

Effect of prior exercise intensity on physiological response and short-term aerobic performance

Efeito da intensidade do exercício prévio na resposta fisiológica e na performance aeróbia de curta duração

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Abstract – Athletes of different sports have frequently used warm-up exercises as preparation for the training session or competition. Increased metabolism and performance, as well as musculoskeletal injury prevention, are among the reasons that lead coaches to adopt this procedure. The effects of prior exercise have been studied to analyze the limiting factors of physiological adjustments at the beginning of exercise and its effects on subsequent exercise performance. Thus, this article analyzes studies that have investigated the effects of prior exercise on the cardiorespiratory and metabolic responses and short-term aerobic performance. In this context, factors such as prior exercise intensity and duration and recovery period between exercise sessions are discussed, and the possible mechanisms that could explain the effects of prior exercise are presented. The effects of prior exercise on the oxygen uptake (VO_2) kinetics do not seem to depend on the prior exercise intensity and recovery period between exercise sessions (i.e., prior and subsequent). However, the effects on exercise tolerance appear to depend on the interaction between the intensity of both exercises and the recovery period between them.

Key words: Exercise intensity; Recovery; VO_2 kinetics; Warm-up

Resumo – Atletas de diferentes esportes têm usado frequentemente exercícios de aquecimento como forma de preparação para a sessão de treinamento ou a competição. Entre as razões que levam os técnicos a adotarem este procedimento estão o aumento no metabolismo e na performance, como também a prevenção de lesões musculoesqueléticas. Os efeitos do exercício prévio têm sido estudados para se analisar os fatores limitantes dos ajustes fisiológicos no início do exercício e seu efeito na performance do exercício subsequente. Assim, este artigo analisa estudos que investigaram os efeitos do exercício prévio nas respostas cardiorrespiratórias, metabólicas e na performance aeróbia de curta duração. Neste contexto, fatores como a intensidade e a duração do exercício prévio e o período de recuperação entre as sessões de exercício prévio e do exercício subsequente são discutidos. São apresentados também os possíveis mecanismos que poderiam explicar os efeitos do exercício prévio nas respostas fisiológicas e na performance. Os efeitos do exercício prévio na cinética do consumo de oxigênio (VO_2) não parecem depender da intensidade do exercício prévio e do período de recuperação entre as sessões de exercício (i.e., prévio e subsequente). Porém, os efeitos na tolerância ao exercício parecem depender da interação entre a intensidade dos dois exercícios e do período de recuperação entre eles.

Palavras-chave: Aquecimento; Cinética do VO_2 ; Intensidade de exercício; Recuperação.

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INTRODUCTION

Warm-up has been considered important in many sports as a way of preparing athletes for competition, seeking increased metabolism and performance and as a possible way to prevent musculoskeletal injuries. This type of intervention has attracted much attention from researchers and coaches in the last decades¹⁻⁵. In general, studies that have investigated the effects of prior exercises have used relatively short durations (5-15 min) and intensity varies according to the characteristics of the subsequent exercise. For exercises involving muscle strength and muscle power, part of warm-up is performed at high intensities¹. For medium and long-duration aerobic exercises, intensity tends to be moderate⁴.

Studies regarding this theme have suggested that, depending on the conditions of prior exercise (i.e., intensity, duration and recovery time) and subsequent exercise, modifications generated by the prior exercise on muscle perfusion⁴, oxygen delivery⁶ and recruitment of motor units⁷ may be important aspects for improved performance in subsequent exercise. Aerobic performance (i.e., time to perform a given distance) and exercise tolerance, i.e., time limit (tlim, maximum exercise time with constant intensity that can be performed without or with different types of pauses, e.g., active or passive) are improved, especially in high-intensity and short-duration exercises (up to 2-9 min approximately)⁸⁻¹¹.

With respect to cardiorespiratory parameters, it has been shown that after prior exercise, the oxygen uptake kinetics (VO_2) response at the beginning of exercise can be accelerated^{3,4,6,8} because the increased blood flow and the more homogeneous distribution of the muscle blood flow tend to provide greater O_2 delivery to active muscles^{2,4,12}. The O_2 extraction by active muscles is increased, reducing demand for alactic and lactic anaerobic systems. Therefore, the aerobic contribution during exercise tends to be increased. Since the depletion of anaerobic energy reserves has been considered an important factor for exhaustion in high-intensity and short-duration exercises, prior exercise can prolong aerobic performance and tlim, since the anaerobic energy reserves are depleted more slowly^{5,13,14}.

The effects of prior exercises on performance and tlim of short-duration aerobic exercise appear to depend on the interaction between intensities (i.e., moderate, heavy or severe) of prior exercise and subsequent exercise^{2,15}. For prior severe exercise, there is evidence that the recovery time between exercise sessions can also modulate the effects of prior exercise on performance^{5,16}. Recently, the interest for more acute interventions (e.g., warm-up, nutritional supplementation, etc.) that may improve performance during exercise has increased significantly, which may be important for athletes, researchers and athletes⁴⁻¹¹. Thus, this review aims to analyze studies that investigated the effect of prior exercise on VO_2 kinetics and short-duration aerobic performance (~ 2-9 min). In this context, the review discussed the characteristics of prior exercise and its effects on short-duration aerobic performance summarizing three main aspects: 1) prior exercise intensity

and duration; 2) subsequent exercise intensity and; 3) specifically for prior severe exercise, the effects of the recovery period between exercise sessions (i.e., prior and subsequent exercises).

DEVELOPMENT

In literature search held on September 2013 and updated on March 2014, the database integrated to the healthcare area was searched using the Athena and Parthenon systems (catalogs and journals and Network of Federal and State Libraries of São Paulo) comprising the Pubmed database and Portal of Capes Journals indexed in the ISI Web of Science base. The following Boolean expressions on the problem of this study have been included: priming exercise and oxygen uptake, priming exercise and performance, prior exercise and oxygen uptake, prior exercise and performance, warm up and oxygen uptake, warm up and performance, prior exercise and oxygen uptake and prior exercise and performance.

After insertion of the keywords on the database, 8293 articles were found. Subsequently, studies with potential relevance, i.e., those that investigated the effects of any type of prior exercise on physiological parameters (e.g., VO_2 kinetics response or blood lactate concentration - [La]) and subsequent exercise performance were selected and 93 articles were found. Then, only studies where prior exercise and subsequent exercise intensity could be clearly identified according to the exercise intensity domains (according to concept described below) were selected. Specifically in relation to subsequent exercise, only those of short duration (~ 2-9 min) where there is predominance of aerobic metabolism were analyzed. Search and selection were conducted by two independent researchers. In case of disagreement that occurred only in the last phase (2 cases), a third researcher was consulted. There were no restrictions on the period of analysis, type of exercise (e.g., cycling, running, rowing, etc.) and training status of volunteers. At the end of the search, 36 articles directly related to the central purpose of the study were selected (Figure 1).

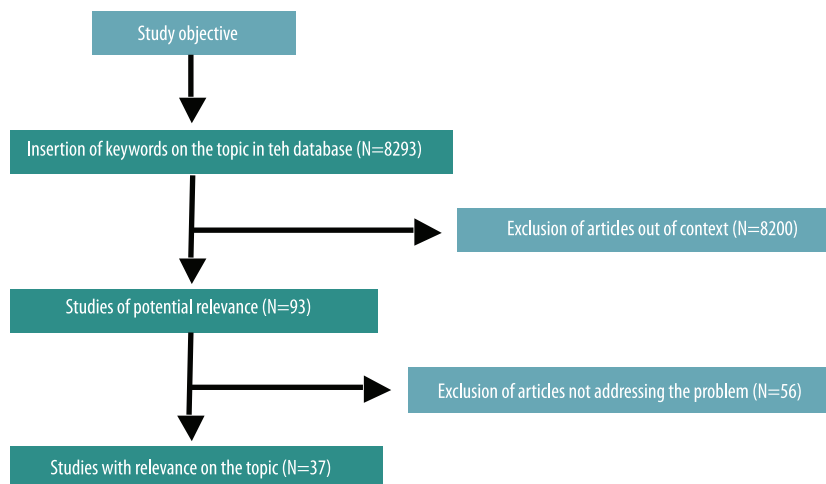


Figure 1. Process of selecting articles for inclusion in the review.

Exercise intensity domains

After analyzing studies that were considered relevant to the central objective, it was found that the intensity of both prior and subsequent exercises may influence (positively or negatively) the physiological responses and performance of the main exercise. Traditionally, classification (e.g., mild, moderate, intense and very intense) and the individualization of the aerobic exercise intensity have been made using certain percentages of the maximal oxygen uptake (VO_2max). However, the cardiorespiratory and metabolic responses to exercise, particularly those of submaximal intensity (i.e., $<\text{VO}_2\text{max}$), may be heterogeneous to a certain percentage of the VO_2max ^{13,17,18}. As a result, many studies that have investigated the effects of prior exercise have used the concept of exercise intensity domains to individualize exercise responses^{3,5-11}.

Using [La] and VO_2 responses during constant workload exercise, three different exercise intensity domains (moderate, heavy and severe) can be characterized¹⁸. In these domains, although absolute (expressed in Watts) and relative intensities (expressed in % VO_2max) may be different, physiological responses tend to be similar with less inter- and intra-individual variation¹⁸. In moderate domain, that is, when exercise is performed up to lactate threshold (LT), [La] does not increase in relation to resting values and the VO_2 response shows a rapid mono-exponential increase up to its stability within 2-3 min. The heavy exercise domain is located from the lowest exercise intensity, where [La] rises ($> \text{LT}$) and has as its upper limit the intensity corresponding to the critical power (CP)¹⁹. In this domain, [La] is high but stable over time and VO_2 reaches a late steady state (~ 15 min) after the presence of an additional increase in VO_2 , defined as slow component (SC), with a demand of 11- 15 $\text{mLO}_2\cdot\text{min}^{-1}\cdot\text{W}^{-1}$ ²⁰. The severe domain is characterized by the lack of stability of [La] and VO_2 , the latter reaches its maximum value (i.e., VO_2max) during exercise if exercise duration is sufficient. The diversity of physiological responses observed in moderate, heavy and severe domains determine that the factors that influence performance / t_{lim} in these domains are different. Therefore, the different combinations that can exist between prior exercise and subsequent exercise intensities can influence performance / t_{lim} of the latter.

Prior exercise intensity

Several studies have sought to analyze the effects of prior exercise on different modalities such as cycling^{5,6} and running^{21,22}. However, the ideal combination of intensity and duration of prior exercise able of optimizing the ergogenic effect of prior exercise on subsequent exercise performance has not yet been fully established, in part due to the different conditions of experimental designs analyzed.

Among the key factors that influence the effect of prior exercise on physiological responses and performance is its intensity. Depending on intensity, the subsequent exercise performance may not modify, improve or even decreases²³. The diversity of these responses is a function of the

different conditions generated by prior exercise on parameters such as [La], VO_2 , blood flow and recruitment of motor units^{3,9,24}. The different effects of prior exercise are described below, according to the domain where they are performed.

Prior moderate exercise

One of the first studies that investigated the effects of moderate prior exercise on metabolic and cardiorespiratory responses was conducted by Gerbino et al.². In this study, the authors analyzed the effect of six minutes of moderate exercise (~ 90% LT) on VO_2 kinetics in healthy young subjects. The authors found that the time constant (τ) of VO_2 kinetics remained unchanged during subsequent exercise performed at moderate domain (~ 90% LT) six minutes after experimental condition (37.5 s) when compared to the cycling condition at 0 W (33.5 s). Similarly, moderate exercise did not affect τ of subsequent heavy exercise (56.2 s) (50% of the difference between LT and $\text{VO}_2\text{max} - 50\%D$), compared to the cycling condition at 0 W (65 s)².

Burnley et al.³ analyzed the effect of exercise performed at 80% LT on the mean response time (MRT - time to reach 63% of the VO_2 increase above baseline) of the VO_2 kinetics, which similarly to τ , is the time to adjust VO_2 at the beginning of the exercise. There was no significant effect on moderate subsequent exercise (34.9 s) when compared to condition without prior exercise (30.5 s). Similarly, moderate exercise yielded no change in heavy exercise performed at 50% D (61.8 s), when compared to condition without prior exercise (65.2 s).

However, Gurd et al.²⁵ analyzed sedentary adult individuals and found for the first time that τ in moderate exercise (80% LT) can be accelerated with the performance of prior exercise (50% D) in this population. In the elderly, the same authors²⁷ have already demonstrated that prior exercise accelerates τ in this domain. The direct relationship between the change in τ and VO_2max reported by Gurd et al.²⁵, as well as the results of other studies^{26,27} suggest that the aerobic fitness level plays a possible role on the metabolic inertia in some individuals, which may interfere on the effects of prior exercise on subsequent moderate exercise (80% LT). This could start a discussion about the adequacy of central (increased O_2 delivery) and peripheral limitation factors (use and modification of the aerobic system activation rate) in individuals with different aerobic fitness levels during moderate exercise. Although there are some antagonistic data^{6,15,28}, prior moderate exercise can also reduce the SC of subsequent exercise^{28,29}.

Few studies have assessed the effects of prior moderate exercise on performance / tlim of the main exercise^{8,28}. Burnley et al.⁸ analyzed the effects of prior moderate exercise (six minutes followed by seven minutes of recovery) on the metabolic response and performance of exercise performed in the severe domain (two minutes at 90% VO_2max followed by five minutes all out). The authors found that prior moderate exercise did not increase [La] (1 mM), but changed the average power (338 W) observed during the fifth minute of sprint compared to the control condition (330 W)

(Box 1). Thus, it was found that prior moderate exercise seems to increase performance (~ 2%) during subsequent exercise performed in the severe domain, even with low [La] at the beginning of the exercise. Moreover, Koppo et al.²⁸ found no effect of prior moderate exercise (6 or 12 min of duration) on tlim performed at 95% VO₂ max (duration ~ 10 min) although SC was attenuated after prior exercise. Thus, as evidence is still scarce and apparently contradictory, one could not recommend at which conditions and whether prior moderate exercise could be used to improve short-duration aerobic performance.

Box 1. Studies investigating the effects of prior moderate exercise on VO₂ kinetics and performance.

Reference	Subjects	Modality	Prior exercise intensity	Prior exercise duration	Recovery	Results
Burnley et al. ³	N = 10 A	Cycling	80% LT	6 min	6 min at 20 W	↔ VO ₂ kinetics
Gurd et al. ²⁵	N = 12 A	Cycling	80% LT	6 min	6 min at 20 W	↓ Tau
Burnley et al. ⁸	N = 12 TC	Cycling	80% VL	10-12 min	10 min	↑ VO ₂ Amplitude, ↑ Mean power
Koppo et al. ²⁸	N = 12 TC	Cycling	50%VO ₂ peak	12 min	6 min	↓ VO ₂ SC ↔ Time limit

A = Active individuals; TC = trained cyclists; LT = Lactate threshold; VL = ventilatory threshold; VO₂peak = peak oxygen uptake; Tau = time constant; SC = slow component.

Prior heavy exercise

Several studies have found that prior exercise on the heavy domain (i.e., above LT), where the tau limitation seems to be a function of the central O₂ delivery³⁰, can change the VO₂ kinetics during subsequent heavy and severe exercises^{6,8,31}.

Gausche et al.³¹ reported that prior exercise performed above LT (50% D), accelerated the VO₂ kinetics in subsequent heavy exercise (50% D). The authors point out that the improvement of O₂ delivery due to vasodilation of muscles and the Bohr effect, which changes the HbO₂ dissociation curve to the right, increased O₂ extraction. Subsequently, Gerbino et al.² also found a faster response of the VO₂ kinetics adjustment (tau - 34.4 vs 27.6 s) in exercises performed in the heavy domain, only after prior heavy exercise, and the same was not observed after prior moderate exercise. Smaller increase in [La] and smaller reduction in pH during heavy exercise after prior heavy exercise were also observed. The authors also suggested that the results were consistent with improved perfusion limitation during heavy exercise as a result of acidosis-induced vasodilation². In both studies, VO₂ kinetics was analyzed using a monoexponential adjustment (MRT) of the total VO₂ response to exercise, not allowing identifying which phase of adjustment of the VO₂ response was modified by prior exercise. However, other studies^{3,33} analyzing the VO₂ response with models of two or three components, which allow identifying the different phases of the VO₂ response adjustment, found different results. In these studies, it was found that tau of the primary phase was not affected by prior exercise, while the primary component amplitude and SC were increased and reduced, respectively. Thus, changes in MRT found in studies by Gausche et al.³²

and Gerbino et al.² probably occurred due to the reduction in SC and not to the acceleration of the initial VO_2 response (i.e., tau of primary phase). Additionally, Burnley et al.³ confirmed that VO_2 kinetics was only altered by prior heavy exercise, and not by prior moderate exercise. The VO_2 kinetics during severe exercise also appears to be modified by prior heavy exercise^{6,10}. Burnley et al.⁶ found that after 10 min of heavy exercise (six minutes at 50% D), the VO_2 amplitude (absolute and primary) was increased in relation to the control condition. Similarly, Jones et al.¹⁰ found that heavy exercise (six minutes at 50% D) increased VO_2 measured in the first minute of exercise performed at intensities of 100, 110 and 120% $\text{VO}_{2\text{max}}$.

Some studies have analyzed the effects of prior heavy exercise on the tlim of heavy and severe exercises^{5,10,24,28}. Koppo et al.²⁸ investigated the effects of prior heavy exercise on tlim at 95% $\text{VO}_{2\text{max}}$. Although SC was reduced (~ 47%), tlim was not different between conditions with (~ 570 s) and without prior exercise (~ 594 s). Bailey et al.⁵ also found no effect of prior heavy exercise (40% D) on tlim performed at 80% D (~ 90-95% $\text{VO}_{2\text{max}}$). Partially antagonistic data were obtained by Burnley et al.²⁴, whose found improvement in tlim 10 min after heavy exercise at intensities of 70%D and 100% $\text{VO}_{2\text{max}}$. At intensities of 60%D and 80%D, tlim was not significantly modified. Jones et al.¹⁰ analyzed the effect of heavy exercise (50% D) on tlim at intensities of 100, 110 and 120% $\text{VO}_{2\text{max}}$ in active individuals and found that there was a significant increase in tlim at 100% (from 386 to 613 s), 110% (from 218 to 284 s) and 120% (from 139 to 180 s) (Box 2).

In whole, these data show that prior heavy exercise can modify the VO_2 kinetics of exercise performed in the heavy and severe domains. However, data show that the improvement of tlim after prior heavy exercise seems to occur only at maximal ($\text{VO}_{2\text{max}}$) and supramaximal intensities (> $\text{VO}_{2\text{max}}$), i.e., in the severe domain where tlim is between 2-3 and 5-7 min.

Box 2. Studies investigating the effects of prior heavy exercise on VO_2 kinetics and performance.

Reference	Subjects	Modality	Prior exercise intensity	Prior exercise duration	Recovery	Results
Burnley et al. ²⁴	N = 10 TC	Cycling	50% Δ (LT - $\text{VO}_{2\text{max}}$)	6 min	10 min	$\uparrow \text{VO}_2$, $\downarrow \text{SC}$, \uparrow Time limit
Burnley et al. ¹⁵	N = 9 A	Cycling	50% Δ (LT- $\text{VO}_{2\text{max}}$)	6 min	6 min	$\uparrow \text{VO}_2$ Amplitude, $\downarrow \text{SC}$
Gerbino et al. ²	N = 11 A	Cycling	50% Δ (LT- $\text{VO}_{2\text{max}}$)	6 min	6 min	$\downarrow \text{Tau}$
Burnley et al. ³	N = 10 A	Cycling	50% Δ (LT- $\text{VO}_{2\text{max}}$)	6 min	6 min	$\downarrow \text{MRT}$
Jones et al. ¹⁰	N = 7 A	Cycling	50% Δ (LT- $\text{VO}_{2\text{max}}$)	6 min	7 min	\uparrow Time limit \uparrow Increased VO_2

TC = trained cyclists; A = Active individuals; 50% D (LT- $\text{VO}_{2\text{max}}$) = Delta of variation of percentage difference between lactate threshold and $\text{VO}_{2\text{max}}$; LT = Lactate threshold; MRT = Mean response time; Tau = time constant; SC = slow component; $\text{VO}_{2\text{max}}$ = maximum oxygen uptake; VO_2 = oxygen uptake.

Prior severe exercise

Prior severe exercise, i.e., that performed above CP is characterized by the continuous use of anaerobic reserves (i.e., anaerobic work capacity - AWC). The depletion rate of AWC is determined by the amplitude of a given in-

tensity in relation to CP, where the time to exhaustion can be predicted by the power vs time hyperbolic model. In fact, this relationship allows estimating CP (the asymptote of the relationship) and AWC (constant amount of work that can be performed above CP)^{7,11}. Thus, unlike moderate and heavy domains, prior severe exercise involves the use of AWC, which can interfere with the performance / tlim of subsequent severe exercise. In this context, the interaction between the prior exercise characteristics (intensity and duration) and the recovery time until the subsequent exercise may influence the effects of prior severe exercise.

The effects of prior severe exercise on VO₂ kinetics in the subsequent exercise appear to be similar to those observed after prior heavy exercise. Ferguson et al.³⁴ found that prior severe exercise did not affect tau of primary response during subsequent severe exercise (tlim between 3 and 12 min). However, primary amplitude and SC were increased and decreased, respectively. In this study, the recovery between exercises was only 2 min. In a similar protocol model, Bailey et al.⁵ found the same results of the previous study, emphasizing only that the recovery periods were longer (3, 9 and 20 min). These different intervals produced the same effects on VO₂ kinetics.

As previously reported, the effects of prior severe exercise on tlim seem to depend on the exercise intensity of the prior exercise and the recovery period between exercise sessions. Prior exercise performed in the severe domain with load to induce exhaustion at 6-8 min followed by shorter (2-6 min)^{34,35} or even longer recoveries (15 min)³⁵ can reduce tlim in severe exercise probably due to insufficient AWC restoration. Similarly, Caritá et al.³⁶ using less intense prior severe exercise (70% D, tlim ~ 15-20 min) and 6 min recovery period found maintenance (95% VO₂max) or decrease of tlim (100 to 110% VO₂max). However, severe exercise performed at this intensity (70% Δ, tlim ~ 15-20 min) and with sufficient recovery periods (9 and 20 min), increases tlim by 15-30% in the severe domain of submaximal intensity (<100 % VO₂max)⁵ (Table 3). Thus, for prior exercise performed in the severe domain, there seems to be an optimal relationship between intensity and recovery duration, so that exercise tolerance can be increased. This combination probably optimizes the balance between the positive effects of prior exercise on VO₂ kinetics and the sufficient recovery time for muscle homeostasis (restoration of creatine phosphate and H⁺ ions).

Therefore, prior severe exercise allowing tlim time between 15-18 min (~ 105% CP) and performed with recovery periods between 9 and 20 min can improve performance during submaximal exercise (<100 % VO₂max), which is also performed in the severe domain. Prior severe exercise of greater intensity (tlim between six and eight minutes) followed by short recovery periods (up to 15 min) can decrease performance in the severe domain (submaximal, maximal and supramaximal) and is therefore not recommended.

Box 3. Studies investigating the effects of prior severe exercise on VO₂ kinetics and performance.

Reference	Subjects	Modality	Prior exercise intensity	Prior exercise duration	Recovery	Results
Ferguson et al. ³⁴	N = 6 A	Cycling	Tlim ~ 8 min	6 min	2 min at 20 W	↔ Tau, ↓ SC, ↑ VO ₂
Bailey et al. ⁵	N = 8 A	Cycling	70%Δ (LT-VO ₂ max)	6 min	9 and 20 min	↑ Tlim
Ferguson et al. ³⁵	N = 6 A	Cycling	Tlim ~ 6 min	6 min	2.6 and 15 min	↔ VO ₂ kinetics, ↔ Tlim
Burnley et al. ²⁴	N = 10 TC	Cycling	Tlim ~ 8 min	6 min	6 min	↑ VO ₂ , ↔ Tlim, ↔ AWC

A = Active individuals; TC = trained cyclists; Tlim = Limit time; LT = Lactate threshold; 70% D (LT-VO₂max) = Delta of variation of percentage difference between lactate threshold and VO₂max; Tau = time constant; VO₂ = oxygen uptake; SC = slow component; AWC = Anaerobic work capacity.

Possible mechanisms

Factors such as increased muscle temperature²⁸ and metabolic acidosis⁴ do not seem to explain the effects of prior heavy exercise on VO₂ kinetics. It is noteworthy that blood lactate concentrations near 3 - 3.5 mM appear to be an important indicator of metabolic conditions that precede main exercise⁴. These values are dependent on the interaction between prior exercise intensity and duration and recovery period between exercise sessions. Exercises performed in the heavy domain during six minutes and recovery intervals between 6 and 10 min tend to produce these values. Same duration exercises performed in the severe domain may need longer recovery periods (> 15 min) in order to reach these lactate values⁵. On the other hand, the more homogeneous distribution of intramuscular blood flow, decreasing the anaerobic contribution and the change in the pattern of muscle recruitment are among the changes that may influence these effects on the VO₂ kinetics⁴.

Burnley et al.⁶ analyzed the recruitment of muscle fibers through integrated electromyography (iEMG) in heavy exercise after prior severe exercise (70% D). In this study, a 19% increase in the iEMG of the gluteus maximus, vastus lateralis, vastus medialis muscles along with an increase in the amplitude of the primary component of VO₂ was observed. However, there was no increase in the median frequency (MPF), which represents a preferential recruitment of motor units, or type II fibers. The authors suggest that these results may indicate an increase in the recruitment of all types of muscle fibers and not only the preferential recruitment of type II fibers.

The factors mentioned above can modify the VO₂ kinetics (increased amplitude of the primary component and decreased SC), which has been consistently found after prior exercise (moderate, heavy and severe). The SC of muscle VO₂ is associated with the slow component of the phosphate creatine (PCr) kinetics and represents a reduction in muscle efficiency. This high O₂ cost of the activity has been explained by the reduced efficiency of the contractile machinery rather than the higher O₂ cost for phosphate production. Thus, it has been proposed that the development of the SC of VO₂ is closely related to exercise (in) tolerance during exercise performed in the severe domain. Indirect evidence has been provided by various interventions that reduce the magnitude of the SC of VO₂. For example, aerobic training³⁷ and nitrate supplementation⁵ are associated with reduc-

tion in the magnitude of the SC of VO_2 and increased exercise tolerance. Therefore, changes in the SC of VO_2 may explain, at least in part, the increased tolerance to aerobic exercise in the severe domain. However, it is noteworthy that changes in the SC of VO_2 determined by prior exercise are not always accompanied by increased exercise tolerance³³. Therefore, changes in the VO_2 kinetics do not seem to be a prerequisite for increased aerobic performance after prior exercise.

FINAL COMMENTS

Prior exercise, which can easily be used in training sessions and competitions, can improve performance / tlim on high-intensity and short-duration aerobic exercises (2-3 up to 7-9 min - severe domain). For this, an optimum combination between the intensities of both exercise sessions (prior and subsequent) and the interval between them is required.

For moderate prior exercise, evidence is still scarce and seemingly contradictory, which in our view prevents its recommendation for use with the goal of improving short-duration aerobic performance.

Using heavy exercise, there is more evidence that the tolerance to severe exercise of maximum and supramaximal intensity ($> 100\% \text{VO}_2\text{max}$ - tlim between 2 and 5 min) can be improved. Exercises in heavy domain with durations six minutes and interval between 6 and 10 min are recommended. For severe exercise of submaximal intensity ($<100\% \text{VO}_2\text{max}$ - tlim between 9 and 12 min), current data do not support the use of prior heavy exercise with the goal of increasing exercise tolerance.

Special attention should be given to prior severe exercise because exercise tolerance can even be reduced, depending on intensity (prior and subsequent) and recovery time. Severe exercises yielding tlim between six and eight minutes (close to $100\% \text{VO}_2\text{max}$), regardless of recovery time (up to 15 min), can maintain or decrease tlim in severe exercise (submaximal, maximal and supramaximal). Severe exercises of lower intensities (tlim 15-18 min) and recovery periods between 9 and 20 min seem to improve tolerance during severe exercise at submaximal intensity ($<100\% \text{VO}_2\text{max}$).

In short, prior exercise performed in different domains (moderate, heavy and severe) can modify the VO_2 kinetics (increasing the amplitude of the primary component and decreasing SC) during short-duration exercise with aerobic predominance (~ 2-9 min). Changes in the SC of VO_2 seem to explain, at least in part, the increased tolerance to aerobic exercise in the severe domain. Regarding performance, it was concluded that for exercises performed in the severe domain at submaximal intensity ($<95\% \text{VO}_2\text{max}$), tolerance can be increased when prior exercise is severe and recovery is sufficient (> 9 min). At these intensities, the depletion rate of AWC is slower and the effects of prior severe exercise seem to optimize changes that increase exercise tolerance. At higher intensities ($\geq 100\% \text{VO}_2\text{max}$), where the AWC depletion rate is proportionally larger, and thus exercise tolerance is more dependent on AWC, prior heavy exercise seems to increase effort tolerance

even more, for not depleting AWC. Thus, there seems to be an optimal relationship between the effects of prior exercise intensity (i.e., greater or lesser use of AWC), recovery time (i.e., AWC restoration rate) and the intensity of exercise performed subsequently (i.e., greater or lesser use of AWC).

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