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Creatine supplementation can improve impact control in high-intensity interval training

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ABSTRACT

Objectives: This study aimed to investigate the effects of creatine (Cr) supplementation on biomechanical parameters related to shock attenuation during a session of high-intensity interval training (HIIT).
Methods: A single-blinded, placebo-controlled, crossover design was adopted to test eight male elite soccer players during HIIT sessions under two conditions: after placebo supplementation and after Cr supplementation. HIIT test sessions consisted of an intermittent test (five bouts of running) with a constant load applied until exhaustion was reached. The vertical component of ground reaction force and electromyography data were recorded by Gaitway and Lynx-EMG Systems, respectively. Heart rate, rated perceived exertion (Borg's Scale) and lactate concentration information were also obtained.
Results: Cr supplementation did not affect heart rate, rated perceived exertion, and lactate concentration. Decreased values of magnitude of the first peak of the vertical component of ground reaction force (17.2–24.2%) and impulse of the first 50 ms (Imp50; 34.3%) were observed for Cr, but higher values of time to reach the first peak were detected for Cr compared with placebo. Significant modifications in muscle activation were also observed, mainly in the pre-activation phase, and changes were observed in intermediary bouts.
Conclusions: Cr supplementation has the potential to influence biomechanical parameters related to impact control during a single session of HIIT based on running. In particular, the findings of the current study indicate possible improvements in shock attenuation and a safer practice of HIIT under Cr supplementation.
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Introduction

High-intensity interval training (HIIT) has become a widespread exercise approach in recent years because of its time-efficient way to induce similar or even improved adaptations of conventional endurance training [1–5]. HIIT consists of repeated bouts of high-intensity intervals of exercise interspersed with low-intensity or passive rest periods. HIIT is an exercise mode designed to repeatedly stress the body with intense stimuli in different types of exercise, including running. Previous studies have shown that HIIT can also lead to high levels of mechanical load [6–9]. Evidence shows that intense running is characterized by increased impact on the human body [8,10].

Consequently, running biomechanical parameters are strongly influenced by exhaustive exercise [8,10]. The main running alterations under exhaustion are decreased step frequency, increased step length [7], and altered running technique (e.g., range of motion) [9,11]. However, the more relevant effects of intense and exhaustive running exercises appear to be related to shock and skeletal muscle control [3,12–16]. Evidence indicates that running at exhaustion can increase impact forces [12,13] and alter muscle activation intensity, mainly in its preactivation phase and during running at high levels of exercise [3,14–16]. These factors could be detrimental to the mechanical load control [9,15] and increase the risk of injury [13].

The energy yielded for adenosine triphosphate re-synthesis during high-intensity intermittent exercise has been reported as mainly obtained by anaerobic metabolism [17–20]. Phosphorylcreatine (PCr) as a high-energy phosphagen and storage molecule within the skeletal muscle plays an important role in supplying

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immediate replenishment of adenosine triphosphate during intense exercise [17], including HIIT. Subsequent and repeated high-intensity exercise trials result in a depletion of PCr stores in the muscle [21–24], possibly resulting in a reduction in the ability of the skeletal muscle to produce force [25].

Skeletal muscles play an important role in shock attenuation [26] by absorbing the impact force and protecting the joints from external load, but the depletion of muscle PCr stores and diminished energy sources may lead to exhaustion and alter the protective functions of the muscle during running [23,24,27]. In turn, creatine (Cr) supplementation has been consistently demonstrated to increase muscle PCr stores [28] and improve performance in high-intensity intermittent training [28–32]. Accordingly, Cr could avoid peripheral fatigue during intense exercise, reduce impairments on shock attenuation, and consequently improve exercise control. However, the effects of Cr supplementation on the biomechanical aspects of exhaustive running exercises and intermittent training, including HIIT, are still unknown.

To the best of our knowledge, no study has examined the effects of Cr supplementation on parameters related to impact control during high-intensity interval running training. Therefore, the aim of this study was to investigate the effects of Cr supplementation on biomechanical parameters related to impact control during a session of HIIT. Based on previous studies that show improvement in performance and muscle strength [28–32] and in prevention of strength reduction and fatigue [31,33,34] during exhaustive running after 2 to 7 d of Cr supplementation, we hypothesized that changes in muscle activation and diminished impact during running will occur with Cr supplementation.

Methods

Experimental approach to the problem

Elite soccer players were recruited for the present study. A single-blinded, placebo-controlled, crossover design was adopted. To evaluate the effects of Cr supplementation on biomechanical parameters of shock attenuation during a session of HIIT, the maximal oxygen uptake (VO_2max), running speed in which the VO_2max was achieved (vVO_2max), and running speed at 120% of vVO_2max were determined first. Thereafter, participants underwent two sessions of familiarization with the HIIT before testing. Eventually, participants were tested under two conditions: after placebo supplementation and after Cr supplementation. The vertical component of ground reaction force (VGRF) and electromyography (EMG) data were recorded by Gaitway and Lynx-EMG systems, respectively. To guarantee the replenishment of PCr stores in the muscle, a 7 d interval between each test was imposed [28].

Participants

Eight Brazilian elite soccer players (male; age: 16.3 ± 0.5 y; weight: 70.7 ± 4.16 kg; height: 1.78 ± 0.06 m) participated in this study. Participants had to have at least 2 y of experience in running, use of a treadmill for training, and have similar VO_2max. Individuals who used an unbalanced diet or nutritional supplement, consumed anabolic steroidal drugs, were smokers, or presented with an orthopedic impairment or injury were excluded from the study. All participants were informed about the study, and written informed consent was obtained before participation per the Helsinki rules. All procedures and the experimental design were approved by the local ethics committee.

Procedures

Determination of VO_2max and vVO_2max

A cardiopulmonary exercise test was conducted on a treadmill to determine VO_2max and vVO_2max. After a 3 min warm-up at 5 km/h, the test began with a speed of 6 km/h, constant inclination of 10%, and increases of 1 km/h each minute until exhaustion. Participants were supported during the test with strong verbal motivational stimuli to induce maximum effort. Oxygen consumption measurements during the test were obtained with a gas analysis system (Quark$_{b2}$, Cosmed, Rome, Italy). VO_2max was determined when at least two of the following criteria were reached: 1) less than 2.1 ml/kg/min increase between two consecutive periods of 1 min; 2) respiratory exchange ratio higher than 1.1; 3) heart rate of exercise (HR) of ±10 beats per min compared with predicted HR (i.e., 220 − age) [35]. vVO_2max was established as the minimum speed capable of inducing VO_2max [36]. Speed equivalents to 120% of vVO_2max were calculated after VO_2max and vVO_2max determinations.

Supplementation procedures

In the absence of data to accurately determine a time interval for Cr wash-out, a single-blinded design of supplementation was applied as suggested by Sewell et al. [37]. First, participants received a placebo dosage (dextrose, 20 g/d, for 7 consecutive d). After 7 d, participants ceased the placebo ingestion and received a dose of Cr monohydrate (0.3 g.kg/d, for 7 consecutive d). Participants were advised to consume the supplements after lunch and dinner (50% of day dosage in each meal), followed by juice (e.g., orange juice). In addition, they were instructed to fill a table with information about their diet and time of the meals. At the end of the study, participants were asked about the supplement ingested in each period. A low hit percentage was observed to ensure the efficiency of blinding. Figure 1 schematically illustrates the experimental design.

Experimental procedures

Participants were tested under two different conditions: after placebo supplementation and after Cr supplementation. The test session for each condition was separated by 7 d. The HIIT sessions were performed on an instrumented treadmill with two piezoelectric platforms assembled on its surface (GAITWAY Instrumented Treadmill System 9810S1; TROTTER Treadmill Model 685, 01-06560201) and consisted of an intermittent test with a constant load applied until exhaustion was reached. To register the EMG signals, the Lynx-EMG System (Lynx-EMG 1000 System; Lynx Electronic Technology LTDA) was used. Earlobe blood samples (25 μl) were drawn before (Pre) and immediately after the HIIT session (Post 0), and 3 (Post 3) and 5 min (Post 5) of recovery were given to evaluate blood lactate concentration (Sport 1500, Yellow Springs, OH).

The muscles selected for measurement were the rectus femoris, vastus lateralis (VL), vastus medialis (VM), biceps femoris long head (BF), gastrocnemius lateralis (GL), and tibialis anterior (TA). Bipolar surface electrodes were placed on the muscle bellies at 10 mm distance from the motor point (i.e., between motor point and distal tendon). As suggested by Roy et al. [38], the motor point location of each muscle was determined experimentally by an electrical pulse (Omni Pulsi-901, Quark).

Subsequently, a 10 min warm-up and familiarization period at 60% of vVO_2max with 10% of inclination were provided. After the warm-up, participants completed 5 bouts of running until exhaustion at 120% of vVO_2max and with constant inclination (10%). Participants had 90 s passive rest periods between each bout of high-intensity exercise. To monitor exhaustion, HR and rated perceived exertion (RPE; Borg's Scale 6–20) rates were obtained at the beginning and end of the HIIT bouts. As soon as participants reported exhaustion and were unable to maintain the exercise bout, VGRF and EMG data were recorded simultaneously (10 s at 1 kHz). This procedure was repeated for each HIIT bout.

To minimize footwear effect, all participants wore habitual running shoes with similar characteristics of construction.

Mathematical analysis

VGRF data were low-pass filtered by a Butterworth filter (second order, 140 Hz). The start and end of each step was determined, and parameters were obtained. VGRF was normalized by individual body weight, and time was normalized by total support time (0–100% of support phase). The raw EMG signals were initially registered at high-pass intensity (first order, 20 Hz) and low-pass intensity (second order, 500 Hz) by Butterworth filters. After these procedures, EMG signal was filtered by notch filters (60 Hz, 120 Hz, and 180 Hz). Based on VGRF curves, EMG signal of each step was determined, and a full-wave rectification was applied. EMG data were normalized by the mean signal. Biomechanical data were mathematically processed through specific Matlab routines (version 6.5; Mathworks, Natick, MA).

The VGRF variables that were obtained were magnitude of first peak (Fy1), time to achieve first peak (tFy1), loading rate of first peak (LR1) calculated by the ratio Fy1/tFy1, and impulse during the first 50 ms of stance (Imp50), calculated from the area under the curve GRF x Time, from 0 to 50ms. These variables are particularly relevant because they are important indicators of impact forces received

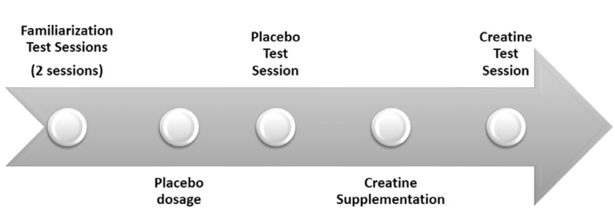

Fig. 1. Overview of experimental design

by human structures during the running cycle. Muscle activation intensity at stance and preactivation (100 ms prior contact) phases was determined through the calculation of root mean square (RMS).

Statistical analysis

After testing for normality and homoscedasticity, a general linear models test for repeated measures was conducted to compare data. The Tukey honest significant difference test was used as a post hoc test at a 5% level of significance (mean ± standard deviation). The statistical analysis was performed with Minitab 15 (Minitab Inc., State College PA).

Results

VO_2max and vVO_2max

The mean VO_2max was 54.00 ± 3.94 ml/kg/min, and the mean vVO_2max 14.00 ± 0.75 km/h. The maximum HR during the test was 199 ± 6 beats per min, the warm-up HIIT session was performed at 8.40 ± 0.45 km/h (60% of vVO_2max), and the speed for the HIIT session's tests was set at 16.80 ± 0.90 km/h (120% of vVO_2max).

Creatine supplementation

Cr supplementation tended to influence the physiologic and biomechanical parameters related to impact control during a session of HIIT. Nevertheless, this influence was significant only for some specific variables and bouts.

After exercise, Cr supplementation did not affect rated perceived exertion (Table 1), HR (Table 1), and blood lactate concentration (Table 2). However, Cr supplementation condition affected VGRF variables related to impact control (Fig. 2). Decreased values of Fy1 were observed for Cr in bouts 2 (17.2%) and 4 (24.2%), but tFy1was higher (28.9%) for Cr in bout 2. Cr supplementation also presented a smaller Imp50 in bout 2 (34.3%) compared with the placebo.

Differences in muscle activation between placebo and Cr supplementation were observed for some muscles and bouts. Only muscles GL and VM presented differences between placebo and Cr for activation intensity during the stance phase (Table 3). Cr supplementation presented decreased RMS (51.5%) for GL in bout 2, but had higher activation intensity (+135.7%) in bout 4. The muscle VM presented a smaller value (40.8%) for CR in bout 2. During the pre-activation phase (Table 4), smaller values of RMS (63.8% and 43.5%, respectively) were observed for muscles VL and BF in Cr, but higher activation intensity (75.8%) was observed for VM in Cr condition. All differences at the preactivation phase occurred in bout 2.

Discussion

The purpose of this study was to investigate the effects of Cr supplementation on running biomechanical parameters related to impact control during a session of HIIT. Previous studies have evidenced the ergogenic effects of Cr supplementation on performance and physiological variables related to intensive and exhaustive exercises [31–33,39]. Intensive and exhaustive running conditions are known to result in changes in biomechanical parameters, mainly those related to shock attenuation [12,13]. Because Cr is a relevant energy source for muscle contraction during high-intense exercise and muscles play a crucial role in shock absorption, Cr supplementation was expected to avoid peripheral fatigue and consequently minimize impairments in impact control.

The main finding of the study indicates that Cr supplementation has the potential to affect the biomechanical parameters of running and may play a relevant role in shock attenuation. As we hypothesized, Cr supplementation induced important changes in variables related to impact control during exercise. Reduced Fy1 and Imp50 and higher tFy1 with Cr indicate that the impact force was diminished during intense running. However, this influence was significant only for intermediary bouts (i.e., bouts 2 and 4). Thus, our results suggest that Cr supplementation has the potential to be effective in maintaining or even improving the mechanical load control during running at HIIT. Such improvements may be related to reduced muscle strength loss and fatigue rates with Cr supplementation reported in the literature [31–34].

A higher impact force during intense and exhaustive exercises may result from unstable and exhausted skeletal muscles, whose efforts are directed to attend the higher demand of external load to keep their protective role [4,26,40]. Our results showed that changes in impact control were followed by modifications in muscle activation as a result of Cr supplementation. Nevertheless, the modifications did not present a consistent pattern and were significant only for a few muscles. The most consistent result was that the significant modifications in muscle activation occurred again in bout 2. The main result was that some muscles, such as VL and BF, showed diminished activation intensity during the preactivation phase of HIIT in bout 2 with Cr supplementation. Because the preactivation phase has a protective role during human movement [4,26,40], our results corroborate to VGRF data and suggest a relationship with the decreased impact force observed with Cr supplementation in the same bout.

The present investigation has some limitations. Indeed, even when using a standard protocol of Cr supplementation, our protocol did not measure intramuscular Cr concentration. In addition, little control was performed for potential changes in body mass (e.g., owing to net water retention or weight gain) or side effects. Sample size and methodologic choices related to EMG signal processing may have also limited the sensitiveness to detect changes. Finally, of note, the effects of Cr supplementation were significant and consistent only for the intermediary bouts (mainly bout 2). The mechanisms that underpin the alterations observed, and the reasons for modifications only in specific bouts, were not assessed and are still unknown. Thus, more studies are needed to better

Table 1
RPE and HR values in each bout of the high-intensity interval training sessions with placebo and creatine supplementation (mean ± standard deviation)

Variable	Experimental condition	Running bout				
		1	2	3	4	5
$HR_{beginning}$	**Placebo**	136.7 ± 10.9	148.5 ± 15.9	151.5 ± 9.4	152.0 ± 15.6	156.6 ± 10.0
(beats/min)	**Creatine**	125.0 ± 20.5	130.3 ± 15.5	133.3 ± 16.0	136.6 ± 19.0	138.3 ± 14.3
HR_{end}	**Placebo**	188.2 ± 4.9	186.2 ± 5.8	189.7 ± 3.7	185.0 ± 7.3	189.3 ± 5.5
(bpm)	**Creatine**	177.0 ± 6.5	176.3 ± 11.9	179.6 ± 14.5	177.0 ± 15.8	179.6 ± 19.2
RPE	**Placebo**	10.0 ± 2	11.0 ± 1.6	13.2 ± 2.0	16.0 ± 3.1	16.0 ± 1.7
(Borg's scale)	**Creatine**	10.3 ± 1.5	11.0 ± 1.0	12.3 ± 1.5	14.0 ± 1.0	14.7 ± 1.5

HR, heart rate; RPE, rate of perceived exertion

Table 2
Lactate concentration Pre, Post 0, Post 3, and Post 5 with placebo and creatine supplementation (mean ± standard deviation)

	Experimental condition	Pre	Post 0	Post 3	Post 5
[Lactate] (mmol/L)	**Placebo**	1.06 ± 0.26	11.12 ± 1.79	9.97 ± 1.34	5.90 ± 2.05
	Creatine	1.16 ± 0.38	10.43 ± 0.38	8.69 ± 1.67	7.61 ± 2.39

HIIT, high-intensity interval training; Post 0, immediately after HIIT; Post 3, 3 min of rest after HIIT; Post 5, 5 min of rest after HIIT; Pre, prior to HIIT

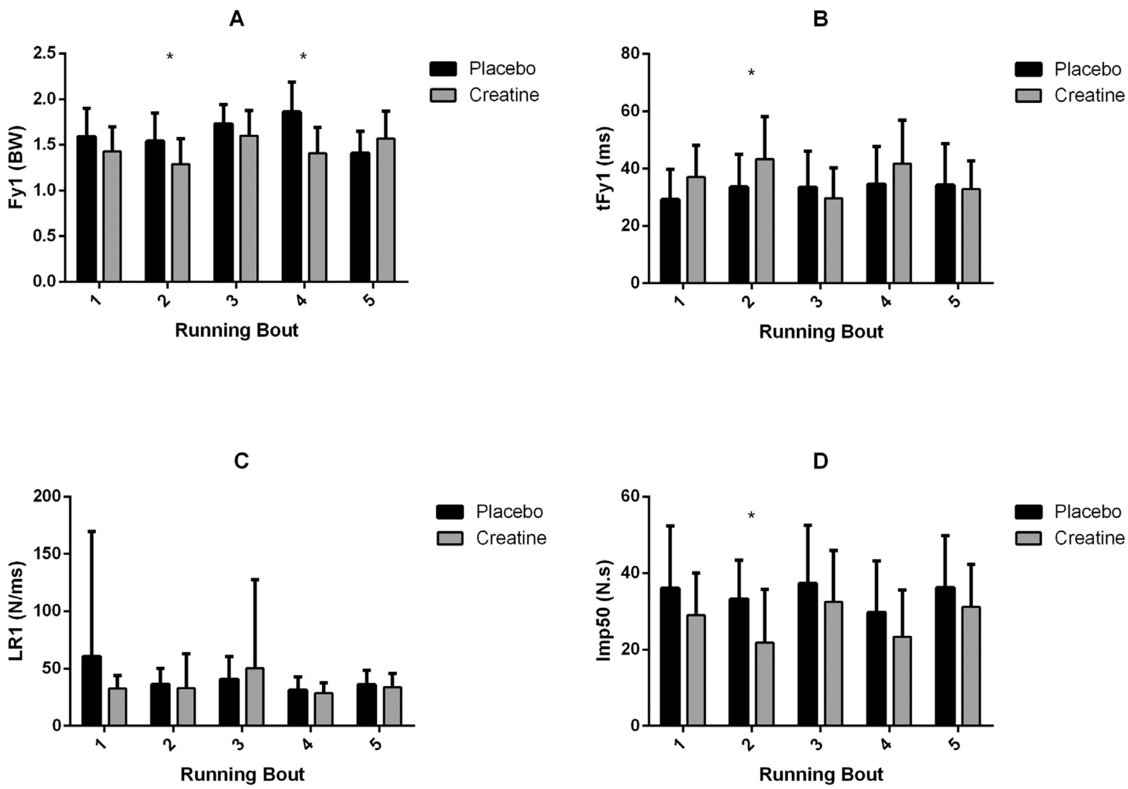

Fig. 2. Mean and standard deviation values for (A) magnitude of first peak, (B) time to reach first peak, (C) loading rate of first peak, and (D) impulse during the first 50 ms of stance in each bout of the high-intensity interval training session with placebo and creatine supplementation. *Difference between experimental conditions (placebo versus creatine) in the bout.

Table 3
Mean and standard deviation values for root mean square of muscles TA, GL, VM, RF, VL, and BF during the stance phase of running in each bout of the high-intensity interval training session with placebo and creatine supplementation

Muscle	Experimental condition	Running bout				
		1	2	3	4	5
TA (AU)	**Placebo**	1.38 ± 0.55	1.53 ± 0.51	1.29 ± 0.45	1.51 ± 0.41	0.92 ± 0.44
	Creatine	1.11 ± 0.62	1.37 ± 0.62	1.31 ± 0.70	1.45 ± 0.62	1.37 ± 0.52
GL (AU)	**Placebo**	2.12 ± 0.51	2.04 ± 0.41*	2.28 ± 0.64	0.98 ± 0.97*	1.31 ± 1.26
	Creatine	1.78 ± 1.30	0.99 ± 0.72*	2.29 ± 0.47	2.31 ± 0.62*	1.51 ± 0.87
VM (AU)	**Placebo**	2.12 ± 1.39	2.45 ± 1.29*	2.11 ± 1.52	2.22 ± 1.42	1.19 ± 1.15
	Creatine	1.84 ± 1.21	1.45 ± 0.91*	2.45 ± 1.14	2.30 ± 1.20	1.74 ± 1.05
RF (AU)	**Placebo**	1.62 ± 0.74	1.54 ± 0.51	1.69 ± 0.44	1.92 ± 0.61	1.26 ± 0.64
	Creatine	1.21 ± 0.54	1.14 ± 0.29	1.95 ± 0.91	2.14 ± 0.84	1.69 ± 0.96
VL (AU)	**Placebo**	2.10 ± 1.27	1.60 ± 1.33	2.05 ± 1.04	1.42 ± 1.47	1.75 ± 1.95
	Creatine	1.82 ± 1.32	0.85 ± 0.97	3.36 ± 1.01	2.86 ± 1.02	2.14 ± 1.45
BF (AU)	**Placebo**	1.55 ± 0.73	1.38 ± 0.40	1.53 ± 0.57	1.72 ± 0.44	0.84 ± 0.26
	Creatine	1.32 ± 0.75	1.08 ± 0.89	1.91 ± 0.66	1.99 ± 0.41	1.50 ± 0.76

*Significant difference between placebo and creatine ($p < .05$) in the bout.AU, arbitrary unit; BF, biceps femoris long head; GL, gastrocnemius lateralis; RF, rectus femoris; TA, tibialis anterior; VL, vastus lateralis; VM, vastus medialis

Table 4
Mean and standard deviation values for root mean square of muscles TA, GL, VM, RF, VL, and BF recorded during the pre-activation phase of running in each bout of the high-intensity interval training session during placebo and creatine supplementation

Muscle	Experimental condition	Running bout				
		1	2	3	4	5
TA (AU)	**Placebo**	1.73 ± 0.33	0.83 ± 0.46	1.92 ± 0.33	1.76 ± 0.39	1.48 ± 0.61
	Creatine	1.85 ± 0.71	1.39 ± 0.62	2.06 ± 0.53	2.02 ± 0.61	1.50 ± 0.46
GL (AU)	**Placebo**	0.78 ± 0.24	1.88 ± 0.95	0.53 ± 0.24	1.02 ± 0.74	1.11 ± 0.54
	Creatine	1.15 ± 0.64	1.23 ± 0.72	0.89 ± 0.21	0.95 ± 0.20	1.15 ± 0.31
VM (AU)	**Placebo**	0.91 ± 0.51	0.62 ± 0.25*	0.62 ± 0.17	1.12 ± 0.58	0.72 ± 0.34
	Creatine	0.68 ± 0.17	1.09 ± 0.41*	0.70 ± 0.31	0.74 ± 0.37	0.77 ± 0.62
RF (AU)	**Placebo**	0.75 ± 0.49	1.41 ± 0.33	1.20 ± 0.55	1.27 ± 0.70	1.10 ± 0.56
	Creatine	1.09 ± 0.57	1.46 ± 0.55	0.92 ± 0.58	0.96 ± 0.48	1.01 ± 0.36
VL (AU)	**Placebo**	0.79 ± 0.32	2.32 ± 1.54*	0.57 ± 0.25	0.60 ± 0.21	0.70 ± 0.35
	Creatine	0.68 ± 0.44	0.84 ± 0.78*	0.99 ± 0.63	0.84 ± 0.48	0.68 ± 0.29
BF (AU)	**Placebo**	1.66 ± 1.00	1.70 ± 0.73*	1.58 ± 0.77	1.67 ± 0.51	0.81 ± 0.62
	Creatine	1.23 ± 0.86	0.96 ± 1.27*	2.38 ± 0.69	2.36 ± 0.84	1.60 ± 1.08

*Significant difference between placebo and creatine ($p < .05$) in the bout.AU, arbitrary unit; BF, biceps femoris long head; GL, gastrocnemius lateralis; RF, rectus femoris; TA, tibialis anterior; VL, vastus lateralis; VM, vastus medialis

elucidate the potential effect of Cr supplementation on impact control and clarify this issue.

Conclusions

Our findings demonstrate that 7 d of Cr supplementation has the potential to influence biomechanical parameters related to impact control during a single session of HIIT based on running. Improvements in shock attenuation and impact control were observed with Cr supplementation. Moreover, muscle activation intensity during the preactivation phase tended to decrease with Cr, which reinforces the potential for an improved protective situation and safer practice of HIIT with Cr supplementation. These results are relevant because evidence indicates that running at exhaustion can increase impact force [12,13] and alter muscle activation intensity, mainly in the preactivation phase [3,14–16], which could be detrimental to practitioners [9,13,15].

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