Warm-up intensity does not affect the ergogenic effect of sodium bicarbonate in adult men.

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ABSTRACT

This study determined the influence of a high (HI) vs. low-intensity (LI) cycling warm-up on blood acid-base responses and exercise capacity following ingestion of sodium bicarbonate (SB; 0.3 $g \cdot kg^{-1}$ body-mass (BM)) or a placebo (PLA; maltodextrin) 3-hours prior to warm-up. Twelve men (21±2 years, 79.2±3.6 kg BM, maximum power output (W_{max}) 318±36 W) completed a familiarisation and four double-blind trials completed in a counterbalanced order: HI warm-up with SB (HISB); HI warm-up with PLA (HIPLA); LI warm-up with SB (LISB); and LI warm-up with PLA (LIPLA). LI warm-up was 15-minutes at 60%$W_{max,}$ while the HI warm-up (typical of elites) featured LI followed by 2 x 30-sec (3-minute break) at W_{max}, finishing 30-minute prior to a cycling capacity test at 110%W_{max} ($CCT_{110\%}$). Blood bicarbonate and lactate were measured throughout. SB supplementation increased blood bicarbonate (+6.4 [95%CI: 5.7 to 7.1 $mmol \cdot L^{-1}$]) prior to greater reductions with high intensity warm-up (-3.8 [95%CI: -5.8 to -1.8 $mmol \cdot L^{-1}$]). However, during the 30-minute recovery, blood bicarbonate rebounded and increased in all conditions, with concentrations ~5.3$mmol \cdot L^{-1}$ greater with SB supplementation ($P<0.001$). Blood bicarbonate significantly declined during the $CCT_{110\%}$ with greater reductions following SB supplementation (-2.4 [95%CI: -3.8 to -0.90 $mmol \cdot L^{-1}$]). Aligned with these results, SB supplementation increased total work done during the $CCT_{110\%}$ (+8.5 [95%CI: 3.6 to 13.4 kJ], ~19% increase) with no significant main effect of warm-up intensity (+0.0 [95%CI: -5.0 to 5.0 kJ). Collectively, the results demonstrate that SB supplementation can improve HI cycling capacity irrespective of prior warm-up intensity, likely due to blood alkalosis.

KEY WORDS: Supplementation, high-intensity, low-intensity, buffering

INTRODUCTION

Muscle acidosis caused by the accumulation of intramuscular hydrogen cations (H^+) can hinder enzymatic energy production and contractility of the muscle (Jubrias, Crowther, Shankland, Gronka, & Conley, 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 to 10-minutes) performance (Carr, Hopkins, & Gore, 2011; Christensen, Shirai, Ritz, & Nordsborg, 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, Siegler, & Vince, 2012), with larger effect sizes in non-trained 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, metabolic and neural stimulation, that can enhance muscle function and subsequent performance (McGowan, Pyne, Thompson, & Rattray, 2015). Pre-exercise 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, Doust, & Jones, 2005; Ingham, Fudge, Pringle, & Jones, 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 3-5mmol·L^{-1} (Bailey, Vanhatalo, Wilkerson, Dimenna, & Jones, 2009;

Ingham et al., 2013) with a sufficient recovery period (>9-minute; (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, Doust, Carter, & Jones, 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. Since lactate/proton co-transport is the predominant lactate transport system in muscle (Juel, 1997), H^+ will also enter circulation. Thus, it is interesting to speculate how much of the pre-exercise 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 performance enhancing effect of SB, many studies have not considered the impact of the warm-up prior to exercise. Many SB studies have employed LI warm-ups with short recovery periods prior to the main exercise task (Froio de Araujo Dias et al., 2015; Saunders, Sale, Harris, & Sunderland, 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 relative short periods or recovery between a warm-up and subsequent exercise. However, it is not uncommon for elite athletes, and required withing the rules of many sports (competition “check-in” time) to finish warm-ups 20-40-minutes prior to competition, allowing for greater recovery (Ingham et al., 2013). It is unknown if SB supplementation prior

103 to a HI or LI warm-up would be similarly effective due to buffering requirements during the
104 warm-up itself.

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106 Although HI athletes will regularly consume SB and perform HI warm-ups, no evidence exists
107 to determine the impact of warm-up intensity on blood acid-base responses and the influence
108 of this upon subsequent HI cycling capacity and performance. Therefore, we examined the
109 effects of warm-up intensity and SB supplementation upon cycling capacity and blood acid-
110 base analyte responses. Our hypothesis is that SB supplementation would enhance exercise
111 performance regardless of warm-up intensity, although the HI warm-up condition would result
112 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 (GI) distress experienced during one of the trials, and one due to an injury not associated with the protocol, therefore twelve men (age, 21±2 years; height, 1.82±0.06 m; body mass (BM), 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 GI problems in the previous six 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 individual's height (m) and body mass (kg) followed by an incremental cycling test to determine maximum power output (W_{max}) and a familiarisation of the main exercise protocol. The incremental exercise test was performed on a cycle ergometer (Lode Excalibur, Groningen, 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, abstained from alcohol and strenuous exercise for the 24h prior and from caffeine on test days. Experimental sessions were separated by a minimum of five days,

with an average of seven days between visits. Resting fingertip blood samples were obtained prior to the supervised consumption of either 0.3g·kg^{-1}BM of SB (Intralabs, UK) or a placebo (PLA; Maltodextrin; MyProtein, UK) provided in identical clear gelatine 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, UK (ISO 17025). Following ingestion, participants remained rested for a three-hour 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 + 6mmol·L^{-1} (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=0.39).

A fingertip blood sample was obtained immediately-prior to a LI (15-minutes of cycling at 60% W_{max} (191±21W)) or HI (5-minutes at 60% W_{max}, 5-minutes at 70% W_{max} (223±25W), 5-minutes at 80% W_{max} (255±29W), 30 s at W_{max} (318±36W), followed by a 3-minute 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-minutes prior to competition (*personal observations/discussions in elite sport via T. Stellingwerff*). Participants remained seated for 30-minutes following completion

of the warm-up, with fingertip blood samples taken at 10-minute intervals. Participants then completed a cycling capacity test to exhaustion at 110% W_{max} ($CCT_{110\%}$; 350±39W) (Saunders, Sale, Harris, Morris, & Sunderland, 2013). A capacity test was chosen here due to the high-intensity nature of the activity and 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 familiarisation 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±34W). Total work done (TWD; in kJ) and time-to-exhaustion (TTE; in s) were recorded as the outcome measure for all cycling capacity tests. Fingertip capillary blood samples were taken immediately and 5-minutes following completion of the $CCT_{110\%}$. All blood samples (80 µL) were collected in heparin-coated clinitubes and immediately analysed for lactate and PCO_2 concentration (Radiometer ABL 900, Radiometer Ltd, UK), with bicarbonate and base excess 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% (α=0.01; within-subject effect in a repeated measures ANOVA with 1 group and 6 measurements) using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007). Calculations were based on TWD from Peart et al., (2012) (Cohen's *d*: 0.6). Data obtained from blood samples were analysed sequentially across the distinct measurement periods to better describe the effects of warmup on blood bicarbonate and lactate kinetics. The measurement periods were separated into four distinct periods for analysis: 1)

Supplementation: Baseline to warm-up onset; 2) Warm-up: Warm-up onset to post-warm-up; 3) Recovery: post-warm-up to exercise onset; 4) 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) whilst 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 were, therefore could only be modelled by a straight line. In contrast, the recovery period comprised three sequential data points and was modelled 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, Brockhoff, & Christensen, 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, Williamson, & Batterham, 2019). TWD and TTE were used as measures of performance, with response defined as improvement beyond the smallest worthwhile change (SWC: calculated as 0.2 x the group standard deviation during the PLA session (Paton & Hopkins, 2006)). Assessment of response was made using recommended group-based data practices (Atkinson, Williamson, & Batterham, 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 [95%CI: 3.6 to 13.4 kJ], P=0.002) and TTE (24.6 [95%CI: 10.4 to 38.8 s], P=0.002). No significant main effects were identified for warm-up intensity (TWD: 0.0 [95%CI: -5.0 to 5.0 kJ], P=0.999; TTE (-0.42 [95%CI: -14.6 to 13.8 s], P=0.954)) or interaction between intensity and supplementation (TWD: -1.8 [95%CI: -8.7 to 5.2 kJ], P=0.627; TTE (-4.7 [95%CI: -24.8 to 15.4 s], P=0.652)). 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.

Bicarbonate

A significant main effect was obtained for SB supplementation demonstrating increased blood bicarbonate concentrations from baseline to pre-warm-up (6.4 [95%CI: 5.7 to 7.1 $mmol \cdot L^{-1}$], P<0.001) with no significant main effect obtained for PLA (0.0 [95%CI: -5.6 to 5.6 $mmol \cdot L^{-1}$], P=0.985; Figure 3). Blood bicarbonate decreased in all conditions following the warm-up period (LISB: -10.0±2.7 $mmol \cdot L^{-1}$; LIPLA: -7.0±2.5 $mmol \cdot L^{-1}$; HISB: -14.5±4.6 $mmol \cdot L^{-1}$; HIPLA: -10.9±1.9 $mmol \cdot L^{-1}$; P<0.001) with significant main effects obtained for both SB supplementation (-3.7 [95%CI: -5.7 to -1.7 $mmol \cdot L^{-1}$], P<0.001) and warm-up intensity (-3.8 [95%CI: -5.8 to -1.8 $mmol \cdot L^{-1}$], P<0.001). These effects did not, however, fully offset the initial increase in blood bicarbonate with supplementation (Figure 3).

During the 30-minute 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=0.630), whereas formation during all other conditions were non-linear (P≤0.024) with rates slowing as time progressed. During the rebound period, blood bicarbonate increased +7.8±1.5 mmol·L^{-1} in LISB, +5.8±1.7 mmol·L^{-1} in LIPLA, +11.2±4.1 mmol·L^{-1} in HISB and +8.2±1.6 mmol·L^{-1} 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 to 2.4 mmol·L^{-1}], P=0.160), whereas on average blood bicarbonate was estimated to be 5.3 mmol·L^{-1} greater (5.3 [95%CI: 3.9 to 6.7 mmol·L^{-1}], P<0.001) with supplementation (Figure 3: Post recovery).

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 to -0.90 mmol·L^{-1}], P=0.003). No significant main effects were identified for warm-up intensity (1.0 [95%CI: -0.5 to 2.5 mmol·L^{-1}], P=0.188) or interaction between intensity and supplementation (0.5 [95%CI: -1.7 to 2.8 mmol·L^{-1}], P=0.637). 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 to 4.0 mmol·L^{-1}], P<0.001), with no significant main effect of warm-up intensity (0.0 [95%CI: -1.1 to 1.1 mmol·L^{-1}], P=0.971). No main effects of warm-up intensity or supplementation (P≥0.095) were obtained for changes in blood bicarbonate concentrations during the 5-minute recovery following the $CCT_{110\%}$.

Lactate

Blood lactate concentrations increased in all conditions following the warm-up (LISB: +10.1±3.4 mmol·L^{-1}; LIPLA: +8.1±3.5 mmol·L^{-1}; HISB: +16.0±6.0 mmol·L^{-1}; HIPLA: 13.1±3.6 mmol·L^{-1}, Figure 4: Post WU) with significant main effects obtained for both SB

supplementation (3.2 [95%CI: 0.5 to 5.8 mmol·L^{-1}], P=0.022]) and warm-up intensity (4.7 [95%CI: 2.2 to 7.2 mmol·L^{-1}], P<0.001).

During the 30-minute recovery period, different rates and profiles were identified (Figure 4). The greatest rate of removal was in HISB which was linear (P=0.080), whereas blood lactate removal during all other conditions were non-linear (P<0.001), rates slowed as time progressed. At the end of recovery period a significant interaction effect was obtained (1.7 [95%CI: 0.2 to 3.3 mmol·L^{-1}], P=0.031) as well as significant main effects of SB supplementation (2.1 [95%CI: 1.1 to 3.1 mmol·L^{-1}], P<0.001) and warm-up intensity (1.3 [95%CI: 0.33 to 2.3 mmol·L^{-1}], P=0.014). As a result, lactate concentrations were substantively higher in the HISB condition compared to all other conditions (LISB: 3.0±1.3 mmol·L^{-1}; HISB: 6.1±2.6 mmol·L^{-1}; LIPLA: 2.6±1.0 mmol·L^{-1}; HIPLA: 4.1±2.1 mmol·L^{-1}; Figure 4: Post Recovery).

Blood lactate concentrations increased substantively during the $CCT_{110\%}$ (Figure 4: $CCT_{110\%}$) but no significant interaction (1.7 [95%CI: -1.1 to 4.5 mmol·L^{-1}], P=0.229) or main effects (SB supplementation: 0.6 [95%CI: -1.2 to 2.5 mmol·L^{-1}], P=0.509; warm-up intensity: 0.6 [95%CI: -1.2 to 2.5 mmol·L^{-1}], P=0.509) were obtained. Post $CCT_{110\%}$ blood lactate concentrations remained on average 2.7 mmol·L^{-1} higher post $CCT_{110\%}$ with SB supplementation (2.7 [95%CI: 1.0 to 4.5 mmol·L^{-1}], P=0.004) with no significant main effect of warm-up intensity (-0.4 [95%CI: -2.3 to 1.6 mmol·L^{-1}], P=0.675).

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 (Figure 3 and 4). Blood bicarbonate was higher, and lactate lower, following 30-minute 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 high-intensity 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 vs. LI warm-up with or without bicarbonate supplementation (Figure 2).

The magnitude of the blood bicarbonate increase following SB ingestion and prior to the warm-up is in line with those previously reported with an identical dose (Bishop, Edge, Davis, & Goodman, 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: 4.7mmol·L^{-1}; HI: 2.7mmol·L^{-1}), 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 +5mmol·L^{-1}

increase in blood bicarbonate is necessary to elicit an ergogenic effect (Carr, Slater, Gore, Dawson, & Burke, 2011). Although the minimal increase necessary to elicit an ergogenic effect is currently unknown (Heibel, Perim, Oliveira, McNaughton, & Saunders, 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 utilisation of the increased buffering capacity with SB.

To ensure high ecological validity, both the HI warm-up and the 30-minute recovery period were implemented to replicate a typical elite track-cycling protocol (*personal observations, T. Stellingwerff*), and to reflect the athlete pre-competition / post warm-up "check-in" constraints at international competitions for most high-intensity 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 towards homeostasis, albeit it appears that SB ingestion impacts this response. This response aligns with recovery in acid base balance following intense exercise when sodium bicarbonate has been ingested (Robergs et al., 2005; Gough et al., 2019). Ingestion of SB influenced the blood bicarbonate response during this short 30-minute 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: +7.8mmol·L^{-1}; PLA: +5.8mmol·L^{-1}) compared to HI

conditions (SB: +11.2mmol·L^{-1}; PLA: +8.2mmol·L^{-1}); probably due to the already higher bicarbonate concentrations following the LI warm-up. These data indicate that the post-exercise 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 h 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, Maddox, Lucci, & Rector, 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 non-specifically 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 SWC as a direct result of supplementation. These improvements are also in excess of those shown with beta-alanine supplementation [+5-14% 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-minute) low-intensity fixed load warm-

up with little recovery time (2-3-minute) 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 optimised 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-minutes prior to the event.

The present study showed similar effects of low and high intensity 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 +3-5mmol·L^{-1} , where subsequent performance may be improved (Ingham et al., 2013), whilst 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 non-athlete volunteers since lactate levels immediately post-warm-up were well above 6mmol·L^{-1} in all sessions. Bishop (2003) reported that warm-ups consisting of workloads above 60% VO_{2max} may have an adverse effects on subsequent exercise performance, likely due to the depletion of high-energy phosphates and the accumulation of H^+. Nonetheless, prior high-intensity exercise can improve exercise tolerance to subsequent high-intensity activity if adequate recovery time is provided (>9-min; (Bailey et al., 2009)). More specifically, for athletes whose competition requires a high-intensity component, warm-ups that elicit a 4-6mmol·L^{-1} increase in lactate followed by a 20-40-minute recovery period is commonplace (Ingham et al., 2013). Despite the substantial recovery period in this study (30-

minute), blood lactate following the HI warm-up remained high and did not return below 4mmol·L^{-1} in either SB (6.1mmol·L^{-1}) or PLA (4.1mmol·L^{-1}). 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 3mmol·L^{-1} when the main exercise bout begins (McGowan et al., 2015). This is also reflected in the similar pre-exercise 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 high-intensity 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.

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FIGURES

Figure 1: Experimental protocol for the main trials. SB: Sodium bicarbonate, PLA: Placebo. HI: High intensity, LI: Low intensity. CCT110%: cycling capacity test to exhaustion at 110% W_{max}.

Figure 2: Total Work Done (TWD) across the four conditions; 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. Data are Means ± SD while individual data points are also plotted.

Figure 3: Group bicarbonate data modelled 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, CCT110%: cycling capacity test to exhaustion at 110% W_{max}. Error bars are centred at group average and represent standard errors.

Figure 4: Group lactate data modelled 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, CCT110%: cycling capacity test to exhaustion at 110% W_{max}. Error bars are centred at group average and represent standard errors.