± 6.8(^b)</td>
<td>181.0 ± 14.3(^b)</td>
<td>191.0 ± 8.4(^a)</td>
<td>182.4 ± 5.7(^c)</td>
</tr>
<tr>
<td>[LAC(_{\text{peak}})] (mM)</td>
<td>Treadmill</td>
<td>9.1 ± 1.9</td>
<td>9.7 ± 1.7</td>
<td>7.7 ± 0.8(^a)</td>
<td>8.3 ± 1.4</td>
</tr>
<tr>
<td></td>
<td>Cycle</td>
<td>10.3 ± 1.4</td>
<td>9.5 ± 2.2</td>
<td>10.1 ± 1.8</td>
<td>8.8 ± 1.7</td>
</tr>
</tbody>
</table>

\(^{a}\) Units in km.h\(^{-1}\); \(^{b}\) Units in watts.
\(^{p} < 0.05\) in relation to the other groups for the same type of exercise.
\(^{c} p < 0.05\) in relation to the type of exercise within the same group.
\(^{d} p < 0.05\) in relation to EC for the same type of exercise.
\(^{e} p < 0.05\) in relation to TR and ER for the same type of exercise.
\(^{f} p < 0.05\) in relation to TR and EC for the same type of exercise.
higher than the one of the EC group for cycling. Likewise, for running, IVO₂peak of the TR group was not different from the one of the ER group, and significantly higher than the one of the EC group.

Table 1 shows maximum HR and serum lactate values at the end of the incremental test performed on the cycle ergometer and on the treadmill. Except for EC group, in which no differences were seen, HRmax was significantly lower in cycling than in running. In cycling, HRmax for EC was higher than for ER and TR groups, and similar to UN group. No differences were found in running among the groups. For LACpeak, EC group presented differences only between the types of exercises.

VO₂max values for cycle ergometer and for treadmill are presented in figure 4 and table 2. VO₂max was significantly higher in running than in cycling for UN, ER and TR groups.

Table 2

<table>
<thead>
<tr>
<th>Variables</th>
<th>Ergometer</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UN (n = 11)</td>
<td>ER (n = 7)</td>
</tr>
<tr>
<td>VO₂AnT (ml.kg⁻¹.min⁻¹)</td>
<td>Treadmill</td>
<td>33.2 ± 4.2a</td>
</tr>
<tr>
<td></td>
<td>Cycle</td>
<td>22.6 ± 3.7ab</td>
</tr>
<tr>
<td>VO₂AnT (%VO₂peak)</td>
<td>Treadmill</td>
<td>76.6 ± 6.4d</td>
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<tr>
<td></td>
<td>Cycle</td>
<td>61.6 ± 5.9b</td>
</tr>
<tr>
<td>HRAnT (bpm)</td>
<td>Treadmill</td>
<td>173.1 ± 9.1</td>
</tr>
<tr>
<td></td>
<td>Cycle</td>
<td>137.6 ± 10.7b</td>
</tr>
<tr>
<td>% HRmax</td>
<td>Treadmill</td>
<td>86.4 ± 2.3</td>
</tr>
<tr>
<td></td>
<td>Cycle</td>
<td>74.1 ± 5.6ab</td>
</tr>
</tbody>
</table>

*p < 0.05 in relation to the other groups for the same type of exercise.

*p < 0.05 in relation to the type of exercise within the same group.

*p < 0.05 in relation to ER and for the same type of exercise.

*p < 0.05 in relation to EC and TR for the same type of exercise.  
*p < 0.05 in relation to ER and TR for the same type of exercise.
For EC group, VO₂peak was higher in cycling. UN group presented a VO₂peak lower than other groups, for both types of exercise. When ER and EC groups were compared, VO₂peak was higher where athletes had specific training. TR group showed a VO₂peak lower in cycling and higher in running, compared to EC group. For ER group, VO₂peak values of TR group were not different for both types of exercise.

HRAnT, AnT%HRmax and AnT%VO₂peak values from cycle ergometer and treadmill are presented in table 2. AnT%VO₂peak values were significantly higher in running than in cycling for ER and UN groups. For TR and EC groups, there were no differences between the exercises. AnT%VO₂peak for cycling in UM group was lower than in ER group, and both groups had lower levels than EC and TR groups. In running, AnT%VO₂peak was lower for UM group compared to EC and TR groups. Except for EC group, in which no differences were found, HRAnT was significantly lower in cycling than running. HRAnT for UN group in cycling was lower than for the other groups. No differences in HRAnT were found for cycling between ER and TR groups, and both were significantly lower compared to EC group. No differences were found in HRAnT for running, among all groups. AnT%HRmax values were significantly higher in running than cycling for ER and UN groups. For TR and EC groups, there were no differences between the exercises. AnT%HRmax for UN group in cycling was lower than for the other groups. No AnT%HRmax differences were found in cycling between ER and TR, and TR and EC groups, but AnT%HRmax was significantly lower for ER group compared to EC group. There were no AnT%HRmax differences in running among all groups.

DISCUSSION

VO₂peak and AnT values presented by our subjects are similar to values found in the literature for the profile of those assessed in our investigation8-10. Even not interfering in the athletes practice, by associating VO₂peak, IVO₂peak, and AnT, we can assume that our subjects underwent adjustments from a long-term aerobic training, regardless of any genetic influence that could raise the levels of such physiologic indices.

According to what is classically demonstrated, TR group tended to make equal their VO₂peak values for both types of exercise18,19. UN and ER groups presented higher values for running, while EC group presented a higher value for cycling. This behavior matches the one found in other studies18-21, suggesting that VO₂peak does not depend only on the muscular mass of the subject, but also on the training specificity. It is interesting to note that VO₂peak values presented by ECs and ERs during non-specific training for each group were not different than for the TR group, and significantly higher than the presented by UNs. This suggests a transference of the training effects in relation to aerobic power, both from cycling to running and from running to cycling. This transference, however, seemed to be only partial, as VO₂peak values from ERs were higher in running, compared to ECs, while ECs presented higher values for cycling than ERs. Thus, specific adjustments in VO₂peak for improvement of both types of exercise seem to be necessary when one targets the highest VO₂peak possible and/or when training is performed for highly trained athletes.

There is a huge body of evidence in the literature showing that VO₂peak in athletes in limited by central factors (maximum heart output)11. Our data, however, suggest this behavior may not occur when one assesses athletes performing exercises for which they were not specifically trained. In these conditions, peripheral mechanisms (adjustments in the muscular blood flow and/or oxidative capacity) seem to play a role in limiting VO₂peak. In running, even with similar HRmax values (and likely maximum heart output) to cycling, VO₂peak values for EC group were higher in cycling. In cycling, peripheral factors seem to be even more present, as both groups, ER and TR, presented lower HRmax (and likely a maximum heart output) for running. It is likely that very specific adjustments are necessary for the muscle groups used in cycling (as discussed below), so that no peripheral limitation may prevent HRmax to be reached during an incremental test.

IVO₂peak is the index that reflects the best the association between maximum aerobic power (VO₂peak) and economy of movement22. As expected, IVO₂peak was higher where the athlete had specific training for the modality, and much lower in both tests for the UNs, with values within the range shown in the literature for this type of sample15 (figures 2 and 3). It is important to mention that higher IVO₂peak values were not due to higher VO₂peak only, but also because of a higher economy of movement in the modality in which the subject had specific training. This can be better seen by observing IVO₂peak values for the modality not particular to that subject. For ER (cycling) and EC (running) groups, VO₂peak values were similar to TR group, whereas IVO₂peak values were significantly lower in ER and EC groups. These data show that economy of movement has an instrumental role in determining IVO₂peak and that transference from one type of exercise to another probably did not occur, or was too small. Economy of movement depends on specific peripheral adjustments (enzymatic, neuromuscular and motor technique), that makes difficult transference of training effects. Our data confirm the importance of determining IVO₂peak and not only VO₂peak, which reinforces findings of other studies that concluded IVO₂peak to be more valid to ex-
plain individual differences in aerobic performance than VO2peak or economy of movement alone.

For submaximal variables, again AnT highest values were for subjects with specific training in the modality (figure 4). The same goes for VO2peak, suggesting that high AnT adjustment levels in response only to specific training. It is to be mentioned, however, that AnT presented by UNs in both exercises are much lower that values found in ECs for running and ERs for cycling, suggesting a transference, even if partial, of training effects. However, different from what was seen with VO2peak, these values (for ECs in running and ERs in cycling) were lower than those presented by TRs, showing that transference of training effects, even if partial, are more specific in lactate response than in VO2peak.

In our study model, AnT expressed in absolute values (mL.kg\(^{-1}\).min\(^{-1}\)) should be analyzed with discretion, as differences among groups for this index may be determined, in great measure, by the different VO2peak values. However, when AnT is expressed as a VO2peak percentage (AnT\(\%\)VO2peak), i.e., relative values, its behavior is not different from what was previously discussed, except for the similarity in UN and ER groups in running. In this scenario, it is to be stressed that the type of exercise seems to interfere in AnT\(\%\)VO2peak, particularly when one observes that UN group presented a value for running similar to the ER group, significantly higher than its value for cycling.

The lower AnT\(\%\)VO2peak (UN) and HRmax (UN, ER and TR) values for cycling compared to running may be due to biomechanical differences among the different modalities. Even using similar muscle groups, the delta efficiency (\(\Delta\) intensity/\(\Delta\)VO2 x 100) for cycling (25%) is much lower than for running (45%)\(^{23}\). Its contractions of isometric characteristics\(^{24}\) somehow may influence, through the decrease of muscular pumping action, venous return and muscular blood flow during exercise. During high-intensity activities, particularly in subjects with no cycling experience, as fatigue develops, one could observe an increase in the work of trunk and upper limb muscles, with no contribution for the generation of external work. This may cause blood flow to be redirected to the upper part of the body, and a possible “competition” for heart output. In addition, high intramuscular pressures developed over the cycling cycle may lead to a partial occlusion of the femoral artery\(^{25}\), which may reduce oxygen supply and promote higher recruitment of type-II fibers. It is thus possible to speculate that, during cycling, more specific adjustments may be necessary in an attempt to decrease these biomechanical limitations.

For running, eccentric muscular action may be of important consequences for energetic expenditure. First, the metabolic expenditure from the eccentric concentration is substantially lower than the concentric contraction. Second, the enlarging-shortening cycle in running allows for the storage of elastic energy during the eccentric stage, which is released later, at the concentric stage, increasing power generation for a given neural impulse. Such biomechanical “benefit” of running seems to justify, in part, the higher transference of AnT\(\%\)VO2peak towards running, and also AnT\(\%\)VO2peak and HRmax behavior in groups that do not train cycling.

Based on data from this study, one may conclude that, regardless of the index (VO2peak\(^{\ast}\)IVO2peak or AnT) or the type of exercise (running or cycling), transferences of training effects seem to be just partial, and there is the need to meet the movement specificity principle, when one intends to get a high degree of physiologic adjustment. As for indices, training specificity seems to be less present, therefore promoting higher level of transference, when adjustments depend more on central factors, such as VO2peak. For IVO2peak (when VO2peak levels are high) and AnT, which are more dependent on peripheral adjustments, the degree of transference may be lower.

All the authors declared there is not any potential conflict of interests regarding this article.

REFERENCES