International Journal of Sport Nutrition and Exercise Metabolism, 2021, 31, 482-489
https://doi.org/10.1123/ijsnem.2021-0076

Human Kinetics
ORIGINAL RESEARCH

Warm-Up Intensity Does Not Affect the Ergogenic Effect of Sodium Bicarbonate in Adult Men

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This study determined the influence of a high- (HI) versus low-intensity (LI) cycling warm-up on blood acid-base responses and exercise capacity following ingestion of sodium bicarbonate (SB; 0.3 g/kg body mass) or a placebo (PLA; maltodextrin) 3 hr prior to warm-up. Twelve men (21 ± 2 years, 79.2 ± 3.6 kg body mass, and maximum power output [W_{max}] 318 ± 36 W) completed a familiarization and four double-blind trials in a counterbalanced order: HI warm-up with SB, HI warm-up with PLA, LI warm-up with SB, and LI warm-up with PLA. LI warm-up was 15 min at 60% $W_{max,}$ while the HI warm-up (typical of elites) featured LI followed by 2 × 30 s (3-min break) at W_{max}, finishing 30 min prior to a cycling capacity test at 110% W_{max}. Blood bicarbonate and lactate were measured throughout. SB supplementation increased blood bicarbonate (+6.4 mmol/L; 95% confidence interval, CI [5.7, 7.1]) prior to greater reductions with HI warm-up (−3.8 mmol/L; 95% CI [−5.8, −1.8]). However, during the 30-min recovery, blood bicarbonate rebounded and increased in all conditions, with concentrations ~5.3 mmol/L greater with SB supplementation ($p < .001$). Blood bicarbonate significantly declined during the cycling capacity test at 110% W_{max} with greater reductions following SB supplementation (−2.4 mmol/L; 95% CI [−3.8, −0.90]). Aligned with these results, SB supplementation increased total work done during the cycling capacity test at 110% W_{max} (+8.5 kJ; 95% CI [3.6, 13.4], ~19% increase) with no significant main effect of warm-up intensity (+0.0 kJ; 95% CI [−5.0, 5.0]). Collectively, the results demonstrate that SB supplementation can improve HI cycling capacity irrespective of prior warm-up intensity, likely due to blood alkalosis.

Keywords: buffering, high intensity, low intensity, supplementation

Muscle acidosis caused by the accumulation of intramuscular hydrogen cations (H^+) can hinder enzymatic energy production and contractility of the muscle (Jubrias et al., 2003; Woodward & Debold, 2018), contributing to the fatigue process during exercise (Fitts, 2016). Sodium bicarbonate (SB) ingestion increases the concentration of blood bicarbonate, leading to a greater efflux of H^+ and lactate anions out of the skeletal muscle, which can be beneficial to high-intensity (HI; ~2–10 min) performance (Carr et al., 2011; Christensen et al., 2017). Ingestion of SB prior to HI exercise has a moderate positive effect size on exercise outcomes (Christensen et al., 2017; Matson & Tran, 1993; Peart et al., 2012), with larger effect sizes in nontrained individuals compared to trained athletes (Peart et al., 2012). Accordingly, SB is one of few performance-enhancing supplements with ample support for performance efficacy (Maughan et al., 2018).

Warming up prior to a specific exercise bout is a commonly employed practice and is considered essential by coaches and athletes to achieve optimal performance. The aim of a warm-up is to elicit various physiological effects, such as increased body and muscle temperature, and metabolic and neural stimulation, that can enhance muscle function and subsequent performance (McGowan et al., 2015). Preexercise HI warm-ups can improve subsequent HI exercise tolerance due to a speeding of VO_2 kinetics and a greater oxidative energy contribution to subsequent exercise (Burnley et al., 2005; Ingham et al., 2013). The beneficial effect of priming exercise has a "Goldilocks zone," and is apparent only when the warm-up intensity leads to blood lactate concentrations of 3–5 mmol/L (Bailey et al., 2009; Ingham et al., 2013) with a sufficient recovery period (>9 min; Bailey et al., 2009). Warm-up intensities that lead to higher and lower increases in blood lactate, and an insufficient recovery period, do not enhance and may even impair subsequent (Bailey et al., 2009; Burnley et al., 2001). HI warm-ups increase glycolytic enzyme and transporter activation, as well as biomechanical and psychological stimuli, which all can positively prime HI performance. The increased muscle lactate production from the HI warm-up, however, needs adequate time to be removed from the muscle. Lactate/proton co-transport is the predominant lactate transport system in muscle (Juel, 1997), therefore H^+ will also enter circulation. Thus, it is interesting to speculate how much of the preexercise bicarbonate concentration is affected by warm-up intensity that precedes it, and if any differences are altered due to prior SB supplementation.

Despite the existing evidence base supporting the performance enhancing effect of SB, many studies have not considered the

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impact of the warm-up prior to exercise. Many SB studies have employed low-intensity (LI) warm-ups with short recovery periods prior to the main exercise task (Froio de Araujo Dias et al., 2015; Saunders et al., 2014), which limits the extrapolation of results to the real-world setting, since athletes involved in HI competitions would likely employ a HI warm-up (Ingham et al., 2013). It might be suggested that the recovery kinetics of bicarbonate following a warm-up and the time taken between warm-up and the subsequent bout of exercise could be important for performance. Despite this, many studies only allow relatively short periods of recovery between a warm-up and subsequent exercise. However, it is not uncommon for elite athletes, and required within the rules of many sports (competition "check-in" time) to finish warm-ups 20–40 min prior to competition, allowing for greater recovery (Ingham et al., 2013). It is unknown if SB supplementation prior to a HI or LI warm-up would be similarly effective due to buffering requirements during the warm-up itself.

Although HI athletes will regularly consume SB and perform HI warm-ups, no evidence exists to determine the impact of warm-up intensity on blood acid-base responses and the influence of this upon subsequent HI cycling capacity and performance. Therefore, we examined the effects of warm-up intensity and SB supplementation upon cycling capacity and blood acid-base analyte responses. We hypothesized that SB supplementation would enhance exercise performance regardless of warm-up intensity, although the HI warm-up condition would result in greater enhancement, compared to the LI condition.

Methods

Participants

Fourteen physically active men volunteered for this double-blind, order-balanced, crossover study. Two participants withdrew, one due to gastrointestinal distress experienced during one of the trials, and one due to an injury not associated with the protocol; therefore, 12 men (age, 21 ± 2 years; height, 1.82 ± 0.06 m; and body mass, 79.2 ± 3.6 kg) completed all experimental sessions. Participants provided written informed consent and completed a health screen questionnaire prior to taking part in the study at Nottingham Trent University, which was approved by Nottingham Trent University Ethical Advisory Committee [#364] in accordance with the Declaration of Helsinki. Participants had not ingested any nutritional supplement or suffered from any gastrointestinal problems in the previous 6 months.

Protocol and Measurements

The current investigation was conducted as part of a wider research project, with all participants completing a total of seven separate laboratory sessions performed in a counterbalanced order. The current investigation will report data from five occasions. The first visit determined each individual's height (m) and body mass (kg) followed by an incremental cycling test to determine maximum power output (W_{max}) and a familiarization of the main exercise protocol. The incremental exercise test was performed on a cycle ergometer (Lode Excalibur, Groningen, The Netherlands) and began at a starting power output of 150 W, exercise intensity increasing by 6 W every 15 s (ramp rate of 24 $W \cdot min^{-1}$) until volitional exhaustion according to Saunders et al. (2013). Participants completed each of the four main trials at the same time of day, having replicated dietary intake and abstained from alcohol and strenuous exercise for the 24 hr prior and from caffeine on test days. Experimental sessions were separated by a minimum of 5 days, with an average of 7 days between visits. Resting fingertip blood samples were obtained prior to the supervised consumption of either 0.3 g/kg body mass of SB (Intralabs, Plymouth, United Kingdom) or a placebo (PLA; Maltodextrin; MyProtein, Cheshire, United Kingdom) provided in identical clear gelatin capsules and ingested with 500 ml of water (Figure 1). Supplements were prepared and allocated by an individual not involved in the study. The allocation code was retained by this individual until the end of statistical analysis at which point the allocation code was released to the experimenters. As such, neither experimenter nor participant was aware of what supplement was being consumed on any given occasion. Supplements were independently tested by HFL Sports Science, United Kingdom (ISO 17025). Following ingestion, participants remained rested for a 3-hr period during which no food was consumed. The supplementation timing was employed so that the onset of exercise occurred at a moment at which peak gastrointestinal discomfort would likely have passed, but blood bicarbonate would still be increased above +6 mmol/L (Jones et al., 2016). Six out of 12 participants were able to correctly guess their supplement during the first and second trials, whereas nine out of 12 and eight out of 12 correctly guessed their supplement in the third and fourth trials. There were no significant differences in the correct guessing rate between trials for all six trials combined (Fisher exact test: $p = .39$).

A fingertip blood sample was obtained immediately prior to a LI (15 min of cycling at 60% W_{max} [191 ± 21 W]) or HI (5 min at 60% W_{max}, 5 min at 70% W_{max} [223 ± 25 W], and 5 min at 80% W_{max} [255 ± 29 W], 30 s at W_{max} [318 ± 36 W], followed by a 3-min break and another 30 s at W_{max}) warm-up. This resulted in four different intervention conditions: HI warm-up and SB (HISB), HI warm-up and PLA (HIPLA), LI warm-up and SB (LISB), and LI warm-up and PLA (LIPLA). The HI warm-up was based on a typical elite track cycling protocol, finishing 30 min prior to competition (T. Stellingwerff, personal observations/discussions in elite sport). Participants remained seated for 30 min following completion of the warm-up, with fingertip blood samples taken at 10-min intervals. Participants then completed a cycling capacity test to exhaustion at 110% W_{max} ($CCT_{110\%}$; 350 ± 39 W; Saunders et al., 2013). A capacity test was chosen here due to the HI nature of the activity, since many sports require athletes to exert themselves maximally to the point of exhaustion to maintain race pace (e.g., athletics) or for the benefit of the team (e.g., domestiques in cycling). The position on the cycle ergometer (Lode Excalibur Sport) was determined in the familiarization session and maintained for all subsequent trials. Due to the intense nature of the exercise test, the first 30 s of the test was incremented (15 s at 80% W_{max} and 15 s at 95% W_{max} [302 ± 34 W]). Total work done (TWD; in kJ) and time to exhaustion (TTE; in s) were recorded as the outcome measure for all CCTs. Fingertip capillary blood samples were taken immediately and 5 min following completion of the $CCT_{110\%}$. All blood samples (80 µl) were collected in heparin coated clinitubes and immediately analyzed for lactate and pH concentrations (Radiometer ABL 900; Radiometer Ltd., Crawley, United Kingdom), with bicarbonate calculated using the Henderson–Hasselbalch equation.

Statistical Analysis

An a priori power calculation indicated that a minimum of 12 participants were required to detect power at >95% ($\alpha = .01$; within-subject effect in a repeated-measures analysis of variance with one group and six measurements) using G*Power (University

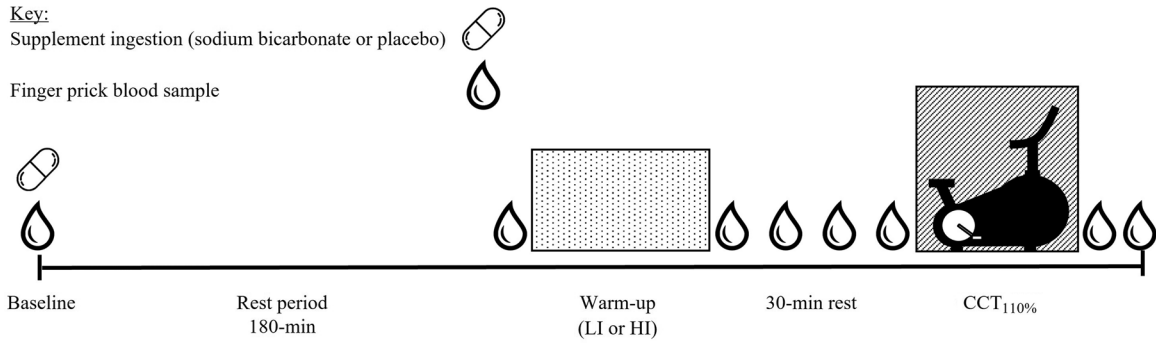

Figure 1 — Experimental protocol for the main trials. HI = high intensity; LI = low intensity; $CCT_{110\%}$ = cycling capacity test to exhaustion at 110% maximum power output; W_{max} = maximum power output.

of Düsseldorf, Düsseldorf, Germany) (Faul et al., 2007). Calculations were based on TWD from Peart et al. (2012) (Cohen's *d*: 0.6). Data obtained from blood samples were analyzed sequentially across the distinct measurement periods to better describe the effects of warm-up on blood bicarbonate and lactate kinetics. The measurement periods were separated into four distinct periods for analysis: (a) supplementation: baseline to warm-up onset, (b) warm-up: warm-up onset to post warm-up, (c) recovery: post warm-up to exercise onset, and (d) exercise: exercise onset to recovery post exercise. Mixed effects regression models were used to assess main and interaction effects of supplementation (PLA vs. SB) and warm-up (LI vs. HI), while participant ID's were included as random effects to account for the repeated-measures nature of the data (Mirman, 2014). The supplementation, warm-up, and exercise phases included two sequential measurement points and therefore could only be modelled by a straight line. In contrast, the recovery period comprised three sequential data points and was modeled with both linear and quadratic regression lines. Standard errors and *p* values for regression coefficients were obtained with the lmerTest library in *R* using Satterthwaite's approximation for degrees of freedom (Kuznetsova et al., 2017). To test whether a linear or quadratic model best fit the data for the recovery period, a likelihood ratio test with appropriate chi-squared asymptotic reference distribution was used (Mirman, 2014).

Proportion of response was used to interpret the "practical significance" of supplementation by estimating the chance a new person from the population of interest would experience a substantive improvement in performance as a direct effect of supplementation (Atkinson et al., 2019). TWD and TTE were used as measures of performance, with response defined as improvement beyond the smallest worthwhile change (calculated as 0.2 × the group *SD* during the PLA session; Paton & Hopkins, 2006). Assessment of response was made using recommended group-based data practices (Atkinson et al., 2019) and not investigation of specific individuals in the samples. Therefore, the spreadsheet of Swinton et al. (2018) was used to calculate uncertainty in the proportion of response estimates.

Results

Exercise Capacity

Significant main effects were identified for SB supplementation (Figure 2) resulting in increases in TWD (8.5 kJ; 95% confidence interval [CI] [3.6, 13.4]; $p = .002$) and TTE (24.6 s; 95% CI [10.4, 38.8], $p = .002$). No significant main effects were identified for warm-up intensity (TWD: 0.0 kJ; 95% CI [−5.0, 5.0], $p = .999$; TTE: −0.42 s; 95% CI [−14.6, 13.8], $p = .954$) or interaction between intensity and supplementation (TWD: −1.8 kJ; 95% CI [−8.7, 5.2], $p = .627$; TTE: −4.7 s; 95% CI [−24.8, 15.4], $p = .652$). The smallest worthwhile change and proportion of response were estimated as 2.2 kJ and 89.2% (95% CI [80.7, 100]) for TWD and 5.5 s and 91.5% (95% CI [82.1, 100]) for TTE.

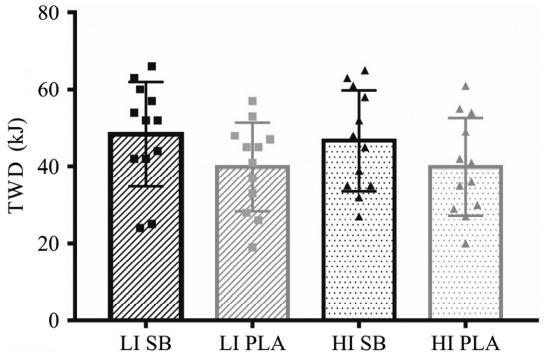

Figure 2 — TWD across the four conditions: HIPLA, HISB, LIPLA, and LISB. HIPLA = high-intensity warm-up with placebo; HISB = high-intensity warm-up with sodium bicarbonate; LIPLA = low-intensity warm-up with placebo; LISB = low-intensity warm-up with sodium bicarbonate; TWD = total work done. Data are mean ± *SD*, while individual data points are also plotted.

Bicarbonate

A significant main effect was obtained for SB supplementation demonstrating increased blood bicarbonate concentrations from baseline to pre warm-up (6.4 mmol/L; 95% CI [5.7, 7.1], $p < .001$) with no significant main effect obtained for PLA (0.0 mmol/L; 95% CI [−5.6, 5.6], $p = .985$) (Figure 3). Blood bicarbonate decreased in all conditions following the warm-up period (LISB: −10.0 ± 2.7 mmol/L; LIPLA: −7.0 ± 2.5 mmol/L; HISB: −14.5 ± 4.6 mmol/L; HIPLA: −10.9 ± 1.9 mmol/L; $p < .001$) with significant main effects obtained for both SB supplementation (−3.7 mmol/L; 95% CI [−5.7, −1.7], $p < .001$) and warm-up intensity (−3.8 mmol/L; 95% CI [−5.8, −1.8], $p < .001$). These

effects did not, however, fully offset the initial increase in blood bicarbonate with supplementation (Figure 3).

During the 30-min recovery period, different rates and profiles of blood bicarbonate formation "rebound" were identified (Figure 3). The greatest rate of increase was in HISB which was shown to be linear ($p = .630$), whereas formation during all other conditions was nonlinear ($p \leq .024$) with rates slowing as time progressed. During the rebound period, blood bicarbonate increased in all conditions (+7.8 ±1.5 mmol/L in LISB, +5.8 ± 1.7 mmol/L in LIPLA, +11.2 ±4.1 mmol/L in HISB, and +8.2 ± 1.6 mmol/L in HIPLA). At the end of the recovery period, no significant main effect of warm-up intensity was obtained (1.0; 95% CI [−0.41, 2.4] mmol/L, $p = .160$), whereas on average blood bicarbonate was estimated to be 5.3 mmol/L greater (5.3; 95% CI [3.9, 6.7] mmol/L, $p < .001$) with supplementation (Figure 3: Postrecovery).

During the $CCT_{110\%}$, a significant main effect was obtained for SB supplementation demonstrating greater decreases in blood bicarbonate concentrations (−2.4; 95% CI [−3.8, −0.90] mmol/L, $p = .003$). No significant main effects were identified for warm-up intensity (1.0; 95% CI [−0.5, 2.5] mmol/L, $p = .188$) or interaction between intensity and supplementation (0.5; 95% CI [−1.7, 2.8] mmol/L, $p = .637$). However, despite these greater decreases, at the end of the $CCT_{110\%}$ absolute blood bicarbonate concentrations remained higher with SB (2.9; 95% CI [1.8, 4.0] mmol/L, $p < .001$), with no significant main effect of warm-up intensity (0.0; 95% CI [−1.1, 1.1] mmol/L, $p = .971$). No main effects of warm-up intensity or supplementation ($p \geq .095$) were obtained for changes in blood bicarbonate concentrations during the 5-min recovery following the $CCT_{110\%}$.

Lactate

Blood lactate concentrations increased in all conditions following the warm-up (LISB: +10.1 ± 3.4 mmol/L; LIPLA: +8.1 ± 3.5 mmol/L; HISB: +16.0 ± 6.0 mmol/L; HIPLA: 13.1 ± 3.6 mmol/L; Figure 4: Post warm-up) with significant main effects obtained for both SB supplementation (3.2; 95% CI [0.5, 5.8] mmol/L, $p = .022$) and warm-up intensity (4.7; 95% CI [2.2, 7.2] mmol/L, $p < .001$).

During the 30-min recovery period, different rates and profiles were identified (Figure 4). The greatest rate of removal was in HISB which was linear ($p = .080$), whereas blood lactate removal during all other conditions was nonlinear ($p < .001$); rates slowed as time progressed. At the end of recovery period, a significant interaction effect was obtained (1.7; 95% CI [0.2, 3.3] mmol/L, $p = .031$) as well as significant main effects of SB supplementation (2.1; 95% CI [1.1, 3.1] mmol/L, $p < .001$) and warm-up intensity (1.3; 95% CI [0.33, 2.3] mmol/L, $p = .014$). As a result, lactate concentrations were substantively higher in the HISB condition compared to all other conditions (LISB: 3.0 ± 1.3 mmol/L; HISB: 6.1 ± 2.6 mmol/L; LIPLA: 2.6 ± 1.0 mmol/L; HIPLA: 4.1 ± 2.1 mmol/L; Figure 4: Postrecovery).

Blood lactate concentrations increased substantively during the $CCT_{110\%}$ (Figure 4: $CCT_{110\%}$) but no significant interaction (1.7; 95% CI [−1.1, 4.5] mmol/L, $p = .229$) or main effects (SB supplementation: 0.6; 95% CI [−1.2, 2.5] mmol/L, $p = .509$; warm-up intensity: 0.6; 95% CI [−1.2, 2.5] mmol/L, $p = .509$) were obtained. Post $CCT_{110\%}$ blood lactate concentrations remained on average 2.7 mmol/L higher post $CCT_{110\%}$ with SB supplementation (2.7; 95% CI [1.0, 4.5] mmol/L, $p = .004$) with no significant

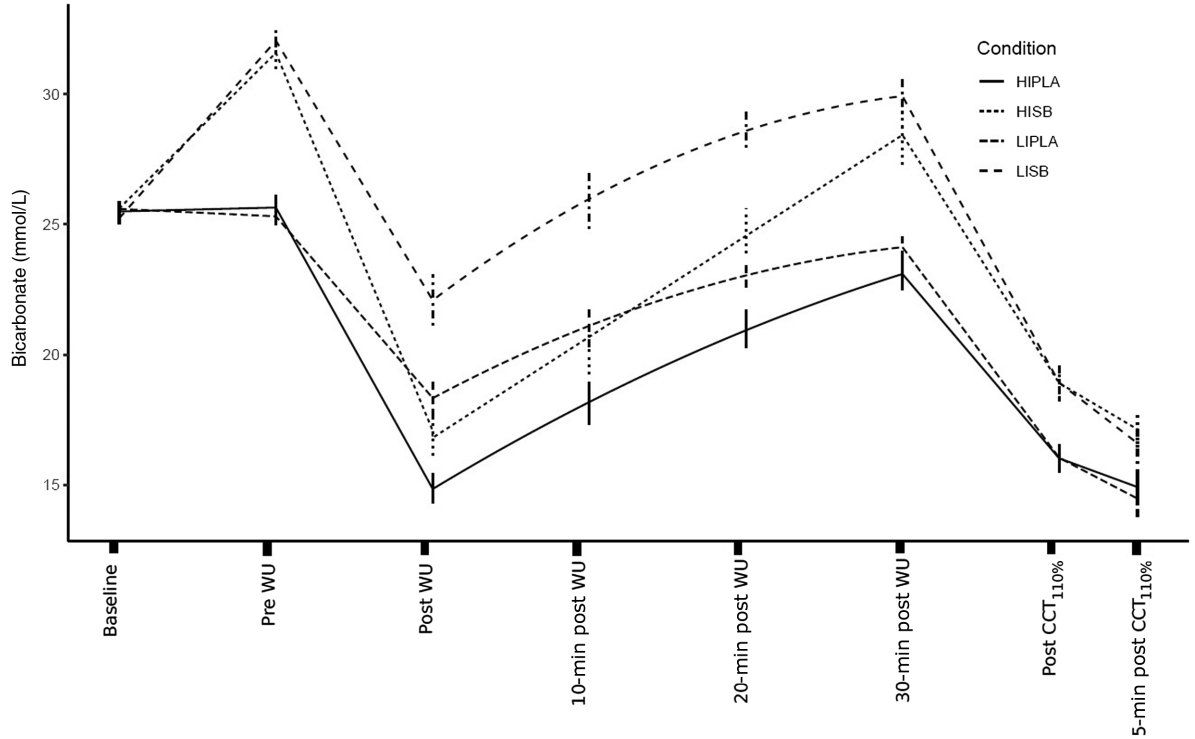

Figure 3 — Group bicarbonate data modeled across study using mixed-level model. HIPLA = high-intensity warm-up with placebo; HISB = high-intensity warm-up with sodium bicarbonate; LIPLA = low-intensity warm-up with placebo; LISB = low-intensity warm-up with sodium bicarbonate; WU = warm-up; $CCT_{110\%}$ = cycling capacity test to exhaustion at 110% maximum power output; W_{max} = maximum power output. Error bars are centered at group average and represent *SE*s.

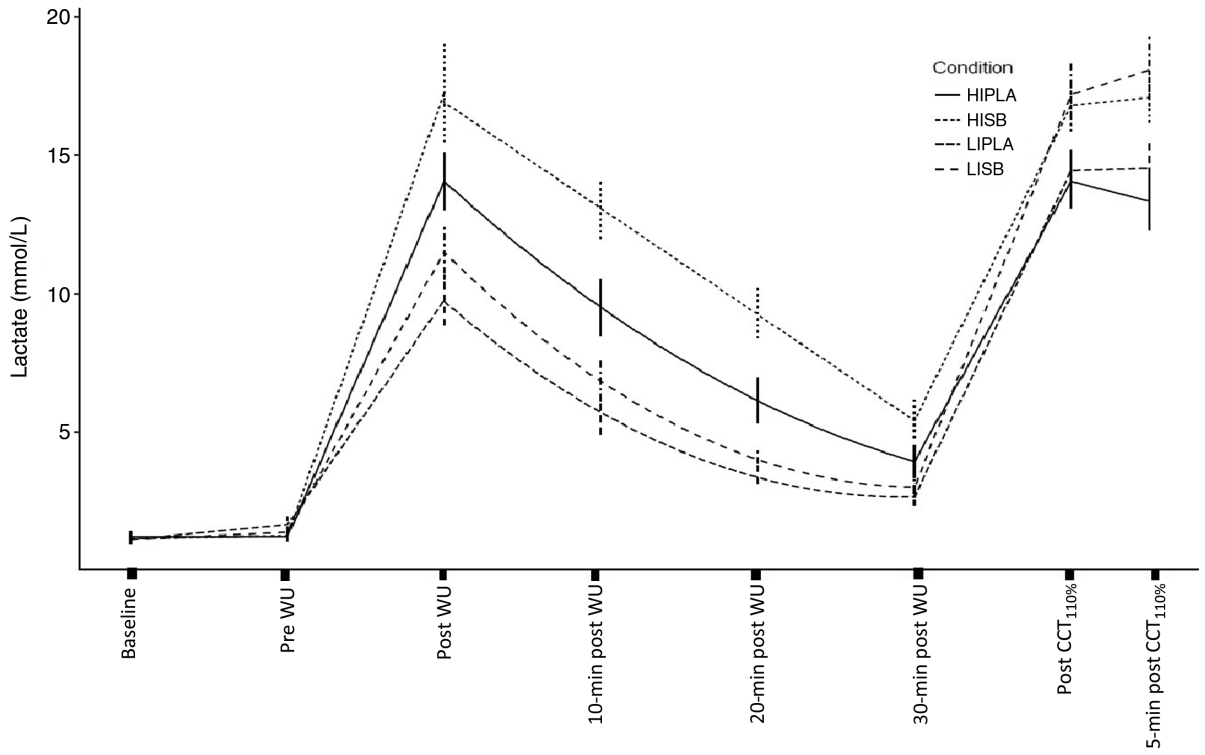

Figure 4 — Group lactate data modeled across study using mixed level model. HIPLA = high-intensity warm-up with placebo; HISB = high-intensity warm-up with sodium bicarbonate; LIPLA = low-intensity warm-up with placebo; LISB = low-intensity warm-up with sodium bicarbonate; WU = warm-up; $CCT_{110\%}$ = Cycling capacity test to exhaustion at 110% maximum power output; W_{max} = maximum power output. Error bars are centered at group average and represent *SE*s.

main effect of warm-up intensity (–0.4; 95% CI [–2.3, 1.6] mmol/L, $p = .675$).

Discussion

Sodium bicarbonate ingestion significantly increased blood bicarbonate concentrations from baseline, while blood bicarbonate reduced and lactate increased following the warm-up; blood responses occurred to a greater degree in the HI warm-up condition compared to the LI, and in SB compared to PLA (Figures 3 and 4). Blood bicarbonate was higher, and lactate lower, following 30-min recovery in SB than PLA, with SB ingestion resulting in improved exercise capacity following both the LI and HI warm-up. In line with previous research, these data suggest that SB supplementation improves HI exercise; the novelty of the current study is that this significant ergogenic effect occurs following either a LI or HI warm-up. However, evidence was not obtained to support our hypothesis that performance capacity would be further improved with a HI versus LI warm-up with or without bicarbonate supplementation (Figure 2).

The magnitude of the blood bicarbonate increases following SB ingestion and prior to the warm-up is in line with those previously reported with an identical dose (Bishop et al., 2004; Jones et al., 2016; McNaughton, 1992; Saunders et al., 2014). Warm-up always reduced blood bicarbonate, with greater reductions following HI than LI; lactate was also increased to a greater extent with the HI warm-up, confirming the greater intensity of the activity. Greater decreases in blood bicarbonate and greater increases in lactate were shown with SB compared to PLA following the warm-up, regardless of warm-up intensity. This likely reflects an increased efflux of lactate and H^+ out of the working muscle (Juel, 1997), with a subsequent increased buffering of the H^+. Pre-$CCT_{110\%}$ bicarbonate levels remained increased compared to baseline with SB (LI: 4.7 mmol/L; HI: 2.7 mmol/L), resulting in an improved exercise capacity compared to PLA. These data can explain the ergogenic effects of SB shown herein, although it contradicts the recently held belief that a minimum threshold +5 mmol/L increase in blood bicarbonate is necessary to elicit an ergogenic effect (Carr et al., 2011). Although the minimal increase necessary to elicit an ergogenic effect is currently unknown (Heibel et al., 2018), theoretically, even minimal increases in circulating bicarbonate would correspond to increases in buffering capacity. One might expect that the greater bicarbonate concentration would allow the individual to perform at a greater intensity for a longer duration, eventually reaching the same acidotic endpoint (i.e., equally depleted bicarbonate and low pH). The current data provide evidence that only small increases in blood bicarbonate are necessary to elicit performance benefits, while further work should investigate what factors limit complete utilization of the increased buffering capacity with SB.

To ensure high ecological validity, both the HI warm-up and the 30-min recovery period were implemented to replicate a typical elite track cycling protocol (T. Stellingwerff, personal observations), and to reflect the athlete precompetition/post warm-up "check-in" constraints at international competitions for most HI sports (e.g., cycling, athletics, swimming, etc.). Interestingly, our novel data showed that there was a restoration, or "rebound," of blood bicarbonate in all sessions following the warm-up,

suggesting this is a normal physiological response toward homeostasis, albeit it appears that SB ingestion impacts this response. This response aligns with recovery in acid–base balance following intense exercise when SB has been ingested (Gough et al., 2019; Robergs et al., 2005). Ingestion of SB influenced the blood bicarbonate response during this short 30-min transition phase; greater increases were shown following SB ingestion with bicarbonate concentrations returning to ~90% of pre warm-up levels and being significantly increased compared to baseline, whereas they remained below baseline levels for PLA. Interestingly, there was a reduced bicarbonate rebound in the LI conditions (SB: +7.8 mmol/L; PLA: +5.8 mmol/L) compared to HI conditions (SB: +11.2 mmol/L; PLA: +8.2 mmol/L); probably due to the already higher bicarbonate concentrations following the LI warm-up. These data indicate that the postexercise recovery of bicarbonate concentration is influenced by both SB supplementation and warm-up intensity. Increased bicarbonate recovery kinetics with SB were likely due to residues from supplementation continuing to affect circulating bicarbonate, since blood bicarbonate remains increased more than 3 hr following supplementation (Jones et al., 2016). The homeostatic mechanism explaining the bicarbonate rebound without SB, and the positive influence of warm-up intensity on these responses, remains unclear and may be related to lactate/proton exchange and removal abilities that are influenced by exercise intensity (Chatel et al., 2016), increased bicarbonate reabsorption (Cogan et al., 1979), and respiratory compensation (Feher, 2012). Further work should investigate the factors that determine the immediate rebound response of blood bicarbonate following both HI and LI exercise.

The effects of SB on cycling capacity during the $CCT_{110\%}$ has been shown to be highly variable (Saunders et al., 2014) and inconsistent (Froio de Araujo Dias et al., 2015) when using nonspecifically trained individuals. In the current investigation, there was a large and significant ~20% increase in cycling capacity (TWD) with SB compared to PLA (Figure 2). The proportion of response analysis estimated that between 80% and 100% of individuals representative of the population studied would be expected to improve TWD beyond the smallest worthwhile change as a direct result of supplementation. These improvements are also in excess of those shown with beta-alanine supplementation (+5%–4% cycling capacity; Sale et al., 2011; Saunders et al., 2017), which increases intracellular buffering capacity. Perhaps both warm-ups employed here induced a greater positive performance capacity influence from supplementation than the aforementioned studies, which used a short duration (5 min) LI fixed load warm-up with little recovery time (2–3 min) prior to the main exercise bout. This may have influenced results since the effectiveness of a warm-up will be determined by both its intensity and duration, and the subsequent recovery period prior to the main exercise task (McGowan et al., 2015). The recovery period in previous studies may not have been of sufficient length to allow blood variables to return to optimal levels, which would have optimized exercise capacity. Based upon the current data, the practice of ingesting SB to elicit an ergogenic effect on exercise performance can be beneficial when undertaking a HI or LI warm-up 30 min prior to the event.

The present study showed similar effects of LI and HI warm-ups on exercise capacity, which is in contrast to research showing that undertaking prior HI activity can improve subsequent HI exercise performance (Burnley et al., 2005). The two warm-up intensities were chosen to elicit different blood lactate responses; the HI warm-up aimed to produce blood lactate responses of +3 to 5 mmol/L, where subsequent performance may be improved (Ingham et al., 2013), while the LI warm-up aimed to remain below this level. Although warm-ups were conducted at relative exercise intensities, both warm-ups may have been too intense for the nonathlete volunteers since lactate levels immediately post warm-up were well above 6 mmol/L in all sessions. Bishop (2003) reported that warm-ups consisting of workloads above 60% VO_2max may have an adverse effect on subsequent exercise performance, likely due to the depletion of high-energy phosphates and the accumulation of H^+. Nonetheless, prior HI exercise can improve exercise tolerance to subsequent HI activity if adequate recovery time is provided (>9 min; Bailey et al., 2009). More specifically, for athletes whose competition requires a HI component, warm-ups that elicit a 4–6 mmol/L increase in lactate followed by a 20–40-min recovery period are commonplace (Ingham et al., 2013). Despite the substantial recovery period in this study (30 min), blood lactate following the HI warm-up remained high and did not return below 4 mmol/L in either SB (6.1 mmol/L) or PLA (4.1 mmol/L). This may explain the lack of a beneficial effect of the HI warm-up, as prior exercise may only improve performance if it elicits a degree of lactic acidosis of less than 3 mmol/L when the main exercise bout begins (McGowan et al., 2015). This is also reflected in the similar preexercise bicarbonate concentrations between warm-ups, irrespective of supplementation; bicarbonate concentration was similarly reduced from baseline without supplementation following the HI and LI warm-up. Thus, a warm-up that is conducted at too high an intensity may result in a reduced buffering capacity, while there may also be an associated reduction in accumulated oxygen deficit and impairment in performance (Bishop, 2003). The intensity of both the HI and LI warm-up for these individuals may be a limitation of this study and further work should determine the interaction of SB supplementation and warm-up intensity on subsequent exercise in trained individuals.

In conclusion, the present data show that SB can improve HI cycling capacity irrespective of prior warm-up intensity, likely due to increased blood alkalosis. Since it is commonplace for elite athletes to combine both SB ingestion and a HI warm-up prior to exercise performance, the current investigation provides relevant insight and confirms the efficacy of this practice. Both supplementation and warm-up intensity modified the recovery kinetics of the measured blood variables, highlighting several potential avenues of future research, specifically regarding the blood analyte responses during the transition period between warm-up and exercise.

Acknowledgments

The authors wish to thank all those who participated within the current study. This study was funded by and completed at Nottingham Trent University. The study was designed as part of a wider research project by R.L. Jones, T. Stellingwerff, G.G. Artioli, B. Saunders, and C. Sale; data were collected by R.L. Jones and analyzed by R.L. Jones and P. Swinton; data interpretation, manuscript preparation, and final version approval were undertaken by all authors. B. Saunders (2016/50438-0) and G.G. Artioli (2014/11948-8 and 2019/25032-9) have been financially supported by Fundação de Amparo à Pesquisa do Estado de São Paulo. B. Saunders has a current scholarship from the Faculty of Medicine of the University of São Paulo (2020.1.362.5.2).

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