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Caffeine and Sodium Bicarbonate Supplementation Improves Repeated High-Intensity Exercise Performance

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A B S T R A C T

The effect of caffeine and sodium bicarbonate (NaHCO3) supplementation as recovery promoting nutritional aids after high-intensity exhaustive exercise performance has sparsely studied. This study tests the hypothesis that when caffeine or sodium bicarbonate ($NaHCO_3$) are ingested after completion of exhaustive high-intensity exercise, a positive performance effect would be observed in subsequent high-intensity exercise. Healthy males (n=20) were assigned in a single-blind, randomized, counter-balanced design to ingest either 0.3 $g.kg^{-1}$ body wt of NaHCO3 or 6 $mg.kg^{-1}$ body wt of caffeine or a placebo after completion of an all-out 2000m rowing exercise (EX1). Participants rested for 90 min before engagement in a second 2000m rowing bout (EX2). Performance in EX2 was reduced ($p<0.05$) by 5.3±7.0 s compared to EX1 within the placebo trials. However, EX2 performance was unchanged ($p>0.05$) when $NaHCO_3$ was consumed during the recovery period. In the caffeine trial EX2 performance was 2% better ($p<0.05$) than the second row within the placebo trial (456.0±17.8 vs. 464.6±21.6 s, respectively). The commencement of EX2 was associated with elevated blood [lactate], with $NaHCO_3$ trials eliciting the highest [lactate], and reduced blood [glucose], apart from caffeine whereby blood [glucose] was maintained. No differences in heart rate of rate of perceived exertion was found between all trials. Caffeine improved same-day performance recovery in 2000m rowing relative to placebo, $NaHCO_3$ supplementation maintained same-day rowing performance. Therefore, these supplements may potentially be beneficial as recovery aids in repeated high-intensity exercise scenarios.

Key words: *2000m rowing, recovery, caffeine, sodium bicarbonate*

Introduction

Recovery of performance from high-intensity exercise is imperative for athletes to maximize quality of training and their competitive potential. Swimmers, rowers and multi-event athletes engage in numerous high-intensity sessions within a single day, often without sufficient time between exercise bouts to effectively digest whole foods such as carbohydrate and protein[1]. Thus, currently, there is a dearth of research assessing the efficacy of nutritional recovery strategies in repeated high-intensity exercise scenarios where fatigue may be associated factors such as disturbances in ion homeostasis or muscle such as 2000m rowing time-trial[2,3].

2000m rowing is highly anaerobic and aerobic in nature, it is unique to both cycle ergometry and treadmill running as it combines both static and dynamic components and simultaneous activation of the arms, legs and trunk demonstrated that thirty minutes after completion of a 2000m row arterial [K^+] remained below resting values, as did pH, whereas plasma [lactate] and [glucose] remained elevated above baseline levels[4,5]. Thus, metabolic disturbances still persisted thirty minutes after completion of the exercise. 2000m rowing has been shown to significantly reduce both blood pH, to ~7.1 and HCO_3^- (4–fold). Blood [lactate] will also rise at least ten-fold, which attests to a high level of physiological stress[6]. Collectively, a 2000m rowing test appears to be a relevant experimental model to taxa the ion regulatory system in human skeletal muscle.

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The ergogenic effects of caffeine are well documented. However, caffeine's utility for exercise that demands high levels of both anaerobic and aerobic elements remains equivocal and a key area of interest[7]. In relation to rowing, some studies demonstrated that caffeine ingestion resulted in a 1.2% and 0.7% performance improvement in 2000m rowing for elite men and women, respectively[8,9]. Furthermore, caffeine was able to prolong time to exhaustion during high intensity cycling from 247s to 296s[10]. Contrasting this, some study failed to find any performance benefit from caffeine supplementation on 2000m rowing performance[11]. To date, studies have only examined the efficacy of caffeine as a recovery supplement when combined with carbohydrate after long-duration low-intensity glycogen depleting exercise[12,13]. Benefits of caffeine ingestion were apparent for long-term glycogen re-synthesis and performance in subsequent high-intensity intermittent shuttle running[12,13].

$NaHCO_3$ supplementation has been shown to ergogenic for exercise protocols consisting of a high anaerobic component, lasting between 1–7 minutes[14]. The rate of H^+ efflux from the muscle cells is dependent on the bicarbonate (HCO_3–) concentration surrounding the interstitium[15]. Ingestion of 0.3 mg.kg^{-1} will increase blood [HCO_3^-] by ~6mmol.L^{-1} with a typical error of 7%[14]. Some studies demonstrated that blood HCO_3^- is reduced markedly further when exercise combines both the arms and legs[16]. Therefore, $NaHCO_3$ supplementation post-exercise might serve as an important means of replenishing the diminished blood HCO_3^- reservoir.

To date, there is limited research comparing caffeine and $NaHCO_3$ directly for the same exercise protocol; some studies showed that mean power during a 2000m row was increased by 2.3% for the caffeine trials and no benefits was observed for $NaHCO_3$ ingestion[14]. Yet, some studies demonstrated that both supplements elicited similar performance benefits for 3 km cycle time trials[17]. No previous investigations have analyzed the effects of post-exercise $NaHCO_3$ supplementation on performance recovery, nor compared $NaHCO_3$ to caffeine as acute recovery agents. The purpose of this investigation is to explore the potential benefits of post-exercise $NaHCO_3$ and caffeine ingestion upon performance recovery in repeated 2000m rowing. The Hypothesis was two-fold; the initial 2000m rowing bout would cause a reduction in subsequent rowing performance and that post-exercise supplementation of either caffeine or $NaHCO_3$ would have a positive effect on secondary rowing performance relative to placebo.

Materials and Methods

Participants

Twelve physically active males (X±SD: age 21.4±1.6 years, body mass 79.3±8.3 kg, height 179.9±6.2 cm) familiar with rowing ergometry, volunteered to participate in this study. The experimental procedures, potential benefits and associated risks were explained in detail to the subjects before all participants provided their written informed consent to participate. All procedures employed were approved by the University of Exeter Ethics Committee.

Study design

Subjects attended the laboratory on 4 separate occasions, separated by 7–14 days, this was deemed a sufficient washout and recovery period. Participants were asked to report in a fully hydrated state and ≥ 2 postprandial. The tests were carried out at the same time of the day (±1h) for each individual. Some studies stated that the benefits of caffeine supplementation are attenuated in habitual caffeine users, therefore all subjects were non-habitual caffeine users and refrained from strenuous exercise, alcohol consumption and common caffeine-containing substances 72 h prior to the experiment[18].

On the initial visit, participants engaged in a familiarization 2000m row, firstly performing a light 500m warmup, which was subsequently standardized for each experimental visit, rested for two minutes, before performing a 2000m maximum 'all-out' row. Subjects were then assigned into experimental groups to receive $NaHCO_3$, caffeine or placebo (plain flour) in a single blind, randomized, counter balanced fashion via a Latin square.). 2000m rowing performance has a standard measurement error of <1%[19]. This high level of reliability is important so that any observation of supplement induced improvements or decrements in performance are likely to be related to the intervention rather than the variation within the exercise protocol.

Experimental protocol

During the 3 subsequent experimental visits, participants engaged in the standardized 500m warmup, before performing a maximal 2000m row (EX1), participants then had 90 min of passive recovery before engaging in the second 2000m row (EX2).

Immediately after the completion of EX1 subjects were given the supplements, either $NaHCO_3$ (0.3 g.kg^{-1} body wt; 23.8±2.5 g), caffeine or placebo (6 mg.kg^{-1} body wt; 476±49.2 mg)[20,21]. Caffeine was matched for color and volume with plain flour. All supplements were taken orally as gelatine capsules, under the supervision of the experimenter and with 7 ml.kg^{-1} of water, drank *ad libitum*. $NaHCO_3$ supplementation protocol began immediately after completion of EX1, capsules (20–24) were ingested in a staggered manor over a 20 min period to minimize gastro-intestinal distress[14]. Caffeine and placebo were administered as a single capsule, 20 minutes after the completion of EX1 (Figure 1).

Rowing protocol

EX1 and EX2 were performed on Concept II rowing ergometer (Concept 2 Inc., Vermont, USA). Standard error of measurement 0.6%[22]. The most widely used ergometer for training purposes[23]. Subjects were given no technical advice; they were asked simply to perform the test

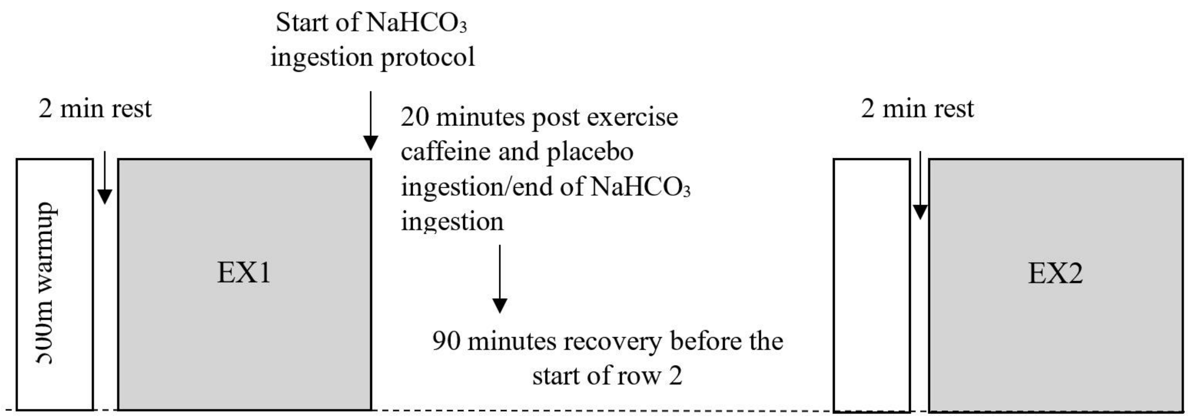


Fig. 1. Schematic representation of the repeated 2000m rowing and supplementation. protocol.

in the fastest possible time. To minimize effects of pacing strategy and experimenter bias subjects and experimenter could only see the distance remaining. Participants were given standardized verbal encouragement from the experimenter. The resistance for each row was set to level six. Time to completion was recorded, as well as the time of each 500m split. EX2 began exactly 90 min post EX1.

Physiological measures

Each experimental visit required ten fingertip capillary blood samples (5 per exercise bouts), the first drop of blood was removed and then 300 µL of blood was collected in heparin-fluoride coated [glucose] Microvette CB 300 tubes (Sarstedt Ltd, UK): Before warmup; immediately after; 1, 3 and 5 min post completion. Blood samples were immediately analyzed for blood [lactate] and [glucose], using (YSI 2500 Lactate Analyzer, YSI, UK), coefficient of variation <2%[21].

Upon arrival, Subjects were fitted with heart rate (HR) monitors (Polar Electro, Finland). HR was monitored continuously throughout each rowing protocol via short-range radiotelemetry. Rate of perceived exertion (RPE) using the Borg scale was recorded[24], during both rows at 500, 1000, 1500 and 2000m.

Statistical analysis

Difference in performance time between EX1 and EX2 within the respective supplementation groups was ascertained via paired-samples t-tests. Differences in performance between EX1 (EX1NaCHO$_3$ vs. EX1caffeine vs. EX11placebo) and EX2 (EX2NaCHO$_3$ vs. EX2caffeine vs. EX2placebo) were analyzed separately using one-way ANOVA with repeated measured. 500m split times between EX1 and EX2 for each supplement were compared using two-way repeated measures ANOVA (test 2 x split 4). Furthermore, absolute reliability of baseline rowing performance was assessed via coefficient of variation (SD/X*100).

Two-way repeated measures ANOVA (test x time) compared the within group differences in blood [glucose], [lactate], HR and RPE variables between EX1 and EX2 for each supplement, this was also employed to determine the between group comparisons for the supplements during EX2 (supplement x time).

The origin of significant main and/or interaction effects were further analyzed via Bonferroni adjusted paired t-tests, to reduce level of significance and attenuate the chance of type 1 errors. All data will be analyzed using SPSS (version 21). Statistical significance was accepted at p<0.05. Results are presented as X±SD.

Results

Performance

No differences in time to completion of EX1 were observed between the $NaHCO_3$, caffeine and placebo trials (461.0±21.8, 459.0±19.8, 459.3±20.6 s; p>0.05, respectively). Coefficient of variation for the baseline row was 1.1% (~5 s). The placebo group displayed a 1.2% (5.3±7 s; $t_{(11)}$=–2.6, p<0.05) reduction in performance in EX2 compared to EX1. However, $NaHCO_3$ and caffeine trials showed no difference in performance between EX1 and EX2 (p>0.05) (Figure 2). Moreover, performance between supplements in EX2 showed that the caffeine trials demonstrated a 1.9% faster performance time than the placebo trials (456.0±17.8, 464.6±21.6 s; p<0.05, respectively) (Figure 2).

In the placebo trial the first 500m were significantly slower in EX2 compared to EX1 (111.6±6.4 vs. 106.6±5.4s; p<0.05). No differences between the remaining splits were observed. Within the caffeine trial there was no significant differences between 500m splits at any time point. Whereas, within the $NaHCO_3$ trial performance was slower in the first 500m (107.4±6.8 vs. 110.8±6.8 s; p<0.05) but the final 500m was faster (118.7±6.1 vs. 115.7±6.8; p<0.05) during EX2 (Figures 3a–c).

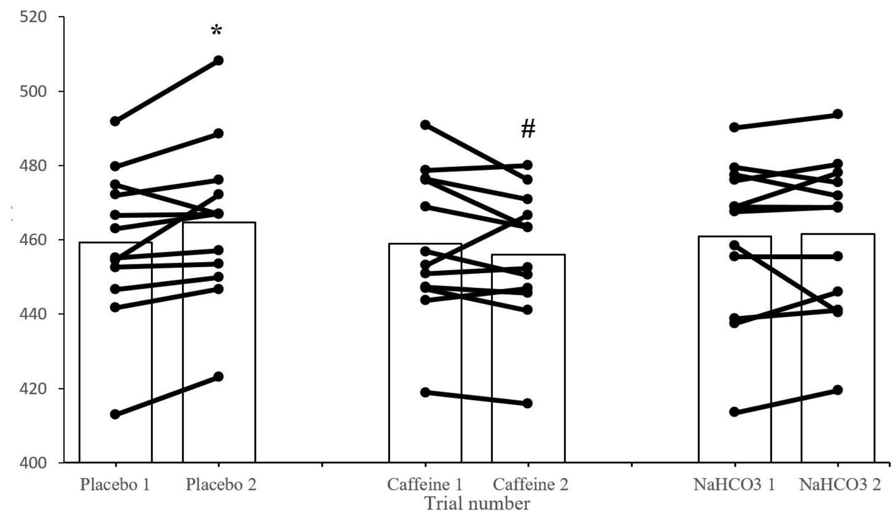
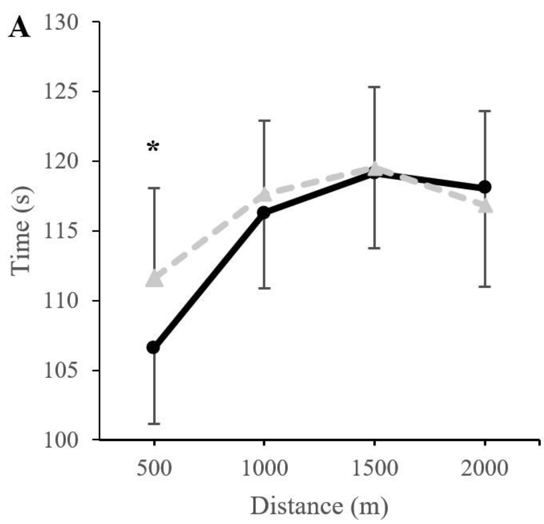
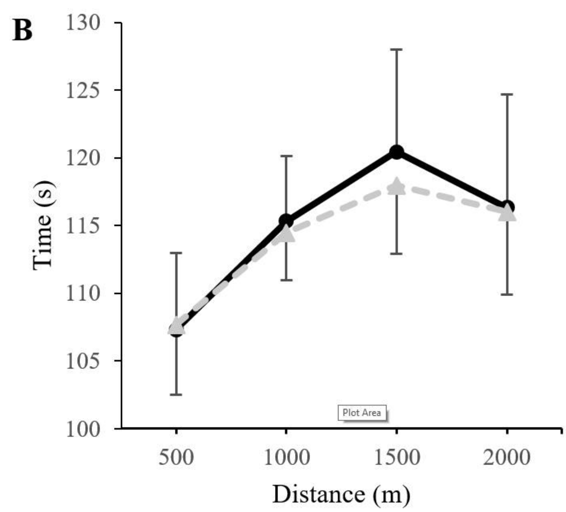


*Fig. 2. Performance time in EX1 and EX2. Solid lines represent individual performance times. Bars represent mean performance time. *Significant difference compared to placebo EX1. #Significant difference compared to placebo EX2. p<0.05.*





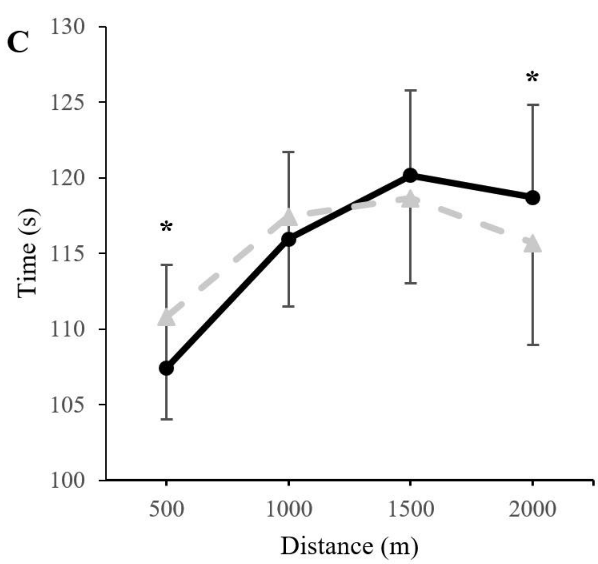


*Fig. 3. a) 500m split times for each supplement – placebo. Solid line represents EX1, dashed line represents EX2. *Significantly different compared to EX1. p<0.05.*

*Fig. 3. b) 500m split times for each supplement – caffeine. Solid line represents EX1, dashed line represents EX2. *Significantly different compared to EX1. p<0.05.*

*Fig. 3. c) 500m split times for each supplement – NaHCO3. Solid line represents EX1, dashed line represents EX2. *Significantly different compared to EX1. p<0.05.*

Blood variables

No differences were apparent in plasma [lactate] at all sampling points during EX1. However, [lactate] was elevated prior to the start of EX2 for all supplement groups compared to initial baseline measurements (1.83±0.55, 1.74±0.44 & 2.5±0.84 mmol·L^{-1}; p<0.05, for placebo, caffeine & $NaHCO_3$ respectively.) Moreover, the $NaHCO_3$ trials elicited a greater [lactate] over and above that of the placebo and caffeine trials (p<0.05) (Figure 4a). Within the placebo trials [lactate] was lower (p<0.05) immediately after completion of EX2 compared to EX1. The caffeine trial displayed no difference (p>0.05) between EX1 and EX2. Throughout all sampling points, the $NaHCO_3$ trial exhibited higher plasma [lactate] in EX2 compared to EX1. Moreover, between supplement comparisons demonstrated that at each sampling point during EX2 both the $NaHCO_3$ and caffeine trials displayed significantly higher [lactate] compared to the placebo trials (p<0.05) (Figure 4b).

Blood [glucose] was similar throughout all sampling points (p>0.05) during EX1. Prior to the start of EX2, [glucose] was significantly reduced within both the placebo and $NaHCO_3$ trials compared to the initial resting values (placebo: 4.5±0.6 vs. 4.1±0.7; $NaHCO_3$: 4.7±0.7 vs. 3.8±0.5 mmol·L^{-1}; p<0.05). Baseline [glucose] between the caffeine trials remained similar. Furthermore, blood [glucose] were significantly elevated (p<0.05) at all sampling points in the caffeine trials compared to the placebo and $NaHCO_3$ trials throughout EX2 (Figure 5).

Heart rate and rate of perceived exertion

There were no significant differences in HR at all recording points both during exercise and throughout recovery (Figure 6). Mean HR_{max} at the end of 2000m rowing for all trials was 178±1.2 b·min^{-1}. However, resting HR within the caffeine group was higher prior to the start of EX2 bout compared to the start of EX1 (67±6 vs. 74±7 b·min^{-1}; p<0.05).

RPE for both the caffeine and placebo trials remained similar at all recording points, there was no significant differences between EX1 and EX2 nor between the supplements (Figure 7).

Discussion

The study demonstrated that 2000m rowing performance was impaired by 5.3s, when repeated after a 90 min recovery interval, when no active supplement was ingested. However, the major findings of current investigation were that ingestion of $NaHCO_3$ throughout the recovery period, resulted in maintenance of subsequent rowing performance with only a 0.6s difference between EX1 and EX2. Moreover, supplementation with caffeine during the rest period resulted in a non-significant trend towards an increase in performance compared to EX1, with EX2 averaging a 3s faster time. Intriguingly, when EX2 in the caffeine trials was compared to EX2 in the placebo trials there was a significant difference in performance of ~9s (Figure 2) which exceeded the coefficient of variation of 1.1% (5.1s) found between the baseline rows. These observations support the hypotheses, as 2000m

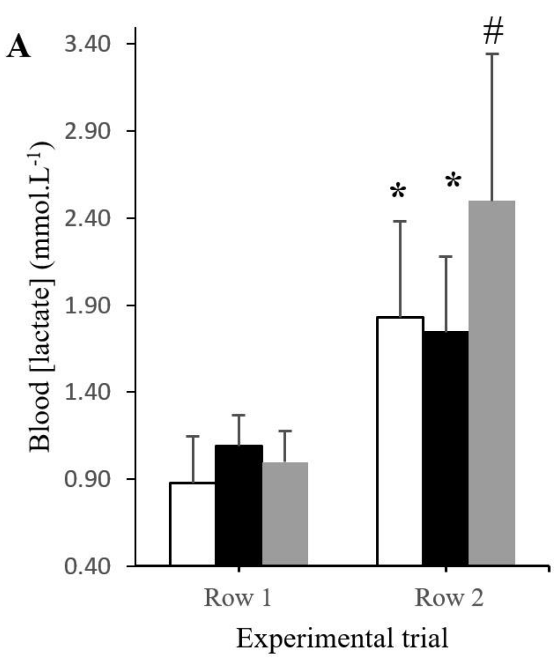


*Fig. 4. a) Resting lactate prior to the start of EX1 and EX2. Placebo (white/triangles), caffeine (black/circles), NaHCO3 (grey/squares). *Significantly different compared to EX1. #Significantly different compared to placebo. p<0.05.*

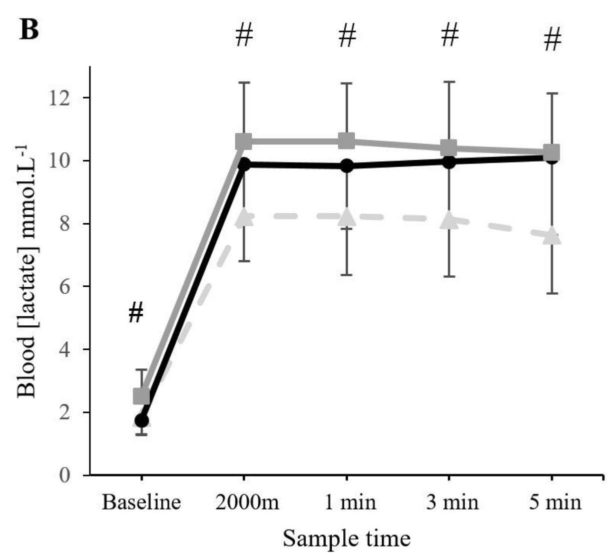


*Fig. 4. b) Comparison of lactate during the second row between all the supplements. Placebo (white/triangles), caffeine (black/circles), NaHCO3 (grey/squares). *Significantly different compared to EX1. #Significantly different compared to placebo. p<0.05.*

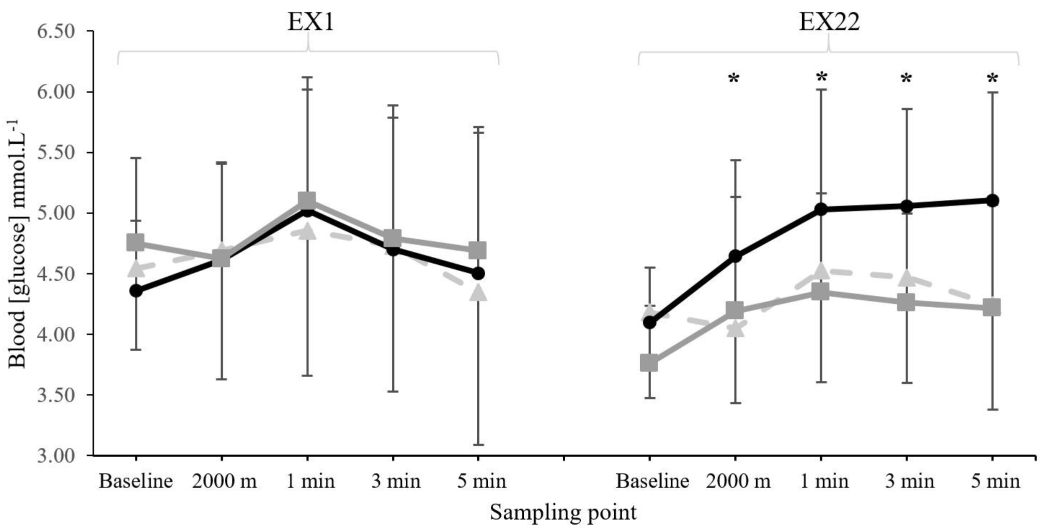


*Fig. 5. Blood [glucose] for all supplements for EX1 and EX2. Placebo (dashed/triangles), caffeine (black/circles), NaHCO3 (grey/squares). *Significantly different from placebo and NaHCO3. p<0.05.*

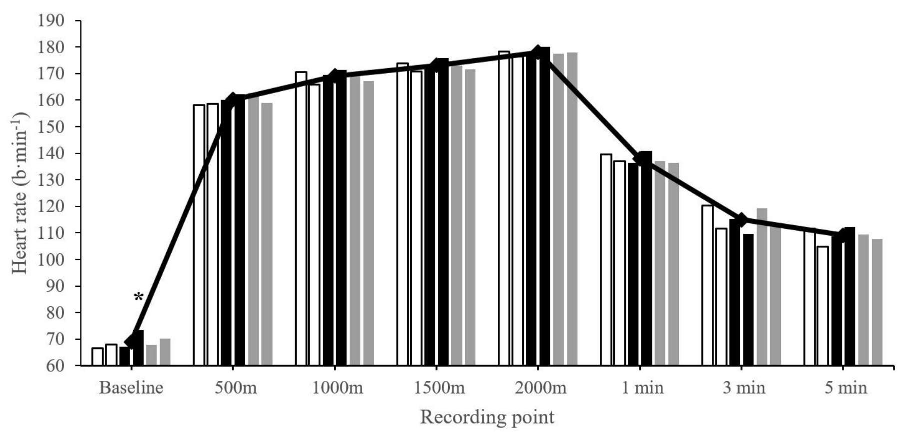


*Fig. 6. Mean heart rate before, during and after 2000m rowing protocols. Bars represent each supplement; placebo (white), caffeine (black), NaHCO3 (grey). Solid line represents the overall mean response. EX1 is represent by bars closest to the Y-axis. *Significantly different from caffeine at baseline during EX1 (p<0.05).*

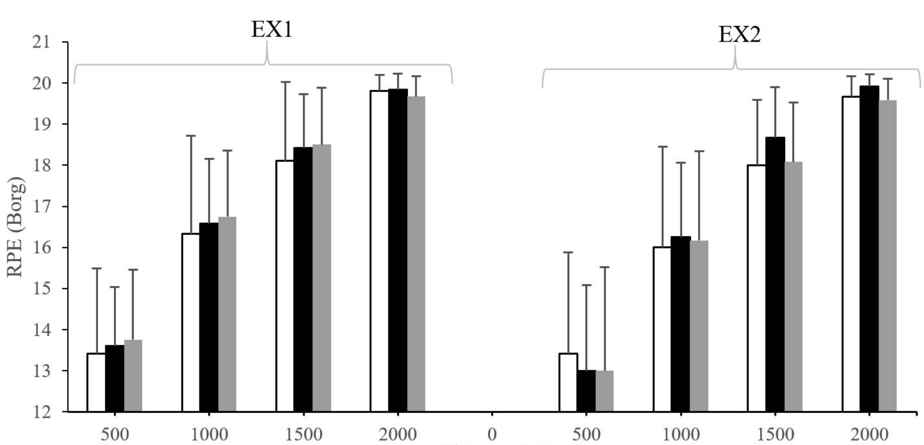


Fig. 7. Rate of perceived exertion. Placebo (white), caffeine (black), NaHCO3 (grey).

rowing was sufficient to induce performance inhibiting fatigue for at least 90 min following completion. Furthermore, both caffeine and $NaHCO_3$ elicited a performance recovery benefit compared to placebo supplementation. This study demonstrates for the first time, that post-exercise caffeine supplementation elicits a beneficial effect on performance recovery. Furthermore, that post-exercise $NaHCO_3$ ingestion can maintain high-intensity exercise performance relative to the previous performance, when the body is in a state of metabolic fatigue.

Finally, the analysis of 500m split times for the placebo trials suggests that previous exercise had a negative impact on the initial stages of subsequent exercise, as the performance decrements during EX2 occurred in the first 500m. $NaHCO_3$ trials also showed a reduction in time through the first 500m, but this was compensated for by a faster last quarter of the time trial. It can be speculated that $NaHCO_3$ provided additional capacity towards the latter stages. Finally, within the caffeine trials, there was no significant differences observed at any of the 500m split times in performance. Therefore, caffeine supplementation during recovery provided the greatest potential for consistency between EX1 and EX2 (Figure 3).

Most of the research assesses the ability of pre-exercise caffeine and $NaHCO_3$ supplementation on improving performance capacity[25,26]. Furthermore, most research on caffeine and recovery relates to its ability to augment muscle glycogen resynthesis when co-ingested with carbohydrate after long-duration, low-intensity, glycogen depleting exercise[12,13], which not appropriate to the present study. Thus, direct comparison with previous literature is difficult. However, in one study caffeine and $NaHCO_3$ administration improved high intensity intermittent exercise performance that was preceded by intense arm cranking to induce metabolic disturbance[27], which supports the findings in the present study.

Regarding physiological explanations for the caffeine and $NaHCO_3$ induced ergogenic effects, they are likely to be multifaceted. The plasma [lactate] remained elevated at the onset of EX2 (Figure 4a), which suggests that the body had not fully recovered from the previous 2000m exercise and that ion homeostasis had yet to have been re-established[28]. Moreover, the $NaHCO_3$ induced greater plasma [lactate] compared to the caffeine or placebo trials, which may be due to higher glycolytic activity due to the expected higher buffering of H^+ at muscular level (REF). Also, it may be speculated that this phenomenon was caused by an augmented activation of the monocarboxylate transporters, increasing H^+ and lactate efflux during the recovery period[29], due to the influence of an increasing muscle-to-blood lactate gradient imposed by the $NaHCO_3$ supplementation[30]. This postulated augmented muscle lactate and H^+ regulation might also increase the activation of the Na^+/K^+ pumps leading to a more rapid restoration of the sarcolemma membrane potential[31]. This can hypothetically be a potential mechanism for the maintenance of performance observed within the $NaHCO_3$ trials. Further, some authors suggested that pre-exercise residual acidosis, might improve muscle vasodilation and perfusion at the onset of subsequent exercise[32]. Moreover, some authors further illustrate this paradoxical phenomenon, as performance in supramaximal exercise was improved when blood lactate was 2.5mmol.L^{-1} compared to 1.1mmol.L^{-1} [33]. It is suggested that acidosis may enhanced sarcolemma excitability via a reduction in chlorine (Cl^-) permeability, thereby reducing the magnitude of the Na^+ influx required to generate an action potential[12]. The greater levels of lactate observed after completion of EX2 for the caffeine trials might be associated with an increased rate of glycolysis due to the improved fatigue resistance induced by the caffeine supplementation, which is in accordance with previous findings[27].

Prior to the onset of EX2, both placebo and $NaHCO_3$ trials had lower blood [glucose] than baseline measurements. However, blood [glucose] in the caffeine trials was unchanged. The increase in blood glucose during the caffeine trial (Figure 5) is expected as the rate of catecholamine production is proportional to the amount of active muscle mass and exercise intensity[34]. Rowing therefor provides extremely favorable stimuli for catecholamine production and parallel increase in hepatic glucose output. Intuitively, an up-regulation in circulating catecholamines, might be in part responsible for the improvement in performance observed in EX2in the caffeine trial in comparison to placebo. As catecholamines are known to increase rates of glycolysis[35] and increase the activation of the Na^+/K^+ pump[36]. Recovery from previous exercise might be related to a higher blood [glucose] minimizing the deterioration of the electrical properties of the sarcolemma and maintaining action potential propagation[20]. Same study also demonstrated that ingestion of caffeine prior to high-intensity knee extensions reduced the accumulation of K^+ in the interstitium, which should facilitate improved exercise capacity[20]. Intriguingly, an insulin increase caused by augmented blood [glucose] induced by caffeine ingestion might lead to enhanced affinity of the inner surface of the Na^+/K^+ pumps to Na^+ thereby, increasing Na^+ efflux and K^+ re-uptake[36].

RPE and HR was similar between all supplementation groups (Figures 6 and 7). This suggests that the aerobic system was under the same level of physiological stress during each 2000m row, irrespective of what supplement was taken. Intriguingly, performance in EX2 for the caffeine trial was 9 s faster than the placebo trial yet HR and RPE remained the same. It can therefore be speculated that supplementation induced a performance improvement without a concomitant increased perception of effort, which lends itself to the intriguing possibility that supplementation influence the recovery of central fatigue as well as peripheral fatigue. Central fatigue might be combatted through caffeine antagonizing the adenosine A_1 and $A2_a$ receptors, enabling greater central recruitment and engagement of more motor units[17,37]. Or possibly via a reduction in interstitium [K^+] might reduce the stimulation of inhibitory group III and IV muscle afferents[38].

Furthermore, post-exercise caffeine ingestion is associated with increased ß-endorphin concentration, which has analgesic properties[39].

Furthermore, possible mechanisms for the apparent enhanced recovery from post-exercise supplementation comes from some author who postulates that caffeine ingestion pre-activates the Na^+/K^+ pump at the onset of high-intensity exercise, thus increases the speed of K^+ kinetics and reducing the early accumulation of K^+ in the muscle interstitium[20]. Some authors have demonstrated that peak K^+ reuptake during recovery is greater in $NaHCO_3$ induced alkali conditions[31]. Finally, the augmented $[Na^+]$ in the plasma after $NaHCO_3$ ingestion, draws water from the muscle cells[40] reducing the diffusion distance within the interstitium which should increase the efflux rate of fatiguing metabolites into the blood[41].

The main limitation to this investigation is the lack of invasive physiological measures. However, the effect on blood $[HCO_3^-]$ and pH after $NaHCO_3$ ingestion is well documented[14]. However, it would be interesting to investigate whether post-exercise $NaHCO_3$ supplementation augments the recovery of blood and/or muscle pH. Furthermore, some authors states that venous $[K^+]$ is not a valid reflection of interstitium concentration[38]. $NaHCO_3$ administration will always need to be prescribed with caution, as even habitual $NaHCO_3$ users might still experience gastro-intestinal distress[14].

Future research should seek to further explore these novel benefits of post-exercise supplementation of either $NaHCO_3$ or caffeine in different types of exercise protocols that induce similar metabolic disturbances of comparable duration to 2000m rowing, such as 5 km cycling or 3km running.

Conclusion

In conclusion, caffeine improved same-day performance recovery in 2000m rowing relative to placebo. $NaHCO_3$ supplementation maintained same-day rowing performance. The mechanisms that might promote recovery after caffeine supplementation probably related to a maintenance of blood [glucose] during the recovery period, mediated by increased catecholamine output, augmenting the activity of Na^+/K^+ pump leading to a more rapid reinstatement of ion homeostasis. Whereas post-exercise $NaHCO_3$ ingestion might enhance Na^+ and HCO_3^- circulation, increasing the extracellular-to-intracellular pH gradient during the recovery period, therefore improving the efficiency of monocarboxylate and Na^+/K^+ transporters, resulting in faster re-establishment of the sarcolemma potential and a more favorable ion milieu within the muscle cells. The results of the current investigation suggest that athletes and coaches might benefit by utilizing either caffeine or $NaHCO_3$ in this novel post-exercise supplementation fashion to potentiate performance in subsequent same-day high-intensity exercise, when there is not sufficient time for carbohydrate and/or protein digestion.

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REFERENCES

1. RITCHETT KL, PRITCHETT RC, BISHOP P, S Afr J Sports Med, 23 (2011) 20. — 2. MCKENNA MJ, BANGSBO J, RENAUD JM, J Appl Physiol, 104 (2008) 288. doi: 10.1152/japplphysiol.01037.2007. — 3. VIGH-LARSEN JF, ØRTENBLAD N, SPRIET LL, OVERGAARD K, MOHR M, Sports Med, 51 (2021) 1855. doi: 10.1007/s40279-021-01475-0. — 4. SECHER NH, Sports Med, 15 (1993) 24. doi: 10.2165/00007256-199315010-00004. — 5. ATANASOVSKA T, PETERSEN AC, ROUFFET DM, BILLAUT F, NG I, MCKENNA MJ, J Appl Physiol, 117 (2014) 60. doi: 10.1152/japplphysiol.01027.2013. — 6. NIELSEN HB, Acta Physiol Scand, 165 (1999) 113. doi: 10.1046/j.1365-201x.1999.00485.x. — 7. DAVIS JK, GREEN JM, Sports Med, 39 (2009) 813. doi: 10.2165/11317770-000000000-00000. — 8. BRUCE CR, ANDERSON ME, FRASER SF, STEPTO NK, KLEIN R, HOPKINS WG, HAWLEY JA, Med Sci Sports Exerc, 32 (2000) 1958. doi: 10.1097/00005768-200011000-00021. — 9. ANDERSON ME, BRUCE CR, FRASER SF, STEPTO NK, KLEIN R, HOPKINS WG, HAWLEY JA, Int J Sport Nutr Exerc Metab, 10 (2000) 464. — 10. JACKMAN M, WENDLING P, FRIARS D, GRAHAM TE, J Appl Physiol, 81 (1996) 1658. — 11. NORDSBORG N, MOHR M, PEDERSEN LD, NIELSEN JJ, LANGBERG H, BANGSBO J, Am J Physiol Regul Integr Comp Physiol, 285 (2003) 143. doi: 10.1152/ajpregu.00029.2003. — 12. PEDERSEN DJ, LESSARD SJ, COFFEY VG, CHURCHLEY EG, WOOTTON AM, NG T, WATT MJ, HAWLEY JA, J Appl Physiol, 105 (2008) 7. doi: 10.1152/japplphysiol.01121.2007. — 13. TAYLOR C, HIGHAM D, CLOSE GL, MORTON JP, Int J Sport Nutr Exerc Metab, 21 (2011) 410. — 14. CARR AJ, SLATER GJ, GORE CJ, DAWSON B, BURKE LM, Int J Sport Nutr Exerc Metab, 21 (2011) 189. — 15. CARR AJ, SLATER GJ, GORE CJ, DAWSON B, BURKE LM, Int J Sports Physiol Perf, 7 (2012) 152. — 16. VOLIANITIS S, SECHER NH, J Physiol, 544 (2002) 977. doi: 10.1113/jphysiol.2002.023556. — 17. KILDING AE, OVERTON C, GLEAVE J, Int J Sport Nutr Exerc Metab, 22 (2012) 175. — 18. FISHER SM, MCMURRAY RG, BERRY M, MAR MH, FORSYTHE WA, Int J Sports Med, 7 (1986) 276. doi: 10.1055/s-2008-1025774. — 19. GREEN HJ, DUHAMEL TA, FOLEY KP, OUYANG J, SMITH IC, STEWART RD, Am J Physiol Regul Integr Comp Physiol, 293 (2007) 354. doi: 10.1152/ajpregu.00701.2006. — 20. MOHR M, NIELSEN JJ, BANGSBO J, J Appl Physiol, 111 (2011) 1372. doi: 10.1152/japplphysiol.01028.2010. — 21. PETTERSEN SA, KRUSTRUP P, BENDIKSEN M, RANDERS MB, BRITO J, BANGSBO J, JIN Y, MOHR M, J Sports Sci, 32 (2014) 1958. doi: 10.1080/02640414.2014.965189. — 22. SCHABORT EJ, HAWLEY JA, HOPKINS WG, BLUM H, J Sports Sci, 17 (1999) 627. doi: 10.1080/026404199365650. — 23. COSGROVE MJ, WILSON J, WATT D, GRANT SF, J Sports Sci, 17 (1999) 845. doi: 10.1080/026404199365407. — 24. Borg G, Borg's perceived exertion and pain scales (Human Kinetics, Champaign, IL, 1998). — 25. GUEST NS, VANDUSSELDORP TA, NELSON MT, GRGIC J, SCHOENFELD BJ, JENKINS NDM, ARENT SM, ANTONIO J, STOUT JR, TREXLER ET, SMITH-RYAN AE, GOLDSTEIN ER, KALMAN DS, CAMPBELL BI, Int Soc Sports Nutr, 18 (2021) 1. doi: 10.1186/s12970-020-00383-4. — 26. GRGIC J, PEDISIC Z, SAUNDERS B, ARTIOLO GG, SCHOENFELD

BJ, MCKENNA MJ, BISHOP DJ, KREIDER RB, STOUT JR, KALMAN DS, ARENT SM, VANDUSSELDORP TA, LOPEZ HL, ZIEGENFUSS TN, BURKE LM, ANTONIO J, CAMPBELL BI, J Int Soc Sports Nutr, 18 (2021) 61. doi: 10.1186/s12970-021-00458-w. — 27. MARRIOTT M, KRUSTRUP P, MOHR M, J Int Soc Sports Nutr, 12 (2015) 13. doi: 10.1186/s12970-015-0075-x. — 28. BANGSBO J, GRAHAM TE, KIENS B, SALTIN B, J Physiol, 451 (1992) 205. doi: 10.1113/jphysiol.1992.sp019161. — 29. ROTH DA, Med Sci Sports Exerc, 23 (1991) 925. doi: 10.1249/00005768-199108000-00007. — 30. YEO SE, JENTJENS RLPG, WALLIS GA, JEUKENDRUP AE, J Appl Physiol, 99 (2005) 844. doi: 10.1152/japplphysiol.00170.2005. — 31. SOSTARIC SM, SKINNER SL, BROWN MJ, SANGKABUTRA T, MEDVED I, MEDLEY T, SELIG SE, FAIRWEATHER I, RUTAR D, MCKENNA MJ, J Physiol, 570 (2006) 185. doi: 10.1113/jphysiol.2005.094615. — 32. BOGDANIS GC, NEVILL ME, LAKOMY HK, GRAHAM CM, LOUIS G, Eur J Appl Physiol Occup Physiol, 74 (1996) 461. doi: 10.1007/BF02337727. — 33. JONES AM, WILKERSON DP, BURNLEY M, KOPPO K, Med Sci Sports Exerc, 35 (2003) 2085. doi: 10.1249/01.MSS.0000099108.55944.C4. — 34. SAVARD GK, RICHTER EA, STRANGE S, KIENS B, CHRISTENSEN NJ, SALTIN B, Am J Physiol, 257 (1989) 1812. — 35. GOLDSTEIN ER, ZIEGENFUSS T, KALMAN D, KREIDER R, CAMPBELL B, WILBORN C, TAYLOR L, WILLOUGHBY D, STOUT J, GRAVES BS, WILDMAN R, IVY JL, SPANO M, SMITH AE, ANTONIO J, J Int Soc Sports Nutr, 7 (2010) 5. doi: 10.1186/1550-2783-7-5. — 36. CLAUSEN T, Physiol Rev, 83 (2003) 1269. doi: 10.1152/physrev.00011.2003. — 37. BOWTELL JL, MOHR M, FULFORD J, JACKMAN SR, ERMIDIS G, KRUSTRUP P, MILEVA KN, Front Nutr, 5 (2018) 6. doi: 10.3389/fnut.2018.00006. — 38. JUEL C, Appl Physiol Nutr Metab, 32 (2007) 846. doi: 10.1139/H07-065. — 39. LAURENT D, SCHNEIDER KE, PRUSACZYK WK, FRANKLIN C, VOGEL SM, KRSSAK M, PETERSEN KF, GOFORTH HW, SHULMAN GI, J Clin Endocrinol Metab, 85 (2000) 2170. doi: 10.1210/jcem.85.6.6655. — 40. MITCHELL TH, ABRAHAM G, WING S, MAGDER SA, COSIO MG, DESCHAMPS A, MARLISS EB, Am J Med Sci, 300 (1990) 88. doi: 10.1097/00000441-199008000-00004. — 41. SJØGAARD G, ADAMS RP, SALTIN B, Am J Physiol, 248 (1985) 190.

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KOFEIN I NATRIJEV BIKARBONAT POBOLJŠAVAJU IZVEDBU PONOVLJENIH VJEŽBI VISOKOG INTENZITETA

S A Ž E T A K

Učinak kofeina i natrijevog bikarbonata (NaHCO3) kao nutritivnih dodataka za poticanje oporavka nakon iscrpljujućeg vježbanja visokog intenziteta nedostatno je proučavan. Ova studija ispituje hipotezu da se nakon iscrpnog vježbanja visokog intenziteta, nakon unosa kofeina ili natrijevog bikarbonata (NaHCO3), javlja pozitivan učinak na izvedbu u kasnijim vježbama visokog intenziteta. U jednostruko slijepom, randomiziranom ispitivanju, zdravi muškarci (n=20) uzimali su ili 0,3 g/kg-1 tjelesne težine NaHCO3 ili 6 mg/kg-1 tjelesne težine kofeina ili placebo nakon završetka vježbe veslanja na 2000 m (EX1). Sudionici su se odmarali 90 minuta prije drugog veslanja na 2000 m (EX2). Izvedba u EX2 smanjena je (p<0,05) za 5,3±7,0 s u usporedbi s EX1 u ispitanika s placebom. Međutim, izvedba EX2 bila je nepromijenjena (p>0,05) nakon uzimanja NaHCO3. U ispitivanju s kofeinom izvedba EX2 bila je 2% bolja (p<0,05) od drugog veslanja u ispitivanju s placebom (456,0±17,8 naspram 464,6±21,6 s). Početak EX2 bio je povezan s povišenim laktatom u krvi, pri čemu su ispitivanja s NaHCO3 pokazala najvišu vrijednost laktata i smanjenu glukozu u krvi, a nakon kofeina glukoza u krvi je bila nepromijenjena. Između svih ispitivanja nisu pronađene razlike u brzini otkucaja srca i stopi percipiranog napora. Kofein je poboljšao performanse istog dana u veslanju na 2000 m u odnosu na placebo, a NaHCO3 suplementacija održala je performanse ponovljenog veslanja na istoj razini. Stoga ovi dodaci mogu potencijalno biti korisni kao pomoć pri oporavku u ponavljanim scenarijima vježbi visokog intenziteta.