Studies of bicarbonate or citrate loading with relevance to sports specific performance

Reference	Subjects	Dose	Exercise protocol	Performance enhancement	Summary
Supplementation as support for training outcomes					
Edge et al. (2006)	16 moderately trained females (team sports and rowing) Parallel group design	400 mg/kg sodium bicarbonate for 8 wk, spread at 90 and 30 min before training. (3/wk interval training with 6-12 reps X 2 min high-intensity + 1 min rest)	Team sport relevance Cycling ● VO_{2peak} ● TTE @ 100% pre-training VO_{2peak}	 No Yes	Both placebo and bicarbonate groups increased VO_{2peak}, lactate threshold and TTE after training. The bicarbonate group had significantly greater improvements in lactate threshold (26 vs. 15%) and TTE (164 vs. 123%) than the placebo group.
Chronic supplementation protocol before an exercise test					
Douroudos et al. (2006)	24 untrained males Parallel group design	0, 300 or 500 mg/kg sodium bicarbonate in 2 divided doses per day for 5 days	Cycling ● Wingate anaerobic cycling test	Yes, in dose dependent manner	Performance increases with bicarbonate supplementation; larger increase in higher bicarbonate group (7.7 W/kg vs. 7.3 W/kg and 6.7 W/kg for 500, 300 and 0 mg/kg, respectively), in line with adjustments in resting blood bicarbonate concentration
McNaughton et al. (2001)	8 recreationally active males Unblinded cross over design	500 mg/kg sodium bicarbonate days in 4 divided doses per day for 6 d (chronic) or 500 mg/kg sodium bicarbonate 90 min pre-trial (acute)	Cycling ● 90 s TT Tests conducted on day of intake, plus following day	Yes, for both acute and chronic ingestion	Similar improvement in performance with acute and chronic bicarbonate supplementation on the first day of testing. However, performance improvement was maintained only in the chronic trial on the day after ceasing last bicarbonate dose. Increase in blood bicarbonate and pH following 1 day of supplementation that was maintained throughout study in the chronic group.
McNaughton et	8 recreationally	500 mg/kg sodium	Cycling	Yes	Greater PPO and total work at end of

Table 16.4 from © 2010 McGraw-Hill Australia / Louise Burke and Vicki Deakin, *Clinical Sports Nutrition fourth edition*. This material may not be transmitted or reproduced without the approval of the publisher. Copies of the book may be purchased at all good bookshops or online at www.mcgraw-hill.com.au.

al. (1999a)	active males Unblinded single group design with order effect	bicarbonate in 4 divided doses per day for 5 days	● 60 s TT Tests conducted pre-trial, post-supplementation and 1 month later (control trial)		chronic bicarbonate supplementation period compared to pre-trial and control test one month after supplementation. Increase in blood bicarbonate and pH following 1 day of supplementation that was maintained throughout study.
Acute supplementation before an exercise test					
Pruscino et al. (2008)	6 elite male swimmers Cross over design	300 mg/kg sodium bicarbonate 120-30 min pre-trial 6 mg/kg caffeine 45 min pre-trial	Swimming ● 2 x 200 m TT on 30 min recovery	No, for a one-off 200 m time-trial Yes, for repeat 200 m time-trials	Bicarbonate enhanced performance, with and without caffeine on repeat performance. Effect was less evident for a single effort. Majority of athletes recorded fastest TT for single and repeat performance from the combination of bicarbonate and caffeine.
Lindh et al. (2008)	9 elite male swimmers Cross over design	300 mg/kg sodium bicarbonate 90-60 min pre-trial	Swimming ● 1 x 200 m TT	Yes	Swimming TT with bicarbonate trial was 1.6% faster than placebo trial in internationally competitive swimmers.
Artioli et al. (2007)	9 national level judo athletes Cross over design	300 mg/kg sodium bicarbonate 120 min pre-trial	Judo • 3 judo specific throwing fitness tests on 5 min recovery	Yes	Bicarbonate supplementation increased total throws completed, primarily in bouts two and three.
	14 national level judo athletes Cross over design	300 mg/kg sodium bicarbonate 120 min pre-trial	• 4 Wingate anaerobic upper body tests on 3 min recovery	Yes	Greater mean power with bicarbonate supplementation in bouts three and four and greater PPO in bout four.
Bishop and Claudius (2005)	7 female team sports players Cross over	2 × 200 mg/kg bicarbonate @ 90 min and 20	Team sport simulation ● Intermittent	Yes	Bicarbonate supplementation failed to produce any effect on performance in first half, but caused trend towards

Table 16.4 from © 2010 McGraw-Hill Australia / Louise Burke and Vicki Deakin, *Clinical Sports Nutrition fourth edition*. This material may not be transmitted or reproduced without the approval of the publisher. Copies of the book may be purchased at all good bookshops or online at www.mcgraw-hill.com.au.

	design	min pre-exercise	cycling protocol of 2 × 36-min 'halves' involving repeated 2 min blocks (all-out 4 s sprint, 100 s active recovery at 35% VO_{2peak}, and 20 s of rest)		improved total work in the second half (P = 0.08). In particular, subjects completed significantly more work in 7 of 18 4-s sprints in second half in the bicarbonate trial.
Van Montfoort et al. (2004)	15 competitive male distance runners Cross over design	300 mg/kg sodium bicarbonate or 525 mg/kg sodium citrate 90–180 min pre-race	Running ● Treadmill run to exhaustion at speed designed to last 1–2 min	Yes for bicarb Perhaps for citrate	Analysis estimated likelihood of treatments increasing endurance compared to placebo by at least 0.5% (considered to be the smallest worthwhile improvement). Bicarbonate produced 2.7% enhancement of endurance (96% chance of improvement); citrate enhanced endurance by 0.5% (50% chance). Overall, authors concluded that bicarbonate is most effective, and citrate is possibly not as effective. No difference in gastrointestinal symptoms.

Table 16.4 from © 2010 McGraw-Hill Australia / Louise Burke and Vicki Deakin, *Clinical Sports Nutrition fourth edition*. This material may not be transmitted or reproduced without the approval of the publisher. Copies of the book may be purchased at all good bookshops or online at www.mcgraw-hill.com.au.

Studies of bicarbonate or citrate loading with relevance to sports specific performance

Bishop et al. (2004)	10 recreational team sports players (F) Parallel group design	0.3 g/kg sodium bicarbonate, 90 min before exercise.	Cycling ● 5 x 6 s maximal sprints, every 30 s	Yes	Compared to the control group there was a significant increase in total work for 5 sprints and peak power output in sprints 3-5.
Mero et al. (2004)	8 male + 8 female national level swimmers Cross over design (30-day washout)	300 mg/kg bicarbonate or gelatin placebo, 2 hr pre-exercise (6 d @ 20 g/d creatine also taken prior to bicarb trial)	Swimming ● 2 × 100 m swims with 10 m passive recovery	Yes (?)	Faster time for second swim with creatine/bicarb trial than with placebo: 1 s reduction in performance from first swim in placebo compared with 0.1 s drop-off in supplement trial ($P < 0.05$). Study unable to indicate individual effect of bicarbonate.
Price et al. (2003)	8 active male runners Cross over design	300 mg/kg sodium bicarbonate 1 hr pre-exercise	Team sport simulation: ● Intermittent cycling protocol of 30 min involving repeated 3-min blocks (90 s @ 40%, 60 s @ 60% $VO_{2\ max}$ and 14 s @ maximal sprint).	Yes	Significant main effect with greater PPO achieved in 14 s sprints across protocol in bicarbonate trial, whereas placebo trial showed gradual decline in PPO across time. Blood lactate levels elevated to 10–12 mmol/L by 10 min and remained elevated across rest of protocol. Such values are higher than is generally reported in team sports; thus movement patterns may not reflect the true workloads or physiological limitations of team sports.
Oopik et al. (2003)	17 male collegiate distance runners Cross over design	500 mg/kg sodium citrate 2 hr pre-exercise	Running ● 5000 m treadmill run	Yes	Performance significantly faster ($p < 0.05$) for citrate trial (1153 s) compared with placebo trial (1183 s). High risk of gastrointestinal distress. Blood lactate concentration higher after race with citrate trial. No change in RPE.
Stephens et al.	6 well-trained	300 mg/kg sodium	Cycling	No	Increase in blood lactate but no difference

Table 16.4 from © 2010 McGraw-Hill Australia / Louise Burke and Vicki Deakin, *Clinical Sports Nutrition fourth edition*. This material may not be transmitted or reproduced without the approval of the publisher. Copies of the book may be purchased at all good bookshops or online at www.mcgraw-hill.com.au.

(2002)	male cyclists/ triathletes and 1 cross country skier Cross over design	bicarbonate 2 hr pre-exercise	● 30 min @ 77% VO_{2max} + TT (~30 minutes)		in TT performance time, muscle glycogen utilisation or lactate.
Shave et al. (2001)	7 elite male + 2 elite female athletes Cross over design	500 mg/kg sodium citrate 1.5 hr pre-race	Running ● 3000 m	Yes	Performance time significantly faster ($p < 0.05$) for citrate trial (610.9 s) compared with placebo trial (621.6 s). High risk of gastrointestinal distress.
Schabort et al. (2000)	8 endurance-trained male cyclists and triathletes Cross over design	200 mg/kg, 400 mg/kg and 600 mg/kg sodium citrate 1 hr pre-exercise	Cycling ● 40 km TT including 500 m, 1 km and 2 km sprints	No	Increasing citrate dose increased blood pH but no effect on sprint performances or overall 40 km TT performance (58:46, 60:24, 61:47 and 60:02 minutes for citrate (200, 400 and 600 mg/kg doses) and placebo.
McNaughton et al. (1999b)	10 well-trained male cyclists Cross over design	300 mg/kg sodium bicarbonate 90 min pre-exercise	Cycling ● 60 min TT	Yes	14% more work completed with bicarbonate
Potteiger et al. (1996a)	8 trained male cyclists Cross over design	500 mg/kg sodium citrate 90 min pre-exercise	Cycling ● 30 km TT	Yes	Reduction in TT time (57:36 min versus 59:22). Sodium citrate raised pH values from 10 km onwards and improved power output in the initial 25 min.
Potteiger et al. (1996b)	7 well-trained male runners Cross over design	300 mg/kg sodium bicarbonate and 500 mg/kg sodium citrate 2 hr pre-exercise	Running ● 30 min @ LT + TTE @ 110% LT	No	Both citrate and bicarbonate supplementation increased blood pH during steady-state run. No differences in run to exhaustion: 287 s, 172.8 s, 222.3 s for bicarbonate, citrate and placebo respectively.
Tiryaki and	11 collegiate	300 mg/kg sodium	Running	No	No performance effect despite significant

Table 16.4 from © 2010 McGraw-Hill Australia / Louise Burke and Vicki Deakin, *Clinical Sports Nutrition fourth edition*. This material may not be transmitted or reproduced without the approval of the publisher. Copies of the book may be purchased at all good bookshops or online at www.mcgraw-hill.com.au.

Studies of bicarbonate or citrate loading with relevance to sports specific performance

Atterbom (1995)	female runners + 4 trained non-athletes Cross over design	citrate or sodium bicarbonate 2.5 hr pre-exercise	● 600 m		changes to acid–base status.
Bird et al. (1995)	10 trained middle-distance runners Cross over design	300 mg/kg sodium bicarbonate (half at 120 and half at 90 min pre-exercise)	Running ● 1500 m	Yes	Performance in bicarbonate trial improved compared with placebo trial (253.9 versus 256.8 s, $p < 0.05$)
Pierce et al. (1992)	7 male collegiate swimmers Cross over design	200 mg/kg bicarbonate, sodium chloride placebo or control, 1 hr pre-exercise	Swimming ● 100 yards freestyle ● 2 × 200 yards swims 20 min recovery between each race (simulation of competition program)	 No No	No difference in swim times between trials.
McNaughton and Cedaro (1991)	5 highly trained male rowers Cross over design	300 mg/kg sodium bicarbonate 95 min pre-exercise	Rowing ● 6 min maximum effort on ergometer	Yes	Increased work and distance rowed in bicarbonate trial (1861 m versus 1813 m). Increased lactate levels.
Goldfinch et al. (1988)	6 trained male runners Cross over design	400 mg/kg sodium bicarbonate 60 min pre-exercise	Running ● 400 m	Yes	Improved running time (56.94 s versus 58.63 [placebo] and 58.46 [control]). Elevated post-exercise values for pH and base excess.
Gao et al. (1988)	10 male collegiate swimmers	250 mg/kg sodium bicarbonate 1 hr pre-exercise	Swimming ● 5 × 100 yard swim with 2 min rest	Yes	Faster times in 4th and 5th swim ($p < 0.05$). Supplementation also associated with higher post-race blood lactate

Table 16.4 from © 2010 McGraw-Hill Australia / Louise Burke and Vicki Deakin, *Clinical Sports Nutrition fourth edition*. This material may not be transmitted or reproduced without the approval of the publisher. Copies of the book may be purchased at all good bookshops or online at www.mcgraw-hill.com.au.

	Cross over design		(simulation of training program)		concentrations.
Wilkes et al. (1983)	6 varsity track male athletes Cross over design	300 mg/kg sodium bicarbonate 2.5 hr pre-exercise	Running ● 800 m	Yes	Improved running time (2:02.9 min *vs* 2:05.1 [placebo] and 2:05.8 [control]). Elevated post-exercise values for pH, lactate and blood bicarbonate.

PO = power output, TTE = time to exhaustion, PPO = peak power output, RPE = rating of perceived exertion, TT = time trial, LT = lactate threshold

References

Artioli GG, Gualano B, Coelho DF, Benatti FB, Gailey AW & Lancha AH, Jr. (2007) Does sodium-bicarbonate ingestion improve simulated judo performance? *Int J Sport Nutr Exerc Metab* **17**, 206-217.

Bird SR, Wiles J & Robbins J (1995) The effect of sodium bicarbonate ingestion on 1500-m racing time. *J Sports Sci* **13**, 399-403.

Bishop D & Claudius B (2005) Effects of induced metabolic alkalosis on prolonged intermittent-sprint performance. *Med Sci Sports Exerc* **37**, 759-767.

Bishop D, Edge J, Davis C & Goodman C (2004) Induced metabolic alkalosis affects muscle metabolism and repeated-sprint ability. *Med Sci Sports Exerc* **36**, 807-813.

Douroudos, II, Fatouros IG, Gourgoulis V, Jamurtas AZ, Tsitsios T, Hatzinikolaou A, Margonis K, Mavromatidis K & Taxildaris K (2006) Dose-related effects of prolonged NaHCO3 ingestion during high-intensity exercise. *Med Sci Sports Exerc* **38**, 1746-1753.

Edge J, Bishop D & Goodman C (2006) Effects of chronic NaHCO3 ingestion during interval training on changes to muscle buffer capacity, metabolism, and short-term endurance performance. *J Appl Physiol* **101**, 918-925.

Gao JP, Costill DL, Horswill CA & Park SH (1988) Sodium bicarbonate ingestion improves performance in interval swimming. *Eur J Appl Physiol Occup Physiol* **58**, 171-174.

Goldfinch J, Mc Naughton L & Davies P (1988) Induced metabolic alkalosis and its effects on 400-m racing time. *Eur J Appl Physiol Occup Physiol* **57**, 45-48.

Lindh AM, Peyrebrune MC, Ingham SA, Bailey DM & Folland JP (2008) Sodium bicarbonate improves swimming performance. *Int J Sports Med* **29**, 519-523.

McNaughton L & Cedaro R (1991) The effect of sodium bicarbonate on rowing ergometer performance in elite rowers. *The Australian Journal of Science and Medicine in Sport* **23**, 66-69.

McNaughton L, Dalton B & Palmer G (1999b) Sodium bicarbonate can be used as an ergogenic aid in high-intensity, competitive cycle ergometry of 1 h duration. *Eur J Appl Physiol Occup Physiol* **80**, 64-69.

McNaughton L, Backx K, Palmer G & Strange N (1999a) Effects of chronic bicarbonate ingestion on the performance of high-intensity work. *Eur J Appl Physiol Occup Physiol* **80**, 333-336.

McNaughton L & Thompson D (2001) Acute versus chronic sodium bicarbonate ingestion and anaerobic work and power output. *J Sports Med Phys Fitness* **41**, 456-462.

Table 16.4 from © 2010 McGraw-Hill Australia / Louise Burke and Vicki Deakin, *Clinical Sports Nutrition fourth edition*. This material may not be transmitted or reproduced without the approval of the publisher. Copies of the book may be purchased at all good bookshops or online at www.mcgraw-hill.com.au.

Studies of bicarbonate or citrate loading with relevance to sports specific performance

Mero AA, Keskinen KL, Malvela MT & Sallinen JM (2004) Combined creatine and sodium bicarbonate supplementation enhances interval swimming. *J Strength Cond Res* **18**, 306-310.

Oopik V, Saaremets I, Medijainen L, Karelson K, Janson T & Timpmann S (2003) Effects of sodium citrate ingestion before exercise on endurance performance in well trained college runners. *Br J Sports Med* **37**, 485-489.

Pierce EF, Eastman NW, Hammer WH & Lynn TD (1992) Effect of induced alkalosis on swimming time trials. *J Sports Sci* **10**, 255-259.

Potteiger JA, Nickel GL, Webster MJ, Haub MD & Palmer RJ (1996a) Sodium citrate ingestion enhances 30 km cycling performance. *Int J Sports Med* **17**, 7-11.

Potteiger JA, Webster MJ, Nickel GL, Haub MD & Palmer RJ (1996b) The effects of buffer ingestion on metabolic factors related to distance running performance. *Eur J Appl Physiol Occup Physiol* **72**, 365-371.

Price M, Moss P & Rance S (2003) Effects of sodium bicarbonate ingestion on prolonged intermittent exercise. *Med Sci Sports Exerc* **35**, 1303-1308.

Pruscino CL, Ross ML, Gregory JR, Savage B & Flanagan TR (2008) Effects of sodium bicarbonate, caffeine, and their combination on repeated 200-m freestyle performance. *Int J Sport Nutr Exerc Metab* **18**, 116-130.

Schabort EJ, Wilson G & Noakes TD (2000) Dose-related elevations in venous pH with citrate ingestion do not alter 40-km cycling time-trial performance. *Eur J Appl Physiol* **83**, 320-327.

Shave R, Whyte G, Siemann A & Doggart L (2001) The effects of sodium citrate ingestion on 3,000-meter time-trial performance. *J Strength Cond Res* **15**, 230-234.

Stephens TJ, McKenna MJ, Canny BJ, Snow RJ & McConell GK (2002) Effect of sodium bicarbonate on muscle metabolism during intense endurance cycling. *Med Sci Sports Exerc* **34**, 614-621.

Tiryaki GR & Atterbom HA (1995) The effects of sodium bicarbonate and sodium citrate on 600 m running time of trained females. *J Sports Med Phys Fitness* **35**, 194-198.

Van Montfoort MC, Van Dieren L, Hopkins WG & Shearman JP (2004) Effects of ingestion of bicarbonate, citrate, lactate, and chloride on sprint running. *Med Sci Sports Exerc* **36**, 1239-1243.

Wilkes D, Gledhill N & Smyth R (1983) Effect of acute induced metabolic alkalosis on 800-m racing time. *Med Sci Sports Exerc* **15**, 277-280.

Table 16.4 from © 2010 McGraw-Hill Australia / Louise Burke and Vicki Deakin, *Clinical Sports Nutrition fourth edition*. This material may not be transmitted or reproduced without the approval of the publisher. Copies of the book may be purchased at all good bookshops or online at www.mcgraw-hill.com.au.

Last Updated: 20/08/2009