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Does Sodium-Bicarbonate Ingestion Improve Simulated Judo Performance?

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The aim of the present study was to investigate whether preexercise sodium-bicarbonate ingestion improves judo-related performance. The study used 2 different protocols to evaluate performance: 3 bouts of a specific judo test ($n = 9$) and 4 bouts of the Wingate test for upper limbs ($n = 14$). In both protocols athletes ingested 0.3 g/kg of sodium bicarbonate or placebo 2 h before the tests. Blood samples were collected to determine lactate level, and levels of perceived exertion were measured throughout the trials. The study used a double-blind, counterbalanced, crossover design. Ingestion of sodium bicarbonate improved performance in Bouts 2 and 3 of Protocol 1 ($P < 0.05$), mean power in Bouts 3 and 4 of Protocol 2 ($P < 0.05$), and peak power in Bout 4 of Protocol 2 ($P < 0.05$). Ingestion of bicarbonate increased lactate concentration in Protocol 1 ($P < 0.05$) but not in Protocol 2. Ratings of perceived exertion did not differ between treatments. In conclusion, sodium bicarbonate improves judo-related performance and increases blood lactate concentration but has no effect on perceived exertion.

Key Words: alkalosis, martial arts, fatigue

Judo is an individual sport characterized by intermittent, high-intensity activity lasting approximately 30 s, with brief recovery periods lasting 10–15 s (4). Such short recovery periods prevent resynthesis of ATP via aerobic pathways (32), making judo efforts highly dependent on the anaerobic glycolytic pathway. Studies have demonstrated this dependence through high blood lactate concentrations after judo matches (8).

Although a fight can end at any time if an *ippon* (perfect throw) occurs, in high-level competitions most fights lasts 4 min or more (4). Considering the intensity of effort, the duration of fights, and the high number of fights completed in a single day (generally more than 5), it is likely that fatigue is an important limiting factor in judo performance.

Accumulation of H^+ ions and consequent intramuscular acidosis are considered a major cause of fatigue in high-intensity, short-term activities such as judo (6, 10,

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18). Reduced intramuscular pH is related to inhibition of key enzymes of energy metabolism, impairment of the coupling process, and decreased sensitivity to and release of Ca^{++} (6, 10).

Several studies have investigated whether induced alkalosis is an efficient means of delaying the onset of fatigue and improving performance in short-term, high-intensity activities. Despite apparently contradictory results in the literature, induced alkalosis probably delays the onset of fatigue in judo combat, potentially contributing to improved performance. Therefore, the purpose of the present study was to investigate the effects of induced metabolic alkalosis on judo-related performance.

Methods

Because of difficulties in evaluating judo performance, the present study employed 2 different protocols. In Protocol 1, performance was evaluated through 3 bouts of a specific judo test (Special Judo Fitness Test [SJFT]) (31). In Protocol 2, performance was evaluated using 4 bouts of the Wingate test for upper limbs.

Subjects

Twenty-three experienced judo competitors, most of whom actively compete in national- or international-level tournaments and train 8 h/wk or more, took part in this study. Nine subjects participated in Protocol 1 (SJFT), and 14 participated in Protocol 2 (Wingate test). Subjects' characteristics are listed in Table 1.

Experimental Design

Experimental design was identical in both protocols except for the test used to evaluate performance. Before tests, participants completed a questionnaire on competitive level, state of conditioning, and judo experience. After they provided written informed consent, anthropometric measurements and body composition were determined. The institutional ethics committee (School of Physical Education and Sport, University of São Paulo) approved the experimental procedure.

Each volunteer was tested on 2 different days, with 2–7 days between trials. Participants ingested 0.3 g/kg body weight of either $NaHCO_3$ or placebo (calcium carbonate—$CaCO_3$), as a gelatinous capsule, 120 min before the beginning of each trial. The experimental protocol did not differ between subjects except for the substance administered. Both protocols used the counterbalanced double-blind crossover design.

Table 1 Subject Characteristics

Protocol	*n*	Age (y)	Judo experience (y)	Weight (kg)	Height (cm)	Body fat (%)
SJFT	9	21.5 ± 3	13.1 ± 4	68.7 ± 7.7	170.5 ± 6	6 ± 1.5
Wingate	14	19.3 ± 2.4	12.5 ± 2.9	77.9 ± 11.1	175.8 ± 6.9	8.7 ± 1.7

SJFT indicates Special Judo Fitness Test.

Volunteers were instructed to arrive well fed and hydrated, but without having ingested any food for 2 h before capsule ingestion. They were also instructed to eat normally on the day preceding each test and to abstain from intense exercise, caffeine, and alcohol for 16 h before each test. Athletes ingested water ad libitum throughout the experimental period.

Blood samples and ratings of perceived exertion (2) were collected several times throughout the experimental procedure in both protocols (Figure 1). The experimental design of both protocols is illustrated in Figure 1.

Judo-Related Performance Evaluation

Protocol 1: Special Judo Fitness Test. In Protocol 1, athletes warmed up freely for 10 min and then performed 3 bouts of the SJFT. This test was developed and described by Sterkowicz (31) and was previously validated (7, 9). Three athletes of similar body weight are needed to perform the SJFT: 1 participant (TORI) is evaluated, and 2 other individuals receive throws (UKEs). The TORI begins the test between the 2 UKEs 3 m from each. On a signal, the TORI runs to one of the UKEs and applies a throwing technique (called *ippon seoi nague*). The TORI then immediately runs to the other UKE and completes another throw. The evaluated athlete (TORI) must complete as many throws as possible within the test time. Each SJFT is composed of 3 periods (15 s, 30 s, and 30 s) separated by 10-s recovery periods. Performance is determined by the total throws completed during the 3 periods.

Protocol 2: Wingate Test for Upper Limbs. In Protocol 2, athletes completed 4 bouts of the Wingate test for upper limbs in a device specifically designed for this test

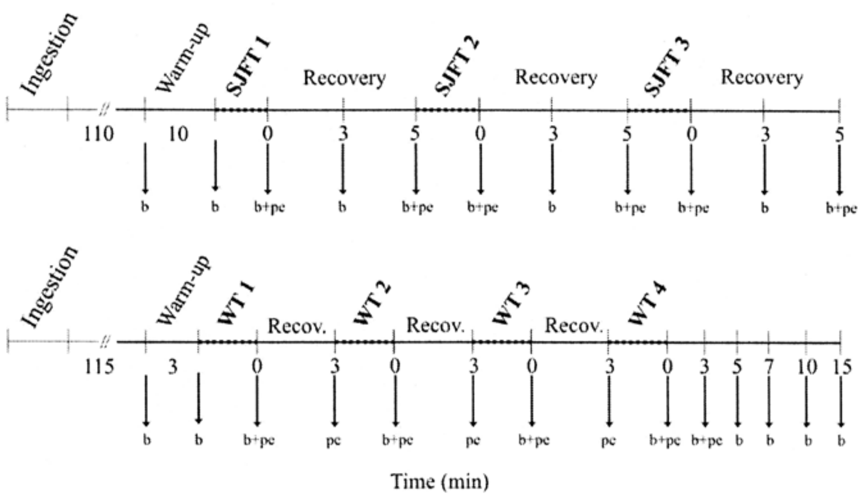

Figure 1 — Experimental design of the present study (both protocols are illustrated). WT indicates Wingate test; b, blood collection for lactate analysis; and pe, perceived exertion.

(Cefise, Brazil). Each bout lasted 30 s, and load was set at 5% of body weight. Bouts were separated by 3-min recovery periods, and strong verbal encouragement was provided during each bout. Athletes warmed up for 3 min on the test device before the first bout. A sensor measured wheel velocity, and computer software (Wingate 1.0, Cefise, Brazil) automatically calculated power output once per second.

Blood Sampling and Lactate Analysis

In order to determine lactate concentration, blood samples were collected from the earlobe at predetermined points throughout each test (Figure 1). The 25-µL samples were immediately stored in 2% NaF solution at approximately 2 °C. Samples were subjected to electrochemical analysis in an automated device (YSI 2300, Yellow Springs, OH) within approximately 5 d.

Anthropometric Measurements

Body composition was determined by underwater weighing, using a digital scale (precision: 5 g). Each athlete was measured at least 8 times with maximum expiration; the lowest value was considered the underwater weight. Body density was determined according to the method of Wilmore and Behnke (37). Body fat was calculated according to the method of Siri (29), and residual volume, according to the method of Goldman and Becklake (11). Body weight was measured with a digital scale (precision: 50 g).

Statistical Analysis

Mixed-models analysis of variance (ANOVA) with repeated measures was performed to compare values between treatments (placebo vs. alkalosis). Four covariance-structure matrices were tested (autoregressive, unstructured, Toeplitz, and compound symmetric), and the smallest BIC (Schwarz's Bayesian criterion) was used to choose the best model for each data set. This procedure permitted parsimonious modeling of the covariance structure, thereby minimizing Type I error (17, 34). A paired *t*-test was used to compare total throws between treatments. The data are presented as mean ± SD. The level of statistical significance was set a priori at $P < 0.05$, and all data analysis was performed using SAS 8.0 software.

Results

Protocol 1: SJFT

Performance. Athletes performed more throws after ingesting bicarbonate than placebo. Statistically significance differences were found in Bouts 2 and 3 and in total throws completed (Figure 2).

Blood Lactate Concentration. Blood lactate concentration was found to be significantly higher after induced alkalosis 3 min after the last bout of SJFT ($P < 0.05$). Lactate concentration also tended to be higher immediately after SJFT 2 ($P = 0.09$; Figure 3).

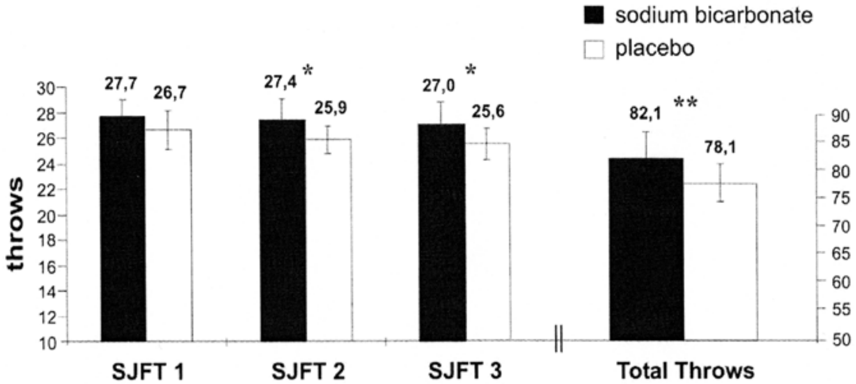

Figure 2 — Throws performed after sodium-bicarbonate and placebo ingestion in each bout of the Special Judo Fitness Test (SJFT) and in the whole experimental period. *Sodium bicarbonate significantly greater than placebo ($P < 0.05$). **Sodium bicarbonate significantly greater than placebo ($P < 0.01$).

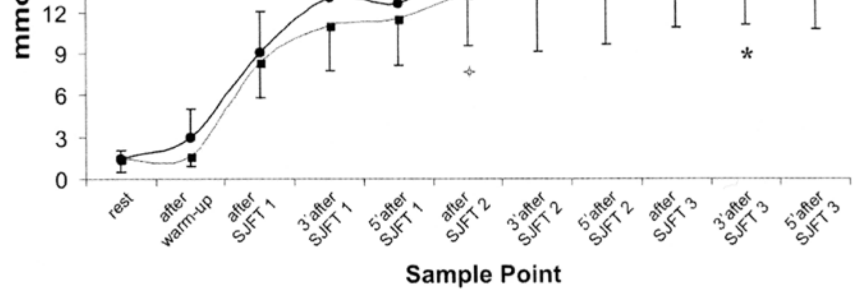

Figure 3 — Blood lactate response to the Special Judo Fitness Test (SJFT) in both treatments. *Sodium bicarbonate significantly greater than placebo ($P < 0.01$). ✧Tendency to sodium bicarbonate significantly greater than placebo ($P = 0.09$).

Protocol 2: Wingate Test for Upper Limbs

Performance. Relative mean power was significantly greater after ingestion of sodium bicarbonate than placebo in Bouts 3 and 4 ($P < 0.05$; Figure 4). Relative peak power was significantly greater after ingestion of sodium bicarbonate in Bout 4 ($P < 0.05$; Figure 4). Figure 5 presents the relative power output for each second in all 4 Wingate bouts.

Blood Lactate Concentration. Blood lactate concentration was higher after ingestion of sodium bicarbonate than placebo, but no significant differences were found using the Wingate protocol (Figure 6).

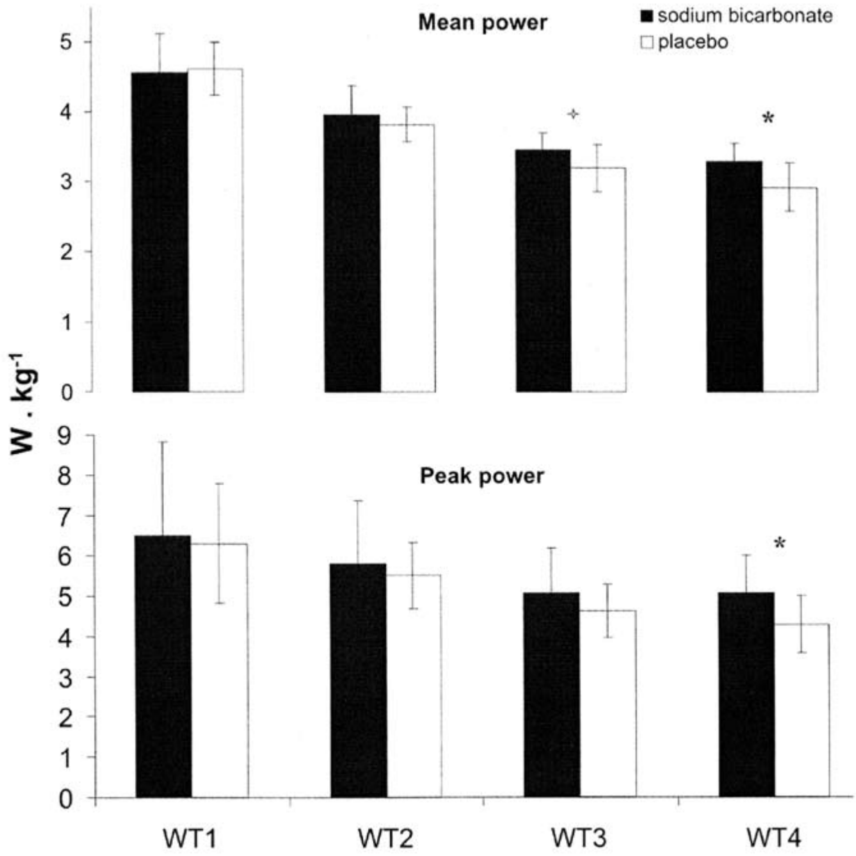

Figure 4 — Mean and peak power in both treatments. WT indicates Wingate test. *Sodium bicarbonate significantly greater than placebo ($P < 0.05$). ✧Tendency to sodium bicarbonate significantly greater than placebo ($P = 0.07$).

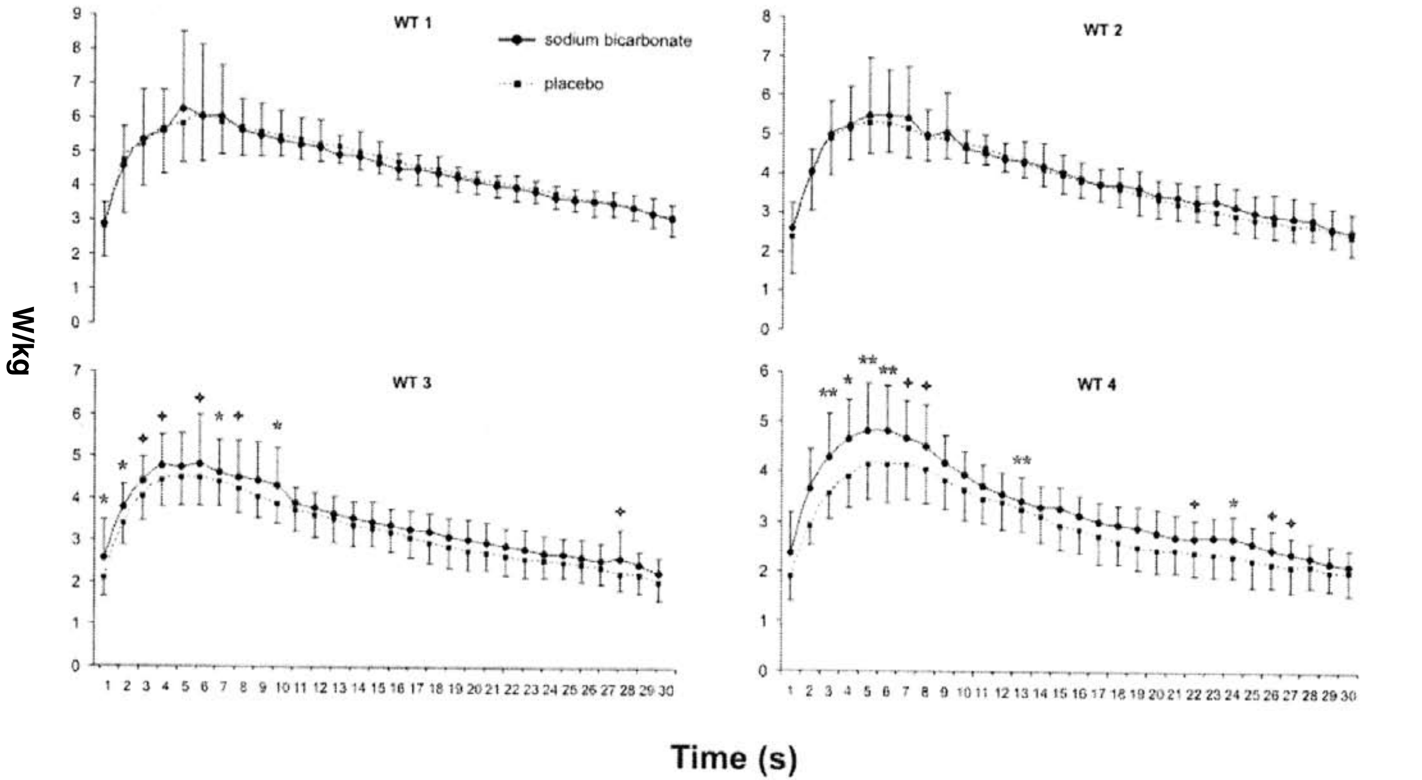

Figure 5 — Power output during each second in the 4 Wingate test bouts for both treatments. *Sodium bicarbonate significantly greater than placebo ($P < 0.05$). **Sodium bicarbonate significantly greater than placebo ($P < 0.01$). ✧Tendency to sodium bicarbonate significantly greater than placebo ($P < 0.1$).

Rating of Perceived Exertion

Ratings of perceived exertion did not differ between treatments at any point in the experimental procedure (Tables 2A and 2B).

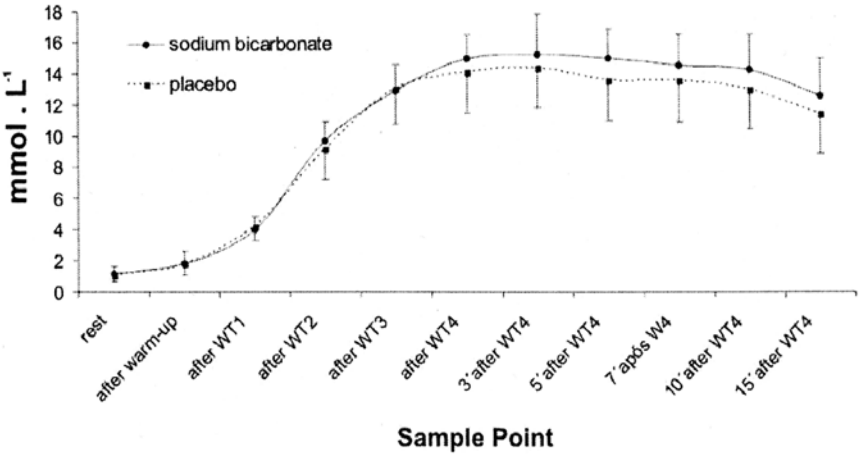

Figure 6 — Blood lactate response to Wingate test (WT) in both treatments.

Table 2A Ratings of Perceived Exertion Related in Both Treatments for Protocol 1

	SJFT 1		SJFT 2		SJFT 3	
Treatment	After	5 min after	After	5 min after	After	5 min after
$NaHCO_3$	13 ± 3	10 ± 2	15 ± 2	11 ± 3	16 ± 3	11 ± 2
Placebo	13 ± 3	10 ± 1	15 ± 1	10 ± 2	16 ± 2	11 ± 3

No significant differences were found between treatments in either protocol. SJFT indicates Special Judo Fitness Test.

Table 2B Ratings of Perceived Exertion Related in Both Treatments for Protocol 2

	WT 1		WT 2		WT 3		WT 4	
Treatment	After	3 min after	After	3 min after	After	3 min after	After	3 min after
$NaHCO_3$	13 ± 2	10 ± 1	15 ± 2	12 ± 2	17 ± 2	13 ± 2	17 ± 2	13 ± 2
Placebo	13 ± 2	10 ± 1	16 ± 2	12 ± 2	17 ± 2	14 ± 2	18 ± 2	14 ± 3

No significant differences were found between treatments in either protocol. WT indicates Wingate test for upper limbs.

Discussion

The main finding of the present study was the ergogenic effect of sodium-bicarbonate ingestion on high-intensity, short-term, intermittent performance (Figures 2, 4, and 5). To our knowledge, only 1 study has previously addressed performance in intermittent sports (20), and the present study was the first to evaluate judo fighters in specific tests.

According to Klinzing and Karpowicz (14), the main limitation of research on wrestling is the dissimilarity between activities performed in a real match and in the laboratory. Similar difficulties beset research on judo. Seeking results with greater ecological validity, we used 2 different tests with different levels of specificity to evaluate judo-related performance. Both the SJFT and arm-crank exercises have been used to evaluate judo and wrestling performance. Both have been shown to be accurate, sensitive to changes in the state of conditioning, and able to differentiate between athletes of different competitive levels (7, 9). In the present study, these tests also showed high sensitivity to the treatment administered.

Results of the present study are in agreement with those of previous studies (5, 12, 13, 15, 36) and support the hypothesis that induced alkalosis is especially efficient in intermittent, high-intensity, short-term bouts of exercise. It should be noted, however, that this improvement was observed only in the final bouts of the SJFT (Figure 2) and Wingate test (Figures 4 and 5). This means that the treatment's ergogenic effect is particularly apparent after the onset of fatigue. This might explain some of the controversy in the literature. Because many studies do not use exercise protocols that provoke extreme acidosis (13, 16, 24, 35), no effect on performance and blood lactate concentration was observed.

Sodium-bicarbonate ingestion increased blood lactate concentration in both protocols (Figures 3 and 6). This effect was not consistent, however; in the SJFT protocol there was a significant increase, and in the Wingate protocol the increase was insignificant. Wide variation among individuals with regard to the blood lactate response is a possible explanation for these results. Differences among statistical analyses might also have contributed to different results in the literature. It is likely that the effects of induced alkalosis on blood lactate are not as evident as suggested by the results cited in the literature, considering that, in order to avoid Type I error, we performed a very rigorous and accurate statistical analysis (17, 34).

Studies that used different exercise protocols and different doses of bicarbonate reached different conclusions regarding blood lactate. Some studies showed significant increase in blood lactate concentration after induced alkalosis (12, 23, 24, 30, 36), whereas others showed no significant changes (5, 13, 16, 33, 35). Clearly, these differences result, at least in part, from the different doses administered and different exercises used. The effects of sodium bicarbonate on blood lactate and performance appear to be more consistent in studies in which exercise protocols resulted in greater decreases in pH (13, 16, 23, 24, 27, 35).

McNaughton (22) demonstrated that doses of bicarbonate higher than 0.3 g/kg do not further enhance performance but provoke important side effects. In addition, doses of less than 0.3 g/kg are less effective than doses of 0.3 g/kg. Although we did not analyze blood gases, there is a strong consensus that ingesting such doses of sodium bicarbonate increases blood bicarbonate, pH, and base excess.

Despite an increase in extracellular bicarbonate, experimental studies have shown that the sarcolemma is not permeable to bicarbonate (19). Thus, H^+ ions are not buffered inside muscle cells. Greater extracellular bicarbonate concentration results, however, in greater H^+ efflux to the blood (18), where it is buffered. This buffering action reduces intramuscular acidosis, which in turn prolongs the function of energy-production systems such as the glycolytic pathway and delays the onset of fatigue (12). Such a mechanism might explain higher lactate concentration after sodium-bicarbonate ingestion. Moreover, other studies have suggested an increased lactate efflux rate and decreased lactate intake by inactive muscles (12, 21). Brooks et al. (3) showed that lactate efflux from muscle cells is enhanced by the presence of sodium bicarbonate. This is probably because of increased activity of MCT 1, which transports H^+ and lactate from muscle cells to extracellular fluid (27).

In this study, the significant improvement in performance observed in the last bouts of both protocols might be explained by lower intramuscular acidosis. In a recent study, Raymer et al. (26) showed that at the point of fatigue, muscle H^+ concentration did not decrease with sodium-bicarbonate ingestion. The acidosis threshold was shifted to the right, however, meaning that during induced alkalosis, muscle acidosis is lower at the same muscle workload. The study clearly demonstrated that induced acidosis does not change the point of fatigue but delays its onset by shifting the acidosis curve to the right.

In addition to increasing mean power, ingestion of sodium bicarbonate increased peak power (Figure 4). Because resynthesis of creatine phosphate depends on transport of H^+ out of the cell (28) and intramuscular pH (1), alkalosis can be expected to improve resynthesis of creatine phosphate. This might have been detectible only in the last bout because intramuscular pH had reached limiting levels and fatigue had already occurred, as demonstrated by the reduced power generated each second (Figure 5).

Lavender and Bird (15) confirmed that the return of pH to baseline values caused by increased efflux of H^+ ions during alkalosis allows more complete recovery between series of intermittent exercises. Thus, we hypothesized that perceived exertion would be reduced as a result of induced alkalosis. We observed, however, that sodium-bicarbonate ingestion had no effect on the level of perceived exertion (Table 2). These results confirm those of Stephens et al. (30), who used the same scale as this study, and Poulus et al. (25), who used a different scale to measure the sensation of fatigue. According to these authors, the sensation of fatigue depends on metabolic, circulatory, and psychochemical changes, among others. Changed acid-base balance caused by alkalosis is only one of many physiological processes involved in the fatigue process. This might explain the lack of significant differences in perceived exertion throughout this experiment.

In conclusion, the present study demonstrated that ingesting sodium bicarbonate causes a significant improvement in judo-related performance, confirming its efficacy in intermittent supramaximal bouts of exercises in which fatigue is evident. This study, however, does not prove that an athlete will fight better as a result of sodium-bicarbonate ingestion, because competitive judo performance depends on numerous technical, tactical, and psychological factors. Nevertheless, this ergogenic aid might contribute to improved performance in real judo matches. Sodium-bicarbonate ingestion also increases blood lactate concentration, but this effect is not consistent. Ingestion does not decrease perceived exertion after exercise or recovery.

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