NutritionX

The Nutrition X—CHANGE

09

SODIUM BICARBONATE: MORE THAN JUST BAKING POWDER

Can baking powder enhance sporting performance?

Felipe Marticorena, Eimear Dolan & Bryan Saunders

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Practical Implications

+ High-intensity exercise can lead to an increase in hydrogen ion (H+) accumulation, causing a reduction in muscle pH (acidosis) which negatively impacts performance via a range of mechanisms, including reducing the capacity for muscle contraction and slowing the rate of ATP regeneration.
+ Sodium bicarbonate is a salt formed by a sodium cation and a bicarbonate anion, forming $NaHCO_3^-$.
+ Sodium bicarbonate supplementation increases blood bicarbonate concentration which increases transport of H+ out of the muscle, allowing better regulation of muscle pH and thus increasing capacity to undertake high intensity exercise.
+ Sodium bicarbonate supplementation improves exercise performance with its greatest effect during high-intensity exercise lasting ~1-10 min duration.
+ Supplementation with sodium bicarbonate throughout training periods may lead to greater adaptations than training alone.
+ Side-effects can occur following supplementation, and include gastrointestinal discomfort, headache, nausea and even vomiting.
+ 0.2 - 0.3 g/kg of sodium bicarbonate approximately 60 – 180 min prior to exercise seems to be optimal for performance gains

Background

You have probably heard that sodium bicarbonate (SB) can be used in a wide variety of situations, such as baking, cleaning, gastritis relief, or even middle-school chemistry experiments, but that this substance is widely used as a sport supplement to enhance performance may be less well known. In fact, SB is considered by the International Olympic Committee as one of just 5 sport supplements with sufficient evidence to support its use in certain sport-specific scenarios (with the other 4 being creatine, caffeine, nitrate and beta alanine) [1]. In this article we will elucidate how sodium bicarbonate supplementation works, what type of activity it benefits most and recommended dosing strategies.

Why do your muscles burn during exercise?

The human organism is a complex and well-orchestrated system composed of thousands of cells, proteins, and enzymes. For this system to work optimally, we rely on our body to provide an optimal environment, including temperature, oxygenation, and pH. The pH is a quantitative scale to measure how acid or basic/alkaline a solution is, and ranges from 0 (most acidic) to 14 (most alkaline) (Figure 1).

Human muscle has a pH of approximately 7.1, but this can be reduced to as low as 6.1 following high intensity exercises [2]. This acidosis is caused by the accumulation of H+ due to an increasing energy demand of the muscle particularly from anaerobic glycolysis, which is a powerful system that supplies energy during high intensity exercises [2]. The build-up of H+ that impairs several crucial enzymes that are working hard inside the muscle cells to provide energy [3], directly interferes with the muscles'

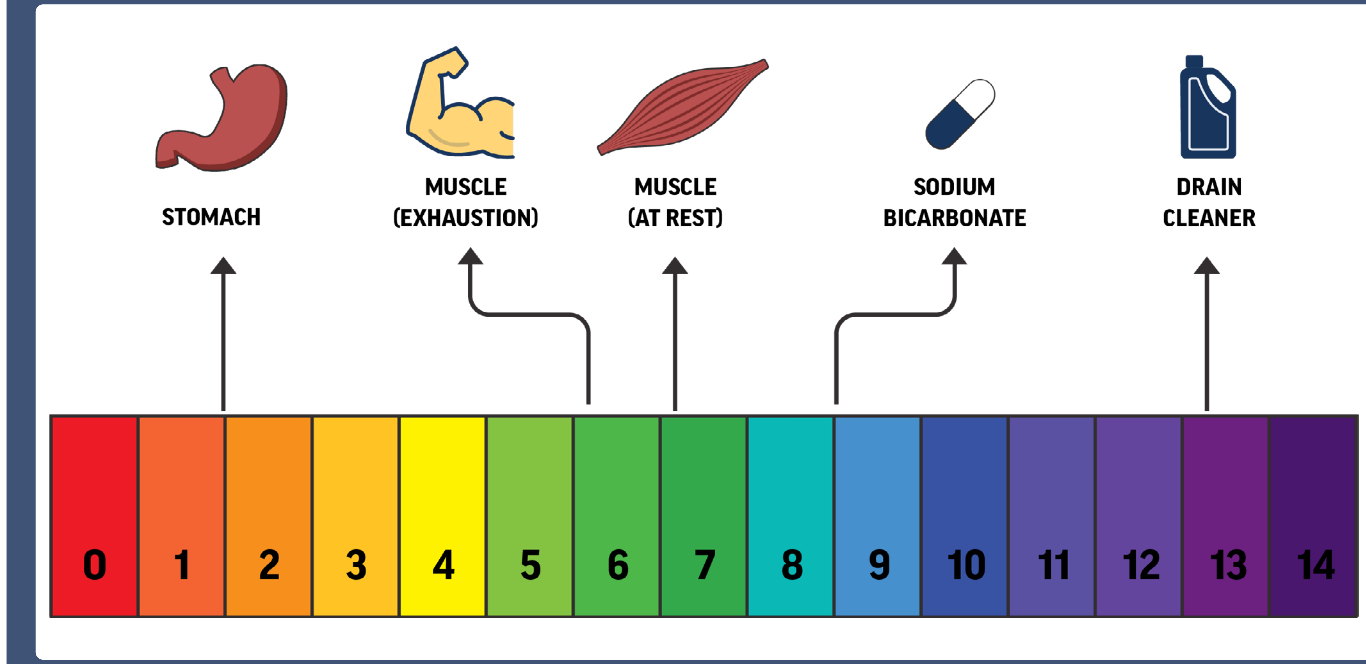

Figure 1. The pH scale.

ability to contract [4] and stimulates the burning sensation felt in the working muscles through the activation of acid-sensitive ion channels (ASIC) family [5]. Luckily, the body has developed several physiological systems that work to combat the negative effect of muscle acidosis.

H+ buffering

The human body has evolved to deal with the muscular acidosis that occurs during high-intensity exercise via highly developed intracellular (within the muscle) and extracellular (within the blood) buffering systems. Intracellular buffers such as carnosine (see Nutrition X-change volume 3), represent the muscle's immediate defense against H+ accumulation in the exercising muscle. Muscle pH homeostasis is also maintained by transport of H+ out of the muscle into the blood primarily via monocarboxylate transporter 1 (MCT1) and 4 (MCT4) (Figure 2) [6] which can facilitate the removal of H+ from the muscle into the blood. In the blood, the buffering system is primarily composed of circulating bicarbonate (HCO_3^-), which can bind the H+ to form carbonic acid and ultimately water and carbon dioxide which can then be released into the environment when you breathe [7]. Nutritional interventions that can increase transport of the H+ produced in the muscle into the blood, thereby indirectly increases pH buffering of the muscle, could lead to improvements during exercise that is limited by muscle acidosis.

How does SB work?

When high-intensity exercise starts without any prior supplementation, the H+ generated from the energy demand accumulates in the muscle, with transport out of the muscle limited by the normal activity of the transports systems, including the MCTs. The efflux of H+ out of the muscle is soon overwhelmed as exercise continues; this scenario leads to muscular acidosis, which as discussed impairs several physiological mechanisms and ultimately performance. However, if this same exercise task is performed following SB supplementation, then we have an increased amount of circulating bicarbonate in the blood which will increase the pH gradient between muscle and blood leading to an increased activity of the MCT transporters [6]. This leads to an increased movement of H+ out of the muscle and consequently better maintenance of the intramuscular pH milieu, which would minimise the detrimental effect that H+ accumulation has within the muscle and could lead to an improved performance.

Effects of SB on exercise outcomes

Many supplements have a mechanistic rationale to improve performance but when tested in the real world, expected results are not achieved. So, does SB supplementation live up to the hype? In general, it would certainly appear so. Meta-analysis is a useful scientific tool that provides a statistical analysis that

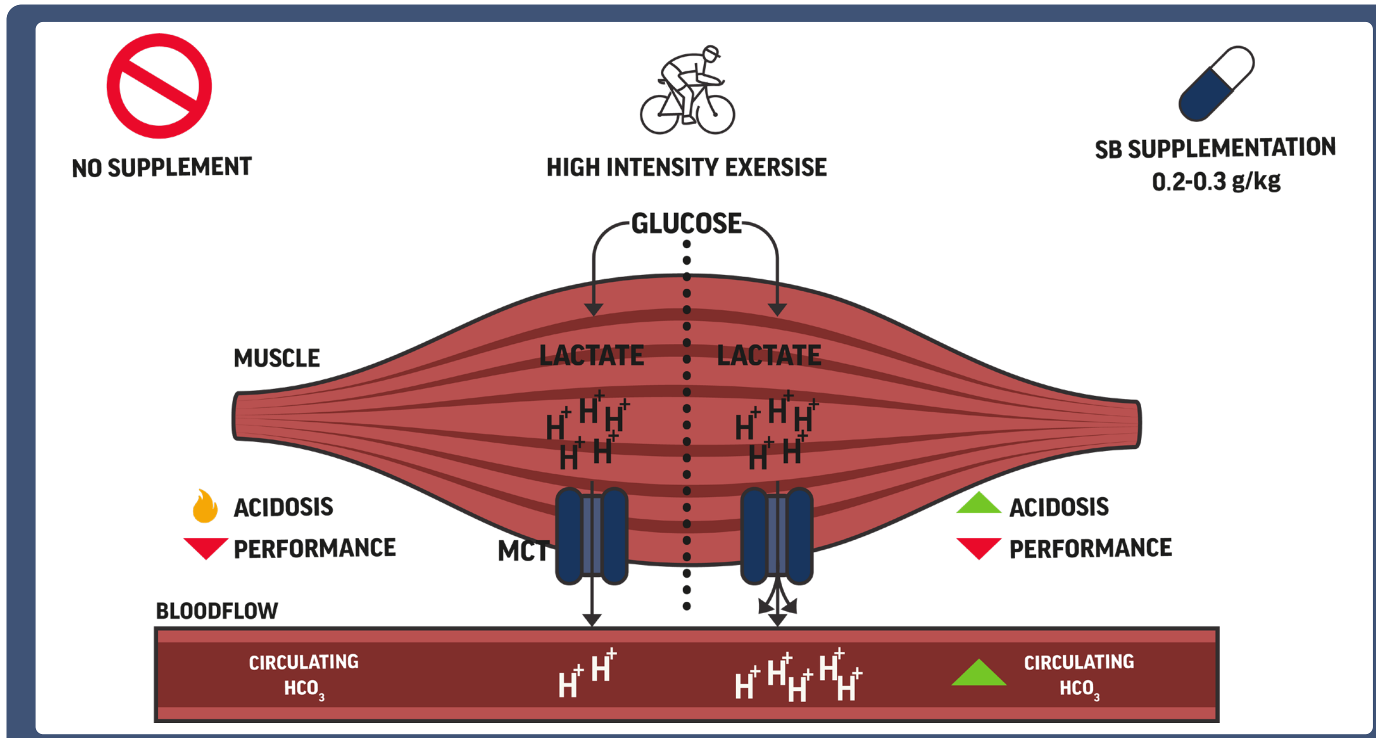

Figure 2. Extracellular buffering capacity of the muscle without (left) and with (right) sodium bicarbonate supplementation.

combines data from several research articles to reach a consensus on whether an intervention is effective or not. Several meta-analyses over the last 30 years have consistently demonstrated a positive effect of SB on exercise outcomes [8, 9, 10]. A meta-analysis from Peart and colleagues (2012) demonstrated a moderate overall effect of SB supplementation on performance outcomes. Another meta-analysis from Carr et al. (2011) also found a moderate enhancement of exercise performance with SB, showing a 1.7±2.0% performance improvement. The difference in medal ranking in events of several Olympic sports can be separated by less than 1%. Thus, translating these data to the real world, this suggests that supplementation with SB could lead to important performance improvements for competitive athletes. The results from these cited meta-analyses are important to know that SB supplementation can lead to improvements in exercise outcomes at the group level, however, it is also important to understand that these effects may vary from person to person. As such, a better understanding of different factors that may modify the size of these gains can lead to more targeted recommendations, in turn, increasing the likelihood of a successful outcome. For example, despite showing an overall benefit of SB for exercise performance, the meta-analysis of Peart et al. (2011) showed an inverse relationship between the size of the effect and training status, which means that the more trained the individual, the smaller the effect of supplementation. This is a common finding with nutritional supplements and may be due to the adaptations associated with chronic training that minimise any effect of a supplement. Other factors may also modify the response to SB supplementation [11] and include:

- Dose: 0.1 g/kg appears to be too low to induce performance improvements, while 0.4-0.5 g/kg might generate more gastrointestinal discomfort without further exercise improvements [12]. A 0.2 –0.3 g/kg is currently considered to be the optimal dose [13].

- Timing: The timing of ingestion before exercise is important because it directly influences the amount of circulating bicarbonate. Coinciding exercise with peak blood bicarbonate levels may optimise your chances of a benefit from supplementation [13,14] although data suggest that bicarbonate peaks and plateaus for a substantial period following supplementation (60 – 180 min) [15] meaning ingestion anytime 1-3 h prior to exercise should lead to similar benefits.

- Duration and Intensity of exercise: High-intensity exercise lasting ~1-10 min is likely to generate large H+ accumulation and appears most susceptible to improvements with SB [11] (Figure 3).

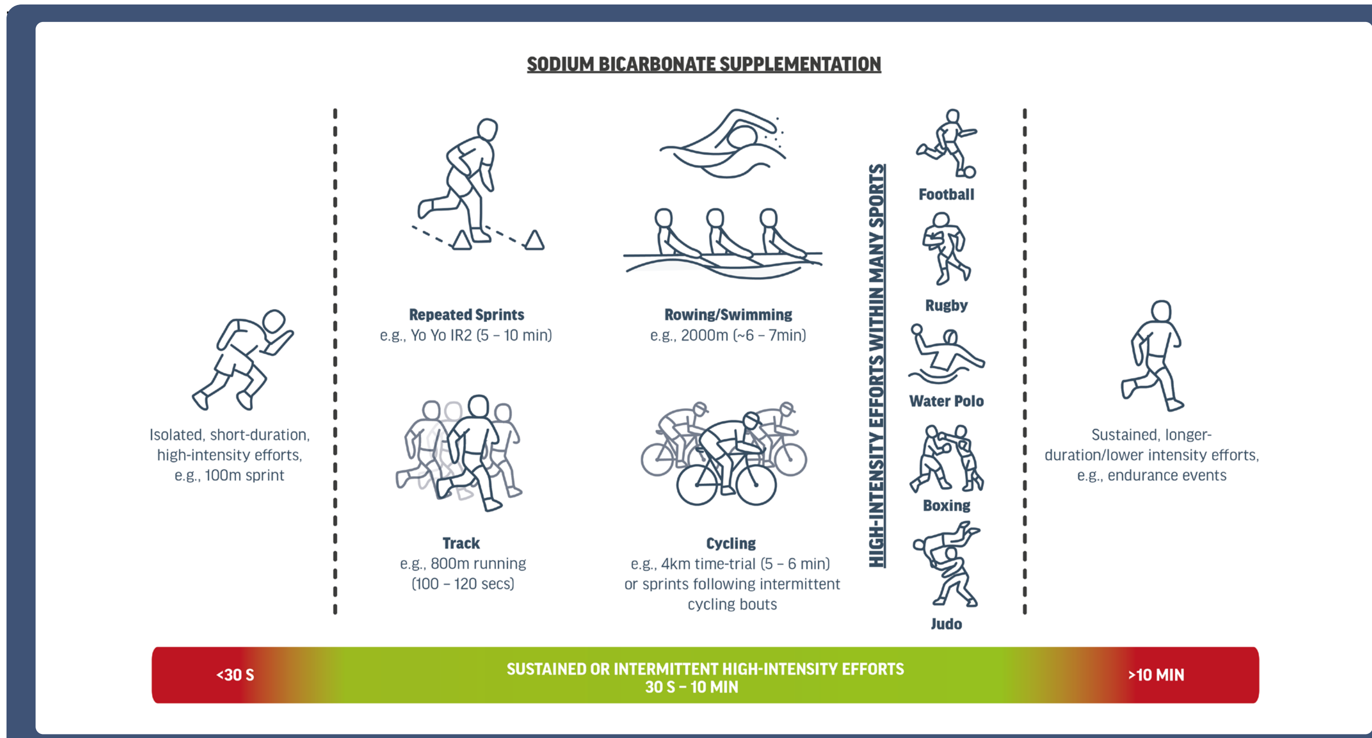

Figure 3. Illustration of the types of sports / activities likely to be aided by SB supplementation. These examples are based on exercise tests that have been directly investigated, but other high-intensity, sustained efforts of similar duration (e.g., as occur in other intermittent sports, or other track and field modalities) may also benefit. It should also be noted that athletes competing in events unlikely to be impacted by SB supplementation (e.g., very short duration, or endurance type events) should consider the demands of training, as well as isolated high-intensity moments during the event itself, to decide if SB supplementation may be of benefit.

This includes, but is not limited to, 100 m and 200 m swimming, 4-km cycling and 2000 m rowing. There is also evidence to suggest that prolonged intermittent activity, such as team sports or even endurance cycling, might benefit from SB during maximal or near-maximal efforts [16]. SB may even improve muscular endurance, but not muscular strength [17].

Most studies have investigated the effect of acute SB supplementation on isolated exercise tests, demonstrating its efficacy to directly influence performance particularly during high-intensity exercise 1 – 10 min in duration. However, it is important to note that SB may also be considered an effective supplement to ingest chronically throughout a training program to optimise gains and performance. For example, one study showed that SB supplementation (0.4 g/kg) prior to each high-intensity training session of an 8-week structured training intervention led to greater improvements in endurance performance than training alone. Thus, SB can be considered an effective supplement to incorporate not only directly prior to competition, but throughout training to optimise gains.

How and when should you take it?

The supplementation strategy for SB should be performed acutely, that is, a single dose before exercise. The two most important variables when dealing with acute supplementation protocols appear to be timing and dose, as these can directly influence the size of the performance effect of supplementation. Regarding the dose, there is a direct relationship between how much SB is being ingested and the extent of blood alkalosis, which appears to relate well to performance improvements [11], but no additional performance gains are evident when exceeding 0.3 g/kg of SB [12]. Studies show that the ideal range of elevated bicarbonate in the bloodstream to promote improved performance is >5 mmol·L-1 [11], and evidence suggests this is consistently achieved by supplementing 0.3 g/kg of SB. As an example, for a 70 kg individual, this equates to 70 x 0.3 g = 21 g of SB to reach this ergogenic range. The supplement can either be ingested diluted in water (preferably with some non-caloric and non-acidic flavouring to improve the salty taste) or in gelatine capsules. A standard sized capsule can hold approximately 1g of SB, meaning that you need to ingest ~20 of these to attain recommended dose. Studies have shown that individualising supplement timing to ensure exercise begins at the moment of peak blood bicarbonate concentration is effective to improve performance [13, 18]. More recently Boegman and colleagues [14] demonstrated that rowers showed a very small but significant improvement in 2000 m time-trial performance when individualising bicarbonate supplementation to time-to-peak compared to a standardised time (60 min). This difference might be worthwhile in a competitive setting although more work is needed to determine if a time-to-peak strategy is truly worthwhile. In the real world however, most athletes do not have access to equipment that will allow them to determine their individual blood bicarbonate response following supplementation. Luckily, work from our group suggests that identifying a solitary peak may not be necessary as it appears that there is a large window of opportunity during which SB remains above >5 mmol/L and around peak values [15]. These data indicate that supplement ingestion should occur 60 – 180 min prior to the moment at which increased buffering capacity is required. Recently, other forms of administration have emerged, such as the topical application of bicarbonate. However, the only study testing this product to date did not show any changes in buffering capacity or performance benefits with topical sodium bicarbonate lotion [19]. Current evidence does not support the use of topical sodium bicarbonate.

Are there any side-effects to worry about?

When ingesting SB, we are adding a basic solution to a highly acidic environment in the stomach. Part of the ingested bicarbonate neutralizes the stomach acid, and this can generate gastric discomfort, a sensation of bloating and eructation (burping). Moreover, diarrhoea can occur after the administration of SB, mainly due to sodium residuals that reach the intestine which favour the attraction of water molecules to the intestinal region, increasing peristaltic bowel movements. These symptoms could negate any benefit of increased buffering capacity via supplementation, and can even be ergolytic to performance (i.e. worsen performance) [20]. Nonetheless, most studies suggest that incidence and intensity of these symptoms are low [21]. The incidence of these symptoms appears variable between, and even within, individuals [22] and anyone planning to use SB should proceed with caution and consider the necessity of SB supplementation according to the importance of the subsequent exercise (for example, athletes may preferentially supplement during training as opposed to prior to competition, to avoid side-effects affecting their competitive edge). Scientific research is currently attempting to determine methods by which to minimise the uncomfortable symptoms that can occur following SB ingestion. One of the main alternatives that has emerged in the search to reduce these symptoms is the administration of SB in gastro-resistant capsules [23]. This is because gastro-resistant capsules avoid disintegration in the stomach, preventing the neutralization of stomach acids and, consequently, reducing some of the symptoms mentioned above. Some studies showed attenuated symptoms following SB supplementation in these types of capsule, although there was a delayed response in the time-to-peak of bicarbonate in the bloodstream that should be considered (120 vs. 70 min). This strategy might modify the ideal timing of supplementation prior to exercise, while performance effects need to be investigated as no study has yet investigated SB in gastro-resistant capsules on exercise outcomes.

Summary:

There are few nutritional supplements considered to be effective for athletes, but SB is certainly one of them. An individualized dose of 0.2 – 0.3 g/kg is enough to increase circulating bicarbonate to optimal levels for approximately 60 – 180 min post-ingestion. This increases the buffering capacity of the body, which may optimize muscle function and improve exercise performance in a variety of exercises, such as short distance swimming, rowing, cycling sprints and intermittent exercises like football. Although there are some side-effects to consider, evidence to support the use of SB supplementation for athletic performance is strong.

Author bios

Eimear Dolan

Eimear completed her undergraduate and postgraduate studies in sport and exercise science in Dublin City University, Ireland. She then worked as a Sports Nutrition lecturer in the Robert Gordon University, Scotland, before moving to Brazil to do a postdoctoral research project. Currently, she is a member of the Applied Physiology and Nutrition Research Group of the University of São Paulo, and leads a research program investigating how exercise and nutrition influence bone, which is funded by the Sao Paulo Research Foundation (FAPESP). Her research interests include pH regulation and high-intensity exercise performance (including the use of buffering supplements such as beta-alanine); the influence of low energy availability on health and performance, and bone metabolism.

Felipe Marticorena

Felipe Marticorena is a nutritionist and PhD student at the Faculty of Medicine of the University of São Paulo. He is a member of the Applied Physiology and Nutrition Research Group. His research focuses on nutritional supplements, sports performance, and placebo effects.

Bryan Saunders

BSc, MSc, PhD

Bryan Saunders is a researcher and lecturer in sport and exercise science at the Faculty of Medicine of the University of São Paulo, Brazil. His main areas of research include nutritional supplementation to improve exercise performance, determination of the mechanisms through which these supplements act and what factors might moderate these effects. Bryan has applied sport science experience having provided performance analysis and physiology support to several UK-based football teams and currently works with elite cycling in Brazil. He is a member of the São Paulo Cycling Federation.

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