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Effect of acute sodium bicarbonate and caffeine co-ingestion on repeated sprint performance in recreationally trained individuals: a randomized controlled trial

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ABSTRACT

Introduction. The acute and isolated ingestion of sodium bicarbonate and caffeine improves performance and delays fatigue in high-intensity tasks. However, it remains to be elucidated if the co-ingestion of both dietary supplements stimulates a summative ergogenic effect. This study aimed to examine the effect of the acute co-ingestion of sodium bicarbonate and caffeine on repeated sprint performance.

Methods. Twenty-five trained participants (age: 23.3±4.0 years; sex(female/male): 12/13; body mass: 69.6±12.5 kg) participated in a randomized, double-blind, placebo-controlled and cross-over study. Participants were assigned to four conditions: a) sodium bicarbonate and caffeine ($NaHCO_3$+CAF); b) sodium bicarbonate ($NaHCO_3$); c) caffeine (CAF); d) placebo (PLA). Thus, they ingested 0.3 g/kg of $NaHCO_3$, 3 mg/kg of caffeine or placebo. Then, participants performed 4 Wingate tests (Wt), consisting of a 30-s all-out sprint against an individualized resisted load, interspersed by a 1.5 min rest period among sprints.

Results. Peak (W_{peak}) and mean (W_{mean}) power output revealed a supplement and sprint interaction effect (P=0.009 and P=0.049, respectively). Compared to placebo, $NaHCO_3$+CAF and $NaHCO_3$ increased W_{peak} performance in Wt3 (3%, P=0.021) and Wt4 (4.5%, P=0.047), while $NaHCO_3$ supplementation increased W_{mean} performance in Wt3 (4.2%, P=0.001). In Wt1 CAF increased W_{peak} (3.2%, P=0.054) and reduced time to W_{peak} (-8.5%; P=0.008). Plasma lactate showed a supplement plus sprint interaction (P<0.001) when $NaHCO_3$ was compared to caffeine (13%, P=0.031) and placebo (23%, P=0.021).

Conclusions. To summarize, although the isolated ingestion of caffeine and sodium bicarbonate improved repeated sprint performance, the co-ingestion of both supplements did not stimulate a synergic ergogenic effect.

Keywords: sports performance, sports nutrition, ergogenic substances, caffeine, sodium bicarbonate, sprint.

INTRODUCTION

Sodium bicarbonate ($NaHCO_3$) and caffeine supplementation are widespread among athletes of different sports modalities since both supplements improve high-intensity tasks that last between 30 s to 8 min[1,2]. Since $NaHCO_3$ and caffeine could enhance performance through different physiological mechanisms[2-4], the co-ingestion of both supplements could stimulate an additive ergogenic effect. However, the interaction between $NaHCO_3$ and caffeine has been scarcely studied in repeated sprint performance[5] despite being a critical performance component in several sports.

Caffeine is one of the most commonly used ergogenic aid whose effect mainly occurs in the CNS by antagonizing adenosine receptors reducing fatigue and perceived effort, increasing alertness and vigour, and facilitating muscle fibers recruitment during muscle contraction[2]. Besides, caffeine may promote intracellular calcium ion (Ca^{2+}) mobilization, stimulating force production[6] and delaying fatigue caused by a gradual reduction in Ca^{2+} bioavailability[7]. $NaHCO_3$ ergogenicity also occurs in skeletal muscle where increased extracellular buffering by stimulating higher extracellular pH and base excess, leading to an increase of H^+ and lactate co-transport out of the exercising muscle cells[8]. Thus, the alkalizing influence of $NaHCO_3$ in blood and muscle during exercise, increasing glycolytic rates[8] and higher rates of ATP re-synthesis and Ca^{2+} utilization to sustain exercise demands delaying the muscular loss of ability to generate force and power[3,4]. Although both supplements may delay fatigue effects, particularly important in repeated effort, the combined effect of both supplements have been scarcely explored.

Considering the isolated effect of caffeine and $NaHCO_3$ on performance and that these supplements seem to promote their ergogenicity through different mechanisms of action, it can be argued that the co-ingestion of both supplements could promote a synergic effect. This idea was explored in Felippe et al.[9] study where the co-ingestion of caffeine and $NaHCO_3$ promoted additive effects in ten male judokas who performed Special Judo Fitness Tests after ingesting 6 mg/kg of caffeine 50 min before exercise and 0.3 g/kg of $NaHCO_3$ divided in three doses ingested at 120, 90 and 60 minutes before[9]. However, this effect was not observed using doses of 3-6 mg/kg of caffeine and 0.3 g/kg of $NaHCO_3$ provided in one or several doses from 120 to 60 min before the trial in eight trained rowers after a 2000 m rowing task[10], in twelve elite rowers after a 6 min rowing test[11], in ten trained cyclist after 3-km time trial[12], in thirteen non-cycling trained individuals after cycling to volitional exhaustion[13], in six elite swimmers after a 2x200m swimming test[14] or in eight karate athletes after a karate-specific aerobic test[15].

Nevertheless, it should be considered that $NaHCO_3$ supplementation protocols in some of the studies[13,14] resulted in high incidence and severity of side effects (e.g., gastrointestinal discomfort) that undoubtedly affected performance. Moreover, the sample sizes of these studies were small, ranging from 6 to 13 participants in most studies. Additionally, since caffeine may increase mood[16], motivation[17] and reduce fatigue[18], it can be argued that the inter-individual response to caffeine may be attributable to variances in these variables[19]. Therefore, further work is required to determine whether co-supplementation of caffeine and $NaHCO_3$ produces larger ergogenic effects than isolated supplementation particularly in repeated high-intensity efforts where evidence is lacking since caffeine may cause an ergogenic effect during the first sprint[2] and sodium bicarbonate after at least two of them[20]. Thus, this study aimed to examine the effect of the acute co-ingestion of $NaHCO_3$ and caffeine on repeated sprint performance in both male and female participants.

MATERIALS AND METHODS

Participants

Twenty-five individuals (age: 23.3±4.0 years; sex (female/male): 12/13; body mass: 69.6±12.5 kg) participated in this study. All participants were recreationally trained (training experience: 3.1±1.2 years and 4.5±1.2 days/week) habituated to anaerobic exercise and to caffeine consumption (81±70 mg/day). Besides, participants had no diagnosis of musculoskeletal, neurological, immunological or cardio-metabolic disorders, a training experience of at least 8 months before the intervention, performing 3 days per week during the previous 3 months, and did not take any medication, drug, stimulant or any other sports supplement during the trial. Six of twelve female participants initiated the trial during the follicular phase of their menstrual cycle.

Procedures, potential risks or discomfort associated with the experiments were explained to participants, who then gave their written informed consent. The Ethics Committee of Investigation and Animal Experimentation from the University of Alcalá approved the experiment (CEIP/HU/2021/1/006), which is in accordance with the Declaration of Helsinki.

Experimental design

The study design was randomized, double-blind, cross-over and placebo-controlled. Each participant reported five times to the laboratory (Faculty of Medicine and Health Sciences, Laboratory: 044.01.047.0). Participants underwent preliminary questionnaires of dietary and physical activity habits and body composition assessment during visit one, and a familiarization session where they experienced all tests performed in the trials.

During visits two to five, volunteers reported to the laboratory at the same time of day (±30 min). They participated in four trials separated by at least 72h to allow a complete recovery and washout period. Participants were assigned to four conditions: a) Sodium bicarbonate and caffeine ($NaHCO_3$+CAF); b) sodium bicarbonate ($NaHCO_3$); c) caffeine (CAF); d) placebo (PLA). The order of the trials was randomized in sequence according to the experimental condition for each participant (www.randomized.org). An external researcher was responsible for elaborating the alphanumeric code assigned to each sequence to blind participants and researchers during the trials. The codes were unveiled after statistical analysis.

Experimental protocol

Body composition, dietary and physical activity habits

As previously reported elsewhere, body composition was assessed using electric bioimpedance (Tanita BC-418, Tanita Corporation of America Inc. IL, USA). Dietary habits were analyzed using a 24h dietary recall and the software MyFitnessPal and DIAL (Alce Ingeniería, Madrid, Spain), while physical activity habits were evaluated using the International Physical Activity Questionnaire (IPAQ). Twenty-four hours before the familiarization session and until the end of the trial, participants were encouraged to refrain from caffeine, stimulants and alcohol intake. Besides, 24h before each visit (familiarization and trials), participants refrained from strenuous exercise and were asked to follow a similar sleep and dietary pattern.

Supplementation protocol

The supplementation protocol started 120 min before the trial. Participants ingested $NaHCO_3$ (0.3 g/kg of body mass) or placebo (3 mg/kg, of maltodextrin, HSN, Granada, Spain) on two occasions at 120 and 90 min before the trial, consuming 0.15 g/kg of $NaHCO_3$ or 1.5 mg/kg of maltodextrin on each time. This supplementation strategy was designed to minimize gastrointestinal problems[9]. Then, 60 minutes before the trial, participants ingested caffeine (3 mg/kg, HSN, Granada, Spain) or placebo (3 mg/kg, maltodextrin).
Supplements were dissolved in 150 ml of tap water and a flavoring with no calories was added to mask the supplements' flavor and smell (MyProtein, Northwich, UK). The beverages were provided in opaque shaker bottles.

Repeated sprint test (4 x 30s) and plasma lactate

Participants performed a standardized warm-up of 5 min of pedaling in an isoinertial cycle ergometer (Monark LC6, Monark. Vansbro, Suecia) at 70 W without any resisted load. Then, participants performed four Wingate tests (Wt), interspersed by a passive 1.5 min rest period among Wt, each consisting of a 30-s all-out sprint against an individualized resisted load (0.075 Nm/kg of body mass). Participants were given verbal encouragement throughout the tests. Peak and mean power, time to reach peak power and fatigue index (FI) were obtained. FI was calculated by taking the minimum power away from the peak power and then dividing it by the peak power and multiplying it by 100.

The number of Wingate tests performed to explore the potential interaction between caffeine and sodium bicarbonate was selected based on the potentially expected ergogenic effect of caffeine during the first sprint[2,21] and $NaHCO_3$ during the third and fourth sprints[20]. Moreover, the passive rest interval between sprints was selected to stimulate a pronounced decrease in pH levels to emphasize the potential buffering capacity of $NaHCO_3$[22].

Before and immediately after Wt1 and immediately after Wt4, capillary blood samples were collected for the assessment of plasma lactate (mmol/l) (Lactate Pro2, ProTM 2 LT-1710 Instrument, Arkray Fatory Inc., KDK Corporation, Shiga, Japan).

Questionnaires and scales

As previously reported, participants' mood was assessed using a reduced version of the profile of mood states questionnaire (POMS) and subjective vitality scale (SVS)[21]. Participants graded a set of 29 items related to the mood on a Likert scale from 0 (not at all) to 4 (extremely) in reply to the question "How do you feel at this moment?" to assess six scales: tension, depression, anger, vigor, fatigue and confusion. Moreover, participants' vitality was evaluated using the subjective vitality scale[23]. Using a 7-point Likert scale where 1 means "total disagreement" and 7 means "total agreement", participants reported their subjective feelings of energy and vitality.

At the end of the trials, participants had to complete a side effects questionnaire about their perception of power, endurance, energy and exertion, heart, muscular and gastrointestinal discomfort[24]. Additionally, a specific question to evaluate the blinding procedure was also included.

Statistical Analysis

The sample size calculation revealed that 20 participants were sufficient for the purpose of the study to show an effect size of 0.35 (α=0.05; 1−β=0.80) (v3.1, G*power, Dusseldorf University, Germany); finally, 25 participants were recruited.

Data collected in the study were analyzed using the statistical package SPSS v27.0 (SPSS Inc., Chicago, IL, USA) and figures were generated using GraphPad Prism (v8, GraphPad Software Inc., La Jolla, CA, USA). Initially, statistical analysis was conducted comparing sex (male vs female), however, due to the lack of difference found, both sex groups were condensed into one and treated as a single group. Firstly, Shapiro-Wilks was used to test the normality of the data ($P>0.05$). Plasma lactate was assessed using a two-way ANOVA for repeated measures according to supplement ($NaHCO_3$+CAF, $NaHCO_3$, CAF and PLA) and time (Baseline, Wt1 and Wt4). Holm-Bonferroni correction was used as a *post hoc* test when significant differences were detected.

Furthermore, body composition, dietary and physical habits were assessed using one-way ANOVA. The Q the Cochran test was used to detect differences in blinding supplement success before and after each trial and the side effects caused by both sports supplements

Values are reported as mean ± standard deviation (SD). The significance level was set at $P\leq0.05$. Effect size (ES) was calculated as partial eta squared statistic (η_p^2) for the two-way repeated measures and Hedges's (g) for partial comparisons based on the following criteria: trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (0.80 and greater) (Cohen, 1992).

RESULTS

No statistically significant differences among experimental conditions were found regarding body composition, dietary or physical activity habits (Table 1). Differences in body composition, dietary and physical activity habits on each experimental group according to sex is shown in Supplementary Table 1.

Repeated sprint test (4 x 30s) and lactate

Differences in peak and mean power output, time to reach peak power output and fatigue index are shown in Figure 1. Differences in repeated sprint performance after the four supplementation protocols according to sex is shown in Supplementary Figure 1.

Peak power output (W_{peak}) revealed a supplement ($P=0.029$, $\eta_p^2=0.133$) and supplement plus sprint interaction effect ($P=0.009$, $\eta_p^2=0.107$). $NaHCO_3$+CAF supplementation increased Wpeak in Wt3 (3.0%, $P=0.021$, $g=0.182$) and Wt4 (4.5%, $P=0.047$, $g=0.303$) compared to placebo. Similarly, compared to placebo, $NaHCO_3$ supplementation increased W_{peak} in Wt3 (3.7%, $P=0.032$, $g=0.178$) and Wt4 (6.8%, $P=0.042$, $g=0.298$). While CAF supplementation showed a W_{peak} increase in Wt1 compared to placebo (3.2%, $P=0.054$).

Mean power output (W_{mean}) revealed a supplement ($P=0.040$, $\eta_p^2=0.201$) and supplement plus sprint interaction effect ($P=0.049$, $\eta_p^2=0.101$). $NaHCO_3$ supplementation increased W_{mean} in Wt3 (4.2%, $P=0.001$, $g=0.184$). No other partial difference was detected.

Time to W_{peak} did not report statistically significant supplement or supplement plus sprint effects (figure 1). However, in Wt1, $NaHCO_3$+CAF (-10.3%; $P=0.015$, $g=0.475$), $NaHCO_3$ (-6.7%; $P=0.045$, $g=0.311$) and CAF (-8.5%; $P=0.008$, $g=0.271$) supplementation reduced time to W_{peak} compared to placebo. Also, in Wt3, $NaHCO_3$ supplementation reduced time to W_{peak} compared to placebo (-7.3%; $P=0.045$, $g=0.414$).

Fatigue Index did not report statistically significant supplement or supplement plus sprint effects (figure 1). However, in Wt4, FI increased in NaHCO+CAF (5.4%, $P=0.050$, $g=0.245$), NaHCO (9.3%, $P=0.037$, $g=0.421$) and CAF supplementation (7.7%, $P=0.049$, $g=0.328$) compared to placebo.

Finally, lactate showed a supplement plus sprint interaction ($P<0.001$, $\eta_p^2=0.244$, Figure 1). Particularly, differences were found immediately after the Wt4, when comparing $NaHCO_3$+CAF to caffeine (17%, $P=0.002$, $g=0.630$) and placebo (28%, $P=0.004$, $g=0.590$). These differences were also found when $NaHCO_3$ was compared to caffeine (13%, $P=0.031$, $g=0.547$) and placebo (23%, $P=0.021$, $g=0.90$).

Questionnaires and scales

No statistical differences were found in depression, anger, vigor, fatigue, confusion or SVS (Table 2). However, in tension, CAF showed an increase compared to the rest of the supplementation protocols ($P=0.020$, $\eta_p^2 = 0.155$).

The side effects questionnaire revealed an interaction effect for gastrointestinal ($P=0.003$, $\eta_p^2=0.262$) and muscular discomfort ($P=0.005$, $\eta_p^2=0.256$). Partial comparison revealed that, immediately after the trials, $NaHCO_3$+CAF increased gastrointestinal discomfort compared to CAF (45%; P=0.005, g=0.910) and placebo (57%; P=0.021, g=1.29), while $NaHCO_3$ increase discomfort compared to CAF (42%; P=0.039, g=0.869) and placebo (54%; P=0.012, g=1.292). Moreover, CAF increased muscular discomfort compared to $NaHCO_3$+CAF (21%; P=0.044, g=0.329), $NaHCO_3$ (48%; P=0.021, g=0.788) and placebo (32%; P=0.041, g=0.263). Also, higher energy perception was found in $NaHCO_3$+CAF (23%; P=0.012, g=0.525) and CAF (15%; P=0.047, g=0.317) compared to the placebo.

Finally, 72% (18 of 25) of participants correctly guessed when they ingested bicarbonate, while 60% (15 of 25) correctly guessed when they ingested caffeine.

DISCUSSION

The purpose of this study was to examine the effect of the acute co-ingestion of $NaHCO_3$ and caffeine on repeated sprint performance. Our results suggest that the isolated ingestion of $NaHCO_3$ increased peak and mean power output, fatigue index and reduced time to reach peak power in the third and fourth Wingate tests, while caffeine reduced time to reach peak power only in the first sprint. Despite the ergogenic effects promoted by isolated ingestion, the co-ingestion of caffeine and $NaHCO_3$ did not provide summative effects in repeated sprint performance.

Power output (W_{peak} and W_{mean}) is commonly measured during a single or repeated sprint task using Wingate tests. Our study shows that $NaHCO_3$ ingestion, isolated or combined with caffeine, increases W_{peak} to a similar extent in the third and fourth Wingate test compared to placebo. In a previous meta-analysis, Grgic[20] showed that $NaHCO_3$ intake increases W_{peak} only in a third of fourth performed Wingate test. However, this evidence was supported only by two studies consisting of four Wingate tests in the upper-body interposed by 6 min of rest in judo athletes[25] and three lower-body Wingate tests interposed by 6 min of rest in recreationally trained males[26]. In contrast, other studies do not support this idea [27-29]. In previous studies developed by Zabala et al.[27,28], $NaHCO_3$ did not improve W_{peak} in 9-10 elite male bicycle motocross riders who performed three Wingate tests with 15-30 min of rest among them. Similarly, Zinner et al.[29] did not find statistical differences in W_{peak} in 11 aerobically well-trained men after four Wingates tests performed in the lower-body with 5 min of rest. In our study, the recovery time among sprints was considerably lower compared to previous studies, 1.5 minutes among Wingate tests. This shorter recovery time may have elicited a higher muscle acidosis which seems critical to facilitate the $NaHCO_3$ effect on the attenuation of W_{peak} diminution through repeated sprints.

In our study, $NaHCO_3$ intake increased W_{mean} in the third Wingate test, an effect that was reported when this supplement was ingested alone. Besides, in the fourth Wingate test, $NaHCO_3$ promoted a non-statistically significant increase in W_{mean} by 2-3%. Previous studies have reported an increase in W_{mean} in the third and fourth Wingate tests performed in the upper-body[25] and lower-body[29]. However, other studies did not find these differences[26-28]. The comparison of these studies revealed that those studies with a short rest interval among sprints (3-5 min) observed a significant effect of $NaHCO_3$ on W_{mean}[25,29], while the studies in which a more prolonged rest period was allowed among sprints (6-30 min) did not found ergogenic effect on this performance parameter. Thus, as it occurs with W_{peak}, these studies together with our results, support the idea that a short rest period (<5 min) is needed to find an ergogenic effect of $NaHCO_3$ on W_{mean} during repeated sprint tests.

Peak power output represents the ability to produce mechanical power in the shorter period possible, whereas W_{mean} reflects the average power produced during 30 seconds. W_{mean}

could be seen as a reflection of the active muscle endurance, and although a more pronounced ergogenic effect of $NaHCO_3$ could be expected on muscle endurance (W_{mean}) compared to W_{peak}[30], a similar increase in performance of W_{peak} and W_{mean} was found in our study. This may be explained due to the fact that the repeated sprint protocol in which four Wingate tests were performed interposed by 1.5 min of rest among sprints caused a considerable amount of fatigue among participants. This is supported by the increase in FI and plasma lactate observed at the end of the repeated sprint protocol. We observed that the three supplement conditions increased FI by 5-9 % in Wt4. FI is dependent on the peak and minimum power produced in a sprint, since acute $NaHCO_3$ intake showed to preserve W_{peak} in the Wt4, it was not surprising to find an elevated FI in this experimental condition and time. Nonetheless, our results are not in line with other previous studies[28,31], maybe due to differences in the number of sprints performed (3 vs 4), the resting protocol used (15-30 min vs 1.5 min) and the sample size compared to our study. On the other hand, caffeine supplementation does not affect W_{peak} in the Wt4 but promotes an improvement in FI in this sprint. Hence, the ergogenic effect of caffeine on FI may be explained by enlarging the range from the peak and minimum power produced in this sprint.

Furthermore, plasma lactate showed a supplement plus sprint interaction observed after $NaHCO_3$ supplementation after the fourth sprint. $NaHCO_3$ ergogenic potential is associated with its effects on dynamic buffering capacity[32]. High-intensity exercise produces an increase in the rate of H^+ accumulation, which can lead to intramuscular acidosis. Considering that acidosis has been identified as a fatigue factor, intramuscular acidosis could interfere with several metabolic and contractile processes, ultimately reducing force and power production associated with fatigue during exercise[1]. Thus, the main effect of $NaHCO_3$ supplementation seems to be related to the increase of blood bicarbonate, which allows a greater efflux of H^+ out of the active muscle cells into the circulatory system. This idea aligns with previous studies where $NaHCO_3$ increases plasma lactate after repeated high-intensity efforts[9,29], and this study in which $NaHCO_3$ was ingested before performing four Wingate tests interposed by 1.5 min of rest among them.

The effect of caffeine on repeated sprint and power performance is mixed, potentially due to some confounding variables such as inter-individual differences, caffeine adverse effects or anxiety feelings among others[2]. In an older study, Greer et al.[33] failed to report caffeine benefits on power output during a 30-s high-intensity cycling bout using the Wingate test, similar to a more recent study performed Duncan et al.[34] who examined the effects of acute caffeine ingestion on upper- and lower-body Wingate test performance in twenty-two males, not reporting significant findings when measuring lower-body W_{peak} and W_{mean}. However, Grgic[35] shows in his meta-analysis that caffeine ingestion stimulates an increase in W_{peak} and W_{mean} during the Wingate test with a modest effect size of 0.27 (+4%) and 0.18 (+3%). Interestingly, another study performed by Lee et al.[36] reported that caffeine ingestion enhanced sprint performance involving a 90-s rest interval but did not benefit repeated sprints with a 20-s rest interval, but that effect seems to be restricted to the first sprint since after repeated sprints total work, best sprint or last sprint performance remained unchanged after acute caffeine supplementation[37]. This evidence seems to align with the result found in this study, where caffeine intake stimulated an increase in time to reach W_{peak} in Wt1, but no other effect on performance was detected.

The isolated and acute caffeine and $NaHCO_3$ intake stimulates ergogenic effects in high-intensity and extenuating tasks. Both caffeine and $NaHCO_3$ have shown to delaying fatigue and the muscular loss of ability to generate force and power[3,4] through central-peripheral and peripheral mechanism[2,6-8]. Hence, it can be hypothesized that the co-ingestion of these supplements may produce a synergic or additive effect since caffeine and $NaHCO_3$ may act through similar (peripheral, Ca^{2+} bioavailability) or different mechanisms of action (central and peripheral). However, in response to repeated sprints, the co-ingestion of $NaHCO_3$ and caffeine did not produce a synergic or additive effect in peak or mean power production. Only it can be argued that the decrease observed in time to reach W_{peak} in the first Wingate in the

$NaHCO_3$+CAF (-10.3%) could be a summative effect of the co-ingestion of both supplements since isolated $NaHCO_3$ (-6.7%) and CAF (-8.5%) promote lower improvements in this performance variable. The limited ergogenic effects produced by caffeine in this repeated sprint protocol and a potential pharmacokinetic and pharmacodynamic interaction between supplements may explain the absence of synergic effects when $NaHCO_3$ and caffeine are acutely co-ingested. Thus, more studies are required to explore the potential synergic effects of $NaHCO_3$ and caffeine in other types of exercise.

Previous studies reported side effects of $NaHCO_3$ and caffeine co-ingestion [5]. In our study, the side effects questionnaire revealed gastrointestinal discomfort after $NaHCO_3$ ingestion, alone or combined with caffeine, compared to placebo and caffeine despite the fact that the bicarbonate intake was taken in two doses as recommended [9]. Although most participants did not report this effect, gastrointestinal discomfort could influence performance in some participants limiting their repeated sprint performance.

No statistical differences were found in depression, anger, vigor, fatigue, confusion or subjective vitality. Other studies found similar results after a 3-4 km cycling time trial in trained cyclists [12,38], four Wingate tests in the upper body [25], or 2-3 bouts of a specific judo test [9,25]. However, in tension, CAF increased compared to the rest of the supplementation protocols. This finding is consistent with Jodra et al.[21], who found a more pronounced effect of caffeine on tension of elite athletes than recreational athletes after a single Wingate test. However, in our study, no differences in vigor and subjective vitality were found, potentially due to the strenuous exercise protocol followed in this study (1 vs 4 Wingates tests). Thus, although in some cases caffeine, and potentially of sodium bicarbonate, effect or lack of effect may be attributable to inter-individual differences caused by mood state or adverse effects [9,19], this does not seem to be the case in this study.

Finally, the major limitation of the present study was the impossibility of measuring plasma levels of caffeine, bicarbonate and pH. This measurement would provide valuable information regarding the absorption and effect of both supplements, as well as the potential pharmacokinetic and pharmacodynamic interaction proposed.

PRACTICAL APPLICATION

This study shows that $NaHCO_3$ and caffeine co-ingestion did not cause a summative ergogenic effect in repeated efforts. Therefore, based on the current results, we would recommend the ingestion of NaHCO3 and caffeine separately, rather than co-ingested, before any sport (e.g., cycling) that involves repeated sprints with a duration of ~30s each sprint. Thus, for athletes seeking to improve performance in a single sprint would be useful the ingestion of 3 mg/kg of caffeine, while for those athletes seeking to maintain their sprint performance after several maximal efforts, the ingestion of 0.3 g/kg of $NaHCO_3$ would be desirable. Nonetheless, some athletes may experience an increase in tension and muscular discomfort after caffeine intake or gastrointestinal discomfort after $NaHCO_3$ intake. These potential health effects should be taken into account in the development of individual nutritional supplement strategies.

CONCLUSION

The co-ingestion of $NaHCO_3$ and caffeine does not provide synergic effects after four Wingate tests interposed by 1.5 min of rest, even though the isolated ingestion of caffeine increases the first sprint performance and $NaHCO_3$ increases the third and fourth sprints performance. Therefore, despite the potential existence of any pharmacokinetic and pharmacodynamic interaction between supplements, acute co-ingestion of caffeine and $NaHCO_3$ does not produce a synergic (central-peripheral or peripheral) effect on repeated sprint performance.

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CONFLICT OF INTERESTS

All the authors declare that they have no conflict of interest derived from the outcomes of this study.

AUTHOR CONTRIBUTIONS

APL conceived the experiment. CF and APL designed the experiment. CF, PGE, DV and APL collected the data. CF and APL analyzed and interpreted the data. CF, ALS and APL drafted the manuscript. All authors read and approved the final version of the manuscript.

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FIGURE LEGENDS

Figure 1. Repeated sprint performance after the four supplementation protocols.

Peak power output (Fig. 1A), mean power output (Fig. 1B), time to reach Wpeak (Fig. 1C), Fatigue Index (Fig. 1D) and plasma lactate (Fig. 1E).

* $P < 0.05$ $NaHCO_3$ + CAF compared to PLA; # $P < 0.05$ $NaHCO_3$ compared PLA; $, $P < 0.05$ CAF compared to PLA.

Abbreviations: Wpeak, peak power output; $NaHCO_3$ + CAF, sodium bicarbonate plus caffeine; $NaHCO_3$, sodium bicarbonate; CAF, caffeine; PLA, placebo.

Supplementary figure 1. Differences in repeated sprint performance after the four supplementation protocols according to sex.

Peak power output in males and females (Suppl Fig. 1A and 1B), mean power output in males and females (Suppl Fig. 1C and 1D), time to reach Wpeak in males and females (Suppl Fig. 1E and 1F), Fatigue Index in males and females (Suppl Fig. 1G and 1H) and plasma lactate in males and females (Suppl Fig. 1I and 1J).

* $P < 0.05$ $NaHCO_3$ + CAF compared to PLA; # $P < 0.05$ $NaHCO_3$ compared PLA; $, $P < 0.05$ CAF compared to PLA.

Abbreviations: Wpeak, peak power output; $NaHCO_3$ + CAF, sodium bicarbonate plus caffeine; $NaHCO_3$, sodium bicarbonate; CAF, caffeine; PLA, placebo.