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BLOOD LACTATE TIME COURSE CHANGES FROM HIGH-SPEED EXERCISE

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Abstract

Introduction: Post-workout blood lactate concentration ([BLa^-]) values aid training prescriptions for athletes.

Objective: To compare changes of [BLa^-] from two workouts, each comprised solely of repetitions that either entailed intermittent (phasic) or continuous (tonic) force exertion, done by competitive (n = 47) and novice (n = 26) athletes.

Methods: Workouts were performed on a high-speed exercise device using the athlete's left arm. Per exercise bout [BLa^-] values were measured pre- as well as at zero, five, ten, 15 and 20 minutes post-exercise. Total work (TW) values for each gender-workout-training status assignment were assessed with a 2x2x2 ANOVA with repeated measures for workout. [BLa^-] data were compared with a 2(gender) x 2(workout) x 2(training status) x 6(time) ANOVA with repeated measures for workout and time.

Results: TW had a two-way interaction, as the tonic bout done by competitive athletes evoked higher values than the other assignments. Inter-gender (male > female) TW differences occurred for the competitive group; none occurred for novices due to higher variability from the limited number of novice males. [BLa^-] values yielded numerous significant gender x workout x training status differences over the time points examined.

Conclusions: Temporal [BLa^-] changes saw competitive athlete values rise sharply from zero to five minutes post-workout, while novice values changed little over the same time interval. This implies post-workout [BLa^-] were impacted by the TW performed. Temporal differences regarding the time peak post-workout [BLa^-] values occur may aid the design of divergent training prescriptions for competitive and novice athletes.

Key words: *work volume, tonic, phasic, training status*

Introduction

Lactate's primary origin within the body is intramuscular, where glycolytic rates may rise 1000-fold as persons go from rest to supramaximal exercise [1]. Thus among metabolites lactate perhaps undergoes the greatest exercise-induced changes [1-3]. As lactate is formed, concurrent H^+ accrual evokes metabolic acidosis and fatigue that impairs exercise performance. Yet if exercise is to proceed at such times intramuscular conditions must include H^+ removal of from cells. Since intramuscular lactate changes parallel similar patterns of H^+ activity, it is important to quantify lactate to know how the body copes with exercise-induced acidosis. Lactate and H^+ efflux lead to their appearance within extracellular spaces such as the blood. Thus post-exercise blood lactate concentration ([BLa^-]) values are an important marker to monitor over time. Most training prescriptions for athletes are based on a single post-workout [BLa^-] measurement, typically obtained five minutes after the cessation of exercise, which presumably represents a peak value [1,4-6].

Supramaximal activity yields very high post-workout [BLa^-] values; however the lactate-exercise performance relationship for anaerobic activity is not well understood [7]. This is in part since lactate entry rates into the blood are hard to discern from anaerobic activity, as high intensities and workloads typically slow lactate's entry into the vasculature and evoke peak values long after exercise cessation [3,7]. This is disconcerting as the measurement of a post-exercise [BLa^-] from supramaximal activity aids in the estimation of kilocalorie costs, the relative contributions of energy systems to ATP resynthesis, and the individual anaerobic threshold [8-10]. Due to this plethora of potentially valuable information, it is important to acquire a greater understanding of [BLa^-] values derived from supramaximal exercise.

Intramuscular lactate may reach 15-25 mM after 30-120 second supramaximal bouts [11]. Sixty-second supramaximal bouts evoked higher post-workout [BLa^-] than either 30- or 90-second efforts [12]. Peak values typically occur 3-9 minutes after ~60 second supramaximal bouts [2,11,12]. Thereafter [BLa^-] gradually declines yet may remain higher than pre-exercise values for up to 60 minutes; thus lactate displays temporal-based changes [10,11]. Work rate, exercise duration, age and muscle fiber type were assessed for their impact on [BLa^-] values [3,13-15]. Yet little is known about the comparative [BLa^-] changes seen before and after supramaximal exercise from persons

with diverse training backgrounds, such those for as competitive and novice athletes. The degree to which athletes incur/cope with lactate and H^+ accrual may vary, even when two such groups perform the same supramaximal bout. Since exercise prescriptions may be based on post-workout [BLa^-] values, athletes with different training backgrounds should to have their prescriptions tailored to address their individual needs [1,11]. Comparative differences may be impacted by a competitive athletes' greater prior exposure to supramaximal activity, which assumes higher performance measures and post-exercise [BLa^-] values.

Yet prior exposure is somewhat negated if workouts occur on novel exercise device such as the Impulse (Impulse Training Systems; Newnan, GA) which may aid speed development in athletes [16]. Impulse workouts entail rapid movement of a weight sled that carries a light mass. Forces to initiate sled movement are modest (~0.45 N); thus strength differences among competitive and novice athletes should not act as a serious workout limitation [17]. Its high-speed nature extends to both types of repetitions performed on the device. Termed tonic and phasic, they entail continual and intermittent force exertion respectively. The intermittent force application of phasic actions mimics repetitive bilateral muscle activity patterns seen with running and other common motor skills. In contrast the continual force exertion of tonic actions raise the amount of time muscles remain under tension, which may yield higher post-exercise [BLa^-] values. Thus our study measures [BLa^-] changes to supramaximal workouts, each comprised exclusively of phasic or tonic repetitions, from competitive and novice athletes. We hypothesize [BLa^-] results will yield significant differences by training group and workout.

Methods

Subjects

Our study adhered to Helsinki Declaration guidelines for human subject data collection. Subjects gave informed written consent. Our sample was comprised of competitive (24 men, 23 women) and novice (4 men, 22 women) athletes. Competitive athletes were university scholarship recipients and habitually engaged in structured exercise programs to improve sport performance for at least 36 months. In contrast novices had no more than 16 weeks of prior exercise experience. The distribution of competitive athletes was: rowing-5, golf-3, American football-15, track-8, basketball-3, softball-6, European football-4, tennis-3. Novices trained 2-3 $d \cdot wk^{-1}$ to enhance their physical conditioning, yet did so without the goal of participation in competitive sports. Characteristics of male competitive athletes (mean ± sd) were as follows: height 185.8 ± 7.3 cm, mass 103.9 ± 24.0 kg, body fat percentage 20.6 ± 7.3%; while those for the women in the same group were: height 167.9 ± 2.9 cm, mass 65.3 ± 6.2 kg, body fat percentage 24.7 ± 1.2%. Novice male athlete characteristics were: height 178.0 ± 6.8 cm, mass 92.5 ± 8.4 kg, body fat percentage 23.3 ± 3.6%; while values for that group's women were: height 160.8 ± 9.4 cm, mass 65.5 ± 15.0 kg, body fat percentage 28.2 ± 10.3%. None had prior Impulse experience, which helped negate inter-group and -workout differences at the start of data collection.

Procedures

Subjects made three laboratory visits, each separated by one week. First visits began with collection of subject's height, mass and body fat data. Heights were assessed as they stood barefoot in an upright posture. Mass and body fat were measured with a bioimpedance scale (BF-350; Tanita Corp., Tokyo, Japan). The scale's accuracy is within ± 5% of values obtained via dual energy x-ray absorptiometry scans, and produce's repeatable results to within ± 1% if test conditions remain consistent [18]. First visits continued with familiarization to the Impulse, in which subjects stood next to the device and performed tonic and phasic rowing (concurrent flexion/extension at the shoulder and elbow joints) repetitions with their left arm. We chose this exercise for the current study in the belief all subjects could easily perform it. Due to the high-speed nature of the current workouts maximal strength, which typically elicits force exertion at low contractile velocities or no movement at all (isometric), no such pre-exercise measurements were made as they have little application to the workout paradigm under investigation. To best accustom subjects with the Impulse, they exerted submaximal effort and focused on proper exercise technique. After tonic and phasic repetitions were done correctly, first visits concluded.

Per subject, second and third visit times were kept constant to limit data variability. They arrived for workouts between 1200-1600 hours. To begin their second visit, subjects were randomized to one of the two types (tonic, phasic) repetitions. Workouts entailed exercise comprised solely of either tonic or phasic repetitions. They performed the opposite repetition assignment for their third visit. Second and third visits began with a baseline [BLa^-] measurement. A lancet extracted ~20 μl of blood from subject's middle finger on their right hand onto a test strip inserted within an analyzer (Accutrend; Hawthorne, NY) that measured [BLa^-] via fluorometric absorbance. Operating and calibration procedures followed the manufacturer's guidelines, which yielded high levels of data reproducibility [19,20]. Subjects then began the exercise portion of their visits. As seen in Figure 1 and with 8 kg of added sled mass, they performed as many repetitions as possible through a full range of motion. The same load was added for all subjects to permit a more fair

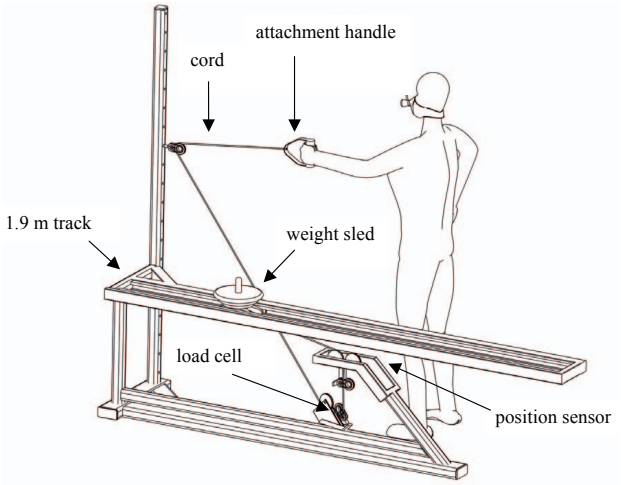


Fig. 1. *The current study exercise (unilateral rowing) done on the Impulse*

comparison of post-exercise [BLa$^-$] values. They were instructed to exert maximal effort and not to pace themselves as they adhered to their repetition (tonic, phasic) assignment. They performed two 60-second sets separated by a 90-second rest period and received verbal encouragement. [BLa$^-$] was measured at zero, five, ten, 15 and 20 minutes post-exercise.

Tonic actions note continual force exertion elicits a commensurate degree of sled displacement along the 1.9 m track. Tonic actions cause the cord, which connects the sled and attachment handle, to remain continually taught. In contrast phasic repetitions see an alternating contraction/relaxation pattern by the involved muscles. This pattern seen with phasic actions causes the cord to become taut and immediately reverses the direction of sled movement. As the sled reverses direction no forces are exerted as the cord becomes slack. The cord does not become taut again until another phasic repetition begins and causes the sled's return back to its initial location on the track. Sled movement during phasic actions notes high rates of acceleration [17,20,21]. Impulse instrumentation entailed a load cell and position sensor to measure force and displacement respectively. Force and sled displacement data were received by software (Labview 8.0; Austin, TX) at 1 kHz and used to quantify the total work (TW) performed.

Statistical analyses

[BLa$^-$] and TW data were each initially treated with Z-scores to identify data outliers. Per dependent variable, Z scores were calculated as differences between individual and mean values for our data set, divided by the standard deviation for that same data. Outliers were omitted from further analysis. Data were also examined for compliance to ANOVA assumptions (normality, independence, homogeneity of variance). TW means were compared with a 2(gender) x 2(workout) x 2(training status) ANOVA with repeated measures for workout and t-tests as a post-hoc. [BLa$^-$] values were compared with a 2(gender) x 2(workout) x 2(training status) x 6(time) ANOVA with repeated measures for workout and time. Scheffe's post-hoc was used as our post-hoc. With data pooled across genders, groups and workouts, a Pearson Product Moment Correlation assessed the strength of the relationship between TW and the delta (baseline to peak) rise in [BLa$^-$]. An $\alpha = 0.05$ denoted significance for all analyses.

Results

Z-score analyses yielded no outliers and each ANOVA assumption was met. Table 1 TW results include a two-way interaction; with data from both genders pooled post-hoc analysis revealed significantly higher values from the tonic workout done by competitive athletes. Versus intra-group and -workout values, Table 1 also displays inter-gender (male > female) TW differences with the competitive group; none occurred with the novices due to higher variability from the limited number of novice males. [BLa$^-$] results appear in Figure 2, which display changes over time per gender-training background-workout assignment. Analysis of [BLa$^-$] data yielded multiple significant post-exercise differences. Scheffe's post-hoc revealed those significant inter-assignment [BLa$^-$] differences occurred at zero, five, ten, 15 and 20 minutes post-exercise.

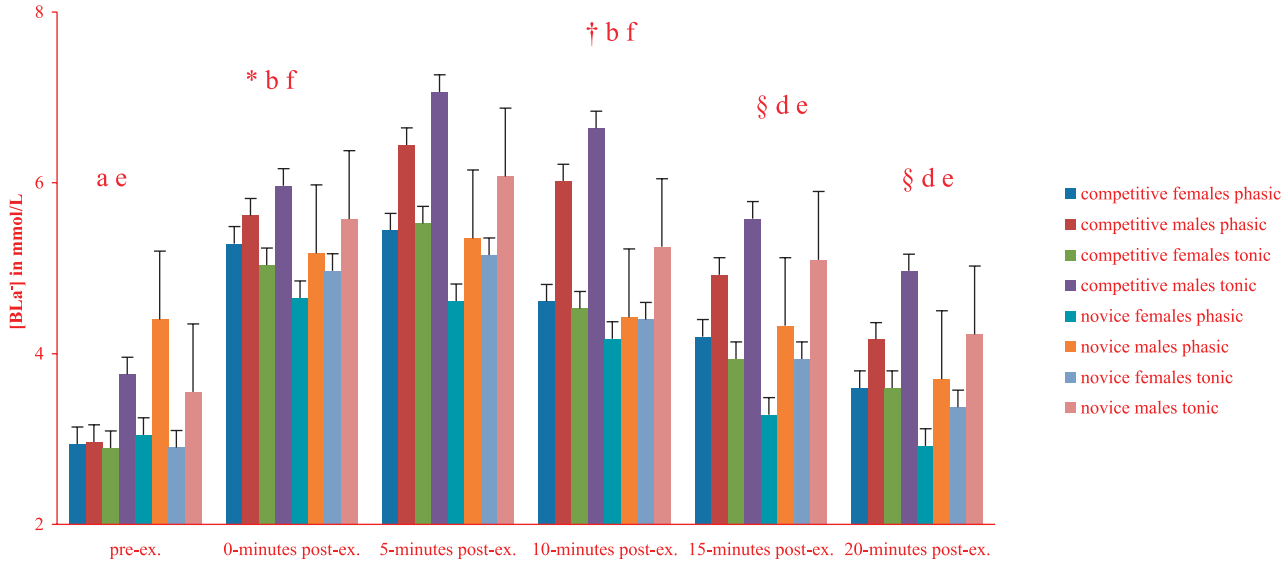
Post-hoc analysis of our [BLa$^-$] data revealed no significant pre-exercise differences by gender, workout or training background. However at zero minutes post-exercise the following significant [BLa$^-$] differences were noted: competitive males phasic, competitive males tonic > novice females phasic; as well as competitive males tonic > competitive females tonic. At five minutes post-exercise the following significant [BLa$^-$] differences occurred: competitive males phasic, competitive males tonic > competitive females phasic, competitive females tonic > novice females phasic; in addition at the same time point novice males tonic > novice females phasic. At ten minutes post-exercise the significant [BLa$^-$] differences were as follows: competitive males tonic > competitive males phasic, novice males tonic > competitive females phasic, competitive females tonic, novice females phasic, novice females tonic. At both 15 and 20 minutes post-exercise demonstrated identical significant [BLa$^-$] differences. Those differences were as follows: competitive males tonic > competitive males phasic > competitive females phasic, competitive females tonic, novice females tonic > novice females phasic; in addition novice males tonic > novice females phasic.

Figure 2's letters (competitive: a-d, novice: e-f) designate time-related group changes with respect to their training backgrounds. While our competitive group produced a biexponential curvilinear pattern, novice

Table 1. *Total work results (in kilojoules, mean ± SD)*

	phasic	tonic
Competitive Athletes		
Men Only	10,323,000 ± 1,431,346†	15,694,423 ± 2,820,773†
Women Only	9,189,696 ± 1,428,394	11,561,727 ± 1,986,715
Genders combined	9,886,161 ± 1,525,558	13,958,700 ± 3,203,695*
Novice Athletes		
Men Only	10,272,075 ± 2,033,943	14,106,925 ± 1,844,932
Women Only	7,891,238 ± 856,849	10,109,099 ± 2,806,094
Genders combined	8,327,881 ± 1,343,456	10,799,281 ± 3,037,242

* source of the group x repetition interaction ($P < 0.05$)
† inter-gender (men > women) differences versus corresponding intra-group and -workout value ($P < 0.05$)



* competitive males phasic, competitive males tonic > novice females phasic, competitive males tonic > novice females tonic
# competitive males phasic, competitive males tonic > competitive females phasic, competitive females tonic > novice females phasic, novice males tonic > novice females phasic.
† competitive males tonic > competitive males phasic, novice males phasic > competitive females phasic, competitive females tonic, novice females phasic, novice females tonic.
§ competitive males tonic > competitive males phasic > competitive females phasic, competitive females tonic, novice females tonic > novice females phasic, novice males tonic > novice females phasic.
Competitive time changes ($P < 0.05$, letters a-d): 5-post > 0-post, 10-post > 15-post, 20-post > pre-ex.
Novice time changes ($P < 0.05$, letters e-f): 0-post, 5-post, 10-post > 15-post, 20-post, pre-ex.

Fig. 2. *[BLa$^-$] (mean ± sd) for our eight gender-workout-training background assignments*

results evoked fewer time-based differences. Perhaps the most unique outcome is the [BLa$^-$] changes from zero to five minutes post-exercise. As the competitive group incurred significant [BLa$^-$] gains over that time interval and produced peak values five minutes post-workout, novice data over that same time period were essentially unchanged. Despite the same protocol as our competitive athletes, comparative data from our novice group produced lower TW values which led to 1): shorter times to a peak post-exercise [BLa$^-$], 2): a lower absolute peak [BLa$^-$] and 3): fewer time-related changes. Finally our Pearson correlation results revealed a significant ($r = 0.41$) association for TW and delta [BLa$^-$] values.

Discussion

Large TW values are indicative of rapid weight sled displacements that attest to the high-speed nature of Impulse workouts. Since work is the product of force x distance, the two-way interaction attributed to the tonic workout done by competitive athletes was likely due to their attainment of higher absolute forces and sled velocities during that exercise bout [6]. Results affirm our hypothesis as analysis of [BLa$^-$] values produced numerous significant gender x workout x training status differences over the time points examined [14], yet may be an important and distinct temporal inter-subject application that can be used to differentiate training protocols between competitive and novice athletes. Since training protocols are

often based on a peak post-workout [BLa^-] [1]; our results imply measurements from competitive athletes should occur five minutes after the cessation of exercise, yet for novice athletes they may essentially occur as soon as workouts are completed. Stark temporal differences offers an important distinction that should aid training prescriptions for competitive and novice athletes.

While our [BLa^-] results concur with prior outcomes, much of the prior literature were collected from both supramaximal and continuous incremental cycle ergometry exercise done to volitional fatigue; as due to the novelty of the Impulse there is comparatively less lactate data from this exercise modality. [BLa^-] are function of the metabolite's entry rate into, and removal from, the vasculature [3]. At low intensities, progressive workload increases are accompanied by proportionate gains in [BLa^-] [1]. Yet when the anaerobic threshold is reached the workload-lactate relationship is not linear, which is problematic for the design of training prescriptions as higher intensities are routinely employed for competition preparation by many athletes [1].

Post-workout [BLa^-] after high intensity exercise exhibit a biexponential curvlinear pattern that entails a rapid rise followed by a gradual decline [7,11,22]. Evidence implies [BLa^-] peak five minutes post-exercise [1,4,6]. Many factors impact lactate's entry and removal rates into and from the bloodstream; some of which help explain the multiple significant post-exercise differences. Regarding exercise durations' impact on [BLa^-], lactate entry rates were compared from ten- and 30-second cycle ergometery sprints [13]. Results showed the longer sprint had 1): a slower lactate entry rate into the blood, 2): a higher absolute [BLa^-] and 3): required more time to reach peak values [13]. Another cycle ergometry trial compared lactate responses from sedentaries and athletes [14]. While peak [BLa^-] were similar, time to peak values (sedentary: 1.8 ± 0.7 minutes, athletic: 4.3 ± 1.1 minutes), an index of lactate's rate of entry, differed significantly [14]. That trial did not report performance measures that could explain why peak [BLa^-] included no inter-group differences, yet their temporal results are like our outcomes that showed peak values occurred at zero (novice) and five (competitive) minutes post-exercise [14].

Workload's effect on lactate's entry rate into blood was also assessed from an incremental cycle ergometry protocol [7]. Subjects pedaled for six minutes each at 300, 600, 900 and 1200 $kg \cdot m \cdot min^{-1}$. Results showed the magnitude of peak values was based on subject's tolerance to higher workloads, which produced a biexponential curvilinear pattern for post-exercise [BLa^-] changes over time [7]. Such an effect concurs with our results, as Figure 2 shows higher peak [BLa^-] for competitive athletes, a biexponential post-exercise pattern and several significant temporal changes across the six measurement periods. Yet our novice athletes who performed less work had post-exercise [BLa^-] data with lower absolute peak values and, with their changes plotted over time, were more linear over those time periods. Thus duration- [13] and workload-based [7] trials noted better performances evoke higher [BLa^-] and require longer lengths of time to reach peak values. This infers entry rates into blood are inversely related to exercise performance, as higher workloads/intensities slow the rate of lactates' appearance in the vasculature [3].

Such differences led to a biexponential response for our competitive athletes while novice values, by comparison, plateaued and led to the multiple significant post-exercise differences shown in Figure 2. Regarding the Figure 2 zero-to-five minute post-workout [BLa^-] changes, lactate entry rates rise dramatically at high exercise intensities, which infer work rate increases cause a proportionally greater rise in the [BLa^-] [12]. It is hard to ascertain the precise intensity that must be crossed to observe this rise with exercise, yet it appears competitive, but not novice, athletes crossed this threshold to a far greater extent. Thus since our results concur with other trials [7,13], that show the disparate work volumes from our competitive and novice groups likely evoked both different lactate entry rates and peak [BLa^-] values.

[BLa^-] are also impacted by rates of clearance from the vasculature. Like its impact on the metabolite's entry into the blood [13], factors that influence lactate's clearance also include exercise duration, which was assessed from three- and six-minute cycle ergometry bouts [5]. Versus a three-minute bout, the six-minute protocol had a slower lactate removal rate but led to a higher volume of work [5]. Such results are not unlike our own, since the tonic bout done by our competitive group elicited the highest TW and, at 20 minutes post-exercise, that assignment's [BLa^-] had yet to return to pre-exercise values. Our results may be in part due to the inverse relationship between lactate clearance and work rates [5]. Higher intensities note removal rates plateau or decline [23]. Some suggest lactate uptake by tissues may be saturated with respect to their ability to receive the metabolite [23]. In contrast the removal of lactate by our novice group who performed less work tended to have 1): a lower absolute peak [BLa^-] that occurred earlier post-exercise and 2): fewer time-based changes. Due to these inter-group differences, lower peak [BLa^-] values in our novice athletes likely meant they experienced few constraints related to lactate's rate of uptake by oxidative (heart, liver, type I muscle fiber) tissues [23]. Yet it should also be noted our results could have been impacted by the gender composition of our groups, as female subjects generally produced

lower TW values than their male counterparts that in turn contributed to the divergent post-exercise lactate kinetic relationships between men and women.

Our novice subjects had a peak [BLa^-] that essentially occurred immediately after workouts, in contrast to results that show [BLa^-] values peak five minutes post-exercise [4,6,22]. Like the current study, other trails that examined differences in training background noted discrepancies to lactate-based outcomes [14,15]. An isokinetic knee extensor/flexor trial with male children, teenagers and adults measured [BLa^-] values from two workouts: a four-set 30-second protocol with one minute rests, and a two-set 60-second paradigm separated by a two-minute rest period [15]. [BLa^-] was assessed pre-, mid- and post-workout. Men produced more work and a higher peak [BLa^-] than male teenagers or boys. Versus their baseline data, men's mid- and post-workout [BLa^-] rose significantly for both exercise bouts, yet minor changes occurred over that same time period to boys from the 2x60-second bout, and for both boys and teenagers for the 4x30-second workout [15]. Those results parallel current outcomes, as despite gender representation far different than the Zaferidis et al [15], current novice subjects produced generally lower TW values and, just like the teenagers and boys from the aforementioned study [15], had fewer significant time-based [BLa^-] changes versus those who performed more work.

Current [BLa^-] values appear to be impacted by the TW produced from different workout-training background assignments; it likely had a substantial effect on lactate entry and removal rates, as well as peak [BLa^-] and the time of its post-exercise appearance. Furthermore our results show a significant correlation between TW and delta [BLa^-]. Yet with respect to the time of our peak post-exercise [BLa^-] values, our data are unlike those from a small sample of sedentary subjects [2]. That data, obtained after 60-second supramaximal runs, had a mean peak [BLa^-] time of 7.65 minutes post-exercise [2]. Yet unlike our study, that data were obtained from a homogeneous sample that engaged a larger amount of muscle mass during exercise. Thus given our study design, exercise protocol and type of subjects examined, we feel our results are a valid representation of temporal post-exercise [BLa^-] changes. Current outcomes suggest, since our study noted marked differences for the times of peak post-workout [BLa^-] between our competitive and novice athletes, training prescriptions should differ among these groups. Coaches should not erroneously assume times of peak post-workout [BLa^-] are the same among different groups of athletes. Furthermore our novice data give reason to question the long-held assumption that [BLa^-] values peak five minutes post-exercise [1,4-6].

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Declaration of interest

The authors report no conflicts of interest.

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