Research in Exercise Nutrition
ISSN: 2980-8960

RESEARCH ARTICLE

Research in Exercise Nutrition 5(2), ---

Effects of Acute Sodium Bicarbonate Ingestion before an Anaerobic Swimming bout on Selected Physiological and Performance indices in Water Polo Players

Ali Shahbazi[1], Javad Mehrabani [*1], Mojtaba Mohammadi[1]

[1] Department of Physical Education and Sport Sciences, University of Guilan, Rasht, Iran.

Open Access

REN

Submitted:
22 February 2026
Revised:
20 May 2026
Accepted:
29 May 2026
Published:
29 May 2026

© The Author(s) retain the copyright.

Research in Exercise Nutrition:

2026, Volume 5 (Issue2), Pages

Publisher: **University of Kurdistan**

ISSN: 2980-8960

Abstract

Introduction: Water polo is a sport with high metabolic demands, requiring the ability to tolerate intense and intermittent activities. Lactate accumulation and the onset of acidosis are among the limiting factors for performance in this sport. Therefore, the intake of alkalizing agents, such as sodium bicarbonate, may reduce fatigue effects by increasing the body's buffering capacity. Hence, the aim of the present study was to investigate the effect of acute sodium bicarbonate ingestion prior to anaerobic swimming activity on the physiological and performance parameters of water polo players.

Methods: In this double-blind, randomized crossover quasi-experimental study, nine elite male water polo players (age: 26.44 ± 2.78 years; height: 181.73 ± 7.27 cm; weight: 83.44 ± 14.37 kg) performed swimming, dribbling, and shooting protocols under three conditions: control, placebo (dextrose), and ingestion of 0.3 g of sodium bicarbonate per kg of body weight, with a six-day interval between conditions, to assess the effect of sodium bicarbonate on performance, heart rate (HR), and rating of perceived exertion (RPE). Data were analyzed using repeated-measures analysis of variance (ANOVA), with the significance level set at $p < 0.05$.

Results: The results of repeated-measures ANOVA and Bonferroni post-hoc tests showed that heart rate increased significantly after swimming and shooting in all three conditions. However, a significant difference in heart rate was observed only after swimming in the sodium bicarbonate condition compared to the placebo condition ($p < 0.05$). No significant differences were found in RPE ($p = 0.12$) or ball throwing velocity between trials ($p = 0.43$). However, a significant difference was observed in throwing accuracy among the three conditions ($p = 0.048$).

Conclusions: It appears that acute sodium bicarbonate ingestion, by improving buffering capacity, may partially improve physiological responses and skill accuracy during anaerobic water polo activities. However, further extensive studies are needed to confirm these effects definitively.

Key Words: Sodium bicarbonate, Heart rate, Water polo, Fatigue, Rating of perceived exertion

Corresponding author: Associate Professor, Department of Physical Education and Sport Sciences, University of Guilan, Rasht, Iran. E-mail: mehrabanij@guilan.ac.ir

Citation:
Shahbazi A, Mehrabani J, Mohammadi M. The Acute Effect of Sodium Bicarbonate Ingestion Before Anaerobic Swimming Activity on Physiological and Performance Indices in Water Polo Players. **Research in Exercise Nutrition.** 2026 May 29. Doi: https://doi.org/10.22034/ren.2026.145550.1161 .

1. Introduction.

Water polo is a highly metabolically demanding sport that requires a high level of physical fitness, swimming proficiency, and throwing skills (1). As a team sport, it challenges both perceptual and physical abilities within a dynamic aquatic environment (2). The combination of throwing velocity and accuracy is one of the key determinants of scoring performance, as higher throwing velocity and accuracy reduce the time available for the goalkeeper and defenders to react (3–5).

The development of fatigue is associated with metabolic and physiological alterations within skeletal muscle, which may result in the accumulation of metabolic by-products generated during energy production (6). In high-intensity intermittent sports such as water polo, the accumulation of lactate resulting from anaerobic metabolism (6–7) may impair muscle contraction and contribute to fatigue and exhaustion (8). Repeated muscle contractions and the accumulation of cellular metabolites can also influence heart rate responses (9). Furthermore, physiological responses during swimming differ from those observed during terrestrial exercise because of the horizontal body position, hydrostatic pressure, and water temperature (10). The supine or horizontal body position may increase stroke volume and reduce heart rate compared with the upright position (11). Collectively, these factors contribute to elevated heart rate and blood lactate concentrations above resting levels in water polo players. Approximately 70% of the activity performed in water polo is anaerobic, and players are repeatedly exposed to hypoxic conditions, which may further contribute to elevations in heart rate and blood lactate concentration. Consequently, water polo players experience substantial metabolic fatigue, which may negatively affect throwing velocity and accuracy and, ultimately, scoring performance during competition (12,13).

Nutritional strategies that influence the body's buffering capacity, such as sodium bicarbonate supplementation, may potentially enhance extracellular buffering capacity (14). Sodium bicarbonate is one of the major physiological buffering agents and may enhance the body's buffering system by facilitating the removal of hydrogen ions (H^+), thereby increasing blood pH and potentially promoting the clearance and utilization of lactate-related metabolites for energy production (15).

Several studies have investigated the effects of sodium bicarbonate supplementation on physiological and performance responses during high-intensity exercise. For example, Platanou et al. (2006) investigated the effects of match duration and playing position on exercise intensity during competitive water polo matches in elite players. They reported that players' heart rates during competition were approximately 85% of their maximal heart rate, while blood lactate concentrations were slightly above the lactate threshold (12).

Huang et al. (2025) investigated the effects of sodium bicarbonate supplementation on 200-m swimming performance and physiological responses. Their systematic review and meta-analysis demonstrated that sodium bicarbonate supplementation significantly increased blood bicarbonate concentration, blood lactate concentration, and blood pH; however, it did not produce a significant improvement in 200-m swimming performance (16). Zajac et al. (2009) examined the effects of sodium bicarbonate supplementation on swimming performance in young athletes. Their findings indicated that ingestion of 0.3 g/kg sodium bicarbonate improved performance during a 4 × 50-m swimming protocol in young male swimmers, although the significant improvement was observed only during the first 50-m bout. Sodium bicarbonate supplementation also significantly increased resting blood bicarbonate concentration and pH, as well as post-exercise blood lactate concentration (17). In another

Galley Proof

study, Gough et al. (2023) investigated the effects of sodium bicarbonate supplementation on swimming performance in women and reported that sodium bicarbonate ingestion could improve sprint swimming performance during the later stages of exercise (18).

Bicarbonate supplementation has primarily been investigated in activities in which muscular performance is a major determinant of exercise capacity. Most previous studies have focused on the ability of sodium bicarbonate to buffer H^+ and its potential effects on anaerobic performance outcomes, including power, strength, muscular endurance, and agility (17,19). However, relatively few studies have examined the effects of sodium bicarbonate supplementation as an ergogenic nutritional strategy on outcome-based performance indicators, such as the velocity and accuracy of skill execution in ball sports. These sports are characterized by highly dynamic and intermittent activity patterns in which technical factors, including ball-throwing velocity and accuracy, may play a critical role in determining competitive outcomes.

Moreover, despite inconsistencies in previous findings regarding the effects of fatigue on throwing velocity and accuracy in water polo and related sports, evidence in this area remains limited, particularly in the Iranian athletic population. Therefore, further investigation is warranted to clarify whether enhancing physiological buffering capacity through sodium bicarbonate supplementation can attenuate fatigue-related impairments in sport-specific performance.

Accordingly, the present study was designed to investigate the effects of acute sodium bicarbonate supplementation prior to an anaerobic swimming exercise protocol on physiological and performance-related indices in water polo players. To the best of our knowledge, the present study represents a novel and timely investigation of the potential effects of sodium bicarbonate supplementation on the velocity and accuracy of anaerobic sport-specific performance.

2. Methods.

2.1. Participants and Study Design

In this quasi-experimental, crossover, double-blind study, the required sample size was calculated using G*Power software based on an effect size of 0.45, a statistical power of 0.80, and an alpha level of 0.05. The analysis indicated that a sample size of 10 participants was required. Accordingly, 10 eligible water polo players were recruited using a random-number table. Eligible participants had engaged in regular training at least three days per week during the preceding year and had participated in at least one season of the national premier league (20).

One week before the experimental trials, participants attended a familiarization session during which they completed the informed consent form, a sports-medical questionnaire, a physical activity readiness assessment, and anthropometric measurements. Participants with hypertension, seizure disorders, pulmonary disease, hypoglycemia, or renal insufficiency were excluded from the study. One participant was subsequently excluded because of high blood pressure, resulting in a final sample of nine participants.

The nine participants completed three experimental conditions in a randomized crossover design: (1) an experimental condition involving sodium bicarbonate supplementation, (2) a placebo condition involving maltodextrin supplementation, and (3) a control condition without supplementation. Each trial was separated by a 6-day washout period.

Galley Proof

 https://doi.org/10.22034/ren.2026.145550.1161

2.2. Experimental Protocol

Prior to the second trial, participants were instructed to refrain from alcohol consumption and any strenuous aerobic or anaerobic exercise for 48 h before each experimental session (21). In each condition, participants completed a 10-min warm-up consisting of dynamic stretching, resistance-band exercises, 400 m freestyle swimming, stationary cycling, and shooting drills. Following a 5-min rest period, the testing protocol commenced.

Participants first performed a 100-m sprint swim, followed immediately by a 25-m high-speed dribbling swim performed with the head above the water. At the end of the swimming protocol, ratings of perceived exertion (RPE) were assessed using the Borg 6–20 scale.

Immediately following the swimming protocol, once participants reached 80–85% of their age-predicted maximal heart rate, heart rate was continuously monitored using a Polar H10 heart-rate monitor connected to a mobile device and the Elite HRV application. Participants then moved to the designated shooting area, where throwing velocity and accuracy were assessed immediately.

Each participant performed 10 shots toward five target zones, each measuring 30.48 cm. A maximum duration of 1 min was allowed to complete the 10 shots. Throwing velocity and accuracy were recorded by three assessors. Heart rate was recorded at four time points: before the warm-up, immediately after the warm-up and before the exercise protocol, immediately after swimming, and at the end of the shooting task. RPE was also assessed immediately after the swimming protocol to quantify perceived exertion during the swimming task.

A Bushnell 1019111 camera was used to measure ball-throwing velocity, whereas throwing accuracy was recorded and quantified by an assessor.

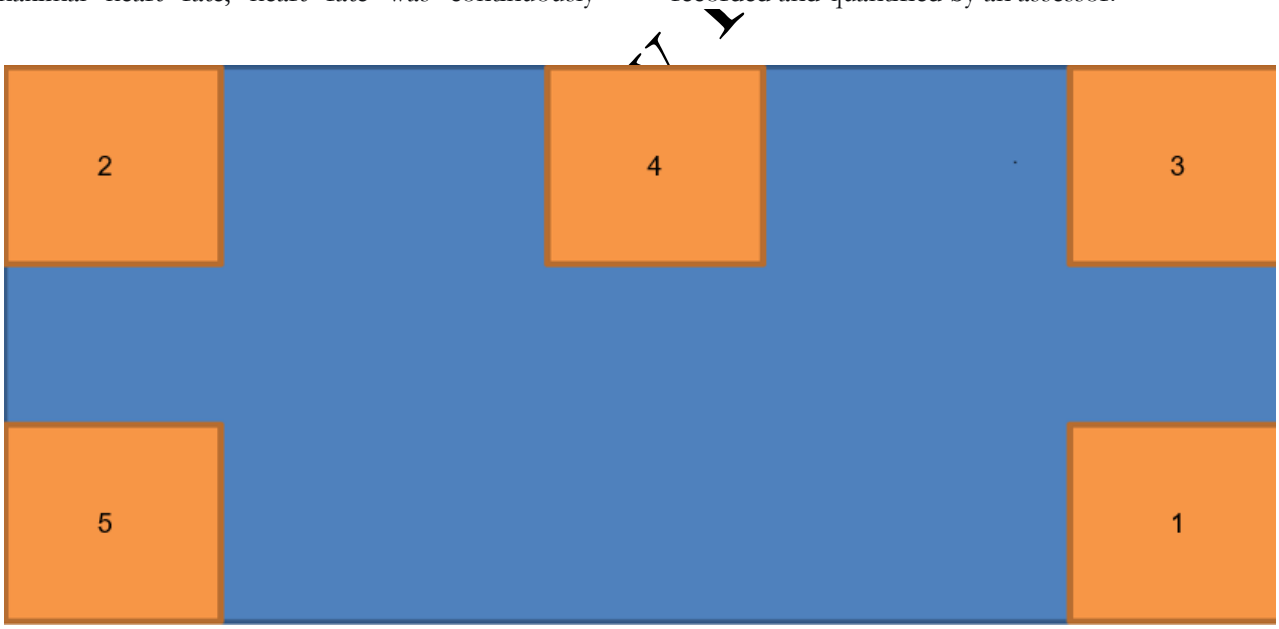


Figure 1. Dimensions of the pool, target area, and placement areas for examiners

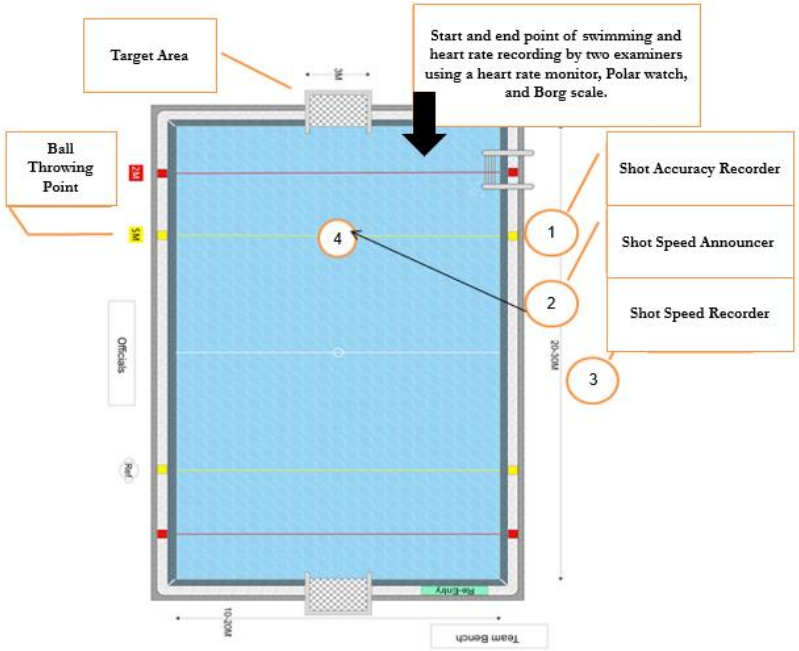


Figure 2. Target areas in the goal

2.3. Control Trial

During the first experimental session, participants completed the testing protocol without consuming any supplement or specific ergogenic substance. This trial served as the control condition and was used to establish baseline performance and physiological responses.

2.4. Placebo Trial

Following a 6-day washout period, participants completed the placebo trial. One hour before the exercise protocol, participants consumed maltodextrin as the placebo. The dextrose was dissolved in 500 mL of distilled water, and cherry extract was added to match the taste of the sodium bicarbonate solution. The experimental protocol was then performed as described above.

2.5. Sodium Bicarbonate Trial

After another 6-day washout period, participants completed the experimental trial. In this condition, participants consumed 0.3 g/kg body mass of sodium bicarbonate 1 h before the start of the exercise protocol. Sodium bicarbonate was dissolved in 500 mL of distilled water, and cherry extract was added to match the taste of the placebo solution. The same swimming and shooting protocol was then performed as described previously (1).

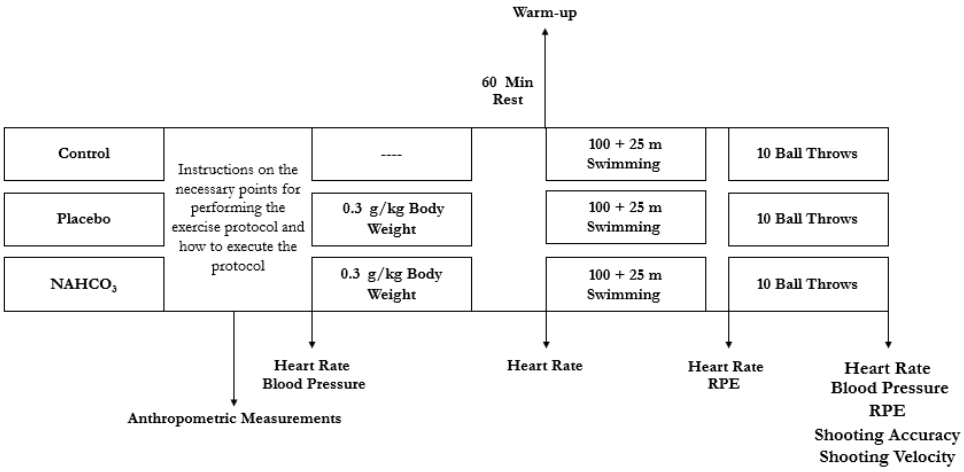


Figure 3. Schematic diagram of the research procedure

2.7. Statistical analysis

 https://doi.org/10.22034/ren.2026.145550.1161

The normality of data distribution and homogeneity of variances were assessed using the Shapiro–Wilk and Levene tests, respectively. Repeated-measures analysis of variance (ANOVA) was used to analyze the data, followed by Bonferroni post hoc tests when appropriate. All statistical analyses were performed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA), with statistical significance set at $p < 0.05$.

3. Results.

The participants' demographic and anthropometric characteristics are presented in Table 1. The means and standard deviations of the study variables, including heart rate, throwing velocity, and rating of perceived exertion (RPE), at the different stages of the shooting protocol are presented in Table 2.

Repeated-measures analysis of variance followed by Bonferroni post hoc tests showed that, in the control condition, heart rate was significantly higher immediately after swimming (mean difference = −97.98, $p = 0.005$) and after the shooting task (mean difference = −84.45, $p < 0.001$) compared with the resting condition. In the placebo condition, heart rate was significantly higher before swimming (mean difference = −46.27, $p = 0.008$), after swimming (mean difference = −105.20, $p = 0.030$), and after the shooting task (mean difference = −91.44, $p < 0.001$) compared with rest. Heart rate was also significantly higher after shooting than before swimming (mean difference = −45.17, $p < 0.001$).

In the sodium bicarbonate condition, heart rate was significantly higher after swimming (mean difference = −96.70, $p = 0.032$) and after the shooting task (mean difference = −86.74, $p = 0.031$) compared with rest. However, heart rate was significantly lower after shooting than after swimming (mean difference = −9.96, $p = 0.040$). Notably, a significant 4.01% reduction in heart rate was observed only immediately after swimming in the sodium bicarbonate condition compared with the placebo condition ($p < 0.05$).

No significant differences were observed among measurement time points or among the three experimental conditions for RPE ($p = 0.12$) or throwing velocity ($p = 0.43$). However, throwing accuracy was 25.08% higher in the sodium bicarbonate condition than in the placebo condition ($p = 0.048$).

Galley Proof

Table 1. Characteristics of the participants.

Table1. Characteristics of the participants

	Mean ± SD
Age (Year)	26.44 ± 2.78
Weight (kg)	83.44 ± 14.37
Height (cm)	181.73 ± 7.27
BMI (kg/m2)	25.26 ± 2.92
Body Fat (%)	12.44 ± 1.13

Abbreviations: BMI, Body mass index.

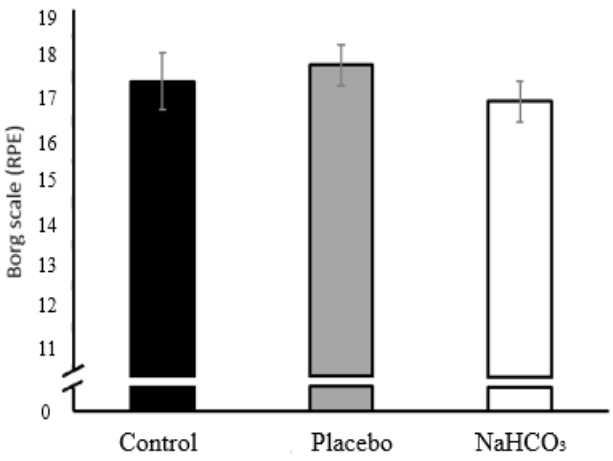
Table 2. Mean and standard deviation of the research variables.

Variable	Trial (Status)	Mean ± SD
Resting Heart Rate (beats/minute)	Control	69.22 ± 4.38
	Placebo	66.12 ± 4.05
	NaHCO3	67.75 ± 3.98
Heart Rate Before Swimming(beats/minute)	Control	115.66 ± 4.89
	Placebo	112.39 ± 7.01
	NaHCO3	119.12 ± 6.95
Heart Rate After Swimming (beats/minute)	Control	168.19 ± 9.23#
	Placebo	171.32 ± 8.96#*
	NaHCO3	164.45 ± 8.29*

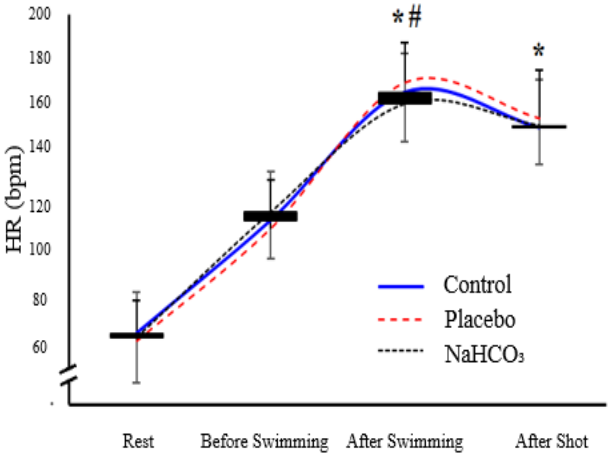
Heart Rate After Shot (beats/minute)	Control	153.67 ± 6.21
	Placebo	157.56 ± 5.89
	NaHCO3	154.49 ± 6.88
RPE (End of Swimming)	Control	17.66 ± 1.38
	Placebo	17.89 ± 0.98
	NaHCO3	17.01 ± 1.01
Z Fatigue Test	Control	1.75 ± 0.83
	Placebo	1.88 ± 0.48
	NaHCO3	1.29 ± 0.22
Ball Throw Speed (km/h)	Control	72.04 ± 4.94
	Placebo	73.73 ± 5.45
	NaHCO3	75.23 ± 6.01
Ball Throw Accuracy (Score out of 100) Percentage of Correct Throws	Control	44.56 ± 5.92
	Placebo	38.84 ± 4.33
	NaHCO3	48.58 ± 5.09*

Significant difference compared to the pre-test ($p < 0.05$).
* Significant difference compared to the other trials ($p < 0.05$).

Galley Proof



A



B

https://doi.org/10.22034/ren.2026.145550.1161

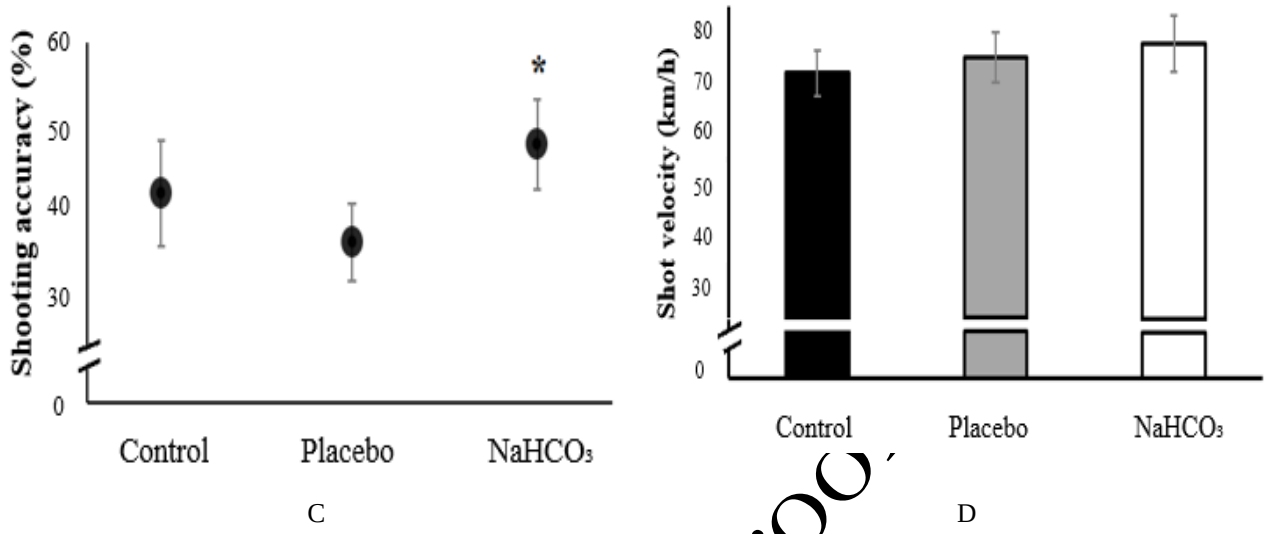


Figure 1. Comparison of RPE (A), HR (B), shooting accuracy (C), and shot velocity (D) between control, placebo, and bicarbonate conditions ($p < 0.05$).
Significant difference from pre-test.
* Significant difference from other trials.

Galley Proof

4. Discussion.

The present study aimed to investigate the effects of acute sodium bicarbonate supplementation prior to anaerobic swimming on perceived exertion, ball-throwing velocity, and throwing accuracy in water polo players. The findings demonstrated that acute sodium bicarbonate supplementation before anaerobic swimming significantly affected throwing accuracy and post-exercise heart rate, but had no significant effect on throwing velocity or perceived exertion.

The findings showed that ingestion of 0.3 g/kg sodium bicarbonate did not significantly affect subjective perceptions of exercise intensity but significantly altered heart rate responses following anaerobic swimming in water polo players. These findings may suggest that the physiological effects of sodium bicarbonate, including enhanced extracellular buffering capacity and improved tolerance to exercise-induced acidosis, may modulate cardiovascular responses without producing a sufficient change in the physiological signals contributing to perceived exertion. As reported in the present study and previous research, ratings of perceived exertion are closely associated with physiological responses such as heart rate, ventilation, and metabolite accumulation. However, this relationship is neither strictly linear nor absolute, and perceptual responses may remain relatively unchanged when physiological adaptations or compensatory mechanisms occur. Therefore, although sodium bicarbonate supplementation altered the cardiovascular response, it did not appear to produce a sufficiently large physiological change to modify perceived exercise intensity, suggesting a limited effect on perceptual measures of exercise strain (23).

One possible explanation is that sodium bicarbonate, by increasing extracellular buffering capacity and attenuating the effects of hydrogen ion (H^+) accumulation, may have reduced the physiological disturbances associated with high-intensity exercise without substantially altering the participants' perception of effort. From a physiological perspective, the accumulation of H^+ is one of the factors associated with fatigue during high-intensity anaerobic exercise. Exercise-induced acidosis may impair muscle contractile function and contribute to an increased perception of effort. By increasing extracellular buffering capacity, bicarbonate supplementation may attenuate these disturbances and potentially reduce the stimulation of afferent sensory pathways associated with fatigue (15).

Increased H^+ availability is also associated with increased ventilatory responses through enhanced CO_2 production and the need to regulate acid–base balance. In the presence of additional bicarbonate, extracellular buffering of H^+ may be enhanced, potentially facilitating CO_2 formation and its subsequent elimination through pulmonary ventilation (24). Following high-intensity exercise, changes in heart rate reflect the interaction of several factors, including metabolic demand, autonomic regulation, venous return, and the redistribution of blood flow. Bicarbonate buffering contributes to acid–base regulation by reacting with H^+ to form carbonic acid, which is subsequently converted to CO_2 and water and eliminated primarily through the lungs (23,25). Thus, the observed alteration in post-exercise heart rate may reflect, at least in part, the physiological consequences of enhanced acid–base buffering.

The findings of the present study are consistent with some previous investigations. Campos et al. (2012) studied 10 swimmers (3 women and 7 men; mean age: 18 years) who completed six maximal 100-m efforts under placebo and sodium bicarbonate conditions. Sixty minutes before the protocol, participants in the supplementation condition consumed 0.3 g/kg sodium bicarbonate, whereas the placebo group received dextrose. Their findings similarly showed no beneficial effect of sodium bicarbonate supplementation on fatigue or overall performance (22). In another study, Saedmocheshi (2024) reported that sodium bicarbonate supplementation did not improve strength or lactate responses (19).

In contrast, several studies using the same sodium bicarbonate dose have reported beneficial effects. Lindh et al. (2008) investigated nine elite male swimmers with a mean age of 20 years who were assigned to control, placebo, and experimental conditions. Participants consumed 0.3 g/kg sodium bicarbonate 90 min before a 200-m freestyle swimming test. The results indicated that sodium bicarbonate supplementation reduced fatigue and improved swimming performance (26). Exercise protocols involving a longer duration and relatively sustained high intensity, such as a 200-m freestyle event, may provide greater opportunity for extracellular buffering to influence performance. In addition, the longer supplementation-to-exercise interval used in that study (90 min) may have allowed bicarbonate availability to reach an effective level before exercise, thereby maximizing its potential contribution to acid–base regulation during the swimming task.

Regarding the effects of sodium bicarbonate supplementation on throwing velocity and accuracy, the present study demonstrated no significant difference in throwing velocity among conditions, whereas throwing accuracy differed significantly, with higher accuracy following sodium bicarbonate supplementation.

Sodium bicarbonate increases extracellular buffering capacity and facilitates the buffering of H^+, thereby attenuating disturbances in acid–base homeostasis during high-intensity exercise and potentially preserving muscle contractile function (27). However, the intensity and nature of the fatigue induced by the anaerobic swimming protocol used in the present study may not have been sufficient for the ergogenic effects of bicarbonate to translate into measurable improvements in the rate of muscle contraction and, consequently, throwing velocity. The absence of an effect on throwing velocity may also be related to the dose administered, the acute nature of supplementation, and individual differences in buffering capacity. In other words, sodium bicarbonate may not have substantially altered the neuromuscular mechanisms governing maximal force and contraction velocity or the rapid resynthesis of anaerobic energy substrates such as phosphocreatine (24).

Overall, the lack of an effect on throwing velocity suggests that the buffering action of sodium bicarbonate alone may not be sufficient to modify the neuromuscular determinants of explosive throwing performance under the conditions examined. In contrast, the improvement in throwing accuracy may indicate that buffering-related physiological effects can contribute to the preservation of motor control and technical performance under conditions of high metabolic stress. One possible mechanism is that attenuation of exercise-induced acidosis may help

Galley Proof

 https://doi.org/10.22034/ren.2026.145550.1161

preserve neuromuscular coordination and the execution of complex motor skills (23).

Bicarbonate reacts with H^+ to form carbonic acid, which is subsequently converted to CO_2 and water, facilitating the removal of CO_2 through pulmonary ventilation and contributing to the restoration of acid–base homeostasis (27). Theoretical evidence suggests that metabolic disturbances associated with high-intensity exercise, including changes in lactate and H^+ concentration, may influence neuromuscular function and motor control and, consequently, the execution of technical skills (28). Throwing accuracy in water polo is determined by the integration of several physiological and neuromuscular processes, including neural drive, neurotransmitter-mediated signaling, excitation–contraction coupling, calcium release from the sarcoplasmic reticulum, and anaerobic energy production during high-intensity efforts. By attenuating disturbances in acid–base balance, sodium bicarbonate supplementation may help preserve some of these processes under conditions of metabolic stress (23,29).

Only a limited number of studies have examined the effects of sodium bicarbonate supplementation on skilled sport-specific performance. Siegler et al. (2010) reported that sodium bicarbonate supplementation increased punching effectiveness by approximately 5% during simulated boxing competition, as assessed by the number of successful punches delivered (30). Similarly, Artioli et al. (2007) found that sodium bicarbonate supplementation increased the number of specific judo throws completed during the second and third rounds of a three-round test (31). The authors attributed these effects to enhanced extracellular buffering capacity, reduced intramuscular acidity, and alterations in strong ion difference, which may influence calcium handling in skeletal muscle (30,31).

In another study, Wu et al. (2010) investigated nine tennis players under placebo and experimental conditions. Following breakfast, participants in the experimental condition consumed 0.3 g/kg sodium bicarbonate, whereas the placebo group received salt. After a standardized warm-up, participants completed a Loughborough tennis skill test involving measures of accuracy, forehand, backhand, and serve performance. The results showed reductions in serve and forehand performance in the placebo condition, whereas these performance measures were maintained at baseline levels in the experimental condition, suggesting that sodium bicarbonate may have attenuated performance deterioration during repeated skill execution (32).

The rate and magnitude of metabolite accumulation during high-intensity exercise, including changes in lactate and H^+ concentration, can influence fatigue and the ability to sustain exercise (33). Individuals with higher physical fitness may exhibit more efficient regulation and clearance of exercise-related metabolites. Excessive metabolic disturbance may contribute to fatigue and impair neuromuscular function, concentration, and the execution of sport-specific skills, potentially reducing movement velocity and accuracy. Under these conditions, in addition to muscular recovery, restoration of energy substrates, and neural mechanisms, the body's buffering systems play an important role in limiting disturbances in acid–base homeostasis. Hemoglobin, myoglobin, plasma proteins, and bicarbonate are among the physiological buffering systems involved in this process, with bicarbonate representing one of the major extracellular buffers (23).

Galley Proof

5.Study Limitations

Despite providing relevant findings regarding the effects of acute sodium bicarbonate supplementation on swimming and throwing performance in water polo players, the present study has several limitations. First, the completion of three separate experimental sessions (control, placebo, and supplementation) may have introduced a learning or familiarization effect, particularly for the repeated shooting task. Second, the assessment of blood lactate and blood pH could have provided more direct evidence regarding the buffering effects of sodium bicarbonate. However, blood sampling during the swimming protocol was not feasible because of the aquatic nature of the exercise and the very short interval between completion of swimming and the shooting task. Third, although participants were instructed to refrain from supplement use, alcohol consumption, and strenuous exercise for 48 h before each experimental session, complete standardization of dietary intake and fluid consumption before testing was not possible. These factors may have contributed to inter-individual variability in physiological and performance responses.

6. Conclusion

The findings of the present study indicate that acute sodium bicarbonate supplementation before anaerobic swimming significantly altered post-exercise heart rate and improved throwing accuracy in water polo players, but did not significantly affect perceived exertion or throwing velocity.

Under the conditions of the present study, ingestion of 0.3 g/kg sodium bicarbonate did not produce significant improvements in perceptual or all performance-related measures associated with fatigue. Individual differences in buffering capacity, training status, exercise intensity and duration, and the timing of supplementation may contribute to variability in responses to sodium bicarbonate. Nevertheless, the observed improvement in throwing accuracy, together with the alteration in post-exercise cardiovascular responses, suggests that sodium bicarbonate supplementation may have potential as an ergogenic nutritional strategy for selected performance outcomes in aquatic and intermittent team sports. Further studies should investigate different doses, supplementation timing, and sport-specific exercise protocols to determine the conditions under which these effects are most consistently observed.

7. Highlights

Acute sodium bicarbonate supplementation reduced the post-exercise heart-rate response and improved throwing accuracy in water polo players. However, sodium bicarbonate supplementation did not significantly affect perceived exertion or throwing velocity.

Statements

Funding

This research received no financial support from any governmental, institutional, or private organization.

Acknowledgments

The authors would like to express their sincere gratitude to all participants who volunteered to take part in this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

A.S. was responsible for data collection and implementation of the exercise protocols and experimental testing. J.M. contributed to study conceptualization, study design, supervision of the experimental procedures, critical revision of the manuscript, and final editing. M.M. was responsible for drafting the initial manuscript, statistical analysis, and interpretation of the findings. All authors reviewed and approved the final version of the manuscript.

References

1. Smith HK. Applied physiology of water polo. Sports Medicine. 1998;26(5):317–334. doi:10.2165/00007256-199826050-00003.

2. Devlin LH, Fraser SF, Barras NS, Hawley JA. Moderate levels of hypohydration impairs bowling accuracy but not bowling velocity in skilled cricket players. Journal of Science and Medicine in Sport. 2001;4(2):179–87. doi:10.1016/S1440-2440(01)80028-1.

3. Van Muijen AE, Joris H, Kemper HC, Van Ingen Schenau GJ. Throwing practice with different ball weights: Effects on throwing velocity and muscle strength in female handball players. Research in Sports Medicine. 1991;2(2):103–13. doi:10.1080/15438629109511906.

4. Şimşek B. Effects of muscle fatigue on shooting accuracy in handball players. Middle East Technical University; 2012.

5. Kluka DA. Motor behavior: From learning to performance. Morton; 1999.

6. Sesboüé B, Guincestre J-Y, editors. Muscular fatigue. Annales de Réadaptation et de Médecine Physique. 2006. doi:10.1016/j.annrmp.2006.04.020.

7. Cairns SP. Lactic acid and exercise performance. Sports Medicine. 2006;36(4):279–91. doi:10.2165/00007256-200636040-00001.

8. Wilmore JH, Costill DL, Kenney WL. Physiology of Sport and Exercise. Human Kinetics; 2004.

9. Robergs RA, Roberts S. Fundamental Principles of Exercise Physiology: For Fitness, Performance, and Health. McGraw-Hill College; 2000.

Galley Proof

10. Barbosa TM, Marinho DA, Reis VM, Silva AJ, Bragada JA. Physiological assessment of head-out aquatic exercises in healthy subjects: a qualitative review. Journal of Sports Science & Medicine. 2009;8(2):179.

11. Bevegård BS, Holmgren A, Jonsson B. Circulatory studies in well trained athletes at rest and during heavy exercise, with special reference to stroke volume and the influence of body position. Acta Physiologica Scandinavica. 1963;57(1–2):26–50. doi:10.1111/j.1748-1716.1963.tb02572.

12. Platanou T, Geladas N. The influence of game duration and playing position on intensity of exercise during match-play in elite water polo players. Journal of Sports Sciences. 2006;24(11):1173–81. doi:10.1080/02640410500457794.

13. Galy O, Zoubir SB, Hambli M, Chaouachi A, Hue O, Chamari K. Relationships between heart rate and physiological parameters of performance in top-level water polo players. Biology of Sport. 2014;31(1):33. doi:10.5604/20831862.1083277.

14. Requena B, Zabala M, Padial P, Feriche B. Sodium bicarbonate and sodium citrate: ergogenic aids? Journal of Strength and Conditioning Research. 2005;19(1):213–24. doi:10.1519/13733.1.

15. Norouzi Z, Pourrazi H, Sadeghi A. The effect of acute beetroot juice supplementation on 100-m swimming performance and some physiological variables across the menstrual cycle. Research in Exercise Nutrition. 2025;3(3):13-23. doi: https://doi.org/10.22034/ren.2025.143579.1086 .

16. Huang D, Wang X, Takagi H, Wang Z, Wang C, Yang L, et al. Effects of sodium bicarbonate on 200 m time trial performance and physiological responses in swimmers: a systematic review and meta-analysis of randomized controlled trials. Research in Sports Medicine. 2025;33(3):291–307. doi:10.1080/15438627.2025.2456630.

17. Zajac A, Cholewa J, Poprzecki S, Waskiewicz Z, Langfort J. Effects of sodium bicarbonate ingestion on swim performance in youth athletes. Journal of Sports Science & Medicine. 2009;8(1):45.

18. Gough LA, Newbury J, Price M. The effects of sodium bicarbonate ingestion on swimming interval performance in trained competitive swimmers. European Journal of Applied Physiology. 2023;123(8):1763–71. doi:10.1007/s00421-023-05192-6.

19. Saedmocheshi S. The effect of sodium bicarbonate supplementation on fatigue response and muscle strength in young non-athlete men. Research in Exercise Nutrition. 2024;3(2):35–41. In Persian. doi:10.22034/ren.2025.143079.1075.

20. Esfahani F, Taghian F, Chami F, Rezaei Z. The effect of sodium bicarbonate supplementation on blood lactate changes and intermittent performance in elite female swimmers. Olympic. 2012;59(20):7–18. In Persian.

21. Gutgesell M, Canterbury R. Alcohol usage in sport and exercise. Addiction Biology. 1999;4(4):373–83. doi:10.1080/13556219971353.

22. Campos EZ, Sangali EB, Gerosa Neto J, Gobbi RB, Freitas Junior IF, Papoti M. Effects of sodium bicarbonate ingestion during an intermittent exercise on blood lactate, stroke parameters, and performance of swimmers. Journal of Exercise Physiology Online. 2012;15(6):84–92.

23. Gough LA, Sparks SA, McNaughton LR, et al. Enhancing exercise performance and recovery through sodium bicarbonate supplementation: a narrative review. European Journal of Applied Physiology. 2024;124:3175–3190. doi:10.1007/s00421-024-05578-0.

24. Siegler JC, Marshall PW, Bishop D, Shaw G, Green S. Mechanistic insights into the efficacy of sodium bicarbonate supplementation to improve athletic performance. Sports Medicine - Open. 2016;2(1):41. doi:10.1186/s40798-016-0065-9.

25. Tanoue Y, Komatsu T, Nakashima S, Matsuda T, Michishita R, Higaki Y, et al. The ratio of heart rate to heart rate variability reflects sympathetic activity during incremental cycling exercise. European Journal of Sport Science. 2022;22(11):1714–23. doi:10.1080/17461391.2021.1994652.

Galley Proof

26. Lindh A, Peyrebrune M, Ingham S, Bailey D, Folland J. Sodium bicarbonate improves swimming performance. International Journal of Sports Medicine. 2008;29(6):519–23. doi:10.1055/s-2007-989228.

27. Grgic J, Grgic I, Del Coso J, Schoenfeld BJ, Pedisic Z. Effects of sodium bicarbonate supplementation on exercise performance: an umbrella review. Journal of the International Society of Sports Nutrition. 2021;18:1–13. doi:10.1186/s12970-021-00469-7.

28. Belcic I, Rodić S, Dukarić V, Rupčić T, Knjaz D. Do blood lactate levels affect the kinematic patterns of jump shots in handball? International Journal of Environmental Research and Public Health. 2021;18(20):10809. doi:10.3390/ijerph182010809.

29. Ma J, Bo S-M, Cheng Y. The role and mechanism of lactate produced by exercise in the nervous system. Progress in Biochemistry and Biophysics. 2025:348–57. doi:10.16476/j.pibb.2024.0010.

30. Siegler JC, Hirscher K. Sodium bicarbonate ingestion and boxing performance. Journal of Strength and Conditioning Research. 2010;24(1):103–8. doi:10.1519/JSC.0b013e3181a392b2.

31. Artioli GG, Gualano B, Coelho DF, Benatti FB, Gailey AW, Lancha AH. Does sodium-bicarbonate ingestion improve simulated judo performance? International Journal of Sport Nutrition and Exercise Metabolism. 2007;17(2):206–17. doi:10.1123/ijsnem.17.2.206.

32. Wu C-L, Shih M-C, Yang C-C, Huang M-H, Chang C-K. Sodium bicarbonate supplementation prevents skilled tennis performance decline after a simulated match. Journal of the International Society of Sports Nutrition. 2010;7:33. doi:10.1186/1550-2783-7-33.

33. Tornero-Aguilera JF, Jimenez-Morcillo J, Rubio-Zarapuz A, Clemente-Suárez VJ. Central and peripheral fatigue in physical exercise explained: a narrative review. International Journal of Environmental Research and Public Health. 2022;19(7):3909. doi:10.3390/ijerph19073909.

Galley Proof