Performance and muscle activity during a high-intensity intermittent task after the ingestion of sodium bicarbonate: A randomized, double-blind, placebo-controlled, crossover study

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ABSTRACT

The aim of the present study was to determine whether the ingestion of sodium bicarbonate ($NaHCO_3$) promotes changes in strength, muscle activity, and perceived exertion in trained individuals following high-intensity intermittent exercise. Twelve trained men were enrolled in a randomized, double-blind, crossover study. Each participant underwent two interventions with a 14-day washout period: i) alkalosis (ALK) – administration of gelatinous capsules containing 0.3 $g.kg^{-1}$ of $NaHCO_3$; ii) placebo (PLA) – administration of capsules containing 0.3 $g.kg^{-1}$ of calcium carbonate ($CaCO_3$). The outcomes (electromyographic activity of the quadriceps, peak torque, pH, lactate, scales of perceived effort and pain) were collected during a dynamic high-intensity intermittent protocol performed on an isokinetic dynamometer. Repeated-measures ANOVA revealed no differences between conditions for any of the outcomes analysed. Based on the present findings, the ingestion of sodium bicarbonate does not promote changes in muscle activity, strength of the quadriceps, or perceptions of effort and pain in trained individuals during high-intensity intermittent exercise on an isokinetic dynamometer.
Keywords: Sport medicine, Electromyography, Isokinetic dynamometer, Sodium bicarbonate, Performance, Muscle fatigue.

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INTRODUCTION

The ingestion of sodium bicarbonate ($NaHCO_3$) has been recommended as an ergogenic agent to improve athletic performance during sports modalities and exercises comprising short duration, high-intensity tasks (A. J. Carr, Hopkins, & Gore, 2011). However, the potential auxiliary effect of this substance has been the object of investigations for decades in studies with different protocols and sports modalities, such as swimming (Gao, Costill, Horswill, & Park, 1988; Siegler & Gleadall-Siddall, 2010; Zajac, Cholewa, Poprzecki, Waśkiewicz, & Langfort, 2009), running (Michael J. Price & Simons, 2010; Mike James Price & Cripps, 2012), rowing (Driller, Gregory, Williams, & Fell, 2013; Hobson et al., 2014), judo (Artioli et al., 2006, 2007), CrossFit (Durkalec-Michalski, Zawieja, Podgórski, Loniewski, et al., 2018), and wrestling (Durkalec-Michalski, Zawieja, Podgórski, Zawieja, et al., 2018).

Although positive effects have been described with the use of $NaHCO_3$ through blood and performance variables as well as specific gains in different types of training and sports modalities (Artioli et al., 2007; Lindh, Peyrebrune, Ingham, Bailey, & Folland, 2008; Michael J. Price & Simons, 2010), the experimental conditions and technical, tactical, and/or psychological factors do not enable a clear understanding of physiological responses related to the use of this supplement.

The most widely employed test protocols have a high-intensity intermittent characteristic, such as judo, sprint swimming (Artioli et al., 2007; Siegler & Gleadall-Siddall, 2010), and resistance exercises used in strength training (B. M. Carr, Webster, Boyd, Hudson, & Scheett, 2013; Duncan, Weldon, & Price, 2014; Siegler, Marshall, Finn, Cross, & Mudie, 2018). Besides the diversity of test protocols, the different clinical outcomes investigated to determine the possible effects of $NaHCO_3$ also hinder a clear understanding of the usefulness of this substance.

An isokinetic dynamometer is important equipment for the analysis of performance measures after the ingestion of $NaHCO_3$ during isometric contractions (Siegler & Marshall, 2015) as well as lower limb power and endurance protocols (Coombes & McNaughton, 1993). However, the effects of the ingestion of $NaHCO_3$ on a high-intensity intermittent protocol have not yet been investigated. Such an investigation could contribute to a better understanding of the impact of $NaHCO_3$ on resistance exercises and sports modalities with these characteristics.

Intermittent modalities are characterized by high-intensity, short duration actions with small recovery intervals (Bishop, Edge, Davis, & Goodman, 2004) and are seen in football (Mohr, 2015), cycling (Matsuura, Arimitsu, Kimura, Yunoki, & Yano, 2007), martial arts (Durkalec-Michalski, Zawieja, Podgórski, Loniewski, et al., 2018; Lopes-Silva et al., 2018), and resistance exercise modalities (Durkalec-Michalski, Zawieja, Podgórski, Zawieja, et al., 2018). Besides involving intermittent tasks, resistance exercises induce acidosis due to the partial or complete vascular occlusion generated during muscle action (Lambert & Flynn, 2002).

Considering these observations, we test the hypothesis that $NaHCO_3$ can improve physical performance during the practices of resistance exercises and alter physiological mechanisms associated with fatigue. Therefore, the aim of the present study was to determine whether the ingestion of $NaHCO_3$ promotes changes in strength, muscle activity, and perceived exertion in trained individuals during high-intensity intermittent exercise performed on an isokinetic dynamometer.

METHODS

Participants

Twelve men (mean age: 28.67 ± 6.08 years; mean body weight: 82.78 ± 9.60 kg; mean height 1.78 ± 0.09 m; mean body mass index: 26.51 ± 2.26 kg) who were regular practitioners of resistance training with ample experience (mean: 6.54 ± 3.00 years) participated voluntarily in a randomized, double-blind, placebo-controlled, crossover study after signing a statement of informed consent. This study received approval from the institutional review board (certificate number: 2.291.349) and was registered in Clinical Trials (NCT03837886).

A crossover design was used to exclude the potential interference of individual differences. Each participant was subjected to a single session of $NaHCO_3$ (alkalosis [ALK] group) or calcium carbonate ($CaCO_3$) (placebo [PLA] group).

The exclusion criteria were a clinical diagnosis of diabetes mellitus, respiratory disease (asthma, COPD), kidney disease, metabolic disease, acid-base disorder, rheumatological disease, gout, cardiovascular disorder, tobacco use, alcohol use, history of lower limb surgery, or any type of joint and/or musculoskeletal disorder that might compromise the execution of the study protocol. Individuals who made continual use of any type of medication, high-protein food supplement, creatine supplement, or anabolic steroids were also excluded.

Outcome measures

The primary outcome of the study was the immediate effect of the ingestion of $NaHCO_3$ on the amplitude and frequency of the electromyographic signal and peak torque of the quadriceps muscle during and after high-intensity intermittent exercise performed on an isokinetic dynamometer. The secondary outcomes were biochemical and psychophysiological effects.

Randomization

The randomization of the volunteers to the different groups (ALK or PLA) was performed through a drawing using two opaque envelopes – one containing a red label (ALK) and the other containing a blue label (PLA). The volunteer selected an envelope on the day of the data collection. It was determined that each group should have 12 subjects. Thus, when one of the groups was complete, the criterion became the volunteer's consecutive order of arrival. All subjects in the study received sodium bicarbonate or placebo on alternate days. To eliminate carry-over treatment effects, a 14-day washout period was respected between treatments.

Supplementation

The participants ingested 0.3 $g.kg^{-1}$ of $NaHCO_3$ for the experimental condition and an equal dose of calcium carbonate ($CaCO_3$) for the placebo condition. The substances were administered in the form of gelatinous capsules fractionated into four equal doses 90 minutes prior to the test and ingested with water (7 ml/kg of body mass) (A. J. Carr, Slater, Gore, Dawson, & Burke, 2011).

The participants were counselled to maintain a balanced diet (70% carbohydrates, 15% lipids, and 15% proteins) at least 24 hours prior to the data collection as well as not ingest caffeine or spicey foods for at least 12 hours prior to the experimental procedure to avoid any influence of metabolic regulation (Maughan, King, & Lea, 2004; Westerterp-Plantenga, Diepvens, Joosen, Bérubé-Parent, & Tremblay, 2006). Compliance was verified using the 24-hour recall method with each participant (Gough, Rimmer, Osler, & Higgins, 2017).

To avoid glycaemic alterations among the participants and between test conditions, a 6% carbohydrate supplement (60 g of maltodextrin. L^{-1}) was administered in fractionated form 60 minutes prior to the test (500 ml) and during the test (500 ml) (Aoki, Pontes Junior, Navarro, Uchida, & Bacurau, 2003; Bacurau et al., 2002; Haff et al., 2000).

Measurement instruments and evaluations

The record of quadriceps muscle strength during the execution of the fatigue-induction protocol was obtained using an isokinetic dynamometer (model: Biodex System 3 Pro, Biodex Medical System, Shirley, NY, USA).

Surface electromyographic (EMG) signals were obtained using a 16-channel module (bandpass filter: 20-500 Hz, amplifier gain of 1000, common mode rejection ratio <120 dB, active bipolar electrodes with a preamplification gain of 20 x, and sampling frequency 2 kHz; EMG System do Brasil Ltda, São José dos Campos, São Paulo, Brazil). A channel of the acquisition system was enabled and the isokinetic dynamometer was connected to synchronize the signals recorded by both pieces of equipment.

After cleaning the skin with alcohol, circular self-adhesive silver chloride electrodes (10 mm in diameter and interelectrode centre-to-centre distance of 20 mm; *Medical Trace*®) were positioned as follows: (i) vastus lateralis muscle: electrodes arranged from a demarcation line between the anterior superior iliac spine to the lateral border of the patella, to 2/3 of the iliac spine; ii) vastus medialis muscle: lower fifth of the distance between the anterior superior iliac spine and the medial joint space of the knee; (iii) rectus femoris: midpoint of a line between the anterior superior iliac spine and the edge of the base of the patella (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The ground electrode was attached to lateral malleolus ipsilateral to the analysed limb.

For the determination of lactate, pH, and glucose, blood samples were collected by a trained nurse registered with the Regional Nursing Council.

Perceived exertion was measured using the Borg Rating of Perceived Exertion (RPE) scale (Borg, 1982) in the Portuguese language version validated for use on athletes (Cavasini & Matsudo, 1986). Perceived pain was measured using the 11-point numeric rating scale (0: no pain; 10: worst possible pain imaginable), which has been translated and cross-culturally adapted for the Brazilian population (Ferreira-Valente, Pais-Ribeiro, & Jensen, 2011). The RPE scale and NRS were administered by the same evaluator prior to the ingestion of the substance, before the test, during recovery intervals between sets, and after the test.

Experimental protocol

The study was conducted on three different days: (1) evaluations and familiarization protocol; (2 and 3) test under placebo or experimental condition.

Independent evaluators performed the following procedures: Evaluator 1: screening, random drawing of treatments to be performed; Evaluator 2: execution of tests on isokinetic dynamometer; Evaluator 3: EMG data collection; Evaluator 4: blood collection; Evaluator 5: collection of psychophysiological data; Evaluator 6: EMG signal processing and statistical analysis. Evaluators 2, 3, 4, 5, and 6 were blinded to the groups.

On the first visit, the participants were submitted to an anthropometric evaluation and a familiarization session with the isokinetic dynamometer and were given orientations regarding the experimental test and data collection procedures. The familiarization protocol consisted of a static contraction task for the determination of maximum voluntary contraction (MVC) and a dynamic contraction task similar to the effective experimental protocol but with lower volume and intensity. All tests were performed with the dominant lower limb, which was determined based on the answer to an oral question (Ayotte, Stetts, Keenan, & Greenway, 2007).

The experimental protocol consisted of an initial maximum strength test (MVC-pre), dynamic test (DYN test), and final maximum strength test (MVC-post). Both the MVC-pre and MVC-post comprised three maximum isometric contractions of the knee extensors with the individual seated on the isokinetic dynamometer with the hip at 120º, knee at 60º (Gayda, Choquet, & Ahmaidi, 2009), arms crossed over the chest, and a two-minute recovery period between sets. The DYN test comprised a high-intensity intermittent task (Dipla et al., 2009; Suzuki et al., 2016) with 10 sets consisting of 10 repetitions of knee extension and flexion at an angular velocity of $120^{\circ}s^{-1}$ and a one-minute recovery period between sets. The range of motion during the protocol was 90º, with a maximum limit of 15º during extension (Escamilla et al., 1998). All strength tests were preceded by a short warmup involving flexion and extension movements of the knees (eccentric/concentric) on the isokinetic dynamometer for five minutes.

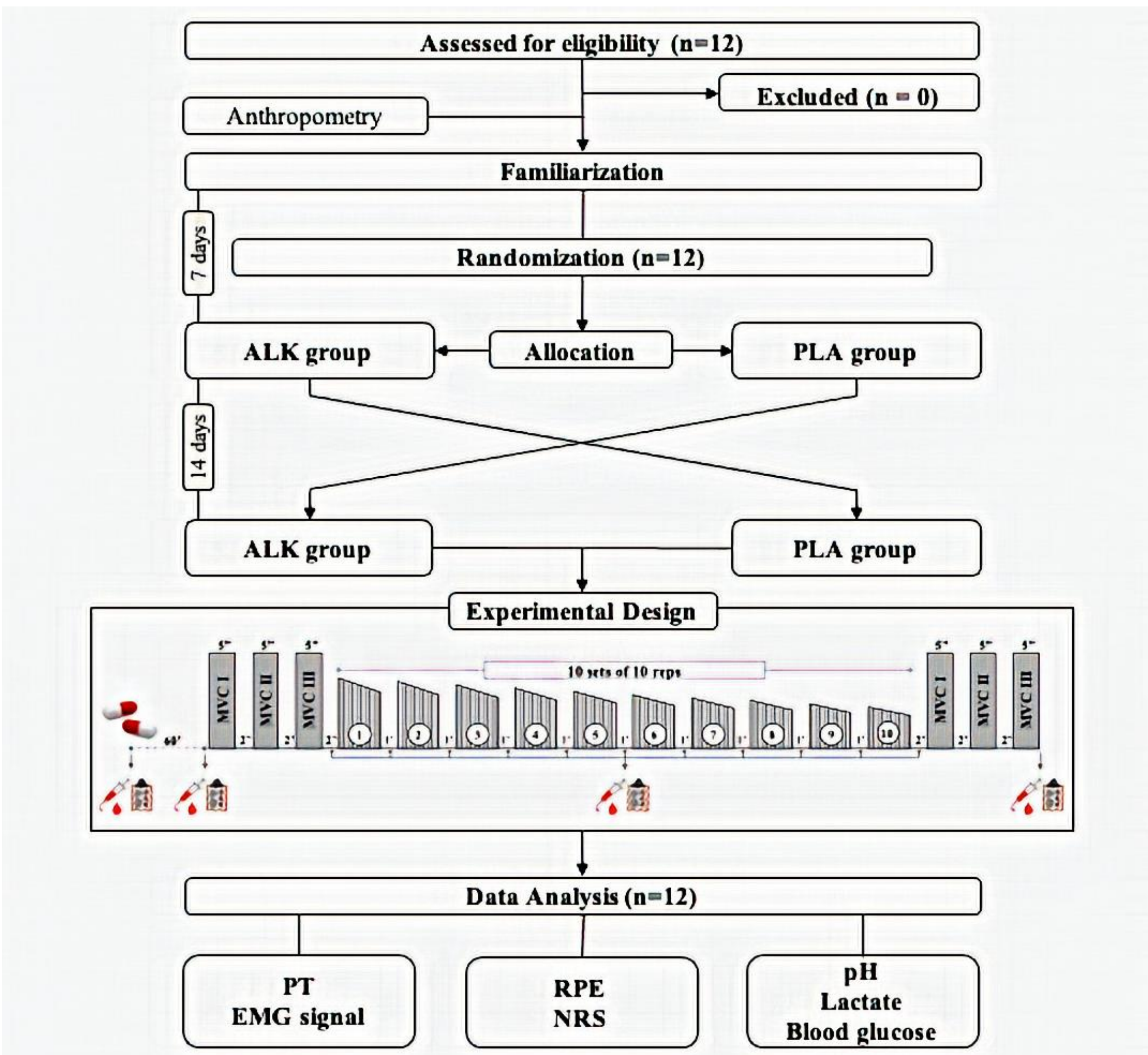

Figure 1. Flowchart of study and experimental protocol. MVC: maximum voluntary contraction; ALK: alkalosis; PLA: placebo; EMG: electromyography; RPE: rating of perceived exertion; NRS – numeric rating scale for pain.

Data processing

The data were analysed offline using specific routines carried out in the MATLAB program (version R2016; The MathWorks Inc., Natick, Massachusetts, USA). Peak torque values were separated cycle by cycle based on the movement of the arm of the isokinetic dynamometer during dynamic test. Mean peak torque values were considered for the comparison between groups.

The EMG signals acquired during MVC-pre and MVC-post were analysed by the amplitude of the signal calculated from the root mean square (RMS) and median frequency (MDF) during five seconds of the recording of the EMG signal. For the DYN test, the RMS and MDF were calculated for each of the 10 cycles of eccentric/concentric contraction. The MDF of the power spectrum was calculated using Welch's averaged periodogram with a Hamming window length zero-padded to the length of 1024 points. Overlap was 50% of the window length.

Statistical analysis

The Shapiro-Wilk test was used to determine the distribution of the data (normal or non-normal). Repeated-measures analysis of variance (ANOVA) with two factors (group vs. pre and post) was employed to determine the influence of $NaHCO_3$ on muscle fatigue, with the Bonferroni correction and Tukey's post hoc test. The level of significance was set to 5% ($p < .05$). All data were analysed using SPSS 20.0 (SPSS Inc., Chicago, USA). Partial eta squared (η_p^2) was used to calculate the effect size (Lakens, 2013), the interpretation of which was based on the values established by Cohen: small effect (less than $\eta_p^2 = 0.01$), moderate effect (approximately $\eta_p^2 = 0.06$), and large effect (greater than $\eta_p^2 = 0.14$) (Cohen, 1988).

RESULTS

Blood findings

The analysis of the blood samples from the ALK group (submitted to $NaHCO_3$) revealed a significant increase in pH (F = 3.50; $p = .03$; $\eta_p^2 = 0.14$), whereas no change was found in the PLA group (F = 0.43; $p = .91$; $\eta_p^2 = 0.02$).

Table 1 displays the lactate and glycemia results before and after the interventions. No significant difference in either variable was found between the groups.

Table 1. Mean blood concentrations before and after ingestion of $NaHCO_3$ or placebo.

	PLA		**ALK**		**Anova**		
	Δ ± SD	(IC95%)	**Δ** ± SD	(IC95%)	F	p	η_p^2
pH	0.01 ± 0.05	(-0.09 to 0.11)	0.06 ± 0.04	(-0.03 to 0.16)	2.79	.11	0.11
Lactate (mmol/L)	0.13 ± 0.75	(-0.60 to 0.34)	0.35 ± 0.35	(-0.37 to 1.07)	0.04	.85	0.00
Glucose (mg/dL)	4.58 ± 5.90	(-7.67 to 16.84)	0.41 ± 6.10	(-12.25 to 13.08)	0.34	.57	0.02

Note. η_p^2: partial Eta squared. Effect size: small effect (less than $\eta_p^2 = 0.01$), moderate effect (approximately $\eta_p^2 = 0.06$), and large effect (greater than $\eta_p^2 = 0.14$).

Strength

Peak torque declined during the sets of the dynamic protocol and at the MVC-post under both conditions ($p < .05$). However, no significant differences were found between the ALK and PLA groups considering the pre-intervention and post-intervention conditions of the dynamic test (ANOVA: F = 1.01; $p = .43$; $\eta_p^2 = 0.04$) or isometric test (ANOVA: F = 0.56; $p = .46$; $\eta_p^2 = 0.02$) (Figure 2).

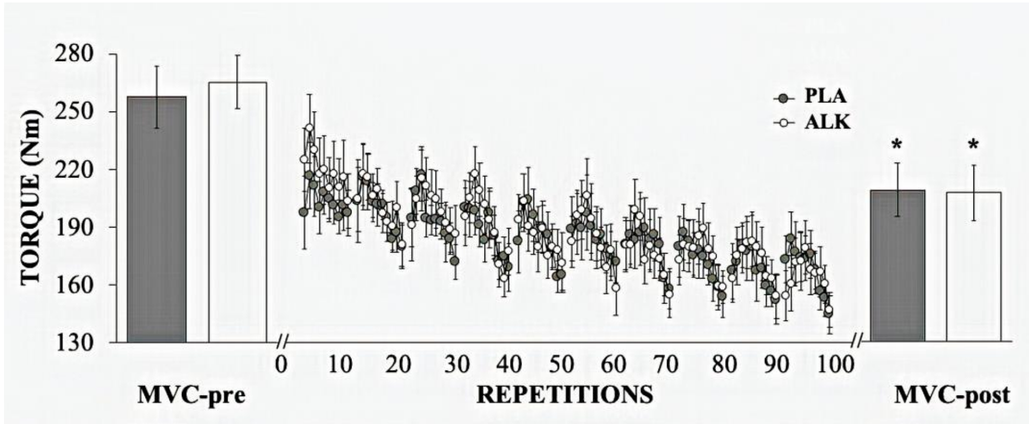

Figure 2. Mean and standard deviation of peak torque during execution of MCV-pre, MVC-post, and dynamic fatigue-induction protocol. (*) Significant difference between pre- and post-test evaluations ($p < .05$).

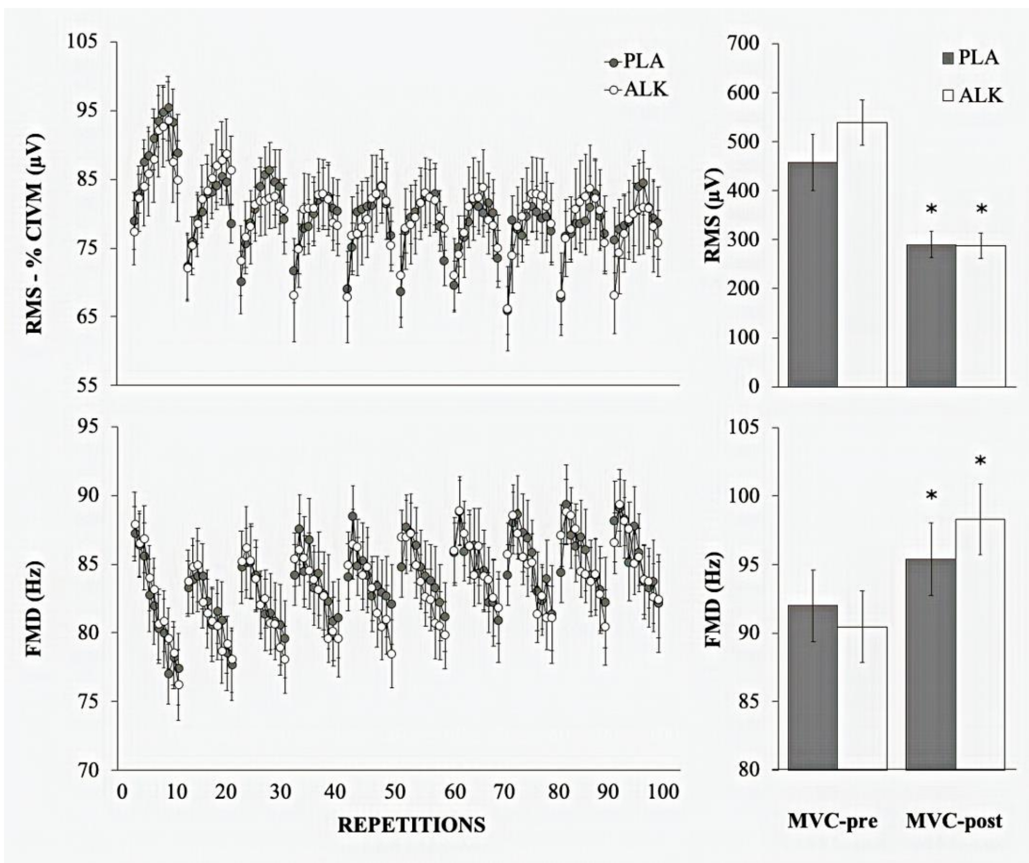

Figure 3. Mean and standard deviation of amplitude (RMS) and median frequency (MDF) of EMG signal during execution of MCV-pre, MVC-post, and dynamic fatigue-induction protocol. (*) Significant difference between pre- and post-test evaluations ($p < .05$).

Electromyography

The analyses of the RMS and MDF of the EMG signal during MVC-pre and MVC-post revealed no significant differences between the PLA and ALK groups ($p > .05$). Figure 3 displays the RMS and MDF before, during, and after the intervention. ANOVA revealed no significant differences between the ALK and PLA groups regarding RMS (F = 3.15, *p* = .09, η_p^2 = 0.12) or FDM (F = 3.39, *p* = .08, η_p^2 = 0.13) considering the pre-intervention and post-intervention conditions calculated from the EMG signal obtained during MVC. Moreover, no significant differences between groups were found regarding the RMS (ANOVA: F = 0.48; *p* = 1.00; η_p^2 = 0.02) and MDF (ANOVA: F = 0.73; *p* = .97; η_p^2 = 0.03) of the EMG signals collected during the dynamic tests.

Psychophysiological variables

The score on the RPE scale increased significantly in both the ALK and PLA groups (*p* < .05) but no significant difference between groups was found (ANOVA: F = 0.56; *p* = .89; η_p^2 = 0.02). Regarding the perception of pain based on the NPRS administered during the execution of the entire test protocol, no significant intra-group (*p* > .05) or inter-group (ANOVA: F = 0.68; *p* = .76; η_p^2 = 0.03) differences were found.

DISCUSSION

The possibility that the ingestion of $NaHCO_3$ could improve physical performance during the practice of resistance exercises and alter physiological mechanisms associated with fatigue, as described in previous studies (Artioli et al., 2007; A. J. Carr, Hopkins, et al., 2011; B. M. Carr et al., 2013; Krustrup, Ermidis, & Mohr, 2015), was not confirmed with the use of a high-intensity intermittent exercise protocol.

Intramuscular acidosis is associated with the process of fatigue stemming from the practice of sports modalities or exercise programs with high volume and intensity (B. M. Carr et al., 2013; Lambert & Flynn, 2002). This effect indicates the ergogenic potential of $NaHCO_3$ for intense intermittent exercises, such as resistance exercise. According to previous studies, the dose administered to the participants in the present study (0.3 $g.kg^{-1}$ of $NaHCO_3$) is effective at inducing metabolic alkalosis (B. M. Carr et al., 2013; Siegler et al., 2018; Yamanaka, Yunoki, Arimitsu, Lian, & Yano, 2011). However, although blood concentrations of bicarbonate (HCO_3) were not measured during the test protocols in the present study, evidence points to an increase in this buffering agent together with an increase in the pH of the blood following the ingestion of $NaHCO_3$ (Artioli et al., 2007; A. J. Carr, Hopkins, et al., 2011; A. J. Carr, Slater, et al., 2011; Siegler, Marshall, Bishop, Shaw, & Green, 2016), as demonstrated in the present results.

Despite the potential increase in the action of the main blood buffering system, the ingestion of $NaHCO_3$ did not provide additional benefits to trained individuals during a high-intensity exercise performed on an isokinetic dynamometer in the present study. The data demonstrated similar behaviour between the conditions studied (ALK and PLA) regarding strength, electromyographic activity, perceived exertion, and perceived pain.

The findings related to muscle performance are in agreement with data described in previous studies analysing the effects of $NaHCO_3$ during resistance exercises used in strength training, in which no increase in strength was found for the bench press and pull press exercises (Materko, Santos, & Novaes, 2008), torque or muscle activity during leg extension exercise (Siegler et al., 2018).

However, these results cannot be considered conclusive, as increases in the number of repetitions during squatting, leg press, and knee extension exercises have been reported (B. M. Carr et al., 2013; Duncan et al., 2014). Moreover, increases in peak torque and total work have been found in supplemented individuals during strength and endurance exercises on an isometric dynamometer, respectively (Coombes & McNaughton, 1993).

These conflicting, inconclusive results may be related to the wide variety of test protocols and/or investigation instruments used in different studies. Despite the broad variation in test protocols, tests composed of exercises that mobilize a greater quantity of muscle mass (squats and leg press) (B. M. Carr et al., 2013; Duncan et al., 2014) and those with more intense loads (higher number of repetitions and/or heavier loads) (Coombes & McNaughton, 1993) suggest a possible ergogenic effect for $NaHCO_3$.

Regarding muscle activity, the present results are similar to those described in previous studies (Hunter, de Vito, Bolger, Mullany, & Galloway, 2009; Matsuura et al., 2007; Siegler et al., 2014; Yamanaka et al., 2011), suggesting that the use of the supplement does not lead to changes in the EMG signal (Figure 3). Therefore, the possibility that acidosis caused by the increase in the concentration of metabolites could generate neuromuscular changes stemming from the attenuation of neural impulses was not found in the present study.

The results of the subjective perceived exertion and pain scales demonstrated similar behaviour between the conditions analysed (Figure 4b). Lower perceptions of exertion and pain were expected in the ALK group due to the effect of the ingestion of $NaHCO_3$ on the buffering of H^+ ions (Amann, 2011; Krustrup et al., 2015) however, such responses were not confirmed. Significant increases in exertion were found in comparison to the initial measures, but without differences between conditions, and no significant intra-group or inter-group differences were found regarding pain.

Regarding the test protocol used in the present study, the high-intensity intermittent characteristic was confirmed by the reported perception of exertion (Dipla et al., 2009; Suzuki et al., 2016) (Figure 4b). The protocol proved to be effective as a muscle performance test, since a significant decline in peak torque was found during the dynamic and isometric exercises (post-test) under both conditions analysed (Figure 2).

The characteristics of the test and variables indicative of efficacy (peak torque and perceived exertion), together with the controlled, highly reliable equipment used for recording the performance measures (isokinetic dynamometer) (Drouin, Valovich-McLeod, Shultz, Gansneder, & Perrin, 2004; Keskula, Dowling, Davis, Finley, & Dell'omo, 1995) enabled a better understanding of the effects of $NaHCO_3$ in sports modalities and resistance exercises with these characteristics.

The recovery period between sets was calculated to enable the collection of blood samples for the necessary measurements and, although within the limits for resistance training (one minute) (Kraemer & Ratamess, 2004; Ratamess et al., 2009), may be considered a limitation of the study, as the intermittent task requires shorter recovery periods. Moreover, the contraction of only the knee extensors and flexors of a single leg may have been insufficient to promote metabolic changes capable of demonstrating the ergogenic effect of $NaHCO_3$.

CONCLUSIONS

The ingestion of 0.3 $g.kg^{-1}$ of $NaHCO_3$ did not promote changes in strength, muscle activity, perceived exertion, or perceived pain in trained individuals during a high-intensity intermittent exercise on an isokinetic dynamometer.

AUTHOR CONTRIBUTIONS

M. M. K.: conception and design, data collection, analysis, manuscript writing and critical revision. R. A. B.: data collection. J. S. B.: critical revision. D. A. B.: conception design and critical revision. J. D. K.: data collection and critical revision. G. S. L.: data analysis and critical revision. D. S. B.: critical revision. F. P.: conception and design, data analysis and manuscript writing.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

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