The gender dependent influence of sodium bicarbonate supplementation on anaerobic power and specific performance in female and male wrestlers

Krzysztof Durkalec–Michalski†1,2*, Emilia E. Zawieja1, Bogna E. Zawieja3, Patrycja Michałowska1 & Tomasz Podgórski4

The aim of this study was the assessment of progressive low-dose sodium bicarbonate (NaHCO₃) supplementation on the anaerobic indices in two bouts of Wingate tests (WT) separated by wrestling-specific performance test and assessing the gender differences in response. Fifty-one (18 F) wrestlers completed a randomized trial of either a NaHCO₃ (up to 100 mg·kg⁻¹) or a placebo for 10 days. Before and after treatment, athletes completed an exercise protocol that comprised, in sequence, the first WT₁, dummy throw test (DT), and second WT₂. The number of completed throws increased significantly in males from 19.3 ± 2.6 NaHCO₃pre to 21.7 ± 2.9 NaHCO₃post. ΔWT₂-WT₁ improved particularly in the midsection of 30-s WT on NaHCO₃. However, no significant differences were found in peak power (PP), power drop (PD) and average power (AP) (analyzed separately for each WT), and ΔWT₂-WT₁ in PP and PD. Interaction with gender was significant for AP, PP and PD, every second of WT₁ and WT₂, as well as DT test. In conclusion, our study suggests that the response to NaHCO₃ may be gender-specific and progressive low-dose NaHCO₃ supplementation allows the advantageous strengthening of wrestling-specific performance in males. It can also lead to maintenance of high anaerobic power mainly in the midsection of the 30-s Wingate test.

Dietary supplement use is greater in athletes than in the general population. Some supplements, when ingested properly, can improve the athlete’s health and performance, but others are taken even though they have no proved influence. One of the supplements whose effectiveness is indicated in International Olympic Committee (IOC) as well as International Society of Sports Nutrition statements, especially for high-performance athletes, is sodium bicarbonate (NaHCO₃). NaHCO₃ supplementation increases extracellular bicarbonate concentration, which causes blood alkalosis. Because of the greater pH gradient between the muscle cells and extracellular fluids, H⁺ produced during exercise are transported more easily leads to greater efflux of H⁺ and La⁻ from the exercising muscle. This is particularly important because intramuscular acidosis can cause muscular fatigue based on different mechanisms: (1) impaired glycolysis because of reduced activity of key enzymes such as glycogen phosphorylase and phosphofructokinase; (2) hindered muscle’s contraction capacity due to the competition of H⁺ with calcium ions; (3) inhibition of oxidative phosphorylation; (4) compromised resynthesis of phosphocreatine at low pH. The increase in buffer capacity by NaHCO₃ supplementation can therefore allow to sustain muscle contractility during intense exercise and delay muscle fatigue.

Improvements in performance contributed to increases in buffering capacity are likely confined to short and high-intensity tasks which can be limited by acid–base disturbances and combat sports are one of them. Wrestling is a high-intensity competitive sport discipline, in which glycolysis is a substantial energy system. For instance,
The interaction with gender was significant for average power (AP) \((p < 0.0001)\), power drop (PD) \((p < 0.0001)\), and peak power (PP) \((p < 0.0001)\). However, no significant differences in AP, PD and PP were found after NaHCO₃ and PLA interventions neither in females nor in males (Table 1). There were no significant gender interactions for the differences between WT₁ and WT₂ \((\Delta W T₂ - W T₁)\) in AP, PD and PP. \(\Delta W T₂ - W T₁\) in AP, PD and PP were not significantly affected by NaHCO₃ and PLA treatments in both genders (Table 2).

The interactions between treatment x period as regards power were significant in seconds 12 \((p = 0.0106)\) and 16 \((p = 0.0398)\) in all wrestlers. Gender interaction was significant in each second of WT. Moreover, gender x
treatment interaction was significant in seconds: 10 (p = 0.0343), 11 (p = 0.0438), 12 (p = 0.0153), 15 (p = 0.0461), 16 (p = 0.0365), 17 (p = 0.0280), 21 (p = 0.0248), 23 (p = 0.0377), 26 (p = 0.0474), 28 (p = 0.0304), 29 (p = 0.0181) and 30 (p = 0.0359). In females significant changes were observed in seconds: 1 (p = 0.0204), 12 (p = 0.0180), 21 (p = 0.0070), 25 (p = 0.0343), 28 (p = 0.0083), 29 (p = 0.0294) and 30 (p = 0.0463). In males in seconds: 12 (p = 0.0269), 16 (p = 0.0409) and 17 (p = 0.0082).

In all participants the difference in power indices between WT2 and WT1 (Δ power WT2-WT1) improved significantly NaHCO3post vs NaHCO3pre in seconds: 12 (p = 0.0413), 16 (p = 0.0199) and 21 (p = 0.0430) (Fig. 1a). Furthermore, Δ power WT2-WT1 NaHCO3post was significantly lower than PLApost in seconds: 12 (p = 0.0144), 16 (p = 0.0370), 17 (p = 0.0125) and 21 (p = 0.0166) (Fig. 2a). In second 12 Δ power WT2-WT1 decreased significantly on PLA (PLApost vs PLApre) (p = 0.0368). The gender interactions were recorded in seconds: 13 (p = 0.0382), 17 (p = 0.0174), 18 (p = 0.0187), 22 (p = 0.0428), 24 (p = 0.0082), 25 (p = 0.0149), 26 (p = 0.0144), 27 (p = 0.0123), 28 (p = 0.0336) and 29 (p = 0.0349), respectively. In females Δ power WT2-WT1 increased significantly NaHCO3pre vs NaHCO3post only in second 21 (p = 0.0475) and was higher NaHCO3post than PLApost (p = 0.0130) (Figs. 1b and 2b). In second 12 (p = 0.0388), 21 (p = 0.0406), 28 (p = 0.0294) and 29 (p = 0.0279) Δ power WT2-WT1 decreased significantly on PLA (PLApost vs PLApre). In males Δ power WT2-WT1 increased significantly NaHCO3pre vs NaHCO3post only in second 12 (p = 0.0488) and in second 17 was higher NaHCO3post than PLApost (p = 0.0063) (Figs. 1c and 2c). Furthermore, in second 16 (p = 0.0316) and 17 (p = 0.0045) Δ power WT2-WT1 decreased significantly on PLA (PLApost vs PLApre).

**Dummy throw test.** The interactions between treatment x period was significant (p < 0.0297). In females the number of completed throws was unchanged NaHCO3pre vs NaHCO3post (from 18.2 ± 2.8 to 19.6 ± 2.2 throws, p = 0.3766) (Fig. 3a). However in males, it increased significantly by ~12% from 19.3 ± 2.6 to 21.7 ± 2.9 throws (p < 0.0001, Fig. 3c). No significant changes were also observed PLApre vs PLApost (males: p = 0.9185; females: p = 0.7174) and NaHCO3post vs PLApost (males: p = 1.0000; males: p = 1.0000) (Fig. 3b,d).

**Blood sample analysis.** Before and after supplementation no significant differences in glucose, lactate and pyruvate concentrations were found neither for female nor for male wrestlers (Table 3).

**Table 2.** The difference in power between WT2 and WT1 (Δ WT2-WT1) before and after supplementation. Data are presented at mean ± SD. NaHCO3pre, before sodium bicarbonate supplementation; NaHCO3post, after sodium bicarbonate supplementation; PLApre, before placebo; PLApost, after placebo.

|          | Peak Power | Power Drop | Average Power |
|----------|------------|------------|---------------|
|          | (W)        | (W·kg⁻¹)   | (W)           | (W·kg⁻¹)     |
| Females  |            |            |               |
| NaHCO3pre| −325 ± 57.1| −0.6 ± 1.1| −30 ± 48.1    | 0.0 ± 0.9    | −22.6 ± 39.6| −0.4 ± 0.8 |
| NaHCO3post| 2.6 ± 28.2| −0.1 ± 0.4| 2.3 ± 24.5    | 0.0 ± 0.5    | −15.1 ± 17.4| 0.0 ± 0.3 |
| PLApre   | −30.7 ± 22.5| −0.5 ± 0.3| −40.7 ± 41.4  | −0.6 ± 0.6   | 3.8 ± 11.6  | 0.1 ± 0.2 |
| PLApost  | −18.4 ± 55.2| −0.3 ± 0.9| −19.8 ± 52.2  | −0.4 ± 0.8   | −14.6 ± 23.9| −0.2 ± 0.4 |
| Males    |            |            |               |
| NaHCO3pre| −57.6 ± 106.3| −0.8 ± 1.4| −26.1 ± 108.3| −0.4 ± 1.4   | −32.7 ± 42.8| −0.4 ± 0.6 |
| NaHCO3post| −22.6 ± 103.8| −0.3 ± 1.3| 18.4 ± 122.4  | 0.3 ± 1.6    | −14.5 ± 28.6| −0.2 ± 0.4 |
| PLApre   | −57.8 ± 120.5 | −0.8 ± 1.5| −24.0 ± 129.6| −0.4 ± 1.7   | −23.3 ± 60.3| −0.3 ± 0.8 |
| PLApost  | −55.6 ± 58.8 | −0.7 ± 0.8| −17.7 ± 78.7  | −0.1 ± 1.1   | −26.6 ± 28.6| −0.3 ± 0.4 |

**Discussion**
In this study we showed that progressive supplementation of up to 100 mg·kg⁻¹ sodium bicarbonate did not significantly influence AP, PD and PP characteristics in two Wingate tests. However, it improved power maintenance in the midsection of the 30-s Wingate test and performance in wrestling-specific dummy throw test. We observed that gender was a significant factor potentially influencing the effectiveness of such a treatment. Gender interaction was significant for AP, PD and PP, but possibly the dose was too small to elicit any significant improvement in those parameters in both males and females. Gender was also significant factor influencing the effect of NaHCO3 on power in each second of the Wingate test and on performance in DT test. What is interesting, males significantly increased the number of throws in DT test, while females did not. That may suggest that the response to NaHCO3 treatment is gender specific.

As previously observed, supplementation with NaHCO3 may improve performance in combat sports⁸⁻¹¹. NaHCO3 resulted in improvement of boxing (punch efficacy: +5.4%)¹⁰, taekwondo (the total attack time in combat: +13%)¹¹ and judo (summed number of throws in three bouts of SJFT: +4 throws)⁸ specific performance, respectively. In contrast, in our study performance in wrestling-specific DT improved significantly on NaHCO3 with significant gender interaction. Then, when analysing genders separately we found that males increased the number of throws by ~11% (~2 throws), while no significant changes were observed in females. This slight, yet important change could contribute to winning in real wrestling competition. Previous studies on NaHCO3 in combat sports did not include female athletes⁸⁻¹².

Gender differences in response to NaHCO3 supplementation are especially worth discussing. Papers with female subjects are scarce. Only one of six studies on women showed the improvement after NaHCO3 intake²⁵⁻²⁶. Kozak-Collins et al.²¹ supplemented seven competitive female cyclists with either 300 mg·kg⁻¹ NaHCO3 or PLA (NaCl). 2h after ingestion participants performed interval cycling protocol consisting of repeating intervals of 1 min 95%VO2max cycling and 1 min recovery at 60 W until exhaustion. They did not find any improvement in the
number of completed intervals. In comparison, Price et al. recruited only male subjects. Investigators also gave them NaHCO₃ or PLA (NaCl) before testing. Participants did two intermittent cycling trials comprised of repeated 3-min blocks (90 s at 40%VO₂max, 60 s at 60%VO₂max, 14-s maximal sprint, 16-s rest). Authors found that compared to PLA, power output was greater throughout exercise during the NaHCO₃ trial. Tiryaki and Atterbom assessed the effect of NaHCO₃ on 600 m running time of trained females and found no differences (121.5 s on NaHCO₃ and 120.4 s on PLA). On the other hand, males improved running time in 400 m distance by 1.52 s on NaHCO₃ and in 800 m by 2.9s. Even though there are no studies assessing the effect of NaHCO₃ on 600 m run in males, it can be expected that it would be also improved. Then, there are four studies on female team sports players. Macutkiewicz and Sunderland observed no influence of NaHCO₃ on Field Hockey Skill Tests and

![Figure 1. Difference in power indices between WT₁ and WT₂ before and after NaHCO₃ supplementation. (a) In all participants, (b) in females, (c) in males. Data are presented at mean ± SD. *NaHCO₃post significantly different from NaHCO₃pre.](image-url)
the Loughborough Intermittent Shuttle Test in elite female field hockey players. In comparison, Krustrup et al. found 14% improvement in Yo-Yo intermittent recovery test level 2 performance (735 ± 61 m on NaHCO₃ vs 646 ± 46 m on PLA) in trained males. Moreover, Ducker et al. and Miller et al. observed improved repeated sprint capacity in males on NaHCO₃. In a study by Ducker et al., subjects did three sets of 6 × 20 m sprints with 4 min of recovery between sets. NaHCO₃ resulted in the best repeated-sprint performance. In a study by Miller et al., male athletes were given NaHCO₃ or PLA and then performed repeated sprint cycling protocol comprising 10 × 6 s sprints with 60 s recovery. Total work completed during the repeated sprint protocol was higher in the NaHCO₃ condition (69.8 ± 11.7 kJ) compared with both - the control (59.6 ± 12.2 kJ) and PLA (63.0 ± 8.3 kJ) conditions. In a study on female team sports athletes NaHCO₃ failed to improve total work in prolonged intermittent

Figure 2. Difference in power indices between WT₂ and WT₁ (Δ WT₂-WT₁) in NaHCO₃post vs PLApost (a) in all participants, (b) in females, (c) in males. Data are presented at mean ± SD. *NaHCO₃post significantly different from PLApost.
sprint performance (IST)\textsuperscript{24}. IST consisted of two 36-min “halves” of repeated ~2-min blocks: all-out 4-s sprint, 100 s of active recovery at 35%VO\textsubscript{2},max, and 20 s of rest. There was a trend toward improved total work in the second half, but it did not reach statistical significance (p = 0.08). Similarly, no improvement was observed in female water-polo players\textsuperscript{25}. After the ingestion of NaHCO\textsubscript{3} or PLA the subjects performed a 59-min match-simulation test (MST) that included 56 × 10 m maximal-sprint swims. NaHCO\textsubscript{3} increased blood pH, but failed to improve mean sprint times. The only study to show improvement on NaHCO\textsubscript{3} in female athletes is a study by Delextrat \textit{et al.}\textsuperscript{26}. Participants in that study were university basketball players. The supplementation protocol differed from

Figure 3. Total number of throws in dummy throw test. (a) In females before and after NaHCO\textsubscript{3}, (b) in females before and after PLA, (c) in males before and after NaHCO\textsubscript{3}, (d) in males before and after PLA. Data are presented at mean ± SD, and individual raw data. *NaHCO\textsubscript{3}post significantly different from NaHCO\textsubscript{3pre}.
and males, respectively), they were not statistically significant (Table 2).

The slow mode lasts 30 s, during which an athlete does four compulsory dummy throws. Whereas, in the quick mode an athlete performs as many throws as possible in 15 s. The test lasts 3 min and comprises four slow and four quick modes, so that it is highly exhausting. Thus, the participants of our study were already fatigued on the onset of the second WT. Even though one of the factors contributing to fatigue is a decrease in intramuscular pH, which may increase the efflux of H⁺ to the active site of troponin, inhibition of oxidative phosphorylation and compromised resynthesis of phosphocreatine. Sodium bicarbonate supplementation results in better buffering capacity of blood, which may increase the efflux of H⁺ and La⁻ out of muscle cells and decrease acidosis.

It was previously established that the effect of NaHCO₃ supplementation may be pronounced predominantly in latter stages of exercise⁹,¹¹–¹⁵. Artioli et al.¹³ supplemented their athletes with 300 mg·kg⁻¹ NaHCO₃ 2 h before exercise. The performance test included four bouts of 30-s upper body WT tests. The significant changes in AP and PP were observed only in the two final bouts. This was attributed to improved resynthesis of phosphocreatine due to alkalosis caused by NaHCO₃ supplementation, since low intramuscular pH may hamper this process⁹.

Tobias et al.¹⁴ assessed the effect of one week NaHCO₃ ingestion on four-bout upper-body WT performance. Single bout was 30 s long with the load of 5% body mass. Seven-day supplementation resulted in 8% increase in total work done (in all four bouts summed). However, when the bouts were analysed separately a significant increase in AP and PP was present only in the last bout (+9.4%, p = 0.038, and +13.7%, p = 0.018, respectively)⁰.

A subsequent study by Oliveira et al.¹⁵ confirmed those results. They adopted a similar protocol of performance testing (four 30-s WT bouts for upper body interspersed by 3-min recovery) and also observed a significant increase in the total work done (+2.86%, p = 0.02) after 5-day NaHCO₃ supplementation compared to PLA. And again the difference was more pronounced in the last two bouts (sum of bout 3 and 4: +5.93%, p = 0.02).

Since aforementioned studies⁶,¹⁴,¹⁷ showed that the effect of NaHCO₃ is apparent the most in latter stages of intense exercise, we aimed at assessing the gender-related effect of NaHCO₃ on the difference between the first and the second WT, which were additionally interspersed by DT. Dummy throw test is a highly strenuous test, specific to wrestling. It is comprised of two alternating modes – slow and fast. The slow mode lasts 30 s, during which an athlete does four compulsory dummy throws. Whereas, in the quick mode an athlete performs as many throws as possible in 15 s. The test lasts 3 min and comprises four slow and four quick modes, so that it is highly exhausting. Thus, the participants of our study were already fatigued on the onset of the second WT. Even though the difference in PP between WT₂ and WT₁ tended to be improved by NaHCO₃ (by 35.1 W and 35.0 W in females and males, respectively), they were not statistically significant (Table 2).

![Table 3. Glucose, lactate and pyruvate concentrations before and after exercise tests in female and male wrestlers. Data are presented at mean ± standard deviation (SD). NaHCO₃pre, before sodium bicarbonate supplementation; NaHCO₃post, after sodium bicarbonate supplementation; PLApre, before placebo; PLAPost, after placebo.](image-url)

In spite of the few significant differences observed in our study, we hypothesise that the dosage of NaHCO₃ might have been too small for female and male wrestlers to elicit more apparent improvements. We used up to 100 mg·kg⁻¹ NaHCO₃ in days 8–10 of supplementation (Fig. 4). The dosage was well tolerated and did not cause any gastrointestinal (GI) problems, but the effectiveness was slight and moderate. Simultaneously, in previous...
studies higher doses were usually implemented. JOIC recommends the intake of 200–400 mg·kg\(^{-1}\) NaHCO\(_3\)
60–150 min prior to exercise. However, in many athletes these doses result in GI distress. This may prevent
the practical use of supplementation with this compound in the conditions of natural high-intensity effort that
is carried out, e.g. in combat sports. On the other hand, smaller doses might be ineffective. For instance, in nine
healthy males the dose of 100 mg·kg\(^{-1}\) failed to induce alkalosis, increase base excess and had no influence on
work output. Furthermore, in six males McKenzie et al. showed that even though induced alkalosis was greater
with 300 than 150 mg·kg\(^{-1}\) NaHCO\(_3\), there were no differences in work produced (133.5 and 133.1 kJ, respec-
tively) and time to fatigue in the last bout (106 and 110s) between those two doses. However, comparing all those
results to ours is limited because all of them used acute supplementation protocol, while participants in our study

Figure 4. Flowchart of the study design.
Progressive low-dose \( \text{NaHCO}_3 \) supplementation allows in combat sports the advantageous suppression of fatigue-induced power decline in the midsection of the 30-s Wingate test and improvement in wrestling specific dummy throw test. The response to \( \text{NaHCO}_3 \) supplementation seems to be gender dependent. It appears that males can benefit more from the sodium bicarbonate supplementation, possibly because of physiological differences.

**Methods**

We would like to clarify that in this work we used the data previously collected in sodium bicarbonate studies involving wrestlers, which we conducted in our lab. We have already partially published the selected results obtained from most of the evaluated participants\(^{13}\). However, the data presented here was analyzed in a completely different fashion. The results for female and male wrestlers were analyzed separately to assess whether the response to the supplementation protocol may be determined by the gender of the athletes. We also focused on previously untouched aspects of the detailed change of power indices during each seconds of the Wingate test. Additional athletes were also included. Thus, we can unequivocally state that there is absolutely no risk of duplicate results, but we want to inform potential readers about the details of the data processing. Lastly, we would like to highlight that in our research only highly-trained female and male wrestlers participated. Therefore, the observed changes related to males wrestling-specific performance and more effective maintenance of anaerobic power during high-intensity efforts, that can be considered beneficial at elite sport level, especially considering the short time duration of supplementation and a low dose of \( \text{NaHCO}_3 \). It is worth bearing in mind, however, that a certain limitation to our study is the lack of verification of the bicarbonates concentration in the blood, which should be included in the subsequent studies, preferably in connection with the attempt to evaluate the effectiveness of supplementation of various doses of \( \text{NaHCO}_3 \). Another limitation is the uneven distribution of participants in study groups. It is possible that if the number of participants was equal in each group the gender differences would be more pronounced.

**Participants.** Forty-six male and thirty-one female wrestlers were initially enrolled in this study. However, thirty-three male and eighteen female athletes participated in the study and were included in the analyses (Fig. 4). Anthropometric characteristics are presented in Table 4. The athletes were members of the Polish Wrestling National Team and/or competed in the highest level of Polish competitions. The inclusion criteria were good health, a valid medical clearance to participate in sports, a minimum of four years of combat sports experience, and that they had not been using any medications and supplements with potential ergogenic effects, other than those supplied by the authors of this study. In accordance with the 1975 Declaration of Helsinki, before enrolment all participants had given their written consents to participate in the study protocol. Informed consents were also obtained from the parents of athletes under the age of 18 years, prior to participation in the study. The approval of the Bioethics Committee at Poznan University of Medical Sciences was obtained for this study. This trial was registered at Clinical Trials Gov (website: https://clinicaltrials.gov/ct2/show/NCT03406065; Clinical Trial Identification Number: NCT03406065). The study was registered retrospectively as registration was not

|             | Females (n = 9) | Males (n = 21) | PLA (n = 9) | PLA (n = 12) |
|-------------|----------------|---------------|------------|-------------|
| Age (yrs)   | 18.7 ± 2.4     | 18.1 ± 2.6    | 19.7 ± 3.8 | 19.5 ± 4.4  |
| Body height (cm) | 165 ± 7       | 169 ± 6       | 176 ± 8    | 174 ± 7     |
| Body mass (kg)   | 53.7 ± 5.1    | 64.5 ± 8.1    | 78.8 ± 13.1| 73.3 ± 13.3 |
| FM (%)       | 17.3 ± 3.0     | 19.1 ± 4.6    | 11.5 ± 4.2 | 10.5 ± 2.8  |
| FM (kg)      | 9.4 ± 2.5      | 12.5 ± 4.3    | 9.4 ± 4.8  | 8.0 ± 3.6   |
| FFM (%)      | 81.6 ± 3.8     | 82.1 ± 6.4    | 88.5 ± 4.2 | 89.7 ± 3.0  |
| FFM (kg)     | 44.3 ± 3.1     | 52.0 ± 4.8    | 69.2 ± 9.5 | 67.3 ± 10.6 |
| TBW (%)      | 59.1 ± 2.9     | 55.9 ± 3.6    | 62.0 ± 5.4 | 63.0 ± 3.5  |
| TBW (kg)     | 31.6 ± 1.5     | 35.8 ± 3.0    | 48.7 ± 6.3 | 46.9 ± 7.2  |

**Table 4.** Anthropometric characteristics of female and male wrestlers. Data are presented at mean ± standard deviation (SD). FM, fat mass; FFM, fat-free mass; TBW, total body water content.

ingested \( \text{NaHCO}_3 \) for ten days. In a previous study done by our lab, progressive-dose protocol of \( \text{NaHCO}_3 \), up to 150 mg·kg\(^{-1}\) was enough to improve CrossFit-like performance and ventilatory threshold\(^{17}\). However, \( \text{NaHCO}_3 \) supplementation protocol similar to the one used in the current study (10 days, up to 100 mg·kg\(^{-1}\)) improved only time to PP in the second WT test with no further influence on anaerobic capacity and performance\(^{13}\). Nevertheless, we would like to highlight that in our research only highly-trained female and male wrestlers participated. Therefore, the observed changes related to males wrestling-specific performance and more effective maintenance of anaerobic power during high-intensity efforts, that can be considered beneficial at elite sport level, especially considering the short time duration of supplementation and a low dose of \( \text{NaHCO}_3 \). It is worth bearing in mind, however, that a certain limitation to our study is the lack of verification of the bicarbonates concentration in the blood, which should be included in the subsequent studies, preferably in connection with the attempt to evaluate the effectiveness of supplementation of various doses of \( \text{NaHCO}_3 \). Another limitation is the uneven distribution of participants in study groups. It is possible that if the number of participants was equal in each group the gender differences would be more pronounced.
Study design and protocol. The study was designed as randomized double-blind placebo-controlled parallel-group trial. The supplementation period lasted ten days. The participants were familiarized with the exercise testing protocol and the equipment on a preliminary meeting with the research team. Anthropometric measurements were also taken on the same day. When enrolled athletes were randomly divided into the treatment groups (the NaHCO₃ group or the PLA group). The random allocation sequence and matching were performed using stratified randomization via impartial biostatistics.

The experiment consisted of two separate visits (T₁–T₂) for each participant. All testing was performed in natural conditions at the Central Olimpic Sports Centers (Spała, Zakopane) and Wrestling Training Centers (Poznań) in Poland. Throughout the study the participants were supplemented with either NaHCO₃ or PLA. Exercise tests were conducted before and after each trial at the same time of day. Testing sessions started between 7.30 and 10.00 a.m. each time. To maintain constant conditions the participants were asked to refrain from any strenuous exercise for 24h before the testing.

Supplementation. The participants were supplemented with NaHCO₃ for ten consecutive days. Initial dose was much smaller than the dose recommended previously 2,3 and was then increased gradually until 0.1 g·kg⁻¹ was reached. This loading protocol was shown to eliminate any GI side effects 13,37. Supplementation protocol is depicted in Fig. 4. Sodium bicarbonate was administered in the form of unmarked disc-shaped tablets (Alkala T, manufacturer–Sanum Kehlbeck GmbH & Co. KG, Germany). The tablets were ingested with at least 250 mL of water and could either be swallowed or dissolved in the mouth. Maltodextrin with NaCl served as PLA. It was administered in a similar tablet prepared by the same producer as of the NaHCO₃ tablets.

Daily doses of both NaHCO₃ and PLA were split into three even portions. On training days, the tablets were ingested in the morning, in the evening, and 1.5h before training session. On rest days, the supplements were administered in the morning, in the afternoon, and in the evening. To increase adherence the participants were also given personal supplementation plans.

Anthropometric measurements. Anthropometric measurements were taken in the fasted state in the preliminary visit in the morning. Body fat and free-fat mass were assessed based on air displacement plethysmography using the Bod Pod® (Cosmed, Italy) 38. Total body water and hydration level were assessed by means of bioelectric impedance, with Bodystat 1500 (Bodystat Inc., UK) 39, and via urine specific gravity measurement, with URYXXON® Relax (Macherey-Nagel, Germany).

Exercise tests. Every testing session consisted of two Wingate anaerobic tests interspersed with a dummy throw test. Wrestling-specific performance capacity was measured using a specific dummy throw test described previously 13. Wingate tests were performed on a cycloergometer (Monark 894E, Sweden). All recommendations for such tests as proposed by Bar-Or were strictly followed 40. External loading was set at 7.5% body weight. The first WT (WT₁) was performed 5 min before DT and the second (WT₂) 10 min after DT (Fig. 4). Prior to testing all athletes completed 5-min warm-up on cycloergometer at approximately 50 W power. During the test, the athletes were verbally encouraged to exert maximum effort. The recorded results were analysed using the Monark Anaerobic Test Software (ver. 3.0.1, 2009, Monark, Sweden).

Blood samples analysis. Fingertip blood samples were taken twice, one sample before the WT₁ and the other 3 min after the WT₂. During blood draws the participants seated in an upright position. Blood samples were immediately transferred to microtubes containing 500 µL of 0.6 M perchloric acid. Glucose concentration was measured using a colorimetric enzymatic method with glucose oxidase (Liquick Cor-GLUCOSE, Cormay, Łomianki, Poland). Lactate and pyruvate measurements were performed according to the method described previously 13. All biochemical analyses were conducted using a Synergy 2 SIAFRT microplate multi-detection reader (BioTek, USA).

Statistical analysis. The study was designed as a randomized parallel trial. Thus, in statistical analysis a mixed model of repeated measures with known error covariance matrix was used 41,42. The random factor was participants nested in groups. Group stand for treatment (NaHCO₃ or PLA). Fixed factors were: period (NaHCO₃pre-WT₁, NaHCO₃pre-WT₂, NaHCO₃post-WT₁, NaHCO₃post-WT₂, PLApre-WT₁, PLApre-WT₂, PLAPost-WT₁, PLAPost-WT₂), gender, times (period) (1–30 seconds of WT), Two-way interactions (gender × treatment, treatment × period, gender × period, and treatment × times (period)) and three-way interactions (gender × treatment × period, and gender × treatment × times (period)) were considered. Tested error covariance matrix structures included: Compound symmetry, Autocorrelation, Toeplitz and Unstructured. The choice of model with adequate covariance matrix structure was done according to Akaike information criterion 43. Because gender and gender interactions with other factors were significantly unique, those analyses were performed also for both genders separately. Statistical significance was set at p < 0.05. The assumptions of normality and homoscedasticity was tested using the Shapiro-Wilk test for normality. If data did not meet the assumptions then the Box-Cox transformation was used. Data were analyzed by own calculations and using the SAS 9.3 software program. Effect size was calculated as Cohen’s f², as follows: f² = 1/2/(1 − h²).
Ethical approval. All procedures performed were in accordance with the ethical standards of the institutional and national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards.

Practical Applications
Our study suggests that 10-day progressive low-dose (from 0.025 g·kg⁻¹·day⁻¹ to 0.1 g·kg⁻¹·day⁻¹) NaHCO₃ supplementation allows the advantageous strengthening of wrestling-specific performance in males and suppression of fatigue-induced average power decline in combat sports, which is a result of specific physical efforts. It can also lead to maintenance of high anaerobic power mainly in the midsection of the 30-second Wingate test. Moreover, the higher dose could be more effective in this respect, which indicates that despite the lack of effect on GI functioning, doses lower than 0.1 g·kg⁻¹ BM do not seem to be effective in combat sports. It seems, however, that the response to NaHCO₃ supplementation may be gender dependent, and males could be more prone to sodium bicarbonate supplementation.

Data availability
The datasets generated during and/or analysed during the current study are available in the figshare database repository (https://figshare.com/s/cf05c5daeb7e4b4f310e; https://doi.org/10.6084/m9.figshare.7907879).

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**Author contributions**

K.D.-M. conceived and designed research. K.D.-M., T.P. and P.M. conducted experiments. K.D.-M., E.E.Z. and B.E.Z. analyzed data. K.D.-M., E.E.Z., B.E.Z., T.P. wrote the manuscript. All authors read and approved the manuscript.

**Competing interests**

The authors declare no competing interests.

**Additional information**

**Correspondence** and requests for materials should be addressed to K.D.-M.

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