THE EFFECT OF DIFFERENT DOSING STRATEGIES OF SODIUM BICARBONATE UPON COLLEGIATE SWIMMERS

A MANUSCRIPT STYLE THESIS PRESENTED

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ABSTRACT

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This study evaluated the efficacy of different dosages of sodium bicarbonate on time trial performance, blood lactate concentrations and incurred side effects. Participants included 10 volunteer male (n = 3) and female (n = 7) members of the University of Wisconsin-La Crosse swimming team. The participants were divided into groups by in-season specialization of 100 yards, 200 yards or 400 yards. Each participant completed a time trial under a control condition, and under 0.1 g/kg body weight, 0.2 g/kg body weight and 0.3 g/kg body weight. Blood lactate was collected before and after the time trial. Side effects were recorded every 10 minutes from consumption to 20 minutes post trial. Performance times were all significantly faster under the experimental conditions vs. control ($p = 0.001$). The 0.1 g/kg body weight produced the fastest time (97% of the control time), then 0.2 g/kg body weight (98.19% of the control time) and 0.3 g/kg body weight (99.10% of the control time). Pre and post-trial lactate values all increased proportionately with the dosage of sodium bicarbonate and were significantly higher than the control values in both pre-trial ($p = 0.02$) and post-trial ($p = 0.001$). Side effects were similar in type and frequency under the 0.1 g/kg body weight (7) and 0.2 g/kg body weight (10) conditions, however they increased in severity under the 0.3 g/kg body weight (27) condition. The findings suggest that bicarbonate loading is effective even at lower dosages, however, as the dosage increases, side effects can impede any ergogenic effect. Reduced water consumption during dosing may help to avoid gastro-intestinal side effects.

COLLEGE OF HEALTH, PHYSICAL EDUCATION, RECREATION AND TEACHER EDUCATION

UNIVERSITY OF WISCONSIN-LA CROSSE

THESIS FINAL ORAL DEFENSE FORM

Candidate: Steven Andrew Bowman

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Exercise and Sports Science – Human Performance

The candidate has successfully completed the thesis oral defense

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This thesis is approved by the College of Health, Physical Education, Recreation and Teacher Education.

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INTRODUCTION

Many competitive sports require sustained high intensity action. Exercise of this nature requires the athlete to use anaerobic glycolysis as a means of deriving ATP for muscle function. This process involves partial metabolism of glycogen, resulting in net lactic acid accumulation, which in turn contributes to a pH decrease within the muscle cell due to the accumulation of H^+ ions.

Sodium bicarbonate loading is a technique that was first used in the 1930's by Denning *et al.* (1931). The technique is theorized to increase the body's natural reserve of bicarbonate. Bicarbonate is a naturally occurring compound, and therefore as an ergogenic agent, appears on few of the sports governing bodies' lists of banned substances. For this reason it represents a potentially viable method of improving performance that doesn't contravene substance abuse guidelines (MacLaren, 1997).

It is proposed that fatigue is attributable to two factors; the first is the direct effect of intracellular acidosis on metabolic enzyme function, and the second is the rate of efflux of H^+ ions due to the extracellular pH (Mainwood & Worseley-Brown, 1975). An imbalance between the intracellular and extracellular pH about a cell causes ions to cross the cell membrane to maintain a balanced pH gradient. If alkaline bicarbonate is deposited around a muscle cell, then acidic H^+ ions must cross the cell membrane to balance this, thus neutralizing the pH level within the cell and potentially delaying fatigue.

Another theory of how the buffering process functions is that bicarbonate ions cross into the cell in the opposing manner; however, this view is largely refuted due to the fact that bicarbonate ions are generally too large to move through the cell membrane (Robin, 1961).

Many studies have been carried out investigating the effects of bicarbonate ingestion. Following a period of absence from the published material, two prominent bicarbonate loading papers were published by Jones *et al.* (1976, 1977), who followed similar protocols in both studies of cycling to exhaustion at 95% VO_2Max. Both of these studies demonstrated positive ergogenic benefits of bicarbonate ingestion. Data published in 1983 by Wilkes *et al.* further supported the concept of performance augmentation through bicarbonate loading. This study moved away from the laboratory and tested bicarbonate loading in the field setting. They found that bicarbonate ingestion improved performance by 2.9 seconds (a 2.38% improvement) in 800m running time.

MacLaren (1997) also presents a summary table with studies where no ergogenic effects were witnessed. However, upon examination of the protocols followed in these studies, there appear to be fundamental flaws that would explain the findings. Where researchers have used optimal exercise and temporal strategies, performance improvements have generally been found (see appendix C).

It is widely published in the literature that 0.3g/kg body weight is the optimum dosage to reap maximum benefits from bicarbonate ingestion (Matson & Tran, 1993). However, such a high dosage has been linked to acute gastro-intestinal distress (Lindermann & Gosselink, 1994). It follows that if the athlete is placed under stress from this discomfort, any ergogenic benefits may be nullified through psychological aspects,

and dehydration. If the gastro-intestinal distress could be avoided and the ergogenic benefits retained, bicarbonate loading would offer a realistic performance enhancing option for athletes.

Other studies have employed lower dosages (Margaria, 1971; Horswill *et al.*, 1988) and found no ergogenic benefit. However, upon examining the protocols and procedures used in the studies, it may be argued that other factors contributed to the lack of effect. When lower dosages are employed, the side effects from bicarbonate ingestion are less frequent.

Past studies have not examined the effects of different dosing strategies in the same group of subjects. Dosages from 0.1 g/kg body weight to 0.4g/kg body weight have been used; however, with the exception of Horswill *et al.* (1988), they were not used upon the same subjects.

Therefore, there appears to be a need to determine the effectiveness of different dosages, and how this is balanced with side effects in a field setting. The first issue that will be addressed is the degree of ergogenic benefit, if any, that is afforded by varying dosages of bicarbonate. The second issue is the severity and frequency of side effects associated with these dosages. With both considerations being assessed in a field setting using the same subject sample, maybe more reliable conclusions can be made rather than piecing together the previous literature.

This investigation may indicate a dosage of bicarbonate that enhances performance, while avoiding the side effects associated with bicarbonate loading. The null hypothesis is that there will be no dosage identified that improves performance while avoiding side effects.

Methods

Participants

The participants for this study were members of the University of Wisconsin–La Crosse men's and women's swimming teams (N = 10). The participants' characteristics are presented in Table 1. All participants provided written informed consent prior to participation (see appendix A) and the protocol was approved by the Institutional Review Board for the Protection of Human Subjects of the University of Wisconsin-La Crosse.

Table 1. Participants' Characteristics (Mean ± Standard Deviation)

	Age (years)	Bodyweight (kg)	N
Males	20.30 ±1.12	80.30 ±4.89	3
Females	18.70 ±0.82	59.92 ±7.55	7

Testing Procedures

The study was conducted at the end of the competitive season when the participants were already well conditioned. Participants reported to the swimming pool on 4 test days, with 2 days between trials. After initial measurement of body weight, subjects ingested sodium bicarbonate in tablet form (United Research Laboratories Inc, PA) in either 0.1g/kg body weight, 0.2 g/kg body weight, 0.3 g/kg body weight, or

completed the control trial with no sodium bicarbonate. Ingestion took between 30 seconds and 2 minutes dependent upon dosage and subject.

The trial order was randomized between participants. The sodium bicarbonate was ingested 60 minutes prior to undertaking the time trial. Water was only consumed while the tablets were being ingested. The amount was less than 300 ml in all cases. After that, drinking was actively discouraged. Participants remained seated and resting after ingestion before starting the warm up.

After 45 minutes, the subjects began a normal pre-competition warm up, which lasted 15 minutes and covered 1100 yards. Immediately after completing the warm up, the time trial took place. The time trials took place in an indoor 6-lane 25 yard competition pool. Distance for the trial was pre-assigned based on each participant's in-season distance specialty, either 100 yards, 200 yards or 400 yards. The participants swam alone.

Split times were recorded at 25 yard intervals for the 100 yard time trial, and at 50 yard intervals for the 200 yard and 400 yard time trials. All participants were given encouragement throughout the trial from the pool side. All participants swam front crawl stroke during the warm up and trial. The participants were instructed to swim at maximal pace throughout the trial. After blood sampling, the participants were required to cool down using a standardized cool down workout, covering 800 yards.

Finger prick blood samples were collected immediately post warm up, and immediately post trial. Twenty five microliters were drawn, and placed in a buffer solution until it could be analyzed. All samples were analyzed for blood lactate

concentration using an enzyme electrode system (YSI 1500 Sport Lactate Analyzer, Yellow Springs, OH, USA).

Side effects were recorded at 10 minute intervals after ingestion, up to 20 minutes post trial, concerning headache, nausea, dizziness, bloating, gas and other. 'Gas' was defined as 'experiencing either flatulence or belching'. 'Dizziness' was defined as 'a feeling of light-headedness or a tingling sensation in the extremities'. 'Bloating' was defined as a 'sensation of fullness or weight' in the stomach. 'Other' covered any side effect or sensation not asked about, that they could describe and that they attributed to the bicarbonate ingestion. A follow up communication was sent to each participant asking about any side effects that were experienced after leaving the pool.

Statistical Procedures

Data were compared using a repeated measures ANOVA with Tukey's *post hoc* analysis. Outcome measures included pre- versus post-mean values for blood lactate accumulation, and performance time between the control trial and the three experimental trials. Statistical significance was pre-set at $p < 0.05$ in all statistical analysis.

RESULTS

Of the recruited sample of 13 subjects, 3 were excluded. One was removed from the study after experiencing gastro-intestinal side effects, and one was removed from the data set as an outlier. One subject was also removed due to scheduling problems.

Performance Time

Time trial results were analyzed as standardized scores initially. The absolute times were converted to percentages of the control time to attain this standardized score. Statistically significant ($p = 0.001$) differences were found between the control trial and the three dosage trials indicating performance improvement under alkalotic conditions. These standardized mean times can be found in Table 2.

Table 2. Experimental Trial Times as a Percentage of the Control Trial Time.

Condition	0.1 g/kg	0.2 g/kg	0.3 g/kg
Relative time (%)	97.00 ±1.27*	98.19 ±1.75*	99.10 ±1.02*

* $p < 0.05$; Experimental trial significantly faster than control trial

Performance times were also analyzed by dosage dependent on trial distance. The best mean improvements were found under the 0.2 g/kg body weight dosage for 100

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Performance times were also analyzed by dosage dependent on trial distance. The best mean improvements were found under the 0.2 g/kg body weight dosage for 100

yards, at 0.3 g/kg body weight for 200 yards, and 0.1 g/kg body weight for 400 yards. The mean times by distance and dosage can be found in Table 3.

Table 3. Mean Times for Each Condition by Distance of Trial

Condition	N	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg
100 yards (sec)	4	61.47 ±3.78	59.95 * ±3.26	59.63 *† ±3.05	60.57 ±3.24
200 yards (sec)	3	124.96 ±4.17	124.51 ±5.59	124.52 ±7.58	123.98 *† ±4.46
400 yards (sec)	3	257.03 ±18.08	250.62 *† ±17.52	255.63 * ±16.00	256.0 ±17.17

* $p < 0.05$; Experimental trial significantly faster than control trial
† Fastest experimental trial vs. control trail

Blood Lactate Accumulation

The blood lactate data demonstrated a statistically significant difference between dosages both pre-trial ($p = 0.02$) and post-trial ($p = 0.001$). There was no statistically significant interaction effect reported between distance and dosage ($p = 0.06$). The mean blood lactate values are displayed in Table 3. Under all experimental dosages, pre-trial lactate was significantly higher than the control trial. Under all experimental dosages, post-trial blood lactate was significantly higher than the control trial ($p = 0.000$). The mean values for post-trial lactate increased proportionately with the increase in dosage of bicarbonate. 0.2 g/kg body weight was significantly higher than 0.1 g/kg body weight

($p = 0.009$). 0.3 g/kg body weight was significantly higher than 0.1 g/kg body weight ($p = 0.001$) and significantly higher than 0.2 g/kg body weight ($p = 0.033$).

Table 4. Mean (± SD) Pre and Post Blood Lactate Values by Condition (mmol/l)

Condition	Pre-Trial	Post-Trial
Control	2.24 ±0.92	7.63 ±2.52
0.1 g/kg body weight	3.52 ±1.31*	8.81 ±2.66
0.2 g/kg body weight	3.20 ±1.01*	11.42 ±3.6* †
0.3 g/kg body weight	4.37 ±1.78*	13.54 ±3.31*†‡

* $p < 0.05$; Experimental trial significantly higher than control trial
† $p < 0.05$; Experimental trial significantly higher than 0.1 dosage
‡ $p < 0.05$; Experimental trial significantly higher that other dosages

The blood lactate accumulation data is reflective of the distance-specific optimum dosage shown by the performance time data. This is shown in Table 5. It could be inferred that this is indicative of degree to which the glycolytic system is used due to the intensity of the events.

Table 5. Mean (± SD) Post-Trial Blood Lactate by Distance and Dosage

Distance	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg
100 yards	7.29 ±3.29	7.01 ±1.89	10.87 ±3.11*	11.68 ±5.28*
200 yards	8.69 ±2.77	9.97 ±3.77*	12.65 ±5.02*	14.44 ±2.40*
400 yards	6.55 ±1.39	9.08 ±1.39*	10.31 ±2.38*	14.20 ±2.33*

*p <0.05; Experimental trial significantly higher than control trial

Side Effects

Side effects were documented at 10 minute intervals from consumption up to 20 minutes post trial. Incidents of gas, bloating, headache, dizziness, a 'burning' sensation, diarrhea, vomiting and nausea were recorded. Breakdowns of side effects are described in Table 6. At 0.1 g/kg body weight, 6 cases of side effects were recorded. At 0.2 g/kg body weight 10 cases were reported. At 0.3 g/kg body weight 27 cases were reported. Table 6 shows the frequency of side effects by type and dosage.

Table 6. Frequency and Type of Side Effect Reported by Dosage

Side Effect Type	0.1 g/kg	0.2 g/kg	0.3 g/kg	Total
Gas	3	3	5	11
Bloating	1	3	5	9
Dizziness	1	0	4	5
Burning sensation	0	2	3	5
Diarrhea	0	0	3	3
Vomiting	0	0	1	1
Nausea	0	0	3	3
Headache	1	2	3	6
Cumulative	6	10	27	

All cases of gas were reported by 30 minutes post consumption, and continued up to 60 minutes post consumption. All bloating was reported by 20 minutes post consumption, and was past by 50 minutes post consumption. Of 5 cases of dizziness, 4 were reported immediately after warm up at 60 minutes post consumption. All cases of headache were reported after the time trial was completed, and lasted up to 5 hours afterwards in one case. However headaches were described only as 'minor headaches'. All 3 cases of diarrhea were experienced after the trial by 2-3 hours. In the subject who dropped out of the study, diarrhea was experienced at 40 minutes post consumption. In this case, the

participant drank excessive water during dosing against the advice of the experimenter. Only three members of the sample in only the 0.2 g/kg body weight and two in the 0.3 g/kg body weight conditions experienced the 'burning' sensation. All subjects were female and all experienced the sensation at 30 minutes post consumption. The sensation was reported to dissipate after 2 hours and after eating. Nausea was only experienced by participants under the 0.3 g/kg body weight dose, and was reported post time trial swim. Vomiting occurred only once, during a 200 yard time trial. This subject reported consuming 600ml of a skim-milk protein shake 20 minutes before reporting for testing, which may have caused the incidence of vomiting.

DISCUSSION

This study compared time trial performance, blood lactate accumulation and symptoms under a control condition and three different dosages of sodium bicarbonate in trained collegiate swimmers. The swimmers had significantly faster times in their respective trials under the influence of sodium bicarbonate in at least one of the dosing conditions. All participants performed faster than the control trial after ingesting sodium bicarbonate.

All dosages of bicarbonate improved mean performance time versus the control time regardless of the distance of the course. The standardized times revealed that the lower the dose, the better the improvement. This is in direct contradiction to the literature, which has reported improvement with the dosage of 0.3 g/kg body weight. The literature has found no improvement with the lower dosages of 0.1 g/kg body weight and 0.2 g/kg body weight. The side effect data collected however may provide further insight into the reason for this however (MacLaren, 1997).

The mean times examined by distance provide support for the concept that regardless of the distance, bicarbonate loading has ergogenic effects. Even though different rates of energy expenditure would dictate differing rates of lactate production, and therefore time to fatigue, bicarbonate loading still proved effective. At the shortest distance of 100 yards, the biggest drop in mean time was 1.84 seconds (2.99%). In an event where all finalists can be within 2 seconds of each other, this represents a major advantage. The same relative improvement is found in 200 yards (0.99 seconds, 1%) and

400 yards (6.41 seconds, 2.5%). In the 400 yards this equates to a difference in mean swimming velocity of 0.04 yards/second.

Improvement did seem to be individualistic however. Even within the same distance group, individuals reacted differently to the dosages. Some improvements were marginal, while others were more drastic. This would support the notion that cross-referencing data from previous studies using different exercise methods and different samples to determine the effectiveness of the technique would be of questionable value. To add to this, there is the problem that performance in the laboratory, which is where much of the bicarbonate research has been done, and performance in the field produce drastically different results with differing degrees of validity.

The blood lactate concentration both pre-trial and post-trial compared favorably with previous literature however (Wilkes *et al.*, 1983). The presence of increased levels of circulating bicarbonate would increase the diffusion gradient at the cell membrane, and therefore explain the fact that the greater the dosage of bicarbonate in the system, the higher the blood lactate concentration. It would be expected that this phenomenon would be seen after the warm up, and reflected to a greater degree after the trial. The warm up consisted of increasing loads upon the glycolytic system to prepare the swimmer for a maximal effort trial, so lactate would have been produced to some degree during the pre-trial preparation. Obviously, the trial was a more sustained and severe tax upon the glycolytic system, so the blood lactate values were significantly higher, but they still increased in a proportionate fashion.

The blood lactate concentrations and the most effective dosage are indicative of the energy systems primarily associated with each distance because of intensity of

exercise and event duration. In the 100 yard trial, with a duration of approximately 60 seconds, one would expect the primary source of ATP to be the ATP-PC system, and to a lesser degree the glycolytic system. However, the intensity of the pacing would invoke moderate lactate production due to the involvement of glycolysis, which reflects the optimum dosage of 0.2 g/kg body weight. The 200 yard time trial involves a duration of approximately 2 minutes, and one would expect that due to the high intensity of the pacing and the duration, the glycolytic system would indeed be the primary energy system activated for ATP production. This is reflected by the mean post-trial blood lactate value, which was higher than the other two distances (11.44 mmol/l versus 10.04 mmol/l and 9.21 mmol/l for 400 and 100 respectively), and also by the optimum dosage for this distance, which was 0.3 g/kg body weight. The 400 yard time trial represents an event in which aerobic production becomes more of a factor. The duration is approximately 4.25 minutes, and swimming velocity is still high, but not as high as the 100 yard or 200 yard distance. In this case ATP will be produced at a slower rate by the glycolytic system, but the longer duration of activation would allow for accumulation of lactate. Arguably, this slower rate of lactate production could explain why the 0.1 g/kg body weight was the more effective dose in this trial distance.

However, an important consideration is that of the effects of the reaction to the bicarbonate. According to the theory, the greater the amount of bicarbonate ingested, the greater the buffer reserve, and therefore the greater the capacity to work without fatiguing. However, this is obviously not the case. The side effects at the highest dosage produced significant discomfort to the subjects, affecting them on both a psychological and physical level. The prevalence of side effects at the highest dosage of 0.3 g/kg body

weight could arguably negate any increased ergogenic benefit from the higher buffering capacity. The relative absence of side effects in the lower dosages may be the reason they appeared to be more effective than the 0.3 g/kg body weight dosage. It is speculation, however, as the reactions were highly idiosyncratic. Nevertheless, it would explain in a feasible way the disparity between the blood lactate values and the performance times.

The highest frequency of side effect type was gas, either flatulence or belching. The combination of the alkaline sodium bicarbonate and the hydrochloric acid in the stomach would induce this. This pH imbalance could also cause the nausea experienced by the participants. The disproportionately high levels of sodium, which would draw water into the stomach and intestinal tract, could explain the bloating, and ultimately the diarrhea.

In the literature there is no report of headaches as a side effect of sodium bicarbonate ingestion (Lindermann & Gosselink, 1994). However, in this study, the subjects were discouraged from fluid ingestion during the dosing stage of the protocol. This was done in order to prevent diarrhea through water being directed into the digestive tract. However, a consequence of this could be dehydration. The decrease in blood plasma volume due to water being pulled into the digestive tract, could lead to increased blood plasma osmolality. Coupled with the increased demand upon the cardiopulmonary system during the high intensity exercise could exacerbate the dehydration, and with increased core temperature due to water temperature and exercise may explain the headaches appearing post-trial.

While only one case of diarrhea was reported during the dosing period, there were 3 more cases reported in the time after leaving the pool. Though supposition, it could be that this occurred after leaving due to the fact that participants were encouraged to drink *ad libitum*. The sudden increase in water in the gastric tract, in the presence of remaining high levels of sodium, could trigger the diarrhea.

Overall, the results of this study reinforce that bicarbonate loading is a technique that must be applied specific to the individual and specific to the event for which it is being used. It demonstrates a more complex interplay to strike a balance between the side effects and the ergogenic benefits than have been proposed in previous literature.

However, it has once again shown support for the technique as a legitimate and legal method to enhance performance significantly. Gains shown in this study alone would arguably be very tempting. The side effects are acute when they are experienced, and at the lowest level of 0.1 g/kg body weight which was shown to have performance enhancing effects, were negligible.

Though the physiological measures in this study were insufficient to be able to describe the actual mechanism by which bicarbonate actually enhances buffering capacity, it may be inferred from previous literature, due to reflection of blood lactate data as a marker, that ingestion does boost the buffer reserve.

It is recommended however, that the best way to select an appropriate dosage would be through working with the individual athlete to find the highest dosage they can tolerate systematically, so that the best benefits can be reaped, and the debilitating side effects avoided.

This study is constrained by the sample size employed. To ascertain statistical power to reinforce the inferences made, a sample size of at least 30 subjects is recommended. It may be beneficial to use a standardized task, and not vary the trial distances.

Further research in this area may be directed towards finding the best way to maintain hydration levels for the athlete, which could possibly eliminate the worst side effects experienced, as it seems that limiting water intake does indeed provide a solution to the diarrhea associated with the technique. The administration period could also be investigated, to determine if a longer and less severe consumption time frame could lessen the side effects.

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APPENDIX A

INFORMED CONSENT

Informed Consent

Effect of Different Dosages of Sodium Bicarbonate Upon Swimming Performance

I, _____ give my consent to participate in this study of how the ingestion of different dosages of sodium bicarbonate affects maximum effort swimming performance. I consent to presentation and publication or any other dissemination of study results so long as the information is anonymous and disguised so that no personal identification can be made. I have been informed that although a record will be kept of my having participated in the study, all experimental data collected from my participation will be identified by number or code only.

1) I have been informed that my participation in this study will involve swimming up to 400 yards at high intensity and ingestion of sodium bicarbonate pills in three of the four experimental trials.
2) I have been informed that the general purpose of this study is to examine the effects of ingesting different dosages of sodium bicarbonate in a field-type 100, 200 or 400 yards time trial relative to my current event specialization. The total time commitment I must make is approximately10 hours.
3) I have been informed of the risks involved due to the intensity of the exercise, and have been informed of the side effects of sodium bicarbonate ingestion. The primary expected risk is acute gastro-intestinal problems, (cramping, diarrhea, nausea, vomiting) and a tendency to retain water due to sodium ingestion.
4) I have been informed that any questions I have may be directed to the experimenter, Steven Bowman (147 Mitchell Hall, 608-785-8185) or his supervisor Dr. Travis McBride (132 Mitchell Hall, 608-785-6546).
5) I have also been informed that there are possible risks and discomforts associated with participation in any exercise testing and training program Every effort will be made to minimize these risks by evaluation of my previous medical and exercise history. I have been instructed to report any injuries regardless of size, and any signs or symptoms, of the previously mentioned problems, that may occur during the study. I am also aware that trained personnel in CPR and certified lifeguards will be present during every stage of the study. I have been informed that my participation in this study is completely voluntary, and I am free to withdraw at any time.

6) In the unlikely event that injury or illness occurs as a result of this research, the Board of Regents of the University of Wisconsin System, and the University of Wisconsin–La Crosse, their officers, agents and employees, do not automatically provide reimbursement for medical care or other compensation. Payment for treatment of any injury or illness must be provided by you or a third party payor, such as health insurer or medicare. If any illness or injury occurs in the course of research, or for more information, please notify the investigator in charge. I have been informed that I am not waiving any rights that I may have for injury resulting from negligence of any person or the institution.

Questions regarding the protection of human subjects may be addressed to Dr. Dan Duquette, Director of Graduate Studies and Chair of the Institutional Review Board for the Protection of Human Subjects, UW-La Crosse, (608) 785-8161.

Investigator Sig.	*Date*	*Subjects Sig.*	*Date*

APPENDIX B

RAW DATA FOR PERFORMANCE TIME AND BLOOD LACTATE CONCENTRATION

Table 7. Raw Data for 100 yards group.

Subject	Performance Times (sec)				Pre-Trial Blood Lactate (mmol/l)				Post-Trial Blood Lactate (mmol/l)			
	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg
1	63.75	61.37	60.00	62.33	2.22	2.55	1.92	2.19	4.44	6.03	7.53	7.86
2	57.11	56.23	56.42	56.83	3.93	4.08	4.2	6.22	10.89	7.23	13.95	17.70
3	63.55	62.26	62.48	62.56	1.35	1.38	2.4	2.88	6.54	7.77	11.40	9.48
4	61.16	60.89	61.06	61.53	1.96	1.85	2.15	3.63	5.96	7.53	6.96	5.24

Table 8. Raw Data for 200 yards group.

Subject	Performance Times (sec)				Pre-Trial Blood Lactate (mmol/l)				Post-Trial Blood Lactate (mmol/l)			
	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg
5	121.39	121.48	120.50	121.38	2.46	4.98	3.00	5.55	9.63	11.94	10.23	13.83
6	122.29	120.15	118.53	119.50	2.58	3.60	4.86	3.42	10.35	12.90	18.27	15.69
7 *	130.62	132.58	135.45	129.48	0.96	2.25	1.92	2.70	4.56	4.50	6.99	11.31
8	125.54	123.82	123.58	125.58	3.00	3.96	3.00	4.44	10.23	10.53	15.12	16.86

* Excluded from study as a statistical outlier. Violated normal distribution.

Table 9. Raw Data for 400 yards group

Subject	Performance Times (sec)				Pre-Trial Blood Lactate (mmol/l)				Post-Trial Blood Lactate (mmol/l)			
	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg	Control	0.1 g/kg	0.2 g/kg	0.3 g/kg
9	241.61	236.57	241.98	241.88	2.34	4.53	3.96	5.61	7.44	10.71	12.39	16.77
10	275.63	271.28	272.28	275.50	2.49	2.49	2.79	4.59	4.95	7.50	7.71	12.21
11	269.24	258.04	266.50	269.74	1.02	5.40	3.96	4.08	7.26	9.63	10.83	13.62

APPENDIX C

REVIEW OF RELATED LITERATURE

The purpose of this study was to better define the optimum strategies to invoke an ergogenic effect by sodium bicarbonate supplementation. This review of literature will examine the different facets associated with the studies investigating sodium bicarbonate loading. This review discusses the following areas: dosing strategies, methods of ingestion, placebo substances, task protocols, laboratory versus field studies, dependent variables examined, statistical analyses and subject and sampling issues. The review will attempt to relate these factors and how they interact to produce a body of evidence that has yet to be honed to a point where it may be reliably used in an applied setting.

Dosing

Matson & Tran (1993), produced a meta-analysis of 29 studies. They identified that dosages ranged from 0.1g/kg body weight, to 0.4 g/kg body weight, with an overwhelming majority of these studies, 54%, using 0.3g/kg body weight. Out of the studies examined, 42% used 0.3g/kg, citing the work of Jones, Sutton, Lin, Ward, Richardson & Toews (1976), Jones, Sutton, Taylor & Toews (1977, 1981) as the source of this being the optimum dosage. Work by McNaughton (1992) supports this supposition. However, further investigation has been carried out, despite this apparent acceptance of 0.3g/kg as the 'bench mark' value. Horswill *et al.* (1988) administered several dosages to subjects (0.1, 0.15 & 0.2g/kg). After considering the design of the study and the activity used, Horswill *et al.* concluded that none of the dosages were high enough to produce performance-enhancing effects. A higher dosage of 0.4g/kg was used

by Goldfinch *et al.* (1988). Here, the authors found a performance increase, which equated to 10m in 400m racing. It is important to consider why 0.3g/kg is deemed to be optimal even though higher dosages defer performance enhancing effects; research has indicated that if dosages exceeding 0.3g/kg are administered, gastro-intestinal distress is more commonly experienced. This being the case, performance could be impaired to the point where slight enhancements due to induced alkalosis would be negated (Gledhill, 1984). Arguably however, the only reason that 0.3 g/kg body weight has been accepted as the 'bench mark' dosage for performance improvement lies in the inadequate investigation of lesser dosages. Even though some studies do employ lower dosages (see appendix D), they found no performance improvement, yet there were other factors that could have resulted in these findings (Katz *et al.*, 1984).

Methods of Ingestion

One method of dealing with the potential gastro-intestinal discomfort is to control how the sodium bicarbonate is ingested. One aspect generally omitted from the literature is how the sodium bicarbonate is ingested. Of the 25 studies, only 7 gave details, though all but two ingested the substance in a carrier liquid. This varied between 250ml and 400ml of water, although one study by Wilkes *et al.* (1983) allowed subjects to consume the solution with as much water as they desired after originally taking the dosage in 500ml. Lindermann & Gosselink (1994) vigorously advocate this practice of taking water *ad libitum*, if only to assuage the taste of the solution, which is difficult to disguise.

Another method of avoiding this discomfort is to manipulate the length of time over which the solution is consumed. Matson & Tran (1993) report 60% of

investigations they examined consumed solution within 1 and 2 hours from beginning the experimental trial. However, as there is no evidence that this practice was adopted to avoid gastro-intestinal discomfort, it could be speculated that this was chosen to ensure the solution was absorbed. None of the studies cited explain as to why they chose this time frame in fact. The final point to be mentioned is whether ingestion in solution is any more effective than other methods, such as capsule form. Matson & Tran concluded there was no difference, based on successful findings in their meta-analysis, while no other citations, either supporting or disputing this, could be found.

Placebo

Although a placebo was not employed in this design, it is an important part of the literature associated with sodium bicarbonate loading. Of the 25 studies examined, 23 used a double blind cross over design, recognising the potential for the Hawthorne effect threatening the internal validity, a placebo was administered. The placebo must be in a position to emulate the experimental supplement, yet must not affect the dependent variable/s. In the papers examined, 8 used sodium chloride, (Costil *et al.* 1984; Hermansen, 1979; Inbar *et al.* 1983; Pierce *et al.* 1992; Klein, Berger & Kearney 1987; Gao *et al.* 1988; Horswill *et al.* 1988). Despite its popularity as a placebo, Heigenhauser & Jones (1991) found that sodium chloride induced metabolic acidosis. Theoretically, this could magnify the differences between control and experimental treatments. However, after examining the effects of these studies, only 5 report a significant enhancement in performance.

The other placebo substance often used in the literature is calcium carbonate. Of the 25 examined, 10 used calcium carbonate (Jones *et al.* 1976, Jones *et al.* 1977, 1981; Wilkes *et al.* 1983; Goldfinch *et al.* 1988; Ibanez *et al.* 1995; Galloway & Maughn, 1996; McKenzie *et al.* 1988). No evidence was found that calcium carbonate had any affect upon blood pH. Other placebo substances used in the studies were a lactulose capsule (Brien & McKenzie, 1989), sucrose (Simmons & Hardt, 1973), starch (Margaria *et al.* 1971), and water (Hooker *et al.* 1987). No patterns emerged to indicate that any of these placebos had an obvious effect upon the dependent variables, nor was there mention of them in the discussions of the papers.

Task Protocols

The studies examined varied little in their protocol, using 0.3g/kg as the dosage with sodium chloride or calcium carbonate as the placebos mainly. Upon examining the protocols developed and followed, however, there were far more differences to be found, which appeared to have effects upon the outcome of the studies. Certainly, all of the activities used in the experiments were of short duration, lasting anywhere from 60 seconds to exhaustion after maximal effort (see appendix D). Maximal effort was the predominant intensity at which subjects were requested to work while other workloads were 80% to 95% of a pre-trial VO_2Max test. Of the 25 studies, only 3 who used this duration and intensity found no effect. These studies, (Kindermann *et al.* 1977; Margaria *et al.* 1971; Horswill *et al.* 1988) all had aspects of their protocol that could have contributed to the lack of support for the sodium bicarbonate use. These were all related

to a dosage of sodium bicarbonate that was lower than 0.3g/kg body weight, and/or inappropriate statistical analysis.

Not all of the papers involved duration of >60 seconds. Inbar *et al.* (1983) used an activity duration of 30 seconds, yet they still found enhanced performance within the sample. While they failed to find an increase in peak power, they did report an increase in mean power. However, using the same exercise task, Parry-Billings & McLaren (1986) did not find this increase. The activity was supramaximal (in the form of a Wingate test) and the lactate values reported for the subjects were high. This relates to the point that it is the degree of lactate accumulation that is important; it is simply expected to be of the >60 seconds duration because at high intensities of exercise this will bring about those conditions. In a study by Galloway & Maughan (1996), the activity used was prolonged in nature, lasting up to 1 hour, working at 80% VO_2Max. Upon reporting the blood lactate concentrations, they found large differences between the experimental and control groups to suggest that working at the same relative intensity, induced alkalosis produced higher blood lactate values. Their contention was that this was due to the increased diffusion of hydrogen ions, and therefore had performance implications, although their study was not examining this. This study, and that of Inbar *et al.* (1983) seems to lend support to the idea that the nature of the experimental trial is about manipulating the metabolic environment of the muscle cells, and there seem not to be 'hard and fast' rules to achieve this. However, a study by Johnson & Black (1953) used a 1.5 mile run as the task. Although no support was found, this may be attributed to the extremely low dosage of the supplement.

Testing the Laboratory versus the Field Setting.

The activities used in the protocols of the studies examined were mainly laboratory based. The rationale was that metabolic factors need to be examined which require sophisticated equipment. Also, if the activity is to be strictly controlled, ergonomic machinery should be employed. Despite this, the clinical studies all relate their results to actual performance in real situations. This represents a threat to environmental validity of the claims the research teams make. Of the studies examined, only 4 took place in the field and examined performance factors as dependent variables (Wilkes *et al.* 1983; Goldfinch *et al.* 1988; Ibanez *et al.* 1995; Pierce *et al.* 1992). Success was reported by Wilkes *et al.* and Goldfinch *et al.* who both using track running. The other two studies used 300m running and a composite program of swimming events simulating a competitive session. Both of these studies reported increases in blood bicarbonate levels, indicating that alkalosis did occur. Aside from both doses being below the level of 0.3g/kg body weight, the Ibanez *et al.* study used an activity duration of 30 seconds at 90% VO_2Max, and Pierce used a $p < 0.01$ level of statistical significance. Upon examining the actual mean times, the swimmers improved by up to 2 seconds in two cases (of 6 subjects), which can translate as being the difference between 1st and 8th place in a 100m freestyle race.

Dependent Variables

For studies that were carried out in a clinical environment, the dependent variables being measured were similar throughout. There appeared to be a mixture of

both respiratory and metabolic measures. The most common variable was related to blood/muscular lactate levels and blood bicarbonate levels. Findings were remarkably similar, however, regardless of whether performance was improved in experimental trials. Alkalosis was induced in all of the studies where sodium bicarbonate was administered apart from one (Costil *et al.* 1984). In this study, though mean power output increased, they found no significant difference in blood lactate concentrations between the groups. The statistical significance level set was at $p < 0.01$, however, and this could explain why no difference was found. (No further details were available however, due to the fact that this was available in abstract form only).

Where the studies investigated peak power output as a dependent variable, they found no improvements (Inbar *et al.* 1983; Klein, Berger & Kearney 1987). This is to be expected, as alkalosis acts in an ergogenic manner by delaying onset of muscle fatigue, and does not increase the actual maximum capacity to perform.

Statistical Analysis

Statistical significance was an issue found to be prominent in the interpretation of effects in the examined paper. Six of the studies reviewed demonstrated no significant enhancements in performance after administration of sodium bicarbonate. Of these six, three had problems related to other aspects of the protocol. Specifically, Horswill *et al.* (1988) and Pierce *et al.* (1992), who used low dosages of bicarbonate, and Ibanez *et al.* (1995) used an activity duration of 30 seconds. Of the remaining three, the alpha level for statistical significance was set at $p < 0.01$ for two of them, (Margaria *et al.* 1971; Kinderman, Kuel & Huber 1977).

The effect sizes within the literature (through using the means and standard deviations) with the equation 'Effect Size = $(M_1 - M_2) / SD$' (Thomas & Nelson, 1996), with the studies who had reported non-significant results were examined. The paper by Margaria *et al.* who previously suggested that there was no change in blood lactate concentrations or performance times of the placebo and experimental group, in fact showed effect sizes of 0.41 and 0.57, respectively. According to Cohen (1969), these effect sizes equate to a moderate effect size, and therefore, this may be another example of looking beyond the reported statistical significance. While the same process was followed with Kinderman, Kuel & Huber (1977), the effect sizes were found to be below 0.1, which concurs with the reported statistically insignificant differences. However, the Kinderman, Kuel & Huber study displays a need to look at the results in context. The experimental group reported a mean time of 62.6s (+/- 4.1) for the 400m run, while the placebo group reported a mean time of 64.2s (+/- 2.4). In the context of high competitive levels, these differences may represent the difference between first and last place in a sprint event such as the 400m. Also, rather than rejecting the results based upon mean times, it may have been prudent to consider how the dosing worked on an individual basis.

Subjects

The last point of the previous paragraph highlights the last aspect of the literature to be explored; that of subjects. The sample size of the papers reviewed varied with the lowest being 6, and the highest being 12. As in most sport science research, this appears inadequate in its capacity to afford enough power to avoid making a type II error. If the

guidelines are followed in Thomas and Nelson (1996) for assignment of subjects, at the $p < 0.05$ level of significance, one would expect a sample size of 12 per group. Therefore, in 10 of the studies examined, the sample sizes were under 25% of the recommendations, with the highest being 50% of the recommendations. This demonstrates that even when statistical significance is found, it is very difficult to be certain that this is actually a representative sample. A small effect size further complicates the contingency of assessing effect size when examining statistically insignificant results. So, even if the effect size is not worth reporting (< 0.2; Cohen, 1990), a small sample may be masking an effect that would be evident with a sample size that was larger, subject to a satisfactory protocol.

Another problem found is that of sample composition, or the competitive experience and training level of the subjects. Of all of the studies, only 2 studies used subjects that were of elite level (Brien & McKenzie, 1989; Hooker *et al.* 1987). The remainder used either college athletes, or those termed 'fit and healthy' participants. It is perhaps an issue that the more highly trained the subjects are, the lower their capacity and potential for improvement by experimental manipulations, such as induced alkalosis.

Conversely, in subjects unused to high intensity exercise, one may question just how consistent their performances are over several trials, how much effort they actually put into a supramaximal performance, and their capacity to produce lactate. Considering much of the literature was laboratory-based, it must also be considered that athletes may not have the motivation to work when compared to actual field performance. This is arguably compounded by the fact that results taken from this different population are then generalized to other populations such as elite athletes. It is reasonable to assume that

problems arise in generalizing results between different sports also, and between clinical trials and competitive conditions.

Summary

Reviewing the literature on sodium bicarbonate supplementation to date reveals that although the theory has been around for over 70 years, there are still fundamental issues that need to be dealt with before the technique becomes both viable and reliable as a means of enhancing performance. Protocols need to be better related to the field in which they will be applied. Larger subject samples need to employed, and a more systematic approach to dosing needs to be considered, rather than arbitrarily selecting values. Results also need to be examined in context, for an improvement that is non-statistically significant to the researcher may actually be the difference between first place and not placing at all.

Also, a greater interest needs to be directed towards side effects and how they interact with the success of supplementation. Many of the studies failed to report side effects in more than one or two sentences. Considering the magnitude that gastric discomfort may have upon an athlete, this arguably represents the biggest challenge to the effectiveness of dosing with bicarbonate. Maybe once this problem is solved, the practice may become more feasible and attractive to the athlete.

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APPENDIX D

SUMMARY TABLES OF EFFECT, DURATION AND DOSAGE IN RELATED LITERATURE

Table 10. Summary of Studies Where an Effect Was Shown

Reference	Dosage	Duration (sec)
Costil (1984)	0.2 g/kg body weight	160
Goldfinch (1988)	0.4 g/kg body weight	60
Ibanez (1995)	0.3 g/kg body weight	30
Jones (1976)	0.3 g/kg body weight	360
Jones (1977)	0.3 g/kg body weight	400
Jones (1981)	0.3 g/kg body weight	300
McKenzie (1988)	0.3 g/kg body weight	120
McNaughton (1992)	0.4 g/kg body weight	60
Wilkes (1983)	0.3 g/kg body weight	120

Table 11. Summary of Studies Where No Effect Was Shown

Reference	Dosage	Duration (sec)
Brien (1989)	0.3 g/kg body weight	120
Horswill (1988)	< 0.2. g/kg body weight	60
Inbar (1983)	0.15 g/kg body weight	60
Katz (1984)	0.2 g/kg body weight	100
Kinderman (1977)	0.2 g/kg body weight	60
Magaria (1971)	0.3 g/kg body weight	120
Parry-Billings (1986)	0.3 g/kg body weight	30
Pierce (1992)	0.1 g/kg body weight	60