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The Effect of Sodium Bicarbonate Ingestion on Back Squat and Bench Press Exercise to Failure

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Abstract

Duncan, MJ, Weldon, A, and Price, MJ. The effect of sodium bicarbonate ingestion on back squat and bench press exercise to failure. *J Strength Cond Res* 28(5): 1358–1366, 2014—This study examined the acute effects of $NaHCO_3$ ingestion on repetitions to failure and rating of perceived exertion in the back squat and bench press in trained men. Eight resistance-trained men took part in this double-blind, randomized crossover experimental study whereby they ingested $NaHCO_3$ (0.3 $g \cdot kg^{-1}$ body mass) or placebo (sodium chloride NaCl: 0.045 $g \cdot kg^{-1}$ body mass) solution 60 minutes before completing a bout of resistance exercise (3 sets of bench press and back squat exercise to failure at an intensity of 80% 1 repetition maximum). Experimental conditions were separated by at least 48 hours. Participants completed more repetitions to failure in the back squat after $NaHCO_3$ ingestion ($p = 0.04$) but not for bench press ($p = 0.679$). Mean $\pm$ *SD* of total repetitions was 31.3 $\pm$ 15.3 and 24.6 $\pm$ 16.2 for back squat and 28.7 $\pm$ 12.2 and 26.7 $\pm$ 10.2 for bench press in $NaHCO_3$ and placebo conditions, respectively. Repetitions to failure decreased as set increased for the back squat and bench press ($p = 0.001$, both). Rating of perceived exertion significantly increased with set for the back squat and bench press ($p = 0.002$, both). There was no significant change in blood lactate across time or between conditions. There were however treatment $\times$ time interactions for blood pH ($p = 0.014$) and blood HCO_3 concentration ($p = 0.001$). After ingestion, blood pH and HCO_3 ($p = 0.008$) concentrations were greater for the $NaHCO_3$ condition compared with the placebo condition ($p < 0.001$). The results of this study suggest that sodium bicarbonate ingestion can enhance resistance exercise performance using a repetition to failure protocol in the first exercise in a resistance exercise session.

Key Words ergogenic aid, alkalosis, pH, buffering, resistance exercise to failure, nutrition

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Introduction

Short-term, high-intensity exercise results in increased blood lactate concentration and an associated increase in hydrogen ions (H^+) (2,6). The increased H^+ concentration causes a drop in both muscle and blood pH (23), slower glycolysis (24), changes in calcium release from the sarcoplasmic reticulum and subsequent calcium ion binding (14), increased perception of fatigue (40), and ultimately poorer exercise performance (32,40). However, the metabolic alkalosis induced by ingestion of sodium bicarbonate ($NaHCO_3$) has been shown to delay acidosis and allow greater lactate flux from muscle to blood during high-intensity (27) and prolonged exercise (24) leading to improved exercise performance (25,26,37). Ingestion of $NaHCO_3$ has also enhanced performance in shorter duration exercise ranging from 3 $\times$ 30-second bouts to 4 $\times$ 3-minute bouts (32,40). Despite this, there is conflicting research suggesting $NaHCO_3$ may not be effective in enhancing sports performance (5,21).

Recent meta-analytical data (22) indicated that $NaHCO_3$ was ergogenic in 38% of the studies examined regardless of performance measure, duration of task, and training status of participants. The meta-analysis also noted that research using time to exhaustion or total work protocols resulted in greater effect sizes compared with studies using performance time or total power protocols concluding that $NaHCO_3$ is ergogenic for short-term, high-intensity exercise. It is also important to note that although the effect sizes were smaller for protocols involving performance times (e.g., time trials), arguably they offer greater ecological validity in terms of sports performance compared with time to exhaustion protocols. Moreover, at the elite standard of performance, although $NaHCO_3$ ingestion may result in only a small effect, such small margins may be practically important (22).

The majority of previous studies examining the efficacy of $NaHCO_3$ on exercise performance have examined individual sprint performance, repeated short-duration sprints, or field-based activities (24,26,32). Few studies have examined the effects of sodium bicarbonate ingestion on resistance exercise performance (19). Arguably, the interval like nature of high-intensity resistance exercise is similar to interval/intermittent protocols used in prior studies of the effect of $NaHCO_3$ on performance in a range of exercise modes (e.g., cycling (40), running (27), and swimming (31)). Moreover, studies that have specifically examined the effect of $NaHCO_3$ on resistance exercise performance are inconsistent in terms of exercise protocol used, timing and administration of $NaHCO_3$, and the population used (18,19,21,38). These studies did not report key physiological variables such as blood lactate concentration and blood pH (19), thus limiting the conclusions that can be drawn from the data and eliciting the suggestion of further research being required in this area (19,38).

Webster et al. (38) examined the effect of $NaHCO_3$ ingestion on leg press performance in trained men (4 $\times$ 12 repetitions at 70% of 1 repetition maximum [1RM]). A fifth set of exercise was undertaken to failure. Although blood lactate concentration increased during exercise, the number of repetitions completed in the final set was not significantly different in $NaHCO_3$ or placebo conditions. Webster et al. (38) concluded that $NaHCO_3$ was not ergogenic for resistance exercise. However, the authors suggested that the leg press protocol may not have been of sufficient intensity to realize any ergogenic benefit from $NaHCO_3$ ingestion with future research potentially benefiting from a repetition to failure protocol. Conversely, study by Coombes and McNaughton (7) reported increased total work done and peak torque during isokinetic leg dynamometry after $NaHCO_3$ ingestion in healthy men. In addition, Marsit et al. (18) reported an increase in performance to failure during multiple sets of leg press exercises at 67.5% of 1RM. More recent research examined the effect of ingesting $NaHCO_3$ on 10RM performance in both bench press and pull press (19). No improvement in 10RM performance was observed after $NaHCO_3$ ingestion, concluding that sodium bicarbonate ingestion was not ergogenic for resistance exercise performance. Materko et al. (19) also suggested their study was limited because of too great a time between $NaHCO_3$ administration and exercise performance and the lack of any measures of blood lactate and pH to determine the magnitude of any alkalosis achieved. Despite this, many of these studies are methodologically limited. Such studies have largely employed protocols requiring a set number of repetitions at a given intensity and also employed exercise intensities within a "moderate" range e.g., 60–70% 1RM (18,19,38). In the context of using nutritional manipulation to enhance performance, examining the efficacy of acute ingestion of potentially ergogenic substances at exercise intensities more indicative of those used by athletes undertaking conditioning for sports performance would seem prudent to determine efficacy of a substance across the range of exercise intensities employed in strength and conditioning program design. The data which have currently been reported in relation to $NaHCO_3$ ingestion on resistance exercise performance are inadequate to fully conclude as to the impact ingestion of $NaHCO_3$ might have on performance, and thus provide practical recommendations for coaches and athletes.

In addition to a lack of training recommendations, more strenuous protocols representing those undertaken by athletes in competition and training are required to determine the efficacy of $NaHCO_3$ ingestion on resistance exercise performance. For example, exercise intensities of 80% 1RM or greater are typically used to elicit strength and hypertrophy gains (12,39), and training to failure at such intensities has been suggested as an effective means by which to increase muscular hypertrophy (39). The use of repetitions to failure, as recommended by Webster et al. (38), is common with resistance training (8) and can lead to increased motor unit recruitment and subsequent greater gains in strength and hypertrophy when compared with other training methods (8,35). Repetition to failure protocols represents high-intensity exercise likely lead to increased blood and muscle acidosis (34). Therefore, $NaHCO_3$ ingestion might impact favorably on such an exercise protocol enabling performers to complete greater volumes of work and thus increase the physiological loading in a given session. Given the lack of prior studies examining the effect of $NaHCO_3$ ingestion on resistance exercise performance, the mechanism by which $NaHCO_3$ is purported to work and the metabolic, cardiovascular, and muscular demands of resistance exercise at 80% 1RM or greater (34) and of training to failure (39), it is perhaps surprising that no studies have yet addressed this gap in the literature. This is despite the fact that any potential ergogenic benefit of $NaHCO_3$ may be more likely to be seen with high intensity, interval-type exercise (22), such as is the case with resistance exercise to failure at loads of 80% 1RM or greater. Therefore, the aim of this study was to examine the effect of sodium bicarbonate ingestion on resistance exercise to failure at 80% 1RM. This study hypothesized that $NaHCO_3$ ingestion would result in improved resistance exercise to failure in trained men.

Methods

Experimental Approach to the Problem

This study employed a within-subjects, repeated measures, double-blind design. Subjects were informed that they were participating in a study examining resistance exercise performance, and that as part of the experiment, they would be asked to perform 1RM tests for back squat and bench press exercises and 2 subsequent performance testing sessions, one after ingestion of $NaHCO_3$ and the other after ingestion of a control solution. In the latter 2 trials, participants would be required to perform 3 sets of the aforementioned exercises to failure at an intensity of 80% 1RM. This intensity of 80% 1RM was chosen because it has been recommended for trained individuals in the development of hypertrophy and maintenance of muscle mass (11), and is therefore typical of the intensity of resistance exercise undertaken by individuals involved in regular strength and conditioning training. All testing took place within the institution's human performance laboratory.

Subjects

After institutional ethics approval and providing informed consent, 8 men (mean $\pm$ *SD*: age, height, and body mass

= 20 ± 0.9 years, age range = 19-23 years, 1.8 ± 0.1 m, and 78.4 ± 15.6 kg, respectively) volunteered to participate. All participants had specific experience performing resistance exercise and were free of any musculoskeletal pain or disorders. All participants competed in team games (rugby union, soccer, basketball) at National level, and testing took place during the preparatory period of their periodized training cycle. They were currently participating in more than 10 hours per week of programmed physical activity including strength- and endurance-based activities. All the participants were specifically resistance-trained, currently undertaking 3 hours of resistance exercise per week in addition to their other conditioning activities (e.g., metabolic conditioning, skills-based training). All the participants had been engaged in this amount of resistance exercise for at least 10 weeks before participating in the study as part of their preparatory training cycle. The mean ± *SD* duration of undertaking programmed strength and conditioning (including resistance exercise) experience was 2.8 ± 0.9 years. All participants were asked to refrain from vigorous exercise and maintain normal dietary patterns in the 48 hours before each testing session.

Procedures

Each participant attended the laboratory on 3 separate occasions. All testing took place between 9.00 AM and 12.00 noon with each condition taking place at the same time of the day for each participant to avoid circadian variation (1). The first visit to the laboratory involved a briefing session and determination of each participant's 1RM on the back squat and bench press. All participants had experience performing general resistance exercises and back squat and bench press exercises in particular. However, before commencing the 1RM testing, proper lifting technique was demonstrated to each participant. Each participant also performed 8–10 unweighted repetitions to minimize any learning effects that could occur in the experimental protocol. The 1RM was determined according to the methods advocated by Kraemer, et al. (16) and was used to set the 80% 1RM intensity undertaken during the subsequent experimental trials. The mean ± *SD* of 1RM for back squat and bench press was 131.4 ± 30.9 kg and 75.3 ± 30.1 kg, respectively, representing an appropriate standard for such a group of athletes (3,15).

During each experimental condition, participants undertook a 5-minute submaximal warm-up on a cycle ergometer and 10 repetitions of each resistance exercise using an unweighted bar. Participants then completed 3 sets of back squat and bench press exercise to failure at 80% 1RM with a 3-minute rest between sets and a 5-minute rest between back squat and bench press exercise in every session. Conditions, separated by 48–72 hours, were randomized and consisted of a sodium bicarbonate condition ($0.3 \cdot g \cdot kg^{-1}$ $NaHCO_3$ in 5 $ml \cdot kg^{-1}$ of artificially sweetened water) and a control condition (0.045 $g \cdot kg^{-1}$ of sodium chloride solution [NaCl] in an artificially sweetened water drink matched for taste). Solutions were refrigerated overnight and consumed 60 minutes before each exercise trial within 5 minutes (28). The specific dose and timing of administration of test solutions was chosen based on that recommended in the literature (15,20) and because 0.3 $g \cdot kg^{-1}$ body mass $NaHCO_3$ has been shown to be erogogenic while reducing any gastrointestinal discomfort (17,20,33). Although less intense loading regimes have been used more recently, the loading regime was consistent with the majority of exercise performance studies in the literature.

Test solutions were presented to participants double-blind in an opaque sports bottle to prevent the researchers administering the solutions or the participants from actually seeing the solutions themselves. Before exercise testing, body height (m) and mass (kg) were assessed using a Seca stadiometer and weighing scales, respectively (Seca Instruments, Hamburg, Germany). Participants were also required to follow the same diet in the 24 hours preceding each exercise trial (based on 24-hour diet and exercise recall) and were required to avoid vigorous physical exercise in the 48 hours preceding each laboratory visit. In addition, participants were instructed to ingest nothing but water in the 3 hours before each trial. Adherence to these requirements was verified using a brief questionnaire administered before each trial.

Lifting Procedures

All exercises were performed using a 20 kg Eleiko bar, Pullum Power Sports lifting cage, and Olympic lifting platform (Pullum Power Sports, Luton, United Kingdom). All lifts were completed in accordance with protocols previously described, by Earle and Baechle, for the bench press and back squat (10). A trained researcher/spotter was present during all testing sessions to ensure proper range of motion. Any lift that deviated from proper technique was not counted. This resulted in 7 repetitions not being counted across the study. There was no visible pattern for repetitions that were not counted being restricted to either 1 particular participant or 1 exercise. In the majority of cases (6 out of the 7), uncounted repetitions occurred in the repetition before task failure in the last set of either the back squat or bench press exercise. During all exercises and across conditions, repetition frequency was paced by a metronome set at 60 $b \cdot min^{-1}$. This cadence resulted in 1 complete repetition every 4 seconds with concentric and eccentric phases, both comprising of 2 seconds. Feedback related to lifting procedures or the number of repetitions completed was not made available to participants until completion of the whole experimental procedure. In all cases and across conditions, participants performed the back squat exercise after bench press. Proper range of motion was determined a priori (during the 1RM session) following recognized guidelines for the back squat and bench press (10). In subsequent experimental trials, purpose-made markers (placed on the outside beam of the lifting cage) were used to indicate to the trained researchers when each movement had reached its upper or lower range of movement. This also provided kinesthetic

Table 1. Mean ± *SD* of repetitions to failure in the back squat and bench press after ingestion of $NaHCO_3$ or placebo.

	$NaHCO_3$		Placebo	
	Mean	*SD*	Mean	*SD*
Back squat (repetitions)				
Set 1	11.6	5.2	11.7	7.3
Set 2	10.9	6.7	6.8	4.5
Set 3	8.8	5.9	6.1	5.4
Total	31.3*	15.3	24.6	16.2
Bench press (repetitions)				
Set 1	12.4	4.8	11.7	3.9
Set 2	8.4	1.9	8.4	2.2
Set 3	7.4	2.2	6.6	1.7
Total	28.2	12.2	26.7	10.2

*$p = 0.04$ between $NaHCO_3$ and placebo conditions.

feedback to the participant as to when the movement had been executed correctly.

Performance Measures

During each set and across conditions, repetitions to failure were counted using a hand tally counter (Tamaco Ltd, Tokyo, Japan). Immediately after each participant had reached failure in each set, they were asked to provide ratings of perceived exertion using the Borg 6–20 rating of perceived exertion (RPE) scale (4) for the active muscle groups involved in each exercise. Participants were all familiar with the use of the Borg's scale for determination of RPE, and memory anchoring was employed to ensure stable reporting of RPE across the experimental protocol in line with prior recommendations (4).

Fingertip capillary blood samples were taken pre-ingestion, 60 minutes postingestion (before exercise), on completion of the back squat exercise, and immediately before and after the bench press exercise. After collection, blood samples were put on ice until analysis at the end of the exercise protocol. A 100-μL sample was analyzed for blood pH and blood bicarbonate concentration ($[HCO_3^-]$) (ABL5 Radiometer, Copenhagen, Denmark). A further 80-μL sample was analyzed in triplicate for blood lactate concentration (Bla, Biosen C-Line Analyzer; EKF Diagnostic GmbH, Magdenberg, Germany).

Statistical Analyses

The effect of $NaHCO_3$ on resistance exercise performance and RPE were analyzed using a 2 (trial; $NaHCO_3$ vs. control) × 3 (set 1–3) repeated measures analysis of variance for back squat and bench press exercise, respectively. Data for blood pH and Bla and blood HCO_3 concentrations were analyzed using a 2 (treatment; $NaHCO_3$ vs. control) × 5 (time; pre-ingestion, postingestion, after back squat, before bench press, after bench press) repeated measures analysis of variance. Where any significant interactions and main effects were found, post hoc analysis using Bonferroni's adjustments were performed. Partial η^2 was used as a measure of effect size. A p value of 0.05 was set to establish statistical significance. The Statistical Package for Social Sciences (version 18.0; SPSS, Inc., Chicago, IL, USA) was used for all analyses.

Results

The mean ± *SD* for repetitions to failure for back squat and bench press for $NaHCO_3$ and control conditions are shown in Table 1 and Figures 1 and 2, respectively. No significant trial × set interactions were evident for either exercise. The back squat demonstrated significant main effects for treatment ($F_{(1,7)} = 5.997$, $p = 0.04$, partial $\eta^2 = 0.461$) with $NaHCO_3$ eliciting a greater number of repetitions. A main effect was also observed for set ($F_{(2,14)} = 10.988$, $p = 0.001$, partial $\eta^2 = 0.611$). Bonferroni's post hoc analysis indicated a decrease in repetitions to failure across the 3 sets for back squat with the number of repetitions being significantly lower in set 3 compared with set 1 ($p = 0.025$, mean difference $= -1.4$, Figure 1). For

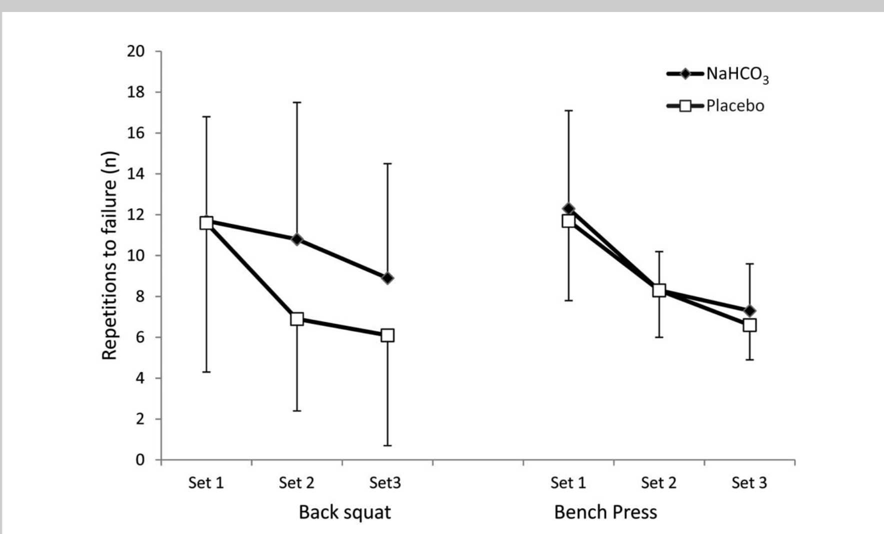

Figure 1. Mean ± *SD* of back squat and bench press repetitions to failure at 80% of 1 repetition maximum per set in the presence of $NaHCO_3$ or control.

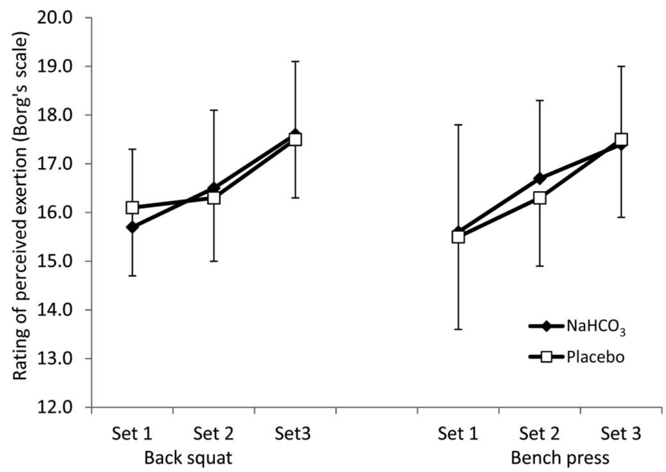

Figure 2. Mean ± *SD* of rating of perceived exertion during back squat and bench press repetitions to failure at 80% of 1 repetition maximum per set in the presence of $NaHCO_3$ or control.

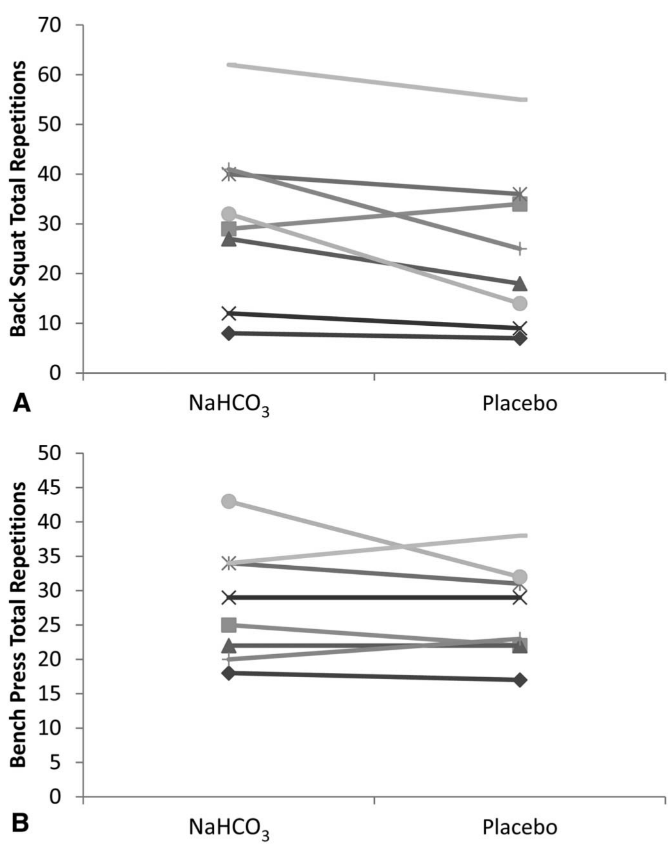

Figure 3. Responder/nonresponder plots for total repetitions completed in: back squat (A) and bench press (B) in $NaHCO_3$ and control conditions.

bench press exercise, results indicated no significant main effect for repetitions to failure ($p = 0.428$). Total repetitions completed across the 3 sets of back squat and bench press exercise in $NaHCO_3$ and control conditions were also plotted (see Figure 3) to determine responder/nonresponder status. In the back squat, 7 of the 8 participants performed a greater number of total repetitions after ingestion of $NaHCO_3$ compared with control with only 4 participants performing a greater number of total repetitions compared with control in the bench press exercise.

There were no trial × set interactions for RPE in either exercise (see Figure 2). However, main effects were observed for set in both back squat ($F_{(2,14)} = 9.976$, $p = 0.002$, partial $\eta^2 = 0.588$) and bench press exercises ($F_{(2,14)} = 9.841$, $p = 0.002$, partial $\eta^2 = 0.584$,). A significant increase in RPE was observed across sets for back squat with RPE being greater in set 3 compared to set 1 (Figure 2). For bench press, RPE was significantly greater in both sets 2 and 3 compared to set 1 ($p < 0.002$).

Blood lactate concentration at rest and throughout the exercise protocol for both trials are presented in Table 2. Results demonstrated a significant main effect for time ($F_{(4,28)} = 29.3$, $p = 0.001$, partial $\eta^2 = 0.807$) but no main effect for trial ($p = 0.958$). Post hoc analysis indicated that Bla concentration after back squat exercise was significantly greater than all Bla concentrations pre-exercise ($p = 0.001$). After back squat exercise, the Bla concentration remained elevated before bench press and after bench press exercises (all $p = 0.002$; mean ± *SD*).

Table 2. Mean ± *SD* of blood lactate (Bla), blood pH, and blood HCO_3 ($mmol\cdot L^{-1}$) pre-ingestion, postingestion but pre-exercise, after back squat, before bench press, and after bench press in $NaHCO_3$ and control conditions.

	Pre-ingestion				Postingestion				After back squat				Before bench press				After bench press			
	$NaHCO_3$		Control		$NaHCO_3$		Control		$NaHCO_3$		Control		$NaHCO_3$		Control		$NaHCO_3$		Control	
	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*	M	*SD*
BLa ($mmol\cdot L^{-1}$)	1.7	0.8	1.5	0.7	1.7	1.1	1.6	0.6	11.9	4.2	10.3	5.1	9.2	4.1	7.8	5.3	11.3	4.8	9.7	4.2
Blood pH	7.4	0.01	7.4	0.01	7.4*	0.01	7.4	0.03	7.4*	0.05	7.3	0.03	7.4*	0.06	7.3	0.03	7.4*	0.03	7.3	0.01
Blood HCO_3 ($mmol\cdot L^{-1}$)	24.6	1.6	25.5	1.1	30.6*	2.5	23.1	4.8	20.9*	3.6	18.9	3.0	22.0*	4.9	19.1	3.2	21.6*	3.4	20.4	2.2

*$p = 0.001$, between $NaHCO_3$ and control conditions.

Blood pH concentration values demonstrated a significant trial × set interaction ($F_{(4,28)} = 3.77$, $p = 0.014$, partial $\eta^2 = 0.350$; Table 2) as did blood bicarbonate concentration ($F_{(4,28)} = 6.047$, $p = 0.001$, partial $\eta^2 = 0.463$; Table 2). Both blood pH and bicarbonate concentration values were similar pre-ingestion, becoming greater during the $NaHCO_3$ condition at all time points after ingestion compared with the control condition (all $p = 0.001$; see Table 2). However, there were no differences in blood pH or bicarbonate concentration between sets for either trial (i.e., after back squat vs. before bench press, before bench press vs. after bench press, after back squat vs. after bench press; $p > 0.05$).

Discussion

Prior research examining the effects of $NaHCO_3$ ingestion on resistance exercise has been equivocal, potentially because of protocols using only moderate intensity exercise (18,19,38) with suggestions that higher intensity protocols to task failure should be examined (38). Furthermore, using an exercise to failure protocol has been cited as one means by which to augment strength gains seen with traditional strength training designs (39) and may therefore be more ecologically valid. Consequently, if $NaHCO_3$ ingestion enhances performance in this mode of exercise, it may allow additional physiological loading and therefore greater adaptation to resistance exercise. The results of this study indicate an enhanced ability to perform repetitions to failure in the back squat at 80% 1RM after ingestion of $NaHCO_3$. However, this augmentation was not evident for bench press exercise to failure performed 5 minutes after the back squat exercise. Although the results of this study support previous observations that $NaHCO_3$ ingestion can enhance high intensity resistance exercise performance (7), they are contrary to other research reporting no ergogenic effect of $NaHCO_3$ ingestion on resistance exercise performance (19,38). The discrepancy between the findings presented in this study and that of previous authors is not unexpected. Both the aforementioned studies suggested that the protocols employed in their research may not have been of a high enough intensity to realize any ergogenic effect of $NaHCO_3$ on resistance exercise performance. The repetitions to failure, at 80% 1RM, protocol employed in this study resulted in high blood lactate values reflecting the intensity of the exercise protocol employed. The blood lactate values reported here are also within the ranges seen in other research using a repetitions to failure protocol (9).

The ergogenic effect of $NaHCO_3$ ingestion in this study was only observed for the back squat exercise. Interestingly, there were a similar number of repetitions to failure in set 1 of the bench press exercise because there were for set 1 of the back squat and similar fatigue profiles in bench press as for the control trial of the back squat exercise. Previous studies of $NaHCO_3$ ingestion on cycling performance have observed reductions in local fatigue (RPE) after ingestion of $NaHCO_3$ (13,36). If a similar effect is present for resistance training exercise, this may help to explain the improvements in repetitions to failure in the second and third sets of back squat exercise observed in this study. Such high intensity resistance exercise is likely to have a greater effect on local muscle RPE rather than total body RPE. In this study, because participants were asked to rate local RPE, they may likely have reported similar values because of focusing more on sensation form the exercising muscle when reporting RPE rather than the total body.

This study demonstrated no differences in RPE between $NaHCO_3$ and control conditions across the whole experimental protocol. These results contradict previous research (13,36), simply suggest that there was no difference in local perception of fatigue between the 2 trials. Previously reported data examining the effects of $NaHCO_3$ ingestion on perceptual responses to exercise are equivocal with some studies suggesting that the relationship between acid-base balance and RPE during exercise may involve negative effects of accumulation of intracellular H^+ on force-generating capabilities of muscle as the muscle fatigues (30). The results of this study are partly in agreement with conclusions made by Requena et al. (29) in their review that ingestion of $NaHCO_3$ does not impact on RPE responses during exercise. However, the absolute RPE responses were similar during the back squat protocol for $NaHCO_3$ and control trials, a greater number of repetitions were achieved in the $NaHCO_3$ treatment.

There were no differences in Bla concentration between trials, which are unusual for such studies because ingestion of $NaHCO_3$ usually elicits greater blood lactate concentration postexercise. This result may strengthen the contribution of attenuated local RPE in improving back squat performance. However, the lack of statistical significance may be because of the large *SD* and thus large interindividual variation present in an otherwise homogenous population. Furthermore, although blood pH did reduce during exercise, values were not as low as reported for cycle ergometry (13) or treadmill running (27). Blood HCO_3 concentrations were also similar after both sets of exercise indicating that the demand on the base reserve was not great.

Three of the participants reported gastrointensitinal distress before commencing the exercise protocol. Of these participants, 1 demonstrated poorer performance, 1 enhanced performance in the $NaHCO_3$ condition compared with the control, and the other demonstrated no difference in performance between conditions. Such gastrointenstinal issues are not uncommon in studies of $NaHCO_3$ ingestion (26,27), and no discernable pattern of the effect of such distress was evident on the performance of participants in this study. A similar response was observed recently for studies of cycle ergometry where responding or not responding positively to $NaHCO_3$ ingestion before exercise to exhaustion was not consistent across (high) exercise intensities (13). Moreover, in the case of responders/nonresponders (see Figure 3), there was no discernable pattern of response status to $NaHCO_3$ ingestion with the participants "responding" to $NaHCO_3$ ingestion in the back squat exercise being different to those responding to $NaHCO_3$ ingestion in the bench press.

Although positive results were observed for the back squat, this study is not however without its limitations. A sample of trained subjects was employed in this study and, given the equivocal nature of studies on the impact of $NaHCO_3$ ingestion on resistance exercise performance, further research is needed examining the impact of $NaHCO_3$ ingestion on resistance exercise performance in a larger sample of participants and also considering training status. In this study, participants had prior experience of resistance exercise and had been engaged in 3 hours per week structured resistance exercise for the 10 weeks before taking part as part of their periodized training within the preparatory phase of their conditioning program after their transition/close-season period. In particular, a recent review (22) has suggested that effect sizes for studies on the effect of $NaHCO_3$ on exercise performance are greater for untrained performers, potentially because untrained participants are more reliant on the extra buffering potential during exercise afforded when $NaHCO_3$ is ingested. Furthermore, in this study, a repetition to failure protocol was chosen based on recommendations of prior authors. Training to failure has been used in other studies (8) but may not be representative of the range of resistance exercise training undertaken by athletes. It is also worthy to note that the repetitions that were not counted in this study because of improper technique will also have contributed to the metabolic and RPE responses within the protocol. Therefore, examination of other variables (e.g., change in EMG activity or force production) during high intensity resistance exercise and different resistance exercise protocols such as plyometric training and resistance exercise employing a predetermined number of sets and repetitions at a predetermined intensity may be of interest to coaches and practitioners. Examining the effect of $NaHCO_3$ ingestion on performance of exercises involving different muscle masses may be useful in informing nutritional practice for athletes. Undertaking a training intervention using $NaHCO_3$ ingestion would also be important in establishing whether $NaHCO_3$ ingestion can augment the changes in muscle strength and performance seen with training alone. Finally, in the protocol employed in this study, participants performed the back squat exercise after the bench press exercise with exercise order not being randomized. We acknowledge that the data presented here may in fact represent a testing order effect; in that the first exercise performed was the one found to be significantly influenced by $NaHCO_3$ ingestion. Future studies need to ensure that exercise order and trial order is randomized, or examined separately, to avoid such potential order effects.

Practical Applications

The results of this study suggest that sodium bicarbonate ingestion can enhance resistance exercise performance in the back squat when using a repetitions to failure protocol and when this is the first exercise in a resistance exercise session. Thus, coaches and practitioners might effectively use sodium bicarbonate ingestion to increase physiological loading placed on the athlete when training to failure with a large muscle mass. Furthermore, the presence of gastrointestinal distress in some performers, although uncomfortable for the athlete, does not appear to offset the potential performance benefits of $NaHCO_3$ ingestion. More specifically, coaches and athletes could employ a bolus of 0.3 $g \cdot kg^{-1}$ $NaHCO_3$ in 5 $ml \cdot kg^{-1}$ body mass of artificially sweetened water to acutely enhance performance of resistance exercise to failure. Such acute ingestion might therefore enable higher physiological loading when employing strenuous resistance exercise protocol. However, such ergogenic effects may be short-lived because of cumulative fatigue effects of training to failure negating any potential ergogenic effect of $NaHCO_3$ during resistance exercise.

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