**Introduction**

Systemic acidosis and alkalosis induced through nutritional supplementation have been shown to affect exercise performance and the onset of fatigue [12,18,32]. These effects are typically ascribed to alterations in an individual’s endogenous H⁺ buffering capacity [17,21] which influences the decline in muscle pH that is associated with a decrease in muscle power output (fatigue) [7,25]. The lowered pH can influence metabolic and neuromuscular function, and may contribute to sarcoplasmic and central components of fatigue during high intensity exercise [4].

The use of sodium bicarbonate (SB) as an alkalinizing agent has received widespread attention. Although in overview the research investigating SB supplementation prior to a single-bout of high intensity exercise appears to be equivocal [17,21,24], the investigations reporting performance improvements make some clear recommendations. First, the lowest effective dose of SB is 300 mg·kg⁻¹ body mass, which should be taken at least 60 min prior to exercise. This has been shown to induce blood alkalosis [2,25,29], and may also induce muscle alkalosis [31]. It has been found to offset the decrease in intramuscular pH during maximal endurance exercise [29,31] whilst limiting the gastrointestinal side effects sometimes associated with SB ingestion [21,24]. Second, the duration of exercise should be between 1 – 10 min for there to be a discernible affect on performance [2,25,29]. When these recommendations have been followed there is demonstrable evidence that SB supplementation can improve 200 m freestyle performance time in elite male competitors, most likely by increasing buffering capacity.

**Abstract**

Sodium bicarbonate ingestion has been shown to improve performance in single-bout, high intensity events, probably due to an increase in buffering capacity, but its influence on single-bout swimming performance has not been investigated. The effects of sodium bicarbonate supplementation on 200 m freestyle swimming performance were investigated in elite male competitors. Following a randomised, double blind counterbalanced design, 9 swimmers completed maximal effort swims on 3 separate occasions: a control trial (C); after ingestion of sodium bicarbonate (SB: NaHCO₃ 300 mg·kg⁻¹ body mass); and after ingestion of a placebo (P: CaCO₃ 200 mg·kg⁻¹ body mass). The SB and P agents were packed in gelatine capsules and ingested 90–60 min prior to each 200 m swim. Mean 200 m performance times were significantly faster for SB than C or P (1:52.2 ± 4.7; 1:53.7 ± 3.8; 1:54.0 ± 3.6 min:ss; p < 0.05). Base excess, pH and blood bicarbonate were all elevated pre-exercise in the SB compared to C and P trials (p < 0.05). Post-200 m blood lactate concentrations were significantly higher following the SB trial compared with P and C (p < 0.05). It was concluded that SB supplementation can improve 200 m freestyle performance time in elite male competitors, most likely by increasing buffering capacity.
from these investigations may lack true ecological validity. Nevertheless, an improvement [11] and no change in repeated sprint performance [28,30] after SB ingestion have been reported. Two of these investigations used a dose of < 300 mg·kg⁻¹ [11,30], and it is unknown if blood alkalosis was achieved in two of the studies as no physiological measures were taken [28,30]. Finally, participants in all 3 investigations were University standard, but not elite level, swimmers.

High post-competition blood lactate concentrations have been found following 200 m freestyle races, indicating significant acidosis and therefore anaerobic (glycolytic) energy contribution to this event (blood lactate concentrations – 12 – 20 mmol·l⁻¹ [3]). In addition, the metabolic contributions to swimming over a very similar distance (200 yd, 182.9 m) were estimated as: 62% aerobic; 25% anaerobic lactic acid (glycolytic); and 14% anaerobic alactic [6]. Considering the metabolic demands of 200 m swimming and the documented ergogenic benefits of SB supplementation for events of similar duration [25,34], it seems likely that SB ingestion may enhance 200 m freestyle swimming performance.

The aim of this study therefore was to investigate the effects of SB supplementation on 200 m freestyle performance in elite male swimmers.

### Methods

#### Participants

Nine male, elite-standard swimmers participated in the study (Table 1). All swimmers were involved in a regular training program at the Great Britain High Performance Centre focusing on 200–400 m distance training, with an average of 10×2.5 hours pool-based and 3×1.5 hours land-based training sessions a week. Personal best times for both long-course and short-course performances were attained during competition within the past year. Three swimmers had a world ranking in the top 5 for their best event and a further two swimmers were ranked in the top 30. The remaining four were ranked in the top 8 nationally. The protocol was approved by the University Ethics Committee, and the swimmers gave written informed consent prior to their participation in the study.

#### Experimental design

A randomised, double-blind counterbalanced design was employed that required participants to complete a maximal effort race simulated 200 m freestyle swim on 3 separate occasions. The first occasion was a control trial (C) with no nutritional intervention. Participants then completed two further trials in a randomised order: after ingestion of NaHCO₃ (SB); after ingestion of calcium carbonate (CaCO₃) which served as a placebo (P). The supplementation trials took place 14 days and 21 days after the control trial. Training workload was kept similar during the 2 days leading up to each trial, with well-being scores taken on the 7 mornings leading up to the test day (adapted from Hoo-per et al., [16]). Participants were required to abstain from alcohol and caffeine-containing products 48 h prior to each test.

#### Supplementation

The SB trial involved a dose of 300 mg·kg⁻¹ body mass delivered in gelatine capsules. In order to maintain an identical protocol in each supplementation trial, the placebo supplement involved a dose of CaCO₃ that was matched by capsule number rather than weight (200 mg·kg⁻¹ body mass). Supplements were consumed over a 30 min period commencing 90 min prior to the start of the performance, with water taken ad libitum following the recommendations of Linderman and Fahey [21].

#### Exercise tests

All swims took place in the same swimming pool (depth 2 m × length 25 m × width 20 m) at the University during the same point in the training microcycle (weekly training schedule), and at the same time of day (15:00 – 17:00 hrs). The athletes were all familiar with competing over the set distance and performed each race in ability-matched pairs as assigned by their coach. This was done to introduce a competitive element to the protocol in keeping with previous research [13,34]. The order of racing was kept the same throughout the assessment period. Each pair completed a standardised warm-up (2000 m, ~30 min duration) prior to each trial. Ten min post warm-up, the pairs performed a 200 m freestyle maximal effort swim. All swims were from a dive start from racing blocks and were timed using an electronic Omega timing system (Swiss Timing, Bienne, Switzerland. ISO 9001:2000 approved).

#### Blood measures

For the SB and P trial, arterialisned capillary blood samples (90 µl) were taken at rest (pre-ingestion), post-ingestion (55 min after supplementation was completed i.e. 5 min pre-performance) and 3 min post-performance in order to measure blood pH, base excess (BEₚₑₓₚ) and bicarbonate concentration ([HCO₃⁻]) with an i-STAT™ dry chemistry analyser (HPM3600A, Hewlett Packard, Les Ulis, France). These measurements with the i-STAT analyser have previously been found to be reliable (ICC = 0.77 – 0.95 following maximal exercise) [8]. In the control trial samples were taken at the post-ingestion and post-performance time points. In order to measure the blood lactate response to exercise additional samples (50 µl) were taken at rest, then 1, 4 and 6 min post-performance, for analysis using a Biosen 5030 lactate analyser (Biosen 5030 analyser, EKF Industrie, Elektronik GmbH, Barleben, Germany). Analysis of blood lactate with this analyser has been reported to have high test-retest reliability (r² = 0.99, CV < 3%) [9]. All blood samples were taken with subjects seated.

#### Data analysis

Data was analysed with two-way analysis of variance (ANOVA) with repeated measures to determine if differences existed between treatment conditions. When significant F values were found, the Ryan-Holm step-wise method was utilised to determine the location of the variance [1]. Data analysis was conducted using SPSS version 12.0 and significance was accepted at the 5% level. Values are expressed as the mean and standard deviation (s) unless otherwise stated.
Results

The training distance completed over the 48 h prior to each trial was consistent: C, 14011 ± 247 m; SB, 13978 ± 211 m; and P, 13967 ± 255.0 m, and the well-being scores were also very similar: C, 63 ± 5; SB, 66 ± 4; and P, 65 ± 5.

Performance

Performance times improved following SB supplementation (C, 1:53.7 ± 3.8; P, 1:54.0 ± 3.6; SB, 1:52.2 ± 4.7 min: ss) with the SB trial faster than the P (1.8 ± 2.1 s; – 1.6%; p = 0.04) and C trials (1.5 ± 1.4 s; – 1.3%; p = 0.03). There was no difference between C and P trials (p = 0.50). Eight of the nine athletes swam faster after the SB treatment than after placebo (Fig. 1).

Blood measures

There were no differences between the resting values of the three trials for any of the blood measures analysed.

pH values

Two-way ANOVA revealed that pH values were affected by time, but there was no overall effect of trial (Fig. 2). However, in the SB trial pH was higher than P and C at post-ingestion, and C at post-exercise (all, p < 0.05). The decline in pH that occurred after exercise (post-ingestion to post-exercise) was not affected by the trial condition (p = 0.55).

Blood bicarbonate and base excess

The blood bicarbonate concentration was higher in the SB trial, compared to P (Fig. 3), being higher at post-ingestion and post-exercise following SB treatment, compared to C and P (all, p < 0.01). There was an effect of trial on the decrease in [HCO3−] in the response to exercise (post-ingestion to post-exercise), with the decrease for SB being greater than for P and C (p = 0.002 and p < 0.001, respectively). BE(ecf) changes followed a similar pattern to [HCO3−], with higher values in the SB trial than P, specifically at post-ingestion and post-exercise BE(ecf) was higher in SB than P or C (all, p < 0.01). There was an effect of trial on the decrease in BE(ecf) following exercise (post-ingestion to post-exercise). The decrease in BE(ecf) with SB was greater than C but not P (p = 0.01 and p = 0.16, respectively).

Lactate

For all trials, lactate values increased from resting to post-exercise (Fig. 4) with the highest lactate values recorded at 4 min post-exercise. Lactate values were higher during the SB trial, in particular at 4 min and 6 min post-exercise compared to C (p < 0.001 and p = 0.001 respectively). There was an effect of trial on the increase in blood lactate concentration in response to exercise (rest to peak post-exercise) with the SB condition showing a greater increase than both P and C (p = 0.007 and p < 0.001, respectively).

Discussion

The main finding was that 200 m freestyle swimming performance was significantly improved after ingesting SB compared with P. Eight of the nine athletes swim faster following induced alkalosis compared to the placebo condition. Given the paucity of research on SB supplementation in swimming this provides a useful addition to our current understanding of this area of research. Also, considering the competitive status of the participants, these findings are applicable to elite performers who are likely to use SB as part of their competitive strategy. Elite performers are able to swim significantly faster than lower standard competitors. They have a greater anaerobic capacity [23] and can attain a higher level of acidosis [27]. Consequently they may benefit from SB supplementation to a greater degree than non-elite performers. The average improvement in the current study was 1.5 s (1.6%), which would typically have a substantial influence on a competitive outcome: the difference between 1st and 4th places in the Athens Olympic Games men's 200 m freestyle final was 1.4 s.

All the swimmers were in the final phase of their training cycle that was designed to prepare them for the British National Championships (n = 6) or the European Championships (n = 3), and all 200 m swims were part of their race preparation programme. There was some concern that as the training programme evolved towards these Championships, the training and well-being of the athletes might change and influence 200 m performance. However, the training volume and well-

Fig. 1 Comparison of individual performances after placebo (P) and sodium bicarbonate (SB) supplementation.

Fig. 2 Effect of supplement ingestion and exercise on blood pH for control (C), sodium bicarbonate (SB) and placebo (P) conditions. Values are mean ± s. * SB significantly higher than C and P (p < 0.05). # SB significantly higher than C (p < 0.05).
During maximal high intensity exercise (i.e. when $H^+$ production is high), higher initial muscle pH and greater $H^+$ efflux from muscle, consequent to metabolic alkalosis, is thought to offset the decline in muscle pH [31], preserve intramuscular homeostasis and delay fatigue.

Other factors contributing to the onset of fatigue in high-intensity exercise may include a decline in neuromuscular signalling, sarcoplasmic reticulum dysfunction and central drive [14]. Alternative explanations for the positive effects of SB ingestion on high intensity exercise performance include improved maintenance of $Na^+/H^+$ gradients, increased intracellular strong-ion difference and a reduction in $La^-$ removal by inactive tissues [29]. The positive effect of SB supplementation on VO$_2$ kinetics [19] and ventilatory control [26] may indicate cardiovascular changes. Finally, there is evidence that attenuation of plasma acidosis can lower ratings of perceived exertion [33], which could act to reduce central fatigue [5]. In conclusion, SB supplementation has an ergogenic effect on 200 m freestyle performance in elite male competitors, most likely due to an increase in blood alkalosis and an enhanced $H^+$ buffering capacity.

References


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