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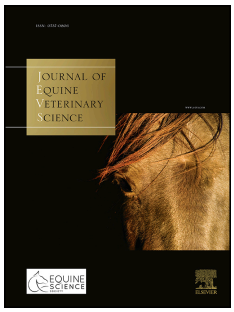

A systematic review and meta-analysis on sodium bicarbonate administration and equine running performance: Is it time to stop horsing around with baking soda?

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PII: S0737-0806(20)30372-5

DOI: https://doi.org/10.1016/j.jevs.2020.103281

Reference: YJEVS 103281

To appear in: *Journal of Equine Veterinary Science*

Received Date: 17 August 2020

Revised Date: 21 September 2020

Accepted Date: 22 September 2020

Please cite this article as: Denham J, Hulme A, A systematic review and meta-analysis on sodium bicarbonate administration and equine running performance: Is it time to stop horsing around with baking soda?, *Journal of Equine Veterinary Science* (2020), doi: https://doi.org/10.1016/j.jevs.2020.103281.

Total document: 3876

Main text: 2977

Abstract: 209

Number of tables: 1

Number of figures: 5

Number of references: 22

Supplementary files: 1

A systematic review and meta-analysis on sodium bicarbonate administration and equine running performance: Is it time to stop horsing around with baking soda?

Running title: $NaHCO_3$ and equine running performance

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Conflict of interest: none.

Keywords: $NaHCO_3$, milkshake, racing, horse, exercise performance

Abstract

Sodium bicarbonate administration in the hours prior to exercise has been used as a performance enhancing substance in horses since the late 1980's. Although sodium bicarbonate administration to racehorses 24 hours before racing is a banned practice in most racing industries, whether or not it improves running performance in racehorses is currently unclear. The aim of this systematic review and meta-analysis was to establish whether or not acute sodium bicarbonate administration improves running performance in trained Standardbred and Thoroughbred horses. Seven randomised controlled trials, including eight experimental (exercise) trials and 74 horses, were included after a comprehensive search for relevant studies that met the inclusion criteria. Results indicated that sodium bicarbonate administration in 2.5 to 5 hours prior to a standardised treadmill test to exhaustion or simulated race (time-trial) does not influence running performance (number of horses, overall effect [95%CI]: 32, -0.13 [-0.64–0.37] and 42, 0.01 [-0.42–0.44], respectively, both $p > 0.05$). The included studies demonstrated minimal heterogeneity ($I^2 = 0–2\%$), low risks of bias according to the Cochrane Risk of Bias Tool and a lack of publication bias. On the basis of these findings there is high-quality evidence to suggest that sodium bicarbonate administration does not improve running performance in trained Standardbred or Thoroughbred horses.

1.0 Introduction

Since the 1930's, sodium hydrogencarbonate, more commonly referred to as sodium bicarbonate ($NaCHO_3$), has been scrutinised for its potential to influence exercise performance in a range of athletic mammals (e.g. humans, dogs, and horses) [1-3]. Sodium bicarbonate is an alkalinising reagent that increases arterial blood pH [4]. Intense exercise above the lactate threshold causes metabolic acidosis through the accumulation of protons (H^+), impacting skeletal muscle contractions leading to fatigue. Sodium bicarbonate ingestion in the hours prior to vigorous exercise acts as a buffer to maintain blood pH and prevent metabolic acidosis in horses during exercise [5-8]. As such, sodium bicarbonate is generally viewed as a performance enhancing substance, when consumed in the hours prior to racing.

Many racing authorities across the globe have banned sodium bicarbonate administration to horses within 24 hours of racing. In horses, sodium bicarbonate loading is commonly achieved via nasogastric intubation 2–5 hours before exercise. Those in the industry refer to sodium bicarbonate by the lay term, 'milkshake' [9]. Although the administration of 'milkshakes' to racehorses within 24 hours of racing violates the rules, and despite regular race-day screening by governing officials, it remains an issue in modern horseracing. The practice can also be distressing to the animal and cause serious harm if not performed correctly. Minor side-effects include gastrointestinal upset and lacerations to the nasopharyngeal structures during intubation, to more serious, such as death of the animal when the tube erroneously enters the trachea rather than the oesophagus, flooding the lungs with a concentrated solution [9].

Whether or not sodium bicarbonate ingestion prior to exercise improves performance in horses is currently unclear. Some human studies support its use as an ergogenic aid that improves exercise performance [10, 11] and the underlying mechanisms of action have been discussed at length [12]. However, the human literature is inconsistent and placebo effects have been reported [10, 13]. Aside from the ethical and animal welfare concerns associated with performing nasogastric intubations to gain a *potential* edge over the competition, the practice is banned and is regularly tested on race-day. Those who administer milkshakes to their racehorses risk heavy sanctions with severe repercussions – financial, to reputation and livelihood. In consideration of the above-mentioned animal welfare concerns, combined with the questionable practice of 'milkshake' usage within the industry, the purpose of this systematic review and meta-analysis was to examine whether or not acute sodium bicarbonate administration improves running performance in trained horses. This was achieved by critically appraising published controlled trials that determined the

impact of sodium bicarbonate administration prior to exercise on running performance in exercise conditioned horses.

2.0 Materials and Methods

2.1 Protocol

This systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14]. This work was conducted in accordance with the Australian code for the care and use of animals for scientific purposes (the Code) developed by the National Health and Medical Research Council of Australia (NHMRC).

2.2 Search strategy

A comprehensive search of the PubMed (National Library of Medicine), Scopus, Wiley and Elsevier ScienceDirect databases was performed by JD in July 2020 using search terms outlined in Supplementary Table 1. The Elsevier ScienceDirect search was restricted to title, abstract and author specified keywords, the Wiley search was restricted to terms in the Abstract and Scopus search was restricted to journals in English. The reference list of key relevant journal articles were reviewed, however, no additional potentially eligible papers were retrieved. Although some conference proceedings and abstracts were identified, they were not included as peer-reviewed status could not be determined as well as the fact information for assessing their risk of bias was lacking. All references were exported from the search databases and managed in EndNote (X9.3.3).

2.3 Types of studies (inclusion/exclusion criteria)

Study synthesis and meta-analysis was restricted to published, peer-reviewed journal articles. Controlled trials analysing the influence of acute (i.e. no more than 6 hours before exercise) sodium bicarbonate administration on running performance in horses were included. Articles were written in English and quantified acute sodium bicarbonate administration on running performance in horses using a treadmill or simulated race protocol (i.e. timed protocol). Case-control, retrospective, *in vitro* or prospective studies involving the long-term administration of sodium bicarbonate, case reports, conference proceedings, reviews, book chapters, and editorials were excluded. Studies analysing the influence of acute sodium bicarbonate administration in conjunction with other substance/s and those that did not have a control arm (i.e. sham [e.g. saline or H_2O administration] or control [i.e. no substance] trial) were also excluded. This was to remove any potential effects of interactions between sodium bicarbonate and other substances on running performance, which was not consistent with the purpose of the review. Full-text manuscripts were retrieved when the

inclusion of a study was uncertain. The primary outcome was equine running performance, as measured by a treadmill exercise tests or simulated races (time-trials).

2.4 Data extraction

Data extraction was performed by JD and checked by AH. Data extraction included authors (date), journal, title of the work, year of publication, horse characteristics (*N*, breed, sex and training status), exercise testing method and performance results, as well as the sodium bicarbonate administration method, timing (prior to exercise) and dosage.

2.5 Quality assessment

Study bias was assessed using the Cochrane criteria and the Cochrane Risk of Bias Tool [15]. The tool defines risk of bias through six domains: (i) selection bias; (ii) reporting bias; (iii) other sources of bias; (iv) performance bias; (v) detection bias; and (vi) attrition bias. The potential source of bias is scored as 3, 2 or 1 if the risk of bias was identified as high, unclear or low, respectively. A cumulative score was calculated to determine the overall risk of each study and pooled to determine the risk associated with all included studies. The risk of bias was calculated by independently by authors (JD and AH) and discrepancies were resolved by discussion until agreement.

2.6 Data analysis

Data were organised using electronic spreadsheet programming (Microsoft Excel). Data analysis was performed by JD and reviewed by AH to ensure the accuracy during data entry and the subsequent analyses. Mean percentage difference was calculated between the sodium bicarbonate and control trials. The mean percentage difference was inverted for simulated races (time-trials), as shorter times reflect superior running performances. Effect sizes for time to exhaustion and simulated races were calculated separately with random effect meta-analysis using the Review Manager (version 5.4) software. Effect size confidence intervals were calculated using the random-effects method with an $\alpha = 0.05$. Publication bias was visually assessed by plotting the effect sizes against the standard error using funnel plots.

2.7 Data presentation

The study overview and characteristics are presented in table format, whilst the Cochrane risk of bias results are in an adjacency matrix plot and forest plots were generated to illustrate the overall meta-effects. The risk of bias and forest plots were created using GraphPad Prism (version 8.4.3). Funnel plots were created using Review Manager (version 5.4).

3.0 Results

3.1 Description of included studies

The search strategy and screening procedure is outlined in Figure 1. The search strategy identified 2864 publications. Of these, 1336 duplicates were removed. The titles and abstracts of 1528 articles were read to assess their suitability for inclusion based on the inclusion criteria and 1514 were removed. The remaining 14 articles were read in their entirety to ensure they met the inclusion criteria and a further seven were removed. Seven studies were retained for the quality assessment (Figure 2).

The study characteristics are summarised in Table 1. All of the included studies were published between 1990 and 2002. The seven included studies involved eight experimental trials and 74 horses. Three studies (four experimental trials) included a sodium bicarbonate dosage of 1 $g \cdot kg^{-1}$ [6, 8, 16], one used 0.6 $g \cdot kg^{-1}$ [17], 0.4 $g \cdot kg^{-1}$ [18] and 0.3 $g \cdot kg^{-1}$ [3], and another used a fixed dose of 454 g [19], which was, on average, equivalent to 1 $g \cdot kg^{-1}$. All horses were trained Standardbreds or Thoroughbreds. Sodium bicarbonate was administered by nasogastric intubation, except for one study that used an oral paste (drench) [3], administered either 2.5 [3], 3 [18, 19], 4 [6, 17], or 5 [8, 16] hours before exercise testing. Four studies included a motorised treadmill time to exhaustion protocol [6, 8, 16, 17], while the remaining three used a simulated (flat) race on a race track [3, 18, 19] to assess running performance. Therefore, we conducted separate analyses on the studies using the two different exercise testing protocols, as running performance is superior with longer times on the treadmill and shorter times on the racetrack.

3.2 Risk of bias

A risk of bias summary is provided in Figure 2. All studies were randomised controlled trials, with low risk of bias associated with allocation concealment, blinding of participants and reporting of results. It was unclear if the outcome assessors (of simulated races) were blinded to the experimental trial (control or sodium bicarbonate) [17-19]. Incomplete data was presented in two studies [3, 18] and it was unclear as to whether or not all studies had other sources of bias. For instance, environmental factors and other effects of jockeys on race times, a lack of information on study funding or studies were funded by an organisation or party with a vested interest in the results, lack of control for diet and water consumption before testing, or control for exercise training habits. Out of a possible score 21 indicating a significantly high risk of bias and a minimum of seven suggesting an exceptionally low risk of bias, four studies scored an 8 [6, 8, 16, 17], two studies scored a 10 [3, 19] and one scored a

12 [18]. When the studies were pooled, the overall risk of bias score was 64 (out of a possible 49–147).

3.3 Meta-analysis

Of the seven studies, four [6, 8, 16, 17] provided data on the influence of acute sodium bicarbonate administration on time to exhaustion treadmill protocols, which included five experimental trials. The meta-analysis indicated no statistically significant or meaningful effect of sodium bicarbonate administration on running performance (N = 32; overall effect [95%CI]: -0.13 [-0.64–0.37], p = 0.61, Figure 3). Minimal heterogeneity was identified between the five experimental trials (I^2 = 2%).

Three studies [3, 18, 19] provided data on the influence of acute sodium bicarbonate administration on racing performance using simulated races. The meta-analysis noted no statistically significant or meaningful effect of sodium bicarbonate administration on race times (N = 42; overall effect [95%CI]: 0.01 [-0.42–0.44], p = 0.96, Figure 4). Heterogeneity was not identified between the three experimental trials (I^2 = 0%).

3.4 Publication bias

Funnel plots of studies investigating the influence of acute sodium bicarbonate ingestion on time to exhaustion treadmill running performance and simulated race performance (Figure 5A and B, respectively). There were only four studies in the first analysis and three in the second making the interpretation of the funnel plots difficult. Nonetheless, they seemed to indicate a lack of publication bias, as larger studies were closer to the top and towards the mid-line.

4.0 Discussion

Investigations into the ergogenic effects of sodium bicarbonate have been explored in horses since the late 1980's [20]. Its early suggestion as performance enhancing in human athletes possibly led racehorse trainers to adopt the practice, which is now banned 24 hours before racing in most countries. Regardless of the illicit nature of the practice, the potential distress caused to the racehorses and the repercussions of getting caught, it seems some racehorse trainers continue to administer milkshakes for a perceived performance enhancing edge on the competition (e.g. highly publicised sanctions against prominent racehorse trainers in the past decade).

The results of the present meta-analysis are two-fold. Firstly, acute sodium bicarbonate administration did not improve running performance measured in time to exhaustion treadmill exercise trials. In fact, the meta-analysis indicated a very small negative effect of sodium bicarbonate on running performance. In the second meta-analysis, sodium bicarbonate administration did not

influence running performance as judged by a simulated race. Therefore, the results from this systematic review and meta-analysis, which included seven randomised controlled studies comprised of eight experimental trials and the inclusion of 74 trained horses, indicated that sodium bicarbonate administration in the hours before exercise does not enhance running performance in horses. Unlike appraising individual studies on their merit, this systematic review and meta-analysis included a comprehensive analysis of the influence of sodium bicarbonate versus a placebo on exercise performance in 74 horses from seven studies. A controlled trial with 74 trained horses would lack feasibility due to financial demands, the personnel required to support the study and other practical considerations (e.g. veterinarians, trainers, specialist equipment, jockeys, time, etc). Importantly, the present study includes a robust analysis and provides much stronger evidence compared to single analyses.

The results from the present study directly oppose the common beliefs that milkshakes enhance running performance in racehorses. The authors cannot think of another reason why individuals would administer milkshakes to their racehorses if not for the potential performance benefits, although not all human beliefs are justified scientifically. Human studies suggest the performance benefits of sodium bicarbonate ingestion prior to exercise are more frequently observed in events lasting less than four minutes (e.g. highly anaerobic events) [10]. Placebo effects have also undermined potential performance enhancing effects of sodium bicarbonate in human trials [13]. Considering all of the simulated races and time to exhaustion protocols from the studies included in this meta-analysis were, on average, completed in approximately two minutes (<4-min), positive effects would have been detectable but were not according to the present findings. These are highly relevant findings since nearly all Thoroughbred flat races are shorter than four minutes, the use of milkshakes on race day violates the rules of racing and there are medical risks associated with nasogastric intubations (e.g. lacerations to the nasopharyngeal structures, administration of sodium bicarbonate into the trachea rather than the oesophagus, etc. [9]) that appear to be completely unnecessary based on the present findings.

A recent systematic review and meta-analysis indicated that out of the 20 controlled trials analysed, 11 showed positive effects of sodium bicarbonate ingestion on exercise performance in tests under four minutes in humans [10]. Another meta-analysis indicated that sodium bicarbonate ingestion prior to a 60-min sprint improves times by 1.7% once outliers were excluded [11], which was a moderate performance enhancing effect and meaningful when races are decided by tenths of seconds at the elite level. To the authors' knowledge, horses do not have expectations on milkshakes that could facilitate placebo effects, unlike humans [21]. Conversely, the reliability of

standardised treadmill tests and simulated race trials may lack the precision to identify meaningful performance enhancing effects of sodium bicarbonate, as acknowledged by others [20]. The means of recording simulated race times are also questionable, as all of the included studies in this meta-analysis used observers with stopwatches [3, 18, 19]. Nonetheless, the horses included in the meta-analysis were all exercise trained and presumably familiar with treadmill exercise testing and racing which aids the reliability of exercise testing. It is important to highlight that gastrointestinal side-effects (e.g. diarrhoea and colic) can occur after sodium bicarbonate administration followed by intense exercise in horses [19] and humans [10, 11], which would undoubtedly impact running performance.

In terms of practical recommendations for future trials, researchers should determine the test-retest reliability of standardised exercise tests and simulated race trials, in trained racehorses and consider the use of timing gates or global positioning systems (GPS) for the time-trial events. Future work should also determine the dosage and timing that could potentially influence any effects sodium bicarbonate may have on running performance in horses. Whilst many studies revealed the alkalising effects of sodium bicarbonate that maintains arterial pH during exercise preventing metabolic acidosis in horses [5-8], it will be worth examining other potential mechanisms by which sodium bicarbonate could elicit any potential performance enhancing effects to give credence to its use as an ergogenic aid (e.g. intra- and extra-cellular ionic flux, modulated membrane potentials and glycolysis, skeletal muscle rate of force development, proton accumulation, etc. [12]). Such studies could provide evidence in favour of its use as a performance enhancing substance in equine athletes, albeit currently a banned substance 24-hr before racing. In the meantime, due to the current lack of evidence for its effectiveness as performance enhancing, the medical risks associated with the procedure, those related to getting caught on race-day, and the subsequent serious repercussions, it would be worth reconsidering milkshakes and redirecting efforts towards other performance enhancing effects, such as exercise periodisation and prescription, nutrition and animal welfare.

Acknowledgements

None.

Declarations of interest

None.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Figure Captions

Figure 1. Prisma diagram [22].

Figure 2. Risk of bias in randomised controlled trials examining the effects of sodium bicarbonate on running performance. Risk of bias was assessed using the Cochrane Risk of Bias Tool [15].

Figure 3. The influence of acute sodium bicarbonate ingestion on treadmill time to exhaustion running performance. Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 4.07$, df = 4 (P = 0.40); $I^2 = 2\%$. Test for overall effect: Z = 0.52 (P = 0.61). Weights are from a random effects model. SMD, standard mean difference; CI, confidence interval.

Figure 4. The influence of acute sodium bicarbonate ingestion on racing performance. Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.92$, df = 2 (P = 0.63); $I^2 = 0\%$; Test for overall effect: Z = 0.05 (P = 0.96). Weights are from a random effects model. SMD, standard mean difference; CI, confidence interval. The favours 'NaCHO3' and 'Control' headings below the x-axis were inverted since less time means faster racing and superior running performance.

Figure 5. Funnel plots of studies investigating the influence of acute sodium bicarbonate ingestion on time to exhaustion treadmill running performance (A) and simulated race performance (B). Standard error (y axis) was plotted against the observed outcome (x axis) for each study.

Table 1. The influence of acute sodium bicarbonate administration on equine running performance.

Ref	Horses[a,b,c,d,e]	Dose	Timing[f]	Exercise trial	$NaHCO_3$ vs control
[6]	8, Standardbred, 0/8, 5–7, trained	1 $g \cdot kg^{-1}$	4 hr	3 m/s for 3 min → 110% VO_{2max} (~10.3 m/s) until fatigue @ 4° incline	-6.90%
[16]	7, Thoroughbred, 7/0, 4–13, trained	1 $g \cdot kg^{-1}$	5 hr	5 min @ 50% VO_{2max} → rest 3 min → 1.5 m/s walk for 2 min → 115% VO_{2max} until fatigue	-10.64%
[19]	12, Standardbred, 6/6, 2–7, trained	454 g (~1 $g \cdot kg^{-1}$; range: 0.88–1.1 $g \cdot kg^{-1}$)	3 hr	Simulated race (1600-m)	^-0.41%
[8]	6, Thoroughbred, 6/0, 4–13, trained	1 $g \cdot kg^{-1}$	5 hr	4 min @ 40% VO_{2max} → 2 min @ 60% VO_{2max} → 2 min @ 80% VO_{2max} → walk 3 min → 115% VO_{2max} until fatigue @ 6° incline	28.19%
[8]	6, Thoroughbred, 6/0, 4–13, trained	1 $g \cdot kg^{-1}$	5 hr	4 min @ 40% VO_{2max} → 2 min @ 60% VO_{2max} → 2 min @ 80% VO_{2max} → walk 3 min → 115% VO_{2max} until fatigue @ 6° incline	-24.69%
[18]	16, Thoroughbred, 8/8, 3–8, trained	0.4 $g \cdot kg^{-1}$	3 hr	Simulated race (1600-m)	^0.05%
[3]	14, Thoroughbred, ?,	300 $mg \cdot kg^{-1}$	2.5 hr||	Simulated race (1600-m)	^0.83%

	>3, trained				
[17]	5, Standardbred trotters, 4/1, 5–9, trained	0.6 $g \cdot kg^{-1}$	4 hr	5 min @ 2 m/s → 5 min @ 4–5 m/s → treadmill increased to 4.5° incline @ 7 m/s → speed increased by 1 m/s every 60 s until fatigue	-5.48%

Studies used nasogastric intubation as the method to deliver the sodium bicarbonate and sham substances unless indicated otherwise. Control is either a no substance trial or a sham substance (e.g. saline or water). ^ Data is inverted as running performance is superior in horses with faster race times; || oral paste administration.

[a] Number

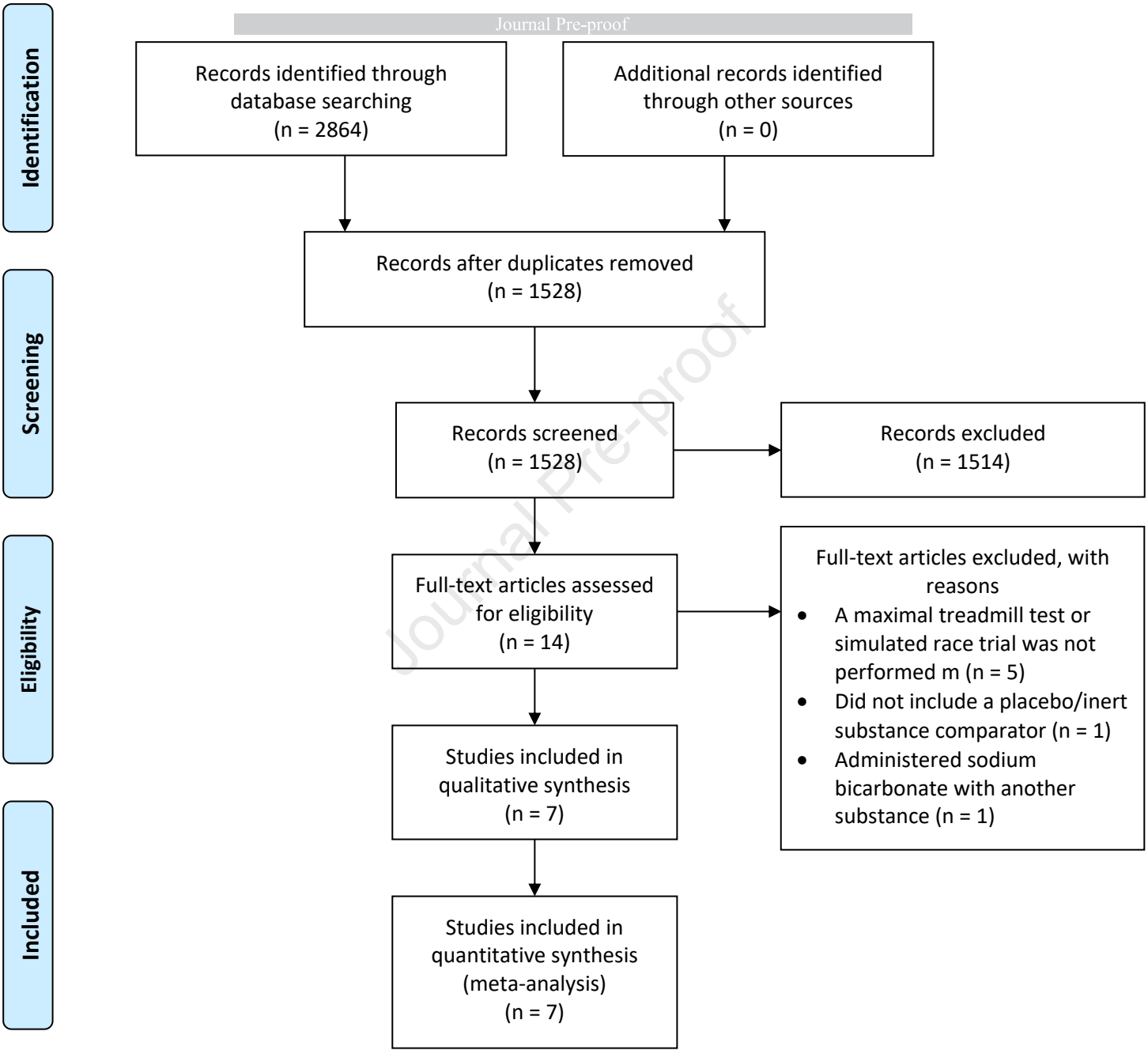
[b] breed

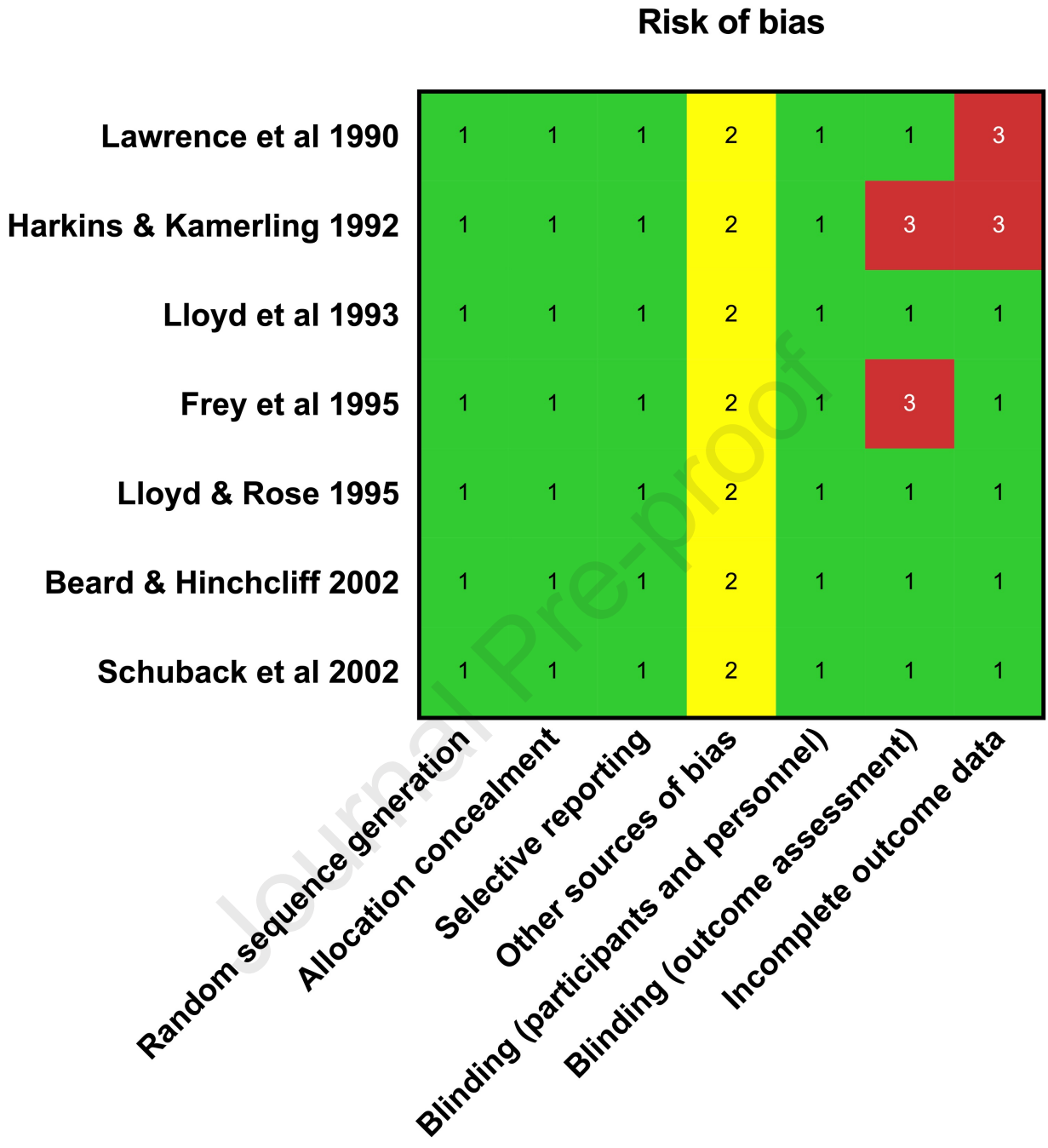
[c] Sex (Male/Female)

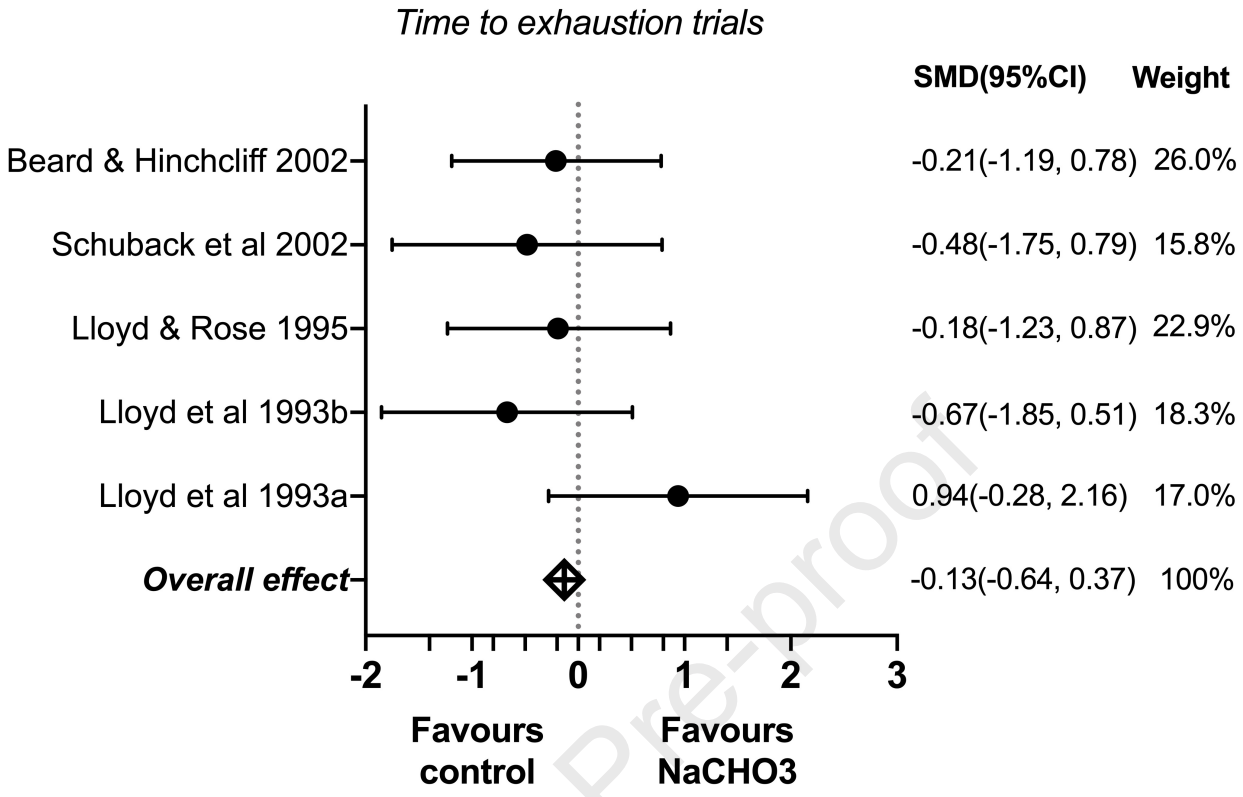
[d] Age (years)

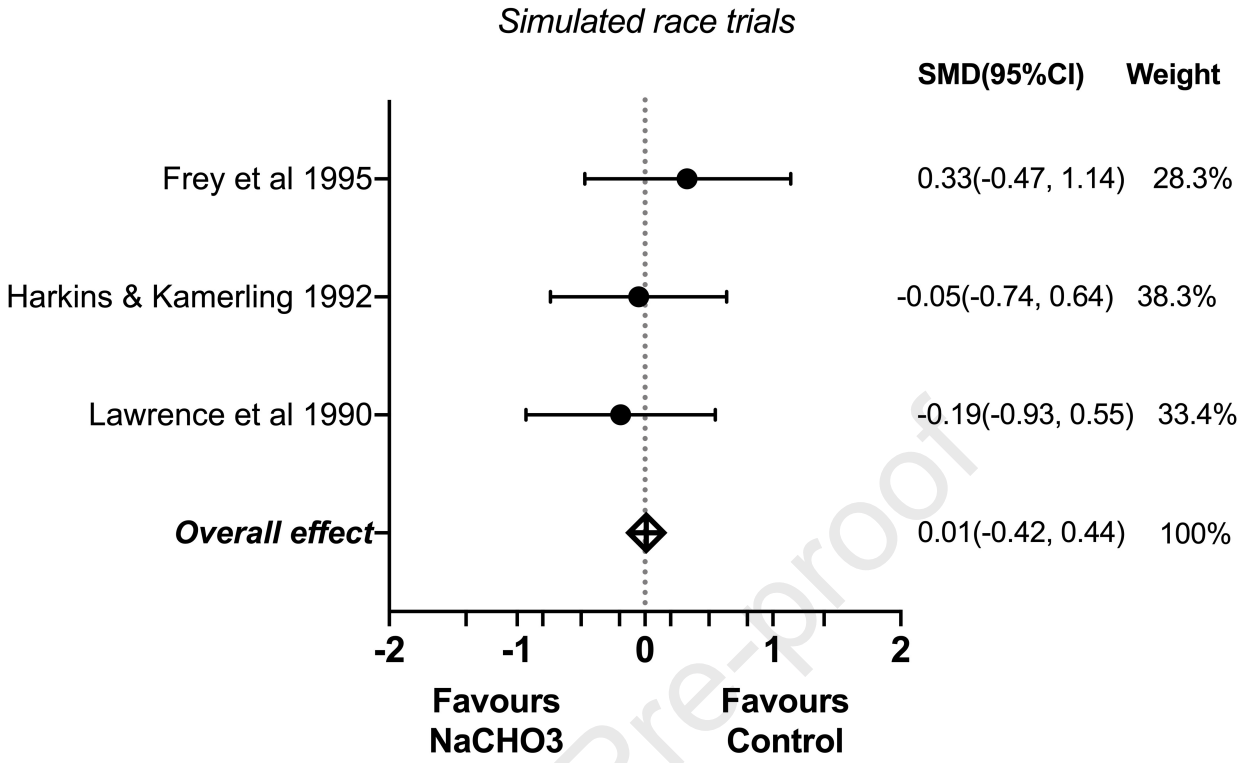
[e] Training status – trained/untrained/unknown (?)

[f] Time prior to completing exercise trial









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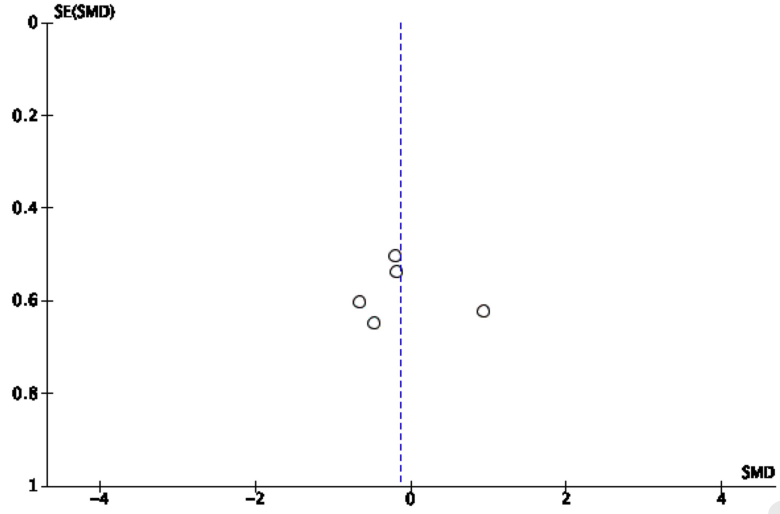

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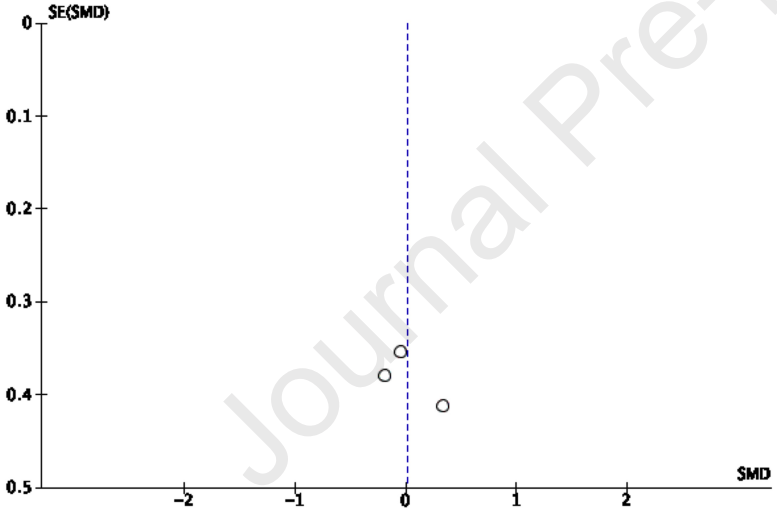

Highlights

- Race-day sodium bicarbonate ($NaHCO_3$) usage remains an issue in horseracing.
- $NaHCO_3$ administration before exercise is believed to enhance racing performance.
- However, the meta-analysis indicates that $NaHCO_3$ is not performance enhancing.

Declarations of interest

None.

Ethical Statement

This work was conducted in according with the Australian code for the care and use of animals for scientific purposes (the Code) developed by the National Health and Medical Research Council of Australia (NHMRC).