Acute and Short-Term Response to Different Loading Conditions During Resisted Sprint Training

Purpose: To analyze the acute and short-term physical and metabolic responses to resisted sprint training with 5 different loading conditions (0%, 20%, 40%, 60%, and 80% body mass). Methods: Fifteen male participants performed 8 × 20-m sprints with 2-minute rests between sprints with 5 different loading conditions. Subjects performed a battery of tests (creatine kinase and lactate concentrations, countermovement jump, 20-m sprint, and isokinetic knee extension and flexion contractions) at 3 different time points (preexercise [PRE], postexercise [POST], and 24-h postexercise [POST24H]). Results: Results revealed significant increases in blood lactate for all loading conditions; however, as sled loadings increased, higher blood lactate concentrations and increments in sprint times during the training session were observed. Significant increases in creatine kinase concentration were observed from PRE to POST24H for all loading conditions. Concerning physical performance, significant decreases in countermovement-jump height from PRE to POST were found for all loading conditions. In addition, significant decreases in 20-m sprint performance from PRE to POST were observed for 0% ($P = .05$) and 80% ($P = .02$). No significant differences with PRE were observed for the physical-performance variables at POST24H, except for 20% load, which induced a significant decrease in mean power during knee flexion ($P = .03$). Conclusions: These results suggest that the higher the load used during resisted sprint training, the higher the physical-performance impairments and metabolic response produced, although all loading conditions led to a complete recovery of sprint performance at POST24H.

Keywords: sled towing, running, fatigue, lactate, muscle damage, recovery

Introduction

One of the most commenly used resisted sprint methods is weighted sled training (consisting of a sled device attached to the athlete by a chest or waist harness). This methodology requires greater demand for horizontal forces evoked by the mass of a weighted sled together with the resulting friction between the sled and the ground surface.[1] Some of the mechanisms by which this training method induces improvements in sprint performance are related to an increase in (1) the horizontal force production during each ground contact,[2] (2) the stride length in the acceleration phase,[3] and (3) the maximal velocity.[4] In a recent review, Alcaraz et al[5] suggested that resisted sprint training is an effective method for the development of sprint performance, mainly in the early acceleration phase (≤10 m), with little impact in the maximum velocity phase (≥20 m). Energy for muscle contraction during brief maximal exercise (≤10 s) is primarily derived from the breakdown of stored muscle phosphagen, such as adenosine triphosphate and phospho- creatine, and anaerobic glycolysis.[6,7] When short sprints are repeated during training sessions, reduction in adenosine triphosphate con- centration, loss of adenine nucleotides,[8] and increased levels of superoxide radicals and creatine kinase (CK) may occur, eventually evoking muscle damage and impairment in muscle force production.[9,10] In addition, from a metabolic point of view, fatigue may be explained as a result of hydrogen ion (H^+) accumulation and increase in inorganic phosphate levels.[11] In this sense, significant increases in lactate levels after running sprints over distances of 40 and 60 m have been found.[12,13] On the other hand, fatigue has been described as any exercise-induced reduction in the maximal voluntary force or power produced by a muscle or a muscle group.[14] In this line, loss of running velocity and countermovement jump (CMJ) height are considered as good markers of fatigue during

sprint training in unresisted conditions.[12,13] Moreover, previous studies have also shown a relationship between blood lactate concentration and CMJ height loss during typical 400 m or repeated sprints ses- sions.[15,16] Studies analyzing exercise-induced muscle damage fol- lowing repeated unloaded sprints reported increases in CK activity together with impairment on the neuromuscular function.[17–19] Despite the widespread use of resisted sprint training, to our knowledge, no previous research has examined the acute effects of this training method on metabolic response, muscle damage, and impairments in athletic performance.

Despite the scientific attention received by sled towing, there still exists controversy over the load that should be used to maximize gains in sprint performance.[5,20] An external load about 10% to 12.5% of body mass (BM), which induces about 10% of decrement in unloaded velocity while allowing to maintain the sprint technique, has been typically recommended.[2,21–23] However, more recently, it has been suggested that heavier loads (≈80% BM) should be used to improve sprinting acceleration, as they allow athletes to produce greater horizontal force in a forward-oriented body position throughout the sprint.[24,25] Morin et al[25] tested the use of very heavy sled load (80% BM) in soccer players and observed a substantial, increased horizontal force production compared with nonresisted sprinting. However, only trivial between-group differ- ences were observed for power output and sprint performance. In addition, Haugen et al[26] proposed that heavy resisted sprinting is likely more appropriate for **sports** where the athletes are required to perform brief sprints while moving an external mass (eg, bobsleigh).

Most of the studies analyzing the acute effects of using different sled loads have focused on kinematic and kinetic variables such as stride length, stride frequency, flight times,

contact times, joint angles, force, rate of force development, and power production.[1,2,5,22,27–29] However, to the best of our knowledge, the metabolic and physical response to different loading condi- tions during resisted sprint training has not been previously analyzed. A better understanding of the physical fitness and metabolic acute and short-term responses to a wide range of loading conditions during resisted sprint training may help to improve the sprint training process and recovery strategies. Therefore, the aim of the present study was to analyze the acute and short-term physical and metabolic responses to resisted sprint training with 5 different loading conditions (0%, 20%, 40%, 60%, and 80% BM).

Methods

Subjects

Fifteen male participants volunteered to this study (age 23.8 [5.3] y, height 1.74 [0.06] m, BM 71.9 [5.9] kg). Subjects were physically active sports science students, and all had experience with strength and sprint training. All participants were injury free and had completed at least 3 training sessions per week in team sports or individual sports such as soccer, futsal, and athletics in the 3 months before testing. Their performance standards ranged from recreational- to regional-level athletes. All participants were fully informed about procedures, potential risks, and benefits of the study, and they all signed written informed consent prior to the tests. The study was conducted in accordance with the Declaration of Helsinki II and was approved by the local ethics committee.

Design

A randomized, cross-sectional, and counterbalanced experimental design was undertaken to examine the acute and short-term physi- cal and metabolic responses to sprint training with 5 different loading conditions (0%, 20%, 40%, 60%, and 80% BM). Follow- ing

familiarization with the testing exercises and the resisted sled training, subjects were randomly assigned to perform the same sprint training protocol in 5 different loading conditions during 5 sessions separated by 1 week. The same number of sprints and interset rest duration were used in all the protocols (8 × 20 m, 2-min rest). The sessions only differed on the sled load used.

To compare the acute and short-term response by the different loading conditions, subjects performed a battery of tests (CK and lactate concentrations, CMJ, 20-m running sprint, and isokinetic knee extension and flexion contractions) at 3 different time points (pre-exercise [PRE], postexercise [POST], and 24-hour postexer- cise [POST24H]).

Participants were asked to abstain from any strenuous physical activity for at least 2 days before each trial and during the POST24H. All sessions took place at a neuromuscular research laboratory and on a semicovered running rigid surface, always under the direct supervision of a researcher. All protocols were performed at the same time of the day for each subject and under similar environmental conditions (20°C and 60% humidity, approximately).

An initial familiarization session, consisting of performing the testing exercises and several sprints with different sled loads, was carried out 1 week before the first trial, and BM was obtained for calculation of the sled loads.

Testing Procedures

During the first testing day of each loading condition, resting blood samples (CK and lactate concentrations) were taken before the warm-up. Then, subjects performed a standardized warm-up protocol consisting of 5 minutes of jogging at a self- selected easy pace, 5 minutes of joint mobilization exercises, 10 squats without an external load, 5 CMJ progressive in intensity, 3 maximal CMJ, four 20-m running accelerations at 80%, 85%, 90%, and 95% perceived effort, and one 10-m sprint at 100% effort with 1-minute

rest periods between them. After the warm- up, PRE tests were performed in the following order: CMJ, 20-m sprint (T20m), and isokinetic knee extension and flexion (peak torques and mean power). Then, the training protocol was carried out, and immediately later, POST tests were performed in the same order (Figure 1). Tests were also performed in the same order for the POST24H measures. A detailed description of test temporization at different time-point measures is presented in Figure 1.

Metabolic Variables

CK Concentration. Plasma CK concentration was assessed at PRE and POST24H tests from 30-µL capillarized whole blood samples collected via fingertip puncture made using a spring- loaded single-use disposable lancet. The whole blood sample was immediately pipetted to a test strip and analyzed for CK concentration using a colorimetric assay procedure (Reflotron; Boehringer Mannheim, Germany). The reliability and accuracy of Reflotron CK have been previously established with coefficient of variation (CV) of 3.1%.[30]

Blood Lactate Concentration. About 5 µL of whole blood sample from the fingertip was used for the quantification of lactate concentration, which was measured with a portable lactate analyzer (Lactate Pro 2; ARKRAY, Kyoto, Japan), at the following 3 different time points: before the training protocol (PRE), 1 minute after the fourth sprint during the training protocol (POST4), and 1 minute after the last sprint (the eighth of the training protocol [POST8]). The reliability and accuracy of Lactate Pro 2 analyzer have been previously established with CVs of 7.6%, 3.5%, and 2.7% for a lactate concentration of ~1, 4, and 12 $mmol \cdot L^{-1}$.[31]

Physical-Fitness Variables

Countermovement Jump. An infrared timing system (Optojump Next; Microgate, Bolzano, Italy) was used for determining jump height. The CMJ was performed with both hands on the waist, while performing a downward movement until about 90° of knee flexion followed by a maximal vertical jump. All participants were instructed to land in an upright position to ensure similar body configuration for takeoff and landing. The participants were required to do 5 trials separated by 30 seconds (the higher and the lower jump values were removed, and mean height of the 3 intermediate jumps was scored) for the PRE and POST24H measurements, and 2 trials separated by 10-second rest for the POST tests measurements, mean height being scored. Test–retest reliability measured by the CV was 2.1%, and the intraclass correlation coefficient (ICC) values were .99 (95% confidence interval [CI], .98−.99).

Sprint Testing. Participants performed two T20m, with 3-minute rest between sprints. Sprint times over 0 to 10, 0 to 20, and 10 to 20 m (T10m, T20m, and T1020m) were measured using photocells (Witty, Microgate). The best time of the 2 trials was scored. Runs were performed from static standing; slit-stanced position with the start line located 1 m behind the start photocell on a rigid surface in a semicovered hall. The timing gates had a vertical height of 0.80 m. The test–retest reliability for running sprint variables was T10m (ICC: .95; 95% CI, .86–.98; CV: 1.8%), T20m (ICC: .94; 95% CI, .83–.98; CV: 1.5%), and T1020m (ICC: .94; 95% CI, .82–.98; CV: 2.4%).

Isokinetic Test. Isokinetic concentric knee extension and flexion of the dominant leg were performed at an angular velocity of 60° s^{-1} using an isokinetic dynamometer (Biodex System 4; Biodex Medical Systems, Shirley, NY). Isokinetic data for peak torque and mean power were obtained at a sample rate of 100 Hz using the Biodex System 4 Advantage software. Warm-up con- sisted of 3 to 4 submaximal contractions of

increasing intensity (from 50% to 90%) for each of the isokinetic contractions and then rested for 1 minute between the warm-up and the beginning of the test. Each participant was seated at an angle of 85° and stabilized with straps at the shoulders, waist, and thighs as per manufacturer's guidelines. Each participant's seat position was recorded so that it could be replicated during subsequent testing. Participants per- formed 3 maximal attempts for each of the isokinetic contractions, and all were given verbal encouragement and visual feedback of the torque signal at each repetition. Peak torque value (N·m), obtained from the highest value of all maximum efforts, and mean power output (W) for each muscle action were chosen for further analysis.

Training Protocol

The training protocol was always the same for the 5 loading conditions (0%, 20%, 40%, 60%, and 80% BM). This training protocol consisted of 8 × 20-m sprint with 2-minute rest between each sprint. Times of each sprint (including partial times T10m, T20m, and T1020m) were recorded, and lactate measurements were taken before the training session, during the training session (1 min after the fourth sprint), and at the end of the training session (1 min after the eighth sprint). Fatigue during each training protocol was calculated from sprint times using the following formula: fatigue index = [100 × (total sprint time/ideal sprint time)] − 100, where total sprint time = sum of sprint times from all sprints and ideal sprint time = the number of sprints × fastest sprint time.[32] This formula seems to be the most suitable because it considers data from each sprint, provides consistent reliability, and shows good construct and logical validity.[33] The mean time of the 8 sprints performed during the training sessions was also calculated (T_{mean}). Speed loss induced for each loading condition was calculated as the decrement in mean sprint velocity elicited by the sled load with respect to the unloaded condition (measured at PRE).

Statistical Analysis

Values are reported as mean (SD). Statistical significance was established at $P < .05$. Test–retest absolute reliability was measured by the standard error of measurement, which was expressed in relative terms through CV. Relative reliability was assessed by the ICC (95% CI) calculated with the 1-way random effects model. The standard error of measurement was calculated as the root mean square of total mean square intrasubject. Homogeneity of variance across groups was verified using the Levene test. The distribution of each variable was examined with the Shapiro–Wilk normality test. A 5 (loading) × 3 (time) repeated-measures analysis of variances was calculated for each parameter. Bonferroni post hoc tests were used when the interaction was significant. Statistical analyses were performed using SPSS for Mac (version 20.0; SPSS Inc, Chicago, IL).

Results

Fatigue During Training

Table 1 shows the description of the results obtained in the training protocol performed for each loading condition. Significant differ- ences were found in T_{mean} in 10 and 20 m for the 8 sprints performed during the training protocol and speed loss between all loading conditions ($P < .001$). Fatigue index increased as sled loadings increased (Table 1). Specifically, significant differences were found in fatigue index in 10 m for 60% compared with 0% ($P = .02$); and for 80% with respect to 0% ($P = .0001$), 20% ($P = .0001$), 40% ($P = .01$), and 60% ($P = .01$). Additionally, fatigue index in 20 m was higher for 60% compared with 0% ($P = .001$) and 20% conditions ($P = .02$), and for 80% compared with the rest of loading conditions (0%: $P = .00002$; 20%: $P = .00001$; 40%: $P = .01$; 60%: $P = .03$).

Metabolic Response

Blood lactate concentrations are depicted in Figure 2. There was a significant protocol by time interaction for lactate concentration ($F = 6.78$; $P = .0001$). Post hoc analysis revealed significantly higher blood lactate concentration for 80% compared with 0% ($P = .0001$) and 20% ($P = .002$) conditions at POST4; and higher lactate concentration for 60% with respect to 0% ($P = .007$), and for 80% compared with 0% ($P = .002$) and 20% ($P = .03$) at POST8. Concerning intragroup differences, a significant increase in blood lactate was observed from PRE to POST4 and from PRE to POST8 for the 5 loading conditions ($P < .0001$). Significant increases in CK concentration were observed from PRE to POST24H for the 5 loading conditions (0%: $P = .001$; 20%: $P = .03$; 40%: $P = .02$; 60%: $P = .01$; 80%: $P = .02$, Figure 3), with no significant differ- ences between loading conditions.

Physical-Fitness Response

Mean (SD) data of the physical fitness variables are reported in Table 2. No differences between loading conditions were found for any of the physical test variables. Significant decreases in CMJ height from PRE to POST tests were found for the 5 loading conditions ($P < .001$, except 60% $P = .004$). As regards the sprint times, significant decreases in T20m performance from PRE to POST tests were observed for 0% ($P = .05$) and 80% ($P = .02$), and in T1020m for 0% ($P = .03$), 40% ($P = .009$), and 60% ($P = .01$). With respect to the isokinetic measurements, only a significant decrease in mean power during knee flexion from PRE to POST24H was found for the 20% loading condition ($P = .03$, Table 2). No significant differences with PRE were observed for the rest of physical test variables at POST24H.

Discussion

To the best of our knowledge, this is the first study analyzing the physical and metabolic

responses to different loading conditions (0%, 20%, 40%, 60%, and 80% BM) during resisted sprint training. Most of the studies examining the acute effects of sprint training have focused on unloaded sprint.[12,13,33,34] However, few studies have analyzed the acute effects during resisted sprint training on the physical response,[35,36] while the metabolic response to different resisted loading conditions has not been studied yet. The major findings of this study were as follows: (1) as sled loadings increased, higher values of fatigue index and blood lactate con- centrations were attained; (2) all loading conditions induced sig- nificant increases in CK concentrations and decreases in CMJ height; (3) loadings of 0% and 80% evoked significant decreases in T20m performance, whereas 0%, 40%, and 60% impaired T1020m performance from PRE to POST tests; and (4) only the 20% loading condition induced a significant decrease in mean power during knee flexion at POST24H.

Fatigue during repeated sprint exercise is defined as an induced reduction in the maximal speed, even though the effort can be sustained.[37] In our study, the fatigue index, considered as the percentage decrement score,[32] increased significantly as the load increased, for both 10 and 20 m (Table 1). Likewise, higher blood lactate concentration was observed as the number of sprints and the load increased. Loads corresponding to 80% induced higher blood lactate concentration than lighter loads (0% and 20% of BM), whereas 60% loading induced higher lactate concentration than 0% condition (Figure 2). Moreover, in agreement with previous stud- ies,[5,20] heavier loads led to a greater speed loss compared with unloaded conditions, and as consequence, slower T_{mean} were attained in each sprint with these loads (Table 1). The fact that heavier sled loads accumulated longer times in each sprint, together with the longer contact times and greater propulsive forces previ- ously observed with heavier loads,[3,38] may explain the higher fatigue index and blood lactate concentrations observed for these loads in the present study. The

elevated levels of blood lactate indicate that anaerobic glycolysis is extensively activated during this type of training. In this line, a high blood lactate concentration suggests high levels of H^+ with the consequent pH decrease, which may induce muscle function impairment.[11]

Creatine kinase is considered another marker of metabolic fatigue and muscle damage. In our study, a significant increase in POST24H was observed for all loading conditions, with no differences between loads. Unfortunately, comparisons with other studies analyzing resisted sprint training are not possible because no research is available about the CK response to resisted sprint training. The CK values observed in this study (318–392 $U \cdot L^{-1}$) were lower than the observed in other study with a repeated unresisted sprint protocol (15 × 30 m) in males (776 [312] $U \cdot L^{-1}$).[17] However, in such study, in addition to the higher volume (sets and distance) and lower recovery time (60 s), a rapid deceleration after each sprint was enforced within 10 m from the finish line, which probably would have elicited high eccentric con- tractions, and so increased muscle damage. Thus, training protocols carried out in the present study induced moderate increase in CK levels, without differences in the loading magnitude used. This seems to be in agreement with the physical responses, as significant decrease in CMJ height was observed for all loading conditions after the training protocol with a complete recovery at POST24H (Table 2).

With respect to the isokinetic tests, no changes were found in the peak torque or mean power during knee flexion or extension for any of the loading conditions except for the 20%, in which a significant decrease was found in the mean power during concentric knee flexion from PRE to POST24H. This result may suggest an increased fatigue in the muscles responsible for the knee flexion (hamstrings) when using such load at POST24H of training. These findings provide practical implications as impairments in hamstring function have been associated with lower levels of sprint acceleration performance.[39] In

this line, Howatson and Milak[17] found significant decreases in isometric maximal voluntary contraction in knee extension after a sprint protocol (15 × 30 m, 60-s rest) after POST24H and 48-hour postexercise, with a complete recovery after 72 hours. Again, the higher volume, shorter recovery time, and rapid decelerations performed after each sprint may explain the differences between the results of both studies.

Another interesting finding was observed when analyzing sprint times, as a significant increase in T20m was observed for 0% and 80% loadings at POST. These results could be explained by different mechanisms as the increase in T20m for 0% was due to a significant increase in the maximum velocity phase T1020m, whereas the 80% load did not increase significantly in that phase. In this line, Whelan et al[35] observed a decrement in 10-m performance after a resisted sprint protocol (3 × 10 m) with loads between 25% and 30% BM, indicating that acute postactivation potentiation did not occur after resisted sprinting. However, the differences observed with respect to our study seem logical as the training protocol characteristics were very different. Still, it should be noted that all loading conditions carried out in the present study led to a complete recovery of sprint performance after POST24H.

Practical Applications

The present findings suggest that if strength and conditioning professionals desire to conduct training programs with low level of physical and metabolic stress, high volume with very heavy loads should be avoided. Anyway, almost all functional measures performed in the present study had a complete recovery from their initial values after POST24H. In this sense, this information might be useful for optimizing recovery time after training and thus being prepared for subsequent training and competition, which might reduce the risk of injury.

Conclusions

Taken together, both the loss of performance induced during training, represented by the fatigue index, and the blood lactate concentration were significantly higher as the load increased, indicating that the higher is the load used during resisted sprint training, the higher is the physical performance impairments and metabolic stress produced. Moreover, blood CK concentration increased significantly for all loading conditions at POST24H. On the other hand, concerning the physical responses, fatigue in CMJ after the training protocol was similar for all loading condi- tions, with a complete recovery at POST24H. Still, T20m perfor- mance was negatively affected only for 0% and 80%, likely due to different mechanisms.

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Figure 1 — Schematic representation of study design:(A) blood sampling and physical-fitness measurements at 3different time points; (B) structure of tests and sprint-training protocol for each loading condition.

Figure 2 — Changes in blood lactate concentration for each loading condition. Intragroup significant differences: **P < .01, ***P < .001 (with respect to PRE); ###P< .01, ††P < .001 (with respect to 0%); #P

Figure 3 — Changes in creatine kinase concentration for each loading condition. Intragroup significant differences: *P < .05, **P < .01, ***P < .001 (with respect to PRE).

Table 1 Descriptive Characteristics of the Sprint-Training Protocol Performed for Each Loading Condition, Mean (SD)

	0%	20%	40%	60%	80%
T_{mean}					
10 m, s	1.79 (0.09)	2.07 (0.08)	2.36 (0.14)	2.63 (0.18)	3.08 (0.32)
20 m, s	3.10 (0.13)	3.55 (0.16)	4.04 (0.25)	4.48 (0.30)	5.25 (0.61)
Speed loss					
10 m, %	2.0 (2.8)	14.4 (2.8)	24.9 (2.3)	32.7 (3.8)	42.6 (4.9)
20 m, %	1.6 (1.9)	13.5 (1.7)	23.9 (2.3)	31.6 (2.9)	41.3 (4.7)
FI					
10 m, %	2.9 (1.6)	3.2 (1.5)	4.4 (2.5)	5.1 (2.2)*	8.2 (3.3)**†††‡##
20 m, %	1.9 (0.9)	2.1 (1.0)	3.5 (1.4)	3.9 (1.7)**†	6.1 (2.1)**†††‡#

Abbreviations: FI 10 m, fatigue index in 10 m over sprints 1 to 8; FI 20 m, fatigue index in 20 m over sprints 1 to 8; speed loss 10 m, decrement in mean sprint velocity elicited by sled load from the fastest sprint time experienced during test in 10 m without load; speed loss 20 m, decrement in mean sprint velocity elicited by sled load from the fastest sprint time experienced during test in 20 m without load; T_{mean} 10 m, mean time in 10 m from the 8 sprints performed during the training protocol; T_{mean} 20 m, mean time in 20 m from the 8 sprints performed during the training protocol.

Intergroup significant differences: *$P < .01$, **$P < .001$ (with respect to 0%); †$P < .05$, ††$P < .001$ (with respect to 20%); ‡$P < .01$ (with respect to 40%); and #$P < .05$, ##$P < .01$ (with respect to 60%).

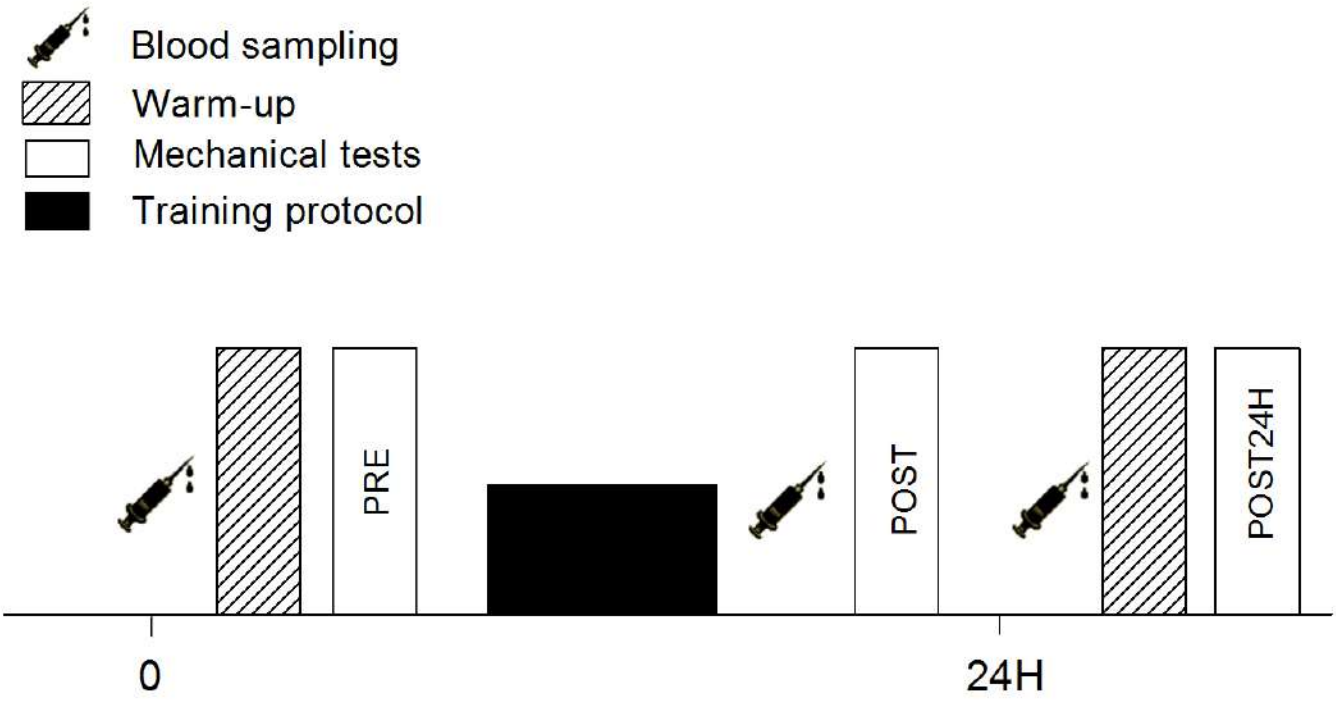
Table 2 Acute and Short-Term Changes in Physical-Fitness Variables for Each Loading Condition

	PRE	POST	POST24H		PRE	POST	POST24H
Loading: 0% BM							
CMJ, cm	39.2 (5.3)	37.0 (5.1)***	39.2 (5.3)###	Peak-Flex, N·m	130.9 (15.4)	128.2 (14.3)	125.8 (21.0)
T10m, s	1.75 (0.09)	1.79 (0.09)	1.75 (0.10)	Peak-Ext, N·m	213.9 (25.7)	202.3 (35.3)	209.2 (35.8)
T20m, s	3.05 (0.12)	3.10 (0.14)*	3.06 (0.13)	MeanP-Flex, W	90.3 (12.5)	88.0 (11.6)	87.3 (16.8)
T1020m, s	1.29 (0.08)	1.31 (0.08)*	1.30 (0.07)	MeanP-Ext, W	135.0 (21.5)	134.6 (25.4)	132.1 (29.6)
Loading: 20% BM							
CMJ (cm)	39.5 (5.6)	37.8 (5.5)***	39.4 (5.8)##	Peak-Flex, N·m	131.4 (20.3)	127.7 (17.3)	123.3 (25.9)
T10m, s	1.77 (0.08)	1.80 (0.08)	1.80 (0.07)	Peak-Ext, N·m	208.1 (34.8)	205.4 (37.9)	204.7 (39.5)
T20m, s	3.07 (0.13)	3.11 (0.14)	3.11 (0.12)	MeanP-Flex, W	96.2 (15.5)	91.3 (12.1)	87.1 (20.2)*
T1020m, s	1.29 (0.08)	1.31 (0.08)	1.30 (0.07)	MeanP-Ext, W	133.7 (29.1)	130.6 (25.6)	133.4 (29.0
Loading: 40% BM							
CMJ, cm	40.0 (5.7)	37.6 (5.6)***	39.5 (5.8)###	Peak-Flex, N·m	133.6 (21.0)	133.9 (22.8)	138.3 (31.2)
T10m, s	1.77 (0.09)	1.79 (0.10)	1.79 (0.08)	Peak-Ext, N·m	211.2 (31.9)	207.2 (36.6)	210.3 (40.5)
T20m, s	3.07 (0.14)	3.10 (0.16)	3.10 (0.13)	MeanP-Flex, W	96.6 (15.7)	93.4 (24.3)	90.6 (25.4)
T1020m, s	1.29 (0.06)	1.32 (0.07)**	1.30 (0.07)#	MeanP-Ext, W	133.8 (22.8)	134.1 (27.1)	134.2 (28.2)
Loading: 60% BM							
CMJ, cm	39.7 (5.8)	38.3 (5.8)**	40.0 (6.0)##	Peak-Flex, N·m	137.2 (21.9)	134.9 (20.6)	131.1 (23.4)
T10m, s	1.76 (0.08)	1.78 (0.09)	1.78 (0.10)	Peak-Ext, N·m	219.4 (30.2)	218.6 (35.9)	216.4 (42.1)
T20m, s	3.06 (0.14	3.10 (0.12	3.09 (0.15)	MeanP-Flex, W	98.2 (17.1)	97.8 (15.6)	95.1 (19.1)
T1020m, s	1.29 (0.07)	1.32 (0.06)**	1.29 (0.07)#	MeanP-Ext, W	134.4 (20.8)	135.1 (24.0)	137.5 (30.8)
Loading: 80% BM							
CMJ, cm	39.5 (4.5)	37.2 (5.9)***	39.4 (6.3)###	Peak-Flex, N·m	137.5 (16.2)	133.2 (24.0)	135.0 (16.9)
T10m, s	1.75 (0.09)	1.79 (0.08)	1.75 (0.07)	Peak-Ext, N·m	213.9 (38.1)	212.9 (47.6)	217.8 (39.3)
T20m, s	3.05 (0.14)	3.11 (0.14)*	3.07 (0.11)	MeanP-Flex, W	97.8 (15.1)	93.8 (16.3)	95.9 (13.7)
T1020m, s	1.30 (0.07)	1.32 (0.08)	1.31 (0.08)	MeanP-Ext, W	136.4 (32.0)	135.2 (35.5)	140.3 (35.1)

Abbreviations: BM, body mass; CMJ, countermovement-jump height; MeanP-Ext, mean power output during knee isokinetic extension at 60° s^{-1}; MeanP-Flex, mean power output during knee isokinetic flexion at 60° s^{-1}; Peak-Ext, peak torque during knee isokinetic extension at 60° s^{-1}; Peak-Flex, peak torque during knee isokinetic flexion at 60° s^{-1}; T1020m, time in 10- to 20-m running sprint; T10m, time in 10-m running sprint; T20m, time in 20-m running sprint.

Statistically significant differences with PRE at the corresponding time point: *$P < .05$, **$P < .01$, and ***$P < .001$. Statistically significant differences with POST at the corresponding time point: #$P < .05$, ##$P < .01$, and ###$P < .001$.

A)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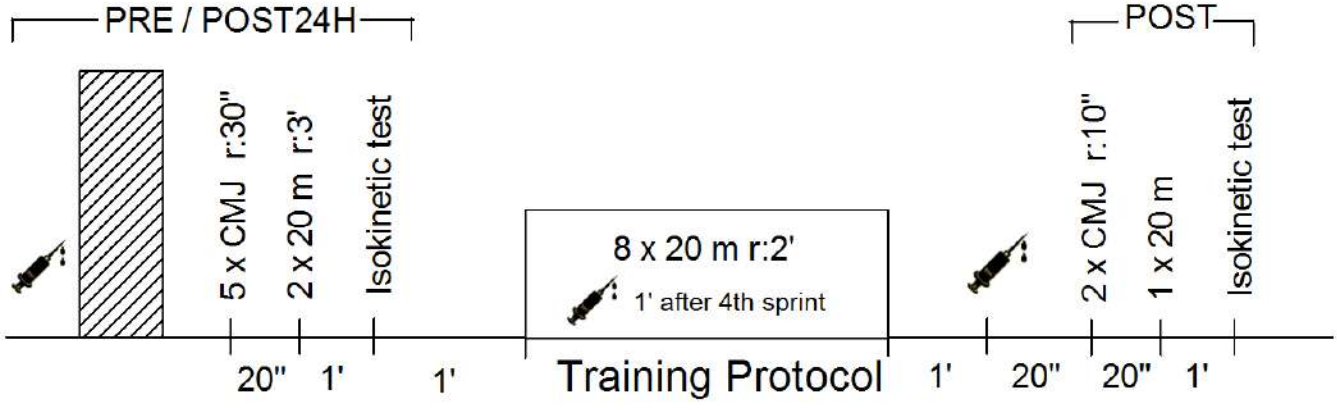
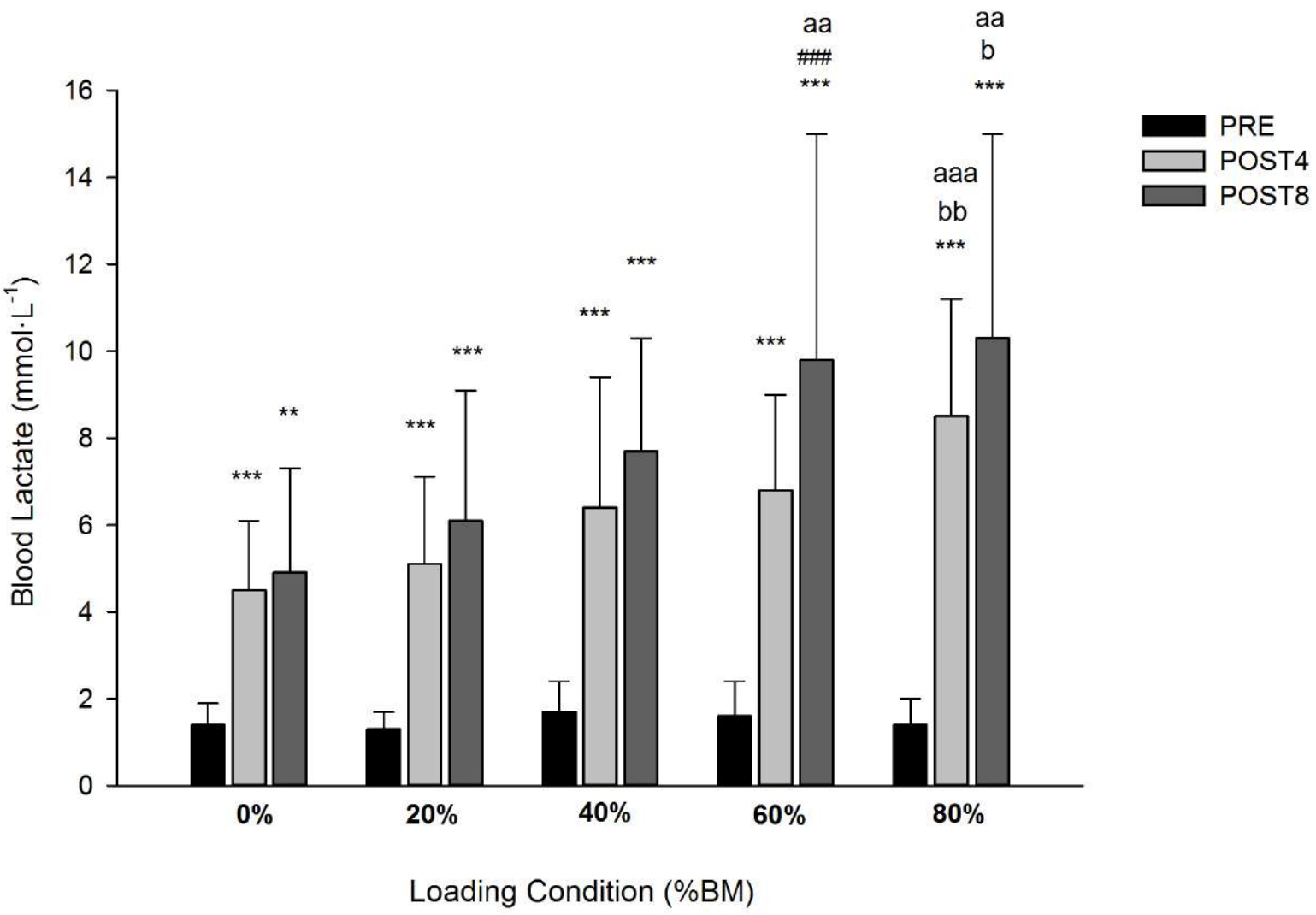
Warm-up
Mechanical tests
Training protocol
PRE
POST
POST24H
0
24H

B)


PRE / POST24H
POST
5 x CMJ r:30"
2 x 20 m r:3'
Isokinetic test
8 x 20 m r:2'
1' after 4th sprint
2 x CMJ r:10"
1 x 20 m
Isokinetic test
20"
1'
1'
Training Protocol
1'
20"
20"
1'


Blood Lactate (mmol·L-1)
16
14
12
10
8
6
4
2
0
0%
20%
40%
60%
80%
Loading Condition (%BM)
PRE
POST4
POST8
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aa
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aaa
bb
***
aa
b
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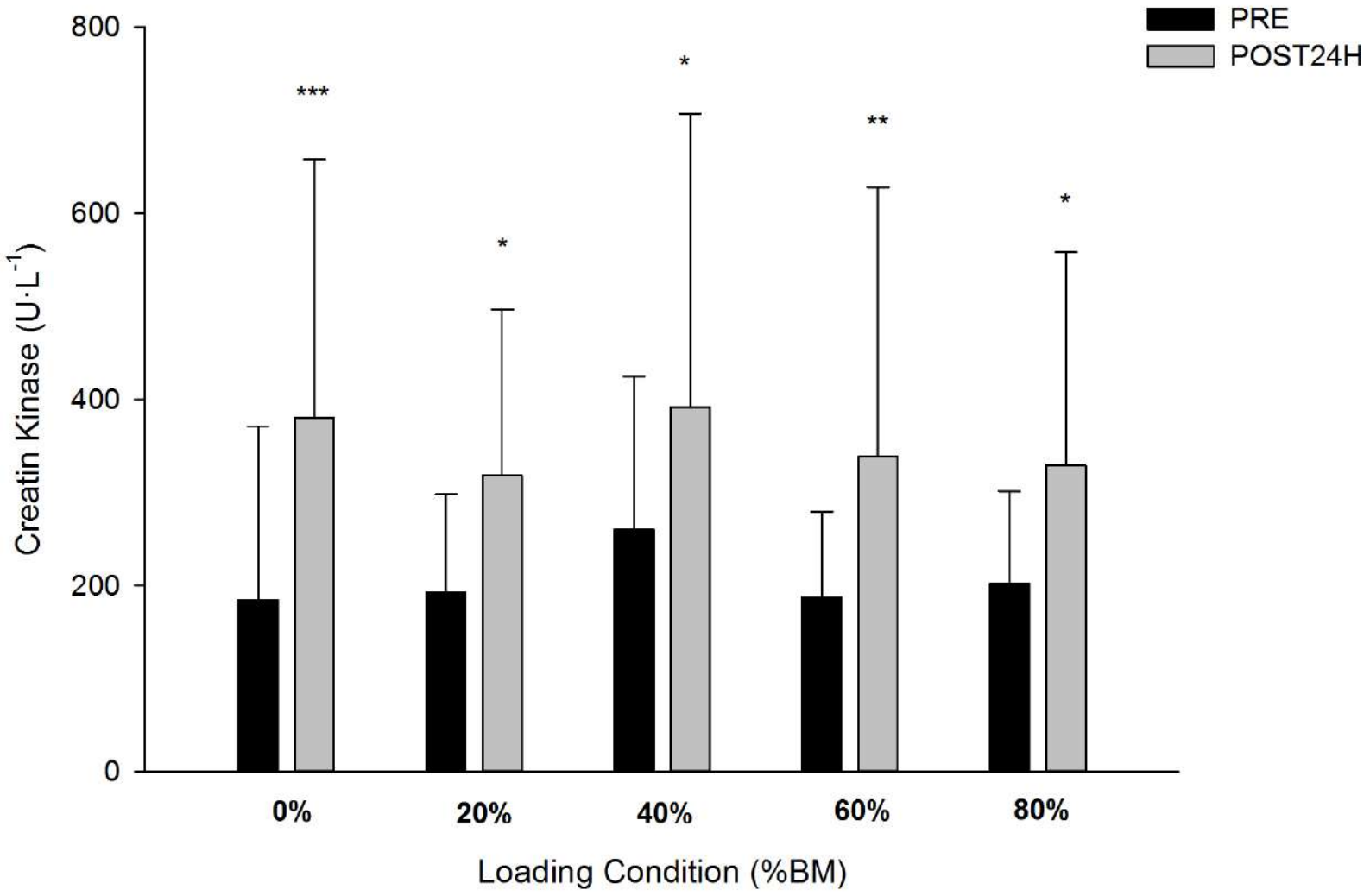
PRE
POST24H
800
600
400
200
0
Creatin Kinase (U·L-1)
***
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0%
20%
40%
60%
80%
Loading Condition (%BM)