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Article

Effects of topical sodium bicarbonate emulsion on exercise exhaustion and training effects following high-intensity interval training in high-level soccer players

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Abstract: Background and Goal: High-level football players' competitive performance and training efficacy are significantly impacted by sports weariness. Verifying the possible use of external sodium bicarbonate lotion in professional sports and investigating its effects on the training effect and sports fatigue of elite football players following high-intensity interval training (HIIT) are the goals of this study. **Methods:** 14 male football players competing at the national level were split into two groups, one experimental and one control, each consisting of seven participants. This study was conducted using a randomized double-blind controlled trial. Twenty min prior to training, the experimental group applied external sodium bicarbonate lotion, while the control group applied a placebo lotion. Group antagonistic training and a seven-day HIIT comprise the training regimen. Assess the effects of the intervention using a variety of multifaceted data, including exercise performance, training impact intensity (TRIMP), delayed onset muscle soreness (DOMS), subjective tiredness scale, perceived fatigue level (RPE), blood biochemical indicators, and heart rate monitoring. **Result:** Following a single HIIT training session, the experimental group's blood lactate level was significantly lower than the control group's ($P < 0.05$); however, no other indicators showed any significant changes. The experimental group's TRIMP values were considerably greater than the control group's during the seven-day training period, and their average DOMS and RPE values were significantly lower ($P < 0.05$). Maximum heart rate and anaerobic training effect were statistically significant ($P < 0.05$), and the experimental group outperformed the control group in terms of maximum EPOC, maximum heart rate, anaerobic training effect, and energy consumption. In conclusion, applying sodium bicarbonate lotion externally can improve athletes' overall performance, increase training stimulus, and considerably lessen muscle soreness and exercise fatigue during high-intensity interval training.

Keywords: topical sodium bicarbonate emulsion; soccer players; high-intensity interval training; exercise fatigue; training effect; blood lactate; delayed onset muscle soreness (DOMS); perceived fatigue level (RPE); TRIMP; randomized double-blind trial

1. Introduction

In current sports research, soccer, one of the most popular sports in the world, places very high demands on players' technical skills, tactical execution and physical fitness. Athletes must maintain quick decision-making and precise technical movements while undergoing high physical and mental stress during high-intensity intermittent movements, especially in elite competitions [1]. As the intensity of competition increases, the problem of fatigue accumulated by athletes during training and competition becomes one of the main factors limiting sports performance.

Therefore, how to improve training effectiveness and reduce sport fatigue scientifically and effectively has become a key research area in sport science [2,3].

The main symptoms of sports fatigue are muscle weakness, bradykinesia, and dysfunction of the nervous and cardiorespiratory systems, which manifests itself as a transient decline in muscular or systemic performance during exercise [4]. Due to the erratic pace and high-intensity intermittent nature of soccer matches, lactate accumulation, energy metabolism problems, and oxidative stress are often directly related to athletes' exercise fatigue. Studies have shown that elite soccer players are prone to severe muscle microinjuries and blood lactate accumulation during high-intensity interval training (HIIT), which in turn affects their performance and subsequent training effects. Effective reduction of exercise fatigue not only significantly improves athletes' training quality and game performance, but also accelerates recovery [5,6].

Sodium bicarbonate ($NaHCO_3$) has received much attention for its potential buffering function. It is able to reduce metabolic acidosis to some extent by increasing the body's base reserves and regulating lactate metabolism [7]. However, its practical application has been limited by the fact that conventional oral sodium bicarbonate may cause side effects such as gastrointestinal discomfort. Although relevant studies are still in the early stages, topical application of sodium bicarbonate lotion is gaining attention as a non-invasive solution with low side effects [8].

The definition of the concept of "external stress and activity" is not clear enough, and the "external stress and activity" training method mentioned in the article does not clearly explain the specifics of this concept. External stressors (e.g., psychological stress, training cycle scheduling, etc.) and external activities (e.g., field training, competition, etc.) may have an impact on athlete recovery, but these factors were not adequately defined and controlled. The authors could further define and measure "external stress and activity" in the experimental design. For example, "external stress" could be quantified as an independent variable (e.g., using the Psychological Stress Scale) and other confounding factors during training or competition could be described to more clearly assess their impact on recovery. Researchers' interest in topical sodium bicarbonate emulsion has grown over time, but its exact mode of action and usefulness in highly competitive sports have not yet been established. There are a number of significant issues and limitations with the current research, including the fact that there aren't many specialist studies on elite athletes, particularly soccer players, and that the majority of studies have concentrated on the general public or non-professional athletes. Single physiological or biochemical indicators, like blood lactate concentration, are the primary focus of current research, while comprehensive indicators, like overall training effect, sports performance, and psychological weariness, are not sufficiently analyzed [9,10]. The majority of pertinent research lack a rigorous randomized controlled double-blind trial design and have small sample numbers, which compromises the findings' credibility and generalizability. Further investigation is still needed to determine whether topical sodium bicarbonate emulsion absorbed through the skin can significantly alter the local or systemic metabolic state.

Given the research background and challenges outlined above, the current study was designed as a randomized double-blind controlled trial to confirm the effects of topical sodium bicarbonate emulsion on exercise fatigue and training effects following high-intensity interval training in elite soccer players. One of the study's primary advantages is that it included 14 male soccer players competing at the national level, a unique demographic that offers more direction for the real-world implementation of the findings. By combining the monitoring of blood biochemical indices (such as blood lactate concentration), conscious fatigue level (RPE), delayed onset muscle soreness (DOMS), and training loads (internal and external loads), the intervention effect of topical sodium bicarbonate emulsion was thoroughly evaluated. A randomized double-blind study design was used, using topical sodium bicarbonate emulsion in the experimental group and a placebo in the control group, to lessen the influence of subjective factors and experimental bias.

This study's importance lies in confirming the usefulness of topical sodium bicarbonate emulsion in reducing tiredness and improving training outcomes during high-intensity interval training, as well as investigating the potential for its use with elite soccer players. This study offers a scientific foundation for soccer players' training and recuperation methods in addition to fresh proof for sports science theories by exposing its mechanism of action and effects.

2. Content and methods of the research

2.1. Research target

The participants were 14 elite male soccer players (ages 18 to 24), all of whom competed at the national level, were in good health, had no family history of sickness or endocrine disorders, and were not addicted to alcohol or tobacco, as shown in **Table 1**. After signing an informed permission form, each participant consented to take part in the study and was prohibited from consuming any meals or beverages that could change their blood pH for two weeks.

Table 1. Subjects' basic information.

Group	**Age**	**Height (CM)**	**Weight (CM)**	**BMI/(kg.cm^{-2})**	**Training years/a**
Experimental group (N = 7)	20.65 ± 1.22	180.5 ± 5.65	75.65 ± 8.57	22.32 ± 2.14	10.78 ± 3.25
Control group (N = 7)	21.65 ± 1.52	182.4 ± 3.54	76.54 ± 5.65	22.65 ± 1.04	10.45 ± 3.21

2.2. Grouping experiments and the experimental process

The experimental and control groups each had seven volunteers assigned to them at random. Thirty min prior to activity, the experimental group applied 10 g of topical $NaHCO_3$ emulsion to the lateral thigh muscles. The training was finished after 10 g of a placebo emulsion (made from moisturizing cream) was applied in the same manner to the control group. Training impulse (TRIMP), maximal heart rate, energy expenditure, running distance, sprinting speed, and time of high-intensity training were all recorded, along with lactate, creatine kinase, and urea nitrogen levels before and after training, as well as the subjects' internal load and performance throughout the training program (**Figures 1** and **2**).

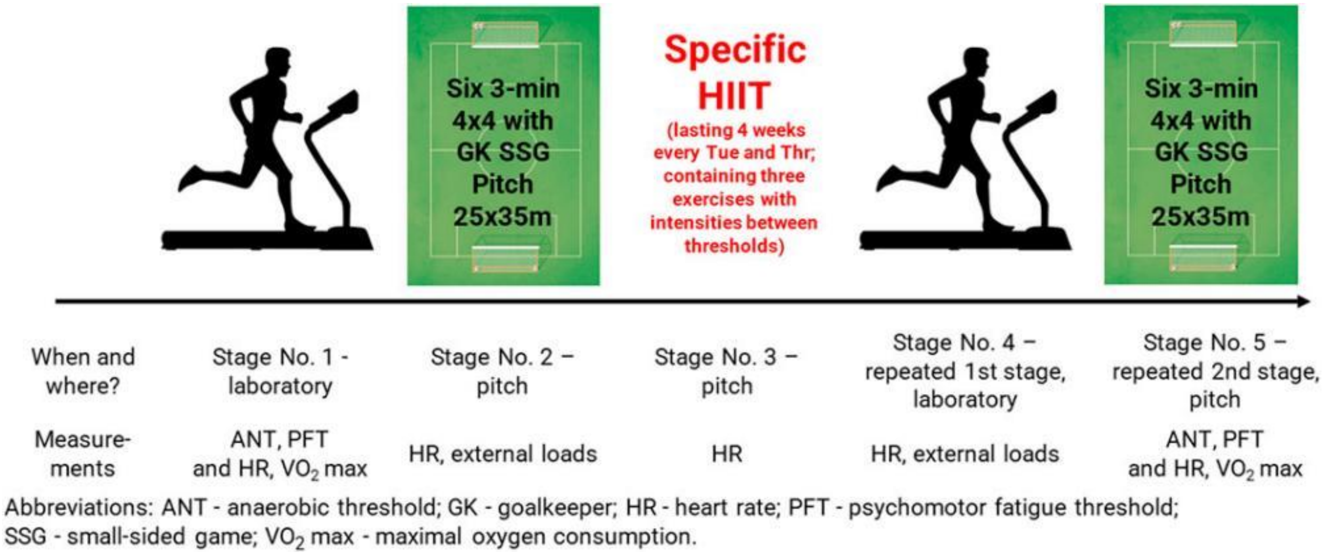

Figure 1. Experiment flow chart.

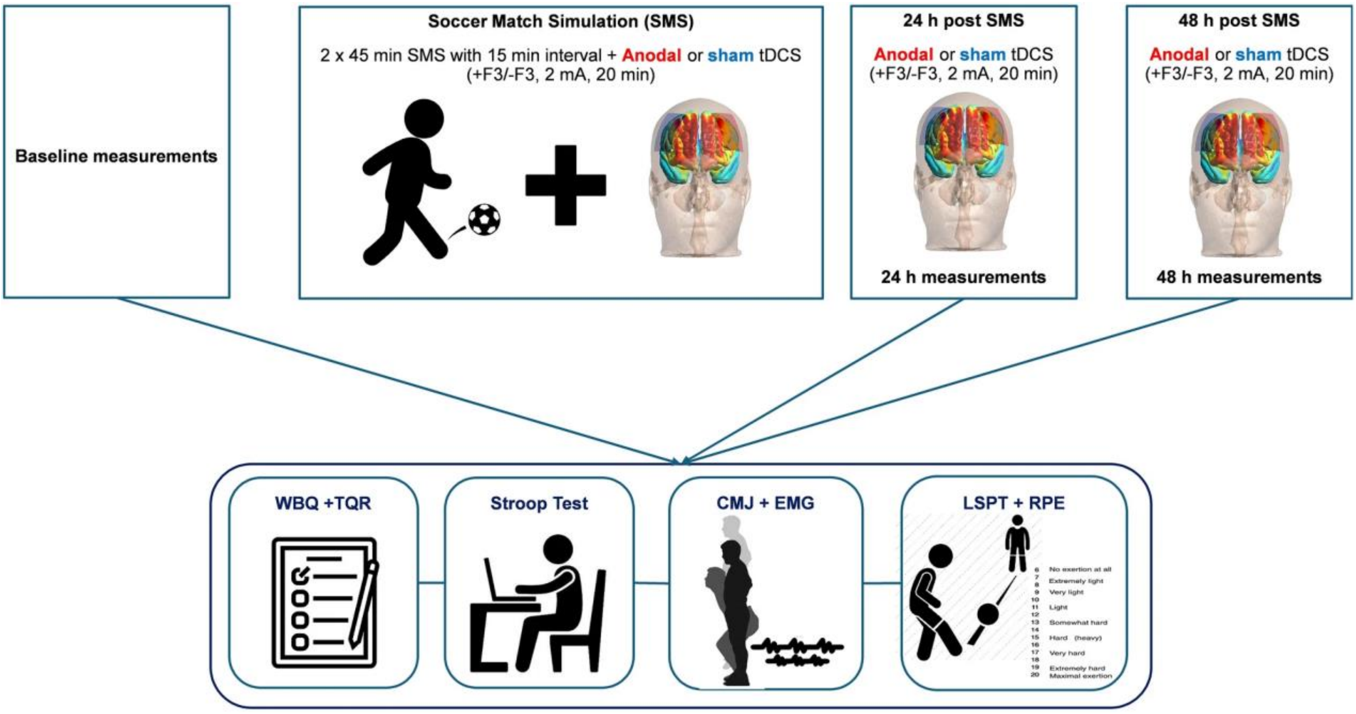

Figure 2. A single high-intensity interval training session's test flow.

2.3. Design of training programs

The two components of the training regimen were confrontation training and HIIT training. The main objective of HIIT training was to raise the athletes' individual endurance level through weight-bearing sprint training. It was developed based on the distinct energy supply of soccer matches and the power characteristics of special motions. Conversely, the main purpose of confrontation training was to examine the effects of the athletes' enhanced specific sports proficiency after HIIT training [11]. 20 pounds (1 pound = 453.59237 grams) of weight-bearing sprinting for 40 meters was used for the HIIT workout. Each training session lasted 20 min and consisted of 7 training sessions, 8 sprinting sets, and 4 returning sets, separated by 15 seconds.

During the HIIT training phase, the maximal heart rate (HR) was kept between 95% and 1100 percent, and during the intervals, it was kept at 90% or higher. The validation program consisted of seven 30-minute sessions of 4 vs. 4 group training in a small field.

2.4. Tests for blood biochemistry both before and after exercise

Before and after the training, the subjects had peripheral venous blood drawn, which was then sent to the lab for routine blood testing, creatine kinase, and urea nitrogen measurements. Additionally, within a minute of the training, peripheral blood was drawn from the individuals' fingers, and a portable EKF Lactate-scout (Germany) was used to measure the blood lactate levels on the spot.

2.5. Subjective weariness following training and testing using the DOMS questionnaire

In accordance with the references, the athletes filled out the DOMS questionnaire [12] and the RPE [13] each day prior to training.

2.6. Monitoring load when training

2.6.1. Internal stresses and training effects during training

During the HIIT training phase, the athletes' heart rates and associated derivatives were monitored using the Finnish heart rate monitoring system (first beat analytics). For every training session, the system also calculated the average internal load data. Training stroke (TRIMP), maximal heart rate, energy expenditure, anaerobic training effect, EPOC, and aerobic training effect were among the test's indicators. Training Rush, or TRIMP, is monitored. The approach used to calculate the relevant indexes of the heart rate monitoring system equipment was based on several previously published literature studies [14,15].

(1) Based on the excess post-exercise oxygen consumption (EPOC) model, a computer evaluation of the impact of aerobic training demonstrates that EPOC accumulates throughout exercise from short-term exercise intensity values (e.g., $Vo_{2\max}$). Peak EPOC determines the impact of aerobic training during rest or low-intensity activity, while EPOC builds up during high-intensity exercise. (2) Anaerobic training effect: determined by calculating the amount of work performed during high-intensity exercise via the anaerobic energy pathway. By simulating intervals with metabolic properties or over $Vo_{2\max}$ maximum effort, the anaerobic training effect is identified. (3) EPOC: heart rate is modeled and converted. (4) Energy expenditure: derived from neural network modeling of respiratory rate and heart rate variability.

$$\mathrm{TRIMP} = 0.64\mathrm{e}^{1.92} T[(HR_{ex} - HR_{rest}) / (HR_{\max} - HR_{rest})] \tag{1}$$

Equation (1) uses T as the training duration, $HR_{\max}$ as the maximum heart rate, HR_{rest} as the calm heart rate, and HR_{ex} as the average heart rate throughout training.

2.6.2. Exercise performance and training external loads

In order to assess the athletes' external performance during the group confrontation training, the Catapult Sports GPS system (MinimaxXS4, Australia) was utilized to gather data at a frequency of 10 Hz. The primary data collected included running distance, running speed, acceleration, high speed running distance, and total load.

3. Results of the study

3.1. Blood biochemical index changes prior to and following a single HIIT exercise session

The chemical alterations in an athlete's blood under varying training loads and load intensities are reflected by blood biochemical indices. White blood cells and hemoglobin indirectly reflect the size of the training load and the athlete's level of adaptation; if the athlete's training load is too high, hemoglobin and white blood cells will temporarily decrease. Blood lactate reflects the relationship between the type of energy metabolism and oxygen consumption; creatine kinase reflects the intensity of a training load; and serum urea nitrogen reflects the size of a training load. Because there were some differences in physiological indexes between the groups before to the experiment, the paired-samples t-test was employed to assess the statistics and compare the changes in blood indexes between the experimental group and the control group before and after the training. According to the findings, both the control and experimental groups' levels of blood lactate, creatine kinase, blood urea nitrogen, leukocytes, and hemoglobin rose somewhat before and after training. As shown in **Table 2**, there was no discernible difference between the experimental and control groups, although the former exhibited greater creatine kinase levels and lower blood urea nitrogen levels prior to and during a high-intensity interval training session ($P \geq 0.05$). Hemoglobin and leukocyte levels, which indicate physical function, did not differ substantially across the groups, however blood lactate levels were lower and there was a significant difference between the groups ($P < 0.05$). The hemoglobin and leukocyte counts did not differ significantly, which reflected the body functions, as well as in the values of white blood cells.

Table 2. Blood biochemical index changes prior to and following a single HIIT training session (n = 14).

Parameters	Experimental group (N = 7)			Control group (N = 7)		
	Before training	**After training**	**After training**	**Before training**	**After training**	**After training**
Blood Lactic Acid (mmol. L^{-1})	2.45 ± 0.45	8.42 ± 2.26	5.98 ± 2.34	2.94 ± 1.45	4.98 ± 2.65	2.14 ± 3.25
Creatine kinase (U. L^{-1})	297.65 ± 124.65	392.32 ± 152.36	98.99 ± 32.54	396.47 ± 195.65	547.21 ± 285.3	142.36 ± 90.85
Blood uric acid nitrogen (mmol. L^{-1})	5.62 ± 0.98	6.45 ± 1.02	1.87 ± 1.15	6.78 ± 1.52	7.26 ± 1.68	0.48 ± 0.26
Leukocyte (10^{9}L^{-1})	7.22 ± 1.65	8.89 ± 1.88	1.65 ± 1.62	6.78 ± 1.14	7.82 ± 2.58	1.04 ± 1.58
Hemoglobin (g.L^{-1})	148.02 ± 6.87	154.32 ± 6.58	4.87 ± 4.62	147.65 ± 4.58	158.75 ± 6.68	5.48 ± 5.62

3.2. Variations in the HIIT training cycle's DOMS, RPE, and TRIMP measures

During high-intensity interval training, athletes' assessments of their perceived exertion (RPE) and DOMS reveal how tired and painful they are from exercise [16]. Twelve to twenty-four hours after exercise, the DOMS scale gauges how sore and uncomfortable the muscles are at the training location. Joint mobility and muscle stiffness will diminish as a result of a decline in muscle strength and performance, which will affect the athletes' performance and reactivity. By measuring an individual's or a team's perceived subjective exhaustion, the RPE scale helps coaches determine the appropriate training intensity based on the data. This affects the responsiveness and performance of the workout. The training impulse, or TRIMP, measures how much the athlete's body is stimulated during training and how hard the training load is applied. The experimental and control groups' DOMS, RPE, and TRIMP values varied over the course of the 7-day training period, as shown by the trend of changes (**Figure 3**). DOMS increased gradually in both groups and decreased on the sixth and seventh days, while RPE displayed a "low-high-low" change. TRIMP increased on the first and second days and started to decrease after two days. TRIMP rose from the first to the second day and started to decline after the second day, while the RPE values displayed a "low-high-low" shift. The TRIMP value rose throughout the first two days and then started to fall after the second day. In 7 days, the experimental group's average TRIMP value was higher than the control group's, but their average DOMS and RPE values were lower, as shown in **Table 3**. The experimental group's average DOMS and RPE levels were higher than those of the control group. The DOMS levels were considerably lower than those of the control group on day 2 ($P < 0.01$) and average ($P < 0.05$) and day 6 ($P < 0.01$) and average ($P < 0.05$) of the high-intensity interval training week. All of them were notably lower than the control group's. The experimental group's mean RPE values were marginally lower than the control group's, but there was no discernible difference ($P \geq 0.05$); on the seventh day, the experimental group's TRIMP values were considerably higher than the control group's ($P < 0.05$). According to the results, soccer players in both groups experienced subjective exercise fatigue, delayed muscle soreness, and elevated DOMS and RPE during the 7-day experimental period following HIIT training. However, the athletes in the experimental group that used $NaHCO_3$ emulsion had lower fatigue overall, and the athletes in the experimental group that used $NaHCO_3$ emulsion had lower fatigue at the start of the HIIT training because of physiological. Following one day of HIIT training, athletes' TRIMP increased noticeably before progressively declining to achieve a better adaptation. The experimental group's reduced subjective exercise exhaustion and delayed muscle soreness may be linked to their higher training stimulation levels as compared to the control group. This could result in a higher level of active training engagement.

Table 3. DOMS, RPE, and TRIMP measures during HIIT training cycles (n = 14).

Date	DOMS/min			RPE/min			TRIMP/min		
	Experimental group	**Control group**	***P***	**Experimental group**	**Control group**	***P***	**Experimental group**	**Control group**	***P***
1	34.25 ± 12.58	38.68 ± 12.58	0.75	10.68 ± 5.21	10.58 ± 3.65	0.66	153.4 ± 25.36	148 ± 26.35	0.88
2	19.85 ± 4.62	40.25 ± 11.23	0.06	11.03 ± 6.25	8.86 ± 5.36	0.58	96.57 ± 18.65	85.64 ± 11.48	0.65
3	32.52 ± 12.68	42.58 ± 10.6	0.32	7.58 ± 6.25	8.86 ± 5.42	0.66	95.68 ± 18.65	85.62 ± 10.87	0.55
4	35.46 ± 12.58	46.58 ± 10.98	0.35	9.25 ± 5.68	15.25 ± 4.65	0.42	119.65 ± 24.36	126.25 ± 18.62	0.58
5	41.32 ± 15.68	45.06 ± 18.65	0.85	12.65 ± 3.68	12.65 ± 6.87	0.85	95.68 ± 18.65	59.68 ± 15.32	0.92
6	38.65 ± 18.65	70.25 ± 26.35	0.02	12.65 ± 4.85	15.68 ± 4.65	0.25	86.35 ± 16.58	60.35 ± 12.5	0.26
7	40.35 ± 22.65	45.68 ± 12.36	0.72	10.68 ± 6.58	13.65 ± 5.68	0.35	106.8 ± 23.5	58.15 ± 22.45	0.04

3.3. HIIT training cycle comparison of loads and training effects

The internal load and training effect numbers indicate the energy metabolism of the athlete's body and the adaptive physiological changes that occur throughout training. The effects of aerobic and anaerobic training are reflected in the duration and intensity of training in the aerobic and anaerobic metabolic zones, respectively; the amount of oxygen consumed during the post-exercise recovery period to make up for the oxygen deficit during the exercise; and the amount of oxygen consumed during the post-exercise recovery period to bring the body's high metabolism back to a quiet level, which reflects the training's stimulating nature and the impact of the body's recovery. The length of high-intensity interval training, exercise intensity, and level of physiological stimulation are all reflected in the mean maximal heart rate; the overall volume of exercise and body energy consumption are reflected in the energy expenditure. As shown in **Table 4**, the anaerobic training effect, peak EPOC, maximal heart rate, energy expenditure, and aerobic training effect of athletes in the experimental group were all higher than those in the control group. Additionally, the anaerobic training effect and maximal heart rate of athletes in the experimental group were significantly different from those of the control group throughout the entire training cycle ($P < 0.05$). According to the experimental findings, topical NaHCO3 emulsion significantly impacted the total training effect of HIIT throughout the cycle, particularly in terms of lengthening the duration and impact of high-intensity anaerobic training. According to the experimental findings, topical application of NaHCO3 emulsion significantly impacted the total training effect during the HIIT training cycle, particularly in terms of lengthening the duration and impact of high-intensity anaerobic training.

Table 4. Mean internal load and training effect values for 7 days of HIIT cycle training (n = 14) are compared.

Internal load parameters	**Experimental group**	**Control group**	***P***
Aerobic training effect	3.28 ± 0.58	3.26 ± 0.65	0.52
Anaerobic training effect	2.65 ± 0.58	2.24 ± 0.55	0.03
EPOC(Ml.kg^{-1})	118.65 ± 38.52	106.72 ± 48.68	0.55
Mean maximum heart rate (min^{-1})	188.65 ± 3.56	178.72 ± 8.56	0.02

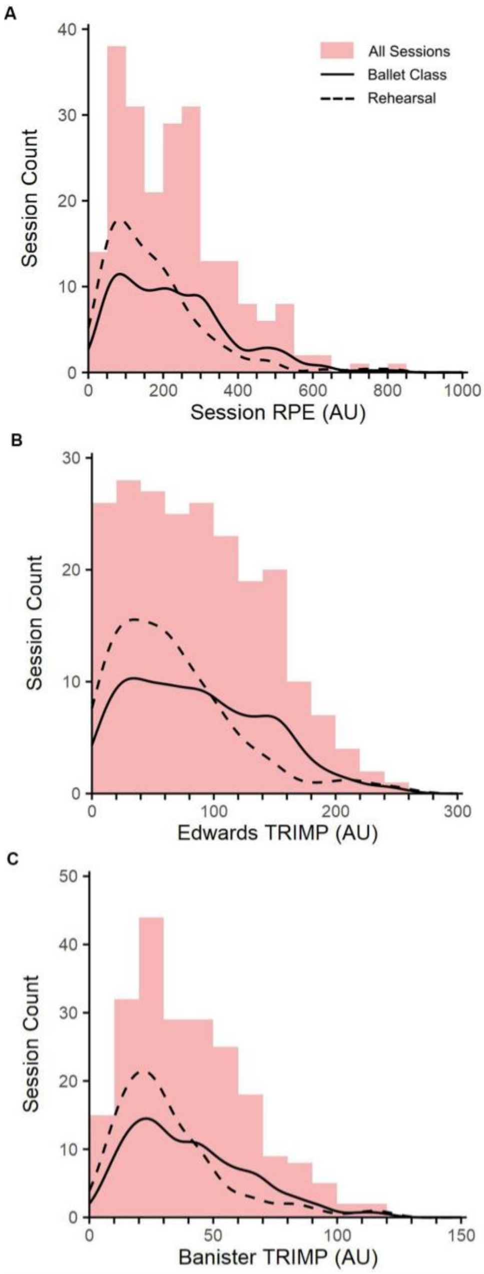

Figure 3. DOMS, RPE, and TRIMP values trended across a 14-person HIIT training cycle **(a)** DOMS change trend; **(b)** RPE change trend; **(c)** TRIMP change trend.

3.4. HIIT training cycles paired with external stresses and activities for training

Performance comparison the external load levels of group antagonistic training reflect the athletes' general athletic ability, training initiative, and training status. Among these, the athletes' total running distance reflects their running ability and endurance; their load intensity reflects their technical movements and running intensity; their distance per minute reflects their speed and frequency; their maximum speed reflects their ability to sprint and accelerate; and their total sports load reflects their motivation to use defensive, offensive, and organizational tactics on the field [16]. As demonstrated in **Table 5**, the experimental results demonstrated that during the 7-day training period, the athletes in the experimental group improved their running ability, sprinting ability, and training motivation through the use of "topical $NaHCO_3$ emulsion + HIIT training." The athletes' total running distance, load intensity, distance per minute, maximal speed, and mean value of total exercise load all increased in comparison to those in the control group.

Table 5. Comparing the average motor performance scores and external loads during 7d group confrontation training in HIIT cycle training (*n* = 14).

External load parameters	Experimental group	Control group	*P*
Total running distance/cm	5942.02 ± 2715.5	4985.15 ± 3026.4	0.22
Load intensity	7.35 ± 3.65	6.04 ± 3.84	0.08
Distance run without points/m	63.92 ± 28.26	56.65 ± 32.45	0.26
Maximum speed/ ($m.s^{-1}$)	6.04 ± 2.15	5.26 ± 2.84	0.14
Total exercise load	6458.68 ± 336.44	596.02 ± 354.65	0.05

4. Analysis and discussion

4.1. Impact of various cold therapy techniques on the quadriceps muscles' oxygen status

SmO2, or the ratio of hemoglobin's oxygen carrying capacity in muscle tissue, is a measure of how well muscle functions and reflects the equilibrium between the body's local muscles' oxygen supply and use. The SmO2 decreases with increasing exercise intensity within a specific range. Less than 10% of the high-intensity running distance was covered in the high-load soccer training sessions in this study, and the change in SmO2 following exercise was not statistically significant. SmO2 was significantly reduced by the CWI intervention and reverted to its baseline the following day, but SmO2 was not significantly affected by the WBC intervention. This is in line with the results of Hohenauer et al., who found that while localized hypothermia (−135 yards, 2 min) did not significantly alter SmO2, a brief CWI intervention (10 yards, 10 min) following exercise resulted in a significant drop in SmO2 that persisted for 40 min after the intervention. Roberts discovered that the SmO2 in venous blood dropped by 25% to 30% following high-intensity resistance exercise CWI (10 benefits, 10 min), and it had not recovered by 6 hours. According to Mawhinney et al. [16], the two cold therapy techniques had distinct impacts on lowering muscle temperature, as evidenced by the considerable drop in muscle temperature 40 min after CWI compared to WBC. Muscle temperature has a direct impact on muscle cell metabolism, vascular permeability, and blood circulation rate, all of which reduce muscle perfusion and blood vessel diameter. Conduction and convection are the primary means of heat exchange in the CWI state, while convection is the primary means of heat dissipation in the WBC condition. Because water conducts heat around 20 times quicker than air, short-term CWI and WBC caused varying degrees of muscle temperature reduction [10]. Skin and muscle temperatures as well as SmO2 were significantly reduced by CWI, however these reductions were only temporary. The next day, SmO2 in the CWI group likewise showed a significant recovery. A potential method to aid in the recovery of muscle physiology, this brief drop in muscle temperature caused a drop in muscle SmO2 and intracellular metabolism, preventing subsequent injury following exercise. Although the method described above is based on animal tests, more human research is required.

4.2. Impact of various cold therapy techniques on markers of bodily weariness

While muscle soreness and muscular pressure pain threshold are markers of localized muscle fatigue injury, RPE is a self-perception scale that captures the accumulation of exercise load and exhaustion. Subjective measures of RPE and muscle soreness increased dramatically following heavy load training in soccer, but the muscular pressure pain threshold remained relatively unchanged. RPE and muscle soreness decreased in all three groups following the intervention, with the CWI and CON groups experiencing the largest decreases. This suggests that CWI has a better effect on recovering from subjective whole-body fatigue and localized muscle fatigue, while the WBC intervention had a smaller effect on subjective fatigue. This could be because a single session of the WBC intervention involved a larger cold stimulation of the entire body, which caused discomfort and obscured objective assessments of subjective fatigue, making subjective fatigue less strong than that of the WBC intervention. The RPE and muscle soreness in the WBC group remained high after the intervention, which could be because a single session of the WBC intervention increased cold stimulation of the entire body, causing discomfort and masking the objective assessment of subjective fatigue. Likewise, Costello's research verified that WBC (−110 yields, 3 min) had no impact on post-centrifugal workout muscle discomfort. WBC, however, has been shown to lower levels of pain and fatigue. WBC can lower the average degree of muscular soreness by 31%, according to studies [17] discovered that following centrifugal training, the results of CWI (10 yards, 10 min) and WBC (−110 yards, 3 min) demonstrated that muscle soreness decreased 24 hours after the intervention, and that the CWI group significantly outperformed the WBC group in reducing muscle soreness 48 hours later 13 [12]. The CWI group was significantly better than the WBC group at 48 h after the intervention [13]. It was also found that the use of local cryotherapy (135 yards, 2 min) and CWI (10 yards, 10 min) after the drop jump improved the muscle soreness [14]. The experimental workout regimen may be the cause of the inconsistent outcomes. Studies on how various cold therapy techniques affect muscular pressure pain thresholds are currently scarce. The present investigation found no significant difference between the three groups immediately following the intervention and the following day, while the muscular soreness threshold rose immediately following the CWI intervention, supporting the hypothesis that CWI had some analgesic effects. Therefore, more research is required to understand the mechanism of CWI [15–17].

5. Conclusion

This study investigated the effects of high-intensity interval training (HIIT) combined with the topical application of $NaHCO_3$ emulsion on various physiological and performance measures in soccer players. The findings indicate that $NaHCO_3$

emulsion has a positive impact on reducing subjective exercise fatigue, delayed onset muscle soreness (DOMS), and perceived exertion (RPE) during the HIIT training cycle. The experimental group, using $NaHCO_3$ emulsion, showed lower levels of DOMS and RPE compared to the control group, especially on specific days of the training cycle. Furthermore, the TRIMP values for the experimental group were higher, reflecting greater training stimulation and better engagement.

In terms of training effects, the experimental group exhibited higher anaerobic training effects, peak EPOC (Excess Post-Exercise Oxygen Consumption), and maximal heart rates, indicating more significant physiological adaptations. Additionally, external load performance measures, such as total running distance, load intensity, and maximum speed, were improved in the experimental group. These results suggest that $NaHCO_3$ emulsion application may help enhance the training effects, particularly in terms of anaerobic performance, and improve overall athletic performance during the training cycle.

The results of this study highlight the potential benefits of combining HIIT training with topical $NaHCO_3$ emulsion, particularly in enhancing recovery and optimizing training performance. However, further research is needed to explore the long-term effects of $NaHCO_3$ emulsion on various athletic populations and to assess the underlying physiological mechanisms. Additionally, while the effects on muscle oxygenation (SmO2) and recovery markers such as RPE and DOMS were significant, the long-term impacts on injury prevention and overall performance improvements require further investigation.

Author contributions: Conceptualization, SM and BZ; methodology, SM; software, SM; validation, BZ; formal analysis, SM; investigation, BZ; resources, BZ; data curation, SM; writing—original draft preparation, SM; writing—review and editing, SM; visualization, BZ; supervision, BZ; project administration, BZ; funding acquisition, BZ. All authors have read and agreed to the published version of the manuscript.

Ethical approval: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Beijing City University (protocol code BCUmed202423076623ty and date of approval (2024,03,21)).

Conflict of interest: The authors declare no conflict of interest.

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