Biochemical Evaluation of Running Workouts Used in Training for the 400-m Sprint

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Abstract

Saraslanidis, PJ, Manetzis, CG, Tsalis, GA, Zafeiridis, AS, Mougios, VG, and Kellis, SE. Biochemical evaluation of running workouts used in training for the 400-m sprint. *J Strength Cond Res* 23(8): 2266–2271, 2009—A 400-m runner relies primarily on the lactate system for energy production. Although several running distances and schemes are used in training for this event, it is not clear which one(s) causes maximal activation of the lactate system so as to optimize adaptations of the lactic capacity. This study examined the effect of 4 running workouts differing in distance (300 vs. 400 m) and mode of execution (continuous/single vs. intermittent) on stimulation of the lactate system and biochemical markers of metabolism and muscle damage. Twelve young men performed 4 runs at maximal effort: 300, 3 × 100, 400, and 2 × 200 m. Blood was drawn before and after exercise for the measurement of lactate, glucose, creatinine, and creatine kinase (CK). Average speed was higher ($p < 0.001$) in the 300- vs. 400-m tests (7.52 ± 0.50 vs. 7.08 ± 0.59 m·s^{-1}) and in the intermittent vs. continuous tests (7.45 ± 0.50 vs. 7.15 ± 0.58 m·s^{-1}). Lactate was higher in the intermittent vs. continuous tests (16.3 ± 2.2 vs. 15.0 ± 2.0 mmol·L^{-1}, $p < 0.05$). Serum glucose, creatinine, and CK increased after exercise ($p \leq 0.001$), and glucose was higher in the 400- vs. 300-m trials (5.76 ± 0.46 vs. 5.33 ± 0.30 mmol·L^{-1}, $p = 0.032$). In conclusion, although all 4 running regimens greatly stimulated the lactate system, it appears that the intermittent workouts are superior compared with continuous ones of the same total distance in increasing the ability for energy production via the lactate system. Thus, intermittent workouts can be successfully used by 400-m athletes to develop specific (speed) endurance and should be considered to precede the continuous runs of racing distance within a macrocycle.

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Introduction

The 400-m run is a highly demanding event. Maintaining near-maximal intensity during this event and diminishing the drop in velocity during the second half require high lactic as well as alactic anaerobic capacity. Thus, it is not surprising that coaches devote a large part of the training time for the improvement of specific (speed) endurance and the lactate system to optimize performance in the 400-m run (30,39).

It is a belief among coaches that the body adapts to the kind of stress that is imposed upon it and performs better under conditions of similar stress. Because the lactate system constitutes the main energy source in a 400-m sprint (20), training programs for the 400-m event aim at maximizing the anaerobic lactic capacity for energy production. Based on the speed and duration of the 400-m event, coaches use continuous/single runs of 300–500 m and sets of shorter repetitive runs (80–200 m) that add up to 300–500 m with short intervals at intensities >90% of best performance (1,30,38,39). While both training programs are used by coaches to stimulate the lactate system for energy production, it is not known which of the 2 approaches (continuous or intermittent runs) stimulates the lactate system to a greater extent. Certainly, the continuous runs of distances close to that of the race (300–500 m) serve an additional goal because they resemble the whole nature of the event in terms of duration of stimulus, tempo, and tactic of the race. The contribution of the lactate system to energy production depends on exercise intensity (speed), duration, and rest intervals. Because the continuous and intermittent modes present these characteristics with different magnitude and configuration, it is difficult to speculate as to which of the 2 training approaches stresses the lactate system to a greater extent. The knowledge of the training method that most effectively stimulates (trains) the athletes' lactate system is of particular importance because it will help coaches to design workouts that fulfill their training goals better.

Furthermore, exercise with repetitive stretch-shortening cycles to exhaustion, such as sprint training, places the muscle

under significant metabolic and mechanical stress causing muscle damage (8). Muscle damage leads to transient loss of force and exercise performance (5,6,31,37). Adequate rest after such exercise is important to enhance muscle regeneration and to prevent the accumulation of muscle damage in successive training sessions (33). Therefore, it is important to know which of various training programs used for the 400-m sprint has a greater potential to produce muscle damage to optimize recovery. In humans, the catalytic concentration of creatine kinase (CK) in plasma is a widely accepted marker of muscle damage and overexertion (21). The postexercise plasma CK concentration may depend on the training status and exercise type, intensity, and duration (3). It has been recently suggested that the postexercise CK rise provides a theoretical basis for recovery strategies and adjustment of subsequent training sessions (35).

Thus, the main aims of the present study were to evaluate and compare 4 running programs used in training for the 400-m sprint and differing in distance (300 vs. 400 m) and mode of execution (continuous vs. intermittent) with respect to (a) stimulation of the lactate system and (b) muscle damage. To achieve our goals, we examined selected biochemical parameters, i.e., blood lactate, glucose, creatinine, and CK. We hypothesized that there would be no differences among the 4 running workouts in stimulation of the lactate system and in muscle damage. Furthermore, we examined changes in running speed during the execution of these training regimes.

Methods

Experimental Approach to the Problem

Each participant performed 4 running tests at maximum effort on an outdoor track with rubber surface in a random counterbalanced design. The tests were (a) 300 m, (b) 3×100 m with 1-minute intervals, (c) 400 m, and (d) 2×200 m with 1-minute interval. Blood was drawn before and after exercise for the measurement of lactate, glucose, creatinine, and CK concentrations. Velocity was measured every 100 m, and the average speed was calculated in all 4 running tests. The rationale for selecting these workout combinations was based on the premise that to train the lactate system (specific endurance/speed), coaches use single runs of 300–500 m and sets of shorter repetitive runs (80–200 m) that add up to 300–500 m with short intervals at intensities >90% of best performance (30,38,39). Furthermore, we used training workouts that approximated the total distance and the average speed of the 400-m race to replicate, as much as possible, the contributions of metabolic pathways for energy production and the tactic of the 400-m race.

Subjects

Twelve healthy men, aged 18.9 ± 0.7 years, having body weight 71.5 ± 5.7 kg and height 182 ± 3 cm, participated in this study. The participants were physical education students engaging in activities such as team sports, running, and jogging on most days of the week. Prior to the investigation, all subjects were informed of the experimental risks and signed an informed consent document. The investigation was approved by the institutional review board for use of human subjects.

Procedures

In preparation for the experimental tests, the participants attended a 4-week training program comprising 2 sessions per week. The aims of this program were to improve physical fitness and to instruct the tactic for properly distributing speed over the racing distances of the experimental tests as well as to record the best times for 100-m and 200-m races.

Each test was preceded by a 40-minute warm-up consisting of slow running for 8–10 minutes, stretching with emphasis on the leg muscles for 10–12 minutes, neuromuscular coordination drills (skipping and heel-to-butt kicks), and three 80-m runs at gradually increasing speed. The tests were spaced 5 days apart and were performed between 11:00 and 13:00 hours in late spring at an ambient temperature of 18–22° C. During the 4 days preceding each test, the volunteers participated in a common program of active recovery from the previous test and preparation for the next one. To control for the effect of nutrition on substrate utilization during exercise, the participants were given standard 2-day dietary plans to be followed before each test. The plans provided 50% of energy from carbohydrate, 35% from fat, and 15% from protein.

In each test, the participants followed a specific pacing strategy that was focused on maintaining, as much as possible, the running speed to maximize performance. This was accomplished by a controlled submaximal start, followed by a progressive increase in running velocity that never reached maximal. To achieve that, the first 100 m in the continuous/single and intermittent 300-m runs was performed at 90% of the best 100-m time, while in the continuous and intermittent 400-m runs, the first 200 m was performed at 90% of the best 200-m time. In the remaining distance of the 300- and 400-m runs, the subjects attempted to maintain the running velocity of the first 100 or 200 m, respectively.

Running Speed. Running time was assessed electronically using (a) 4 pairs of photocells (Tag Heuer, La Chaux-de-Fonds, Switzerland) with the respective reflectors placed on tripods at a height of 1–1.2 m at intervals of 100 m and (b) an electronic chronometer with capacity to measure thousandths of a second (Omega, Geneva, Switzerland), which was connected to the photocells and a printer (Chronoprinter 503). The participants started each test from the standing position and 1 m behind the first pair of photocells to avoid the effect of reaction time on performance. Average running speed was calculated as the ratio of distance to time for every 100 m and over the entire running distance.

Biochemical Parameters. For lactate determination, the participants provided capillary blood samples from a fingertip 5 minutes after each running test. The blood was immediately

Table 1. Running speeds per 100 m in the 4 running tests (mean ± *SD*, $n = 12$).*

Test (m)	First 100 m ($m \cdot s^{-1}$)	Second 100 m ($m \cdot s^{-1}$)	Third 100 m ($m \cdot s^{-1}$)	Fourth 100 m ($m \cdot s^{-1}$)
300	7.3 ± 0.4	7.2 ± 0.4	7.0 ± 0.3	
3 × 100	7.7 ± 0.4	7.4 ± 0.4	7.4 ± 0.3	
400	7.1 ± 0.4[ab]	6.8 ± 0.4[cd]	6.5 ± 0.3[ac]	6.4 ± 0.5[bd]
2 × 200	7.3 ± 0.4[ab]	7.2 ± 0.4[cd]	6.8 ± 0.4[ac]	6.7 ± 0.3[bd]

*Values with the same index letter in each test are different ($p < 0.05$).

mixed with a 10-fold volume of 0.3 $mol \cdot L^{-1}$ perchloric acid and was stored at −20°C until analyzed. On the day of analysis, the samples were thawed and centrifuged at 1,500*g* for 5 minutes. Lactate was measured in the supernatant according to an enzymic photometric method from Sigma Diagnostics (St. Louis, MO; method no. 826-UV).

For glucose and creatinine (an index of creatine metabolism) determination, the participants provided venous blood samples before and 1 minute after each test. The blood was left to clot and was centrifuged at 1,500*g* for 5 minutes. Glucose and creatinine were measured in the resulting serum through enzymic photometric methods with the aid of reagent kits from Best (Athens, Greece) and Roche Diagnostics (Mannheim, Germany; kit CREA plus), respectively.

Finally, CK was measured through a kinetic photometric method with the aid of a kit from Dialab (Vienna, Austria) in serum samples obtained before and 24 hours after each run. The coefficients of variation were 3% for lactate, 2% for glucose, 2% for creatinine, and 8% for CK.

Statistical Analyses

All data are presented as the mean ± *SD* and were analyzed by using Statistica, version 5 (StatSoft, Tulsa, OK). Running speeds per 100 m in each test were compared by analysis of variance (ANOVA) with repeated measures. Speeds over the entire running distance in the 4 tests and blood lactate concentrations after the tests were compared by 2-way (distance × mode) ANOVA with repeated measures on both factors. Two levels of distance (300 and 400 m) and 2 levels of mode (continuous and intermittent) were entered in the analysis. Serum glucose, creatinine, and CK concentrations were compared by 3-way (distance × mode × time) ANOVA with repeated measures on all 3 factors. Two levels of time were added to the analysis (before and after the run). To eliminate the effect of possible differences in the resting values of each parameter on the statistical analysis, we also calculated the percent changes in glucose, creatinine, and CK concentrations after exercise and compared them by 2-way (distance × mode) ANOVA. Significant differences were followed up by the Tukey test. The level of statistical significance was set at $\alpha = 0.05$ for all analyses.

Results

The ANOVA on running speed per 100 m in each of the 4 tests (Table 1) showed no significant differences within the 300- and 3 × 100-m runs. By contrast, within the 400- and 2 × 200-m runs, the speeds in the first two 100-m intervals were higher than those in the latter 2 intervals ($p < 0.05$).

Data on the average speed over the entire running distance and lactate concentrations in the 4 running tests are presented in Table 2. The 2-way ANOVA on average speed showed significant main effects of distance and mode. Average speed was higher in the 300-m tests compared with the 400-m tests (7.52 ± 0.50 vs. 7.08 ± 0.59 $m \cdot s^{-1}$, $p < 0.001$) and higher in the intermittent tests compared with the continuous tests (7.45 ± 0.50 vs. 7.15 ± 0.58 $m \cdot s^{-1}$, $p < 0.001$). The same

Table 2. Average speed in the 4 running tests and blood lactate concentration after them (mean ± *SD*, $n = 12$).*

	Average speed ($m \cdot s^{-1}$)		Lactate ($mmol \cdot L^{-1}$)	
	Mode		Mode	
Distance (m)	Continuous	Intermittent (3 × 100)	Continuous	Intermittent (2 × 200)
300	7.38 ± 0.56	7.66 ± 0.45	14.5 ± 2.8	16.1 ± 2.7
400	6.93 ± 0.62	7.23 ± 0.58	15.4 ± 1.6	16.5 ± 2.5

*Two-way analysis of variance indicated significant main effects of total distance and mode on average speed (higher in the 300- vs. 400-m tests and higher in the intermittent vs. continuous tests, $p < 0.001$) and of mode on lactate (higher in the intermittent vs. continuous tests, $p < 0.05$).

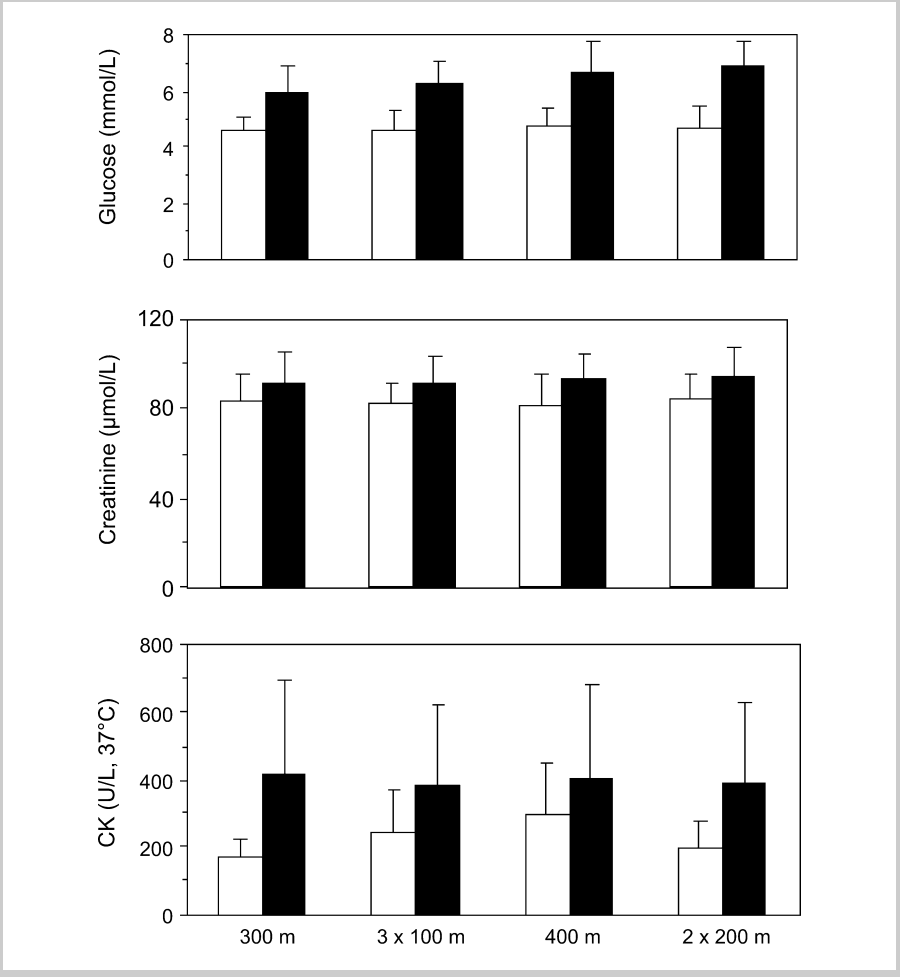

Figure 1. Serum concentrations (mean and *SD*, $n = 10$) of biochemical parameters before (open bars) and after (full bars) the 4 running tests. There were significant main effects of time on all 3 parameters (significantly higher after exercise, $p \leq 0.001$) and a significant main effect of distance on glucose concentrations (higher in the 400- vs. 300-m tests, $p = 0.032$).

statistical analysis showed significant main effect of mode on blood lactate, which was higher in the intermittent tests compared with the continuous tests (16.3 ± 2.2 vs. 15.0 ± 2.0 mmol·L^{-1}, $p < 0.05$). Pairwise comparisons among the 4 running tests did not reveal any significant differences in lactate concentrations.

Figure 1 presents the biochemical parameters measured in serum. The 3-way ANOVA on glucose values indicated significant main effects of time and distance. Glucose concentrations increased after exercise (from 4.66 ± 0.35 to 6.42 ± 0.56 mmol·L^{-1}, $p < 0.001$) and were higher in the 400-m trials compared with the 300-m trials (5.76 ± 0.46 vs. 5.33 ± 0.30 mmol·L^{-1}, $p = 0.032$). Regarding creatinine and CK, the same statistical analysis showed only significant increases ($p \leq 0.001$) after exercise (from 83 ± 11 to 92 ± 12 µmol·L^{-1} for creatinine and from 226 ± 44 to 396 ± 124 U·L^{-1} at 37°C for CK). When the 4 tests were compared with regard to the changes of these parameters after exercise, no significant difference was found.

Discussion

The main finding of the present study was that overall, the intermittent runs totaling 300 or 400 m stimulated the lactate system, as indicated by blood lactate concentrations, to a higher degree compared with continuous/single runs of the same total distance. However, all 4 runs caused similar muscle damage, as indicated by the serum CK concentrations. Furthermore, the average speed of the participants was higher in the intermittent runs compared with the continuous runs. To the best of our knowledge, this is the first study to compare biochemical markers related to exercise metabolism and muscle fiber damage, as well as average speed, between continuous and intermittent runs of 300 and 400 m that are used in training. Previous studies have concentrated primarily on monitoring changes in energy substrates and running velocity during single 300- and 400-m runs (12,16,26,27).

In the present study, blood lactate concentrations reached high values (14.5–16.5 mmol·L^{-1}) following all 4 running tests, indicating that these types of training place considerable demands on the lactate system for energy production. Although these values are high as far as moderately trained individuals (as the participants in this study) are concerned, they are nevertheless low compared with values reported after 300- or 400-m single runs (19–25 mmol·L^{-1}) for high-level athletes (15,26,27). It should be noted that the intermittent training regimens (3 × 100 and 2 × 200 m) produced on average 1.3 mmol·L^{-1} higher lactate concentration compared with the continuous regimens (300 and 400 m).

Peak blood lactate concentration following exercise depends on exercise intensity, duration, and mode. In continuous high-velocity runs up to 400 m, blood lactate accumulation is a function of both velocity and distance (12,13,17). In intermittent shorter runs (100–200 m), although the rest intervals allow for partial lactate removal and creatine

phosphate (CP) resynthesis, thus taxing the lactate system less, the greater number of accelerations to near-maximal velocities, along with the higher average speed, increases the demand for high power production in the initial phase of the run. The effect of the interplay between exercise intensity, duration, and mode on blood lactate concentration is partially supported by the fact that the difference in lactate concentration between the continuous 300-m test and the 2×200-m test barely failed to reach statistical significance ($p = 0.06$) and had a large effect size (0.74, calculated as a difference between the means divided by the pooled *SD*).

Serum CK peaks 1–4 days after exercise, depending on the type of exercise, and reflects the leakage of the enzyme from damaged muscle fibers to the plasma (23). It has been suggested that the CK determination is useful in evaluating muscle stress (11), and it has been used extensively for detecting muscle damage. However, there is controversy over whether muscle function and/or its recovery following fatiguing exercise is (14,24,25,28,31) or is not (18,19,34) associated with the serum CK concentration. In this study, serum CK increased significantly in all running regimens by 34–144% 1 day after exercise, while no significant differences were observed among protocols. The rise in CK suggests that muscle damage occurred following all 4 running tasks. This observation is consistent with those of previous studies that have documented increases in CK following various dynamic or eccentric exercise protocols (3). The lack of significant differences among protocols may imply similar muscle stress and damage.

The comparison of the concentrations of serum glucose and creatinine revealed increases in both biochemical parameters after the running tests. The increase in serum glucose by 28–49% is a typical effect of short-term intense exercise (22) and is apparently because of the stimulation of glycogenolysis in the liver, which results in increased supply of glucose to the bloodstream (4). Although the 3-way ANOVA showed a significantly higher glucose concentration in the 400-m tests compared with the 300-m tests, there were no differences in the percentage changes among the 4 running tests, implying a similar glucose response. Similarly, there was a relatively uniform increase in serum creatinine (by 10–14%). An increase in the serum creatinine concentration after short maximal exercise has been reported in greyhounds that ran 235–420 m at about twice the speed of humans (32,36). This increase may be because of the degradation of CP to creatine and P_i during the runs and to the subsequent conversion of part of this creatine to creatinine. Alternatively, the increase in the serum creatinine concentration may be ascribed to an exercise-induced decrease in glomerular filtration rate, therefore decreased renal excretion of creatinine (29).

The finding that the average speed of the participants was higher in the 300-m tests compared with the 400-m tests can be explained by the higher contribution of CP, the fastest source of ATP resynthesis, to total energy expenditure during the shorter bouts (10). Likewise, the finding that the average speed was higher in the intermittent tests compared with the continuous tests can be explained by the higher contribution of CP to total energy expenditure during the intermittent bouts (7,9). This is because CP is partly resynthesized during the intervals (2); therefore, CP is able to contribute more to total energy supply in the subsequent exercise bout.

It should be pointed out that this study used individuals who were not 400-m runners. Even though the extent of stimulation of the lactate system may be different in 400-m runners, there is no evidence that the *relative* differences among the 4 running workouts will vary in a 400-m runner.

Practical Applications

The results of this study show that all 4 running workouts that are used for training in the 400-m event stimulated greatly the lactate system. However, the intermittent workouts appeared to boost the lactate system to higher degree and demonstrated higher average speed. Thus, intermittent workouts, in particular 2×200 m, are superior than continuous runs of the same total distance in increasing the ability for energy production via the lactate system and therefore can be successfully used by 400-m athletes to develop specific (speed) endurance. Certainly, the continuous runs rely more on the aerobic system for energy production, as indicated by the lower lactate concentrations. The planning of training constitutes personal coaching strategy that depends on general coaching theory and individualized training of the athletes. However, based on the view that training for specific (speed) endurance should precede that for tempo and proper pace, it appears that intermittent runs should be placed before the continuous ones of the racing distance within a macrocycle. Muscle damage, as indicated by serum CK concentration, was similar 24 hours after all 4 runs. Therefore, all 4 schemes may be used in training for the 400-m event with no consideration for different recovery times. It is hoped that the findings of this study will prove useful to trainers and athletes competing in the 400-m event to better achieve their training goals and to improve performance in the 400-m race.

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