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Research Article / Araştırma Makalesi

A Comparative Analysis of Carbohydrate and Caffeine Mouth Rinsing Strategies on Cognitive, Technical and Kinematic Performance in Young Soccer Players During 4-a-Side Small-Sided Game

Genç Futbolcularda 4'e 4 Dar Alan Oyun Sırasında Karbonhidrat ve Kafeinli Ağız Çalkalama Stratejilerinin Bilişsel, Teknik ve Kinematik Performans Üzerine Etkilerinin Karşılaştırmalı Analizi

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ABSTRACT

Objective: This study aimed to evaluate the impact of mouth rinsing (MR) with carbohydrate (MR_{CHO}), caffeine (MR_{CAF}), and their combinations ($MR_{CAF+CHO}$ and $MR_{CHO+CAF}$) on mental effort, technical activities, and kinematic variables in 4-vs-4 small-sided soccer games (SSGs).

Materials and methods: This study employed a single-blind, randomized repeated measures design. Sixteen young amateur soccer players participated (age: 16.56 ± 0.51 years). The participants were categorized into balanced groups based on their Yo-Yo Intermittent Recovery Test Level 1 scores. Subsequently, they participated in the SSG format, consisting of four sets of four minutes each, with two minutes of rest between sets. Players were instructed to rinse their mouths with four different 25-ml solutions for 10 s before starting the task. The solutions comprised CHO (maltodextrin at 6.4%, equal to 1.6 g), CAF (caffeine at 1.2%, equating to 300 mg), a combination of CHO and CAF (6.4% and 1.2%, respectively), and a combination of CAF and CHO (1.2% and 6.4%). This study measured the rating scale of mental effort (RSME), technical activities of games, and kinematic profiles, including walking (0.0-7.1 km-h-), jogging (7.2-14.3 km-h-¹) and running (14.4-19.7 km-h-¹), and high-speed running (>19.8 km-h-¹) during the games.

Results: Significant enhancements in kinematic performance at jogging and running speeds were observed with $MR_{CHO+CAF}$ ($p < 0.05$), whereas $MR_{CAF+CHO}$ most effectively improved the walking performance ($p < 0.05$). No significant differences were observed in kinematic performance during high-speed running or technical performance (total passes, shots, and interceptions) across any intervention ($p > 0.05$). There were no significant differences between the interventions in the RSME group ($p > 0.05$).

Conclusions: In summary, the $MR_{CHO+CAF}$ combination markedly improved the low-intensity jogging and running kinematic performance, whereas $MR_{CAF+CHO}$ showed more advantages for walking. However, neither intervention significantly affected the high-speed running, technical performance, or mental effort levels.

Keywords: *sports nutrition, game performance, cognitive performance, game-based training*

ÖZ

Amaç: Bu çalışmanın amacı, karbonhidrat (Karb), kafein (Kaf) ve bunların kombinasyonlarıyla (Kaf+Karb ve Karb+Kaf) ağız çalkalama uygulamasının 4'e 4 dar alan oyunları (DAO) sırasında zihinsel çaba, teknik aktivite ve kinematik değişkenler üzerindeki etkisini araştırmaktır.

Gereç ve Yöntem: Bu çalışmada tek kör, randomize, tekrarlı ölçüm tasarımı kullanılmıştır. Çalışmaya 16 genç amatör futbolcu (yaş: 16.56 ± 0.51 yıl) katılmıştır. Katılımcılar Yo-Yo Aralıklı Toparlanma Testi Seviye 1 sonuçlarına göre gruplara ayrılmıştır. Daha sonra, setler arasında iki dakika dinlenme ile dört dakikalık dört setten oluşan DAO formatına katılmışlardır. Çalışmada katılımcılara, oyundan önce 25 ml'lik dört farklı solüsyonla 10 saniye boyunca çalkalamaları istenmiştir. Çözeltiler Karb (%6,4 oranında maltodekstrin, 1,6 g'a eşit), Kaf (%1,2 oranında kafein, 300 mg'a eşit), Karb+Kaf kombinasyonu (6.4% ve 1.2%, sırasıyla) ve kaf+karb kombinasyonlarını (1.2% ve 6.4% sırasıyla) içermiştir. Bu çalışmada oyunlar sırasında, zihinsel çaba skalası, teknik aktivite ve yürüme (0.0-7.1 km-h-), hafif koşu (7.2-14.3 km-h-¹) ve koşu (14.4-19.7 km-h-¹) ve yüksek hızlı koşu (>19.8 km-h-¹) hızlarında kinematik profiller ölçülmüştür.

Bulgular: Bulgular, Karb+Kaf'ın koşu ve hafif koşu hızlarında kinematik performansı önemli ölçüde artırdığını ($p < 0.05$), Kaf+Karb'ın ise yürüme için en yüksek etkinliğe sahip olduğunu göstermiştir ($p < 0.05$). Yüksek hızlı koşudaki kinematik profilde veya teknik performansta (toplam pas, şut ve top çal-

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ma) hiçbir müdahale arasında istatistiksel olarak anlamlı bir fark olmadığı görülmüştür ($p > 0.05$). Zihinsel çabada oyunlar arasında istatistiksel olarak anlamlı bir fark olmadığı tespit edilmiştir ($p > 0.05$).

Sonuçlar: Sonuç olarak, Karb+Kaf kombinasyonu hafif koşu ve koşu dahil kinematik performansı önemli ölçüde geliştirirken, Kaf+Karb sıralaması yürüme performansı için daha faydalı olmuştur. Bununla birlikte, her iki müdahale de yüksek hızlı koşu, teknik performans veya algılanan efor seviyelerini önemli ölçüde etkilememiştir.

Anahtar Sözcükler: *spor beslenmesi, oyun performansı, bilişsel performans, oyun temelli antrenman*

INTRODUCTION

Soccer demands a wide range of sport-specific skills, often executed while in motion or following periods of running at varying speeds, from jogging to high-intensity sprints [1]. However, the increased speed of a match accelerates player fatigue, impacting physical capabilities and cognitive functions and resulting in diminished skill execution during the match [2,3]. Therefore, coaches and researchers have been directed to explore various fields, such as mindfulness practice [4], sleep optimization [5], and different nutritional strategies [6], in addition to other training methods that can potentially influence performance. In recent years, dietary interventions and the utilization of ergogenic aids have become prevalent in soccer players' preparation, reflecting the widespread interest in performance-enhancing strategies, particularly those derived from nutritional sources [7]. Convenient nutrition strategies support the demands of the nervous and peripheral mechanisms to optimize performance.

Recent studies [1,8] have increasingly focused on various methods of utilizing caffeine (CAF) and carbohydrates (CHO), which are prevalent in soccer-related studies. In particular, mouth rinsing (MR) with caffeine (CAF) and carbohydrates (CHO) (MR_{CAF} and MR_{CHO}), which demonstrate greater efficacy, practicality, and cost-effectiveness, have gained recognition in scientific research and clinical practice [9,10]. MR is an innovative method that circulates CHO and CAF solutions in the mouth through the taste buds without swallowing, affecting perception of exertion, cognition and motor skills. Lee and Owyang [11] stated that activating taste receptors T1R2 and T1R3 on the tongue elicits a response in the brain's reward centresthrough dopaminergic pathways. Unlike sweet carbohydrates, CAF engage with receptors for bitter tastes (TAS2R family), primarily located on the posterior portion of the tongue [12]. When CAF binds to receptors responsive to bitter compounds, it triggers a response in taste-bud sensory cells and relays a reaction to the central nervous system through taste perception nerves [13]. Mouth rinsing with ergogenic aids such as CAF and CHO may provide immediate sensory stimuli to the central nervous system, potentially enhancing performance without gastrointestinal distress associated with ingestion [14]. However, research remains controversial because MR_{CAF} and MR_{CHO} solutions can improve soccer performance by utilizing the effects triggered by the presence of these substances in the mouth without ingesting CHO and CAF.

As soccer skill performance is contingent on the interaction of cognitive, perceptual, and motor skills in dynamic environments [15], interventions that enhance these aspects are likely to interest soccer players and those involved in their technical development [6]. However, considering the well-established impact of specific nutritional interventions (such as the provision of CHOs, fluids, and CAF) on attenuating declines in physical performance, an increasing number of studies are investigating how these approaches can contribute to the maintenance of skilled performance throughout game performance [1,8]. Nevertheless, most studies have predominantly focused on technical or physical test performance rather than game performance. Only one study [10] on the ergogenic effects of MR_{CHO} exists using a game-based training approach on soccer players' physical or psychophysiological performance. Previous studies have shown that MR can enhance soccer performance in terms of mean power, endurance, and sprinting [16,17]. However, Bortolotti et al. [18] reported no improvement in sprint performance after MR intervention. Conversely, Rollo et al. [19] observed improved jogging pace and enhanced repeated sprint performance with MR compared to placebo. A recent study found no significant impact of single or serial MR on Yo-Yo Intermittent Recovery Test Level 1 performance [20]. Previous studies have primarily observed the effects of MR_{CHO}, and only Gough et al. [9] conducted a study on the impact of combining MR_{CHO} and MR_{CAF} on soccer performance. However, there have been no studies on MR_{CAF} and soccer performance.

Recent studies have indicated that mouth rinsing with CHO and CAF may exert effects through distinct neurophysiological mechanisms. CHO rinse activates sweet taste receptors (T1R2/T1R3), stimulating brain regions associated with reward processing and motor control, whereas CAF interacts with bitter taste receptors (TAS2R), modulating arousal and cognitive function [14, 21, 7). Given these distinct pathways, CHO and CAF perception may influence neural activation in different ways. CHO rinsing may enhance reward-related motor responses before introducing CAF arousal effects. Conversely, CAF rinsing may increase alertness, but potentially attenuate CHO's impact of CHO on re–

ward signaling. Despite the growing body of literature on the ergogenic effects of CHO and CAF supplementation in sports, limited research has directly compared the individual and combined effects of these substances when administered via MR on soccer players' performance, particularly in the cognitive and kinematic domains during the dynamic and physically demanding context of SSGs. This study aimed to 1) evaluate the individual and combined effects of $MR_{CHO}$and MR_{CAF} on mental effort, technical performance, and kinematic profiles during SSGs and 2) determine whether initial taste dominance modulates exercise and cognitive performance by investigating the effects of sequencing.

MATERIAL and METHODS

Experimental Design

Employing a single-blind repeated measures design, this study investigated the influence of carbohydrate and caffeine and their combinations of mouth rinses (MR_{CHO}, MR_{CAF}, $MR_{CHO+CAF}$, $MR_{CAF+CHO}$, respectively) on mental effort (ME), technical performance, and kinematic responses during small-sided soccer games (SSGs). The study was conducted 12 days before the soccer season, with players participating in six SSG sessions (one familiarization, one control session and four experimental MR intervention sessions). The order of the experimental conditions was randomized (www.randomization.com). The SSGs were scheduled 48 hours apart for psychophysiological recovery. Games were consistently held between 17:00 and 19:00 to avoid circadian rhythm disruptions. SSGs were performed on a standard artificial grass pitch under similar weather conditions (27–30°C, 35-37% humidity). The participants performed the Yo-Yo IRT-1 test on the first intervention day to determine VO_2max. Based on Yo-Yo IRT-1 scores, playing positions, training experience, and coach evaluation, they were divided into balanced four-player teams. On experimental days, participants arrived two hours before the sessions, consumed identical meals with the same CHO amount as their last pre-experiment meal, and remained in a controlled environment until the experiment started. Participants received a list of caffeine-containing foods and beverages to control dietary caffeine intake and were instructed to avoid caffeine sources during the study period. Each mouth rinse was administered immediately prior to the start of the game. The participants rinsed their mouths with 25 mL of the assigned solution for 10 seconds before expectoration.

Participants

Sixteen young amateur soccer players (age 16.56 ± 0.51 years, height 174.63 ± 4.26 cm, weight 61.77 ± 5.28 kg, training Experience 5.50 ± 0.63 years, and body mass index 20.26 ± 1.82 kg/m2) voluntarily participated in the study. The study was conducted during the pre-season period. The inclusion criteria were as follows: (i) players must not have had any injury in the last 6 months; (ii) players must have actively attended a minimum of four training sessions per week played and licensed soccer for at least 5 years; (iii) their average daily CAF consumption must be below 200 mg. The exclusion criteria were as follows: (i) players who had any injury during the experiment; (ii) players who did not participate in the experiment; (iii) players who took any medication or ergogenic substance during the experiment; and (iv) players who did not comply with the nutritional restrictions during the experiment. Before data collection, the participants and their parents were informed about the benefits and risks of the study and signed a written informed consent form. Throughout the study, participants maintained their dietary routines, hydration status, and sleep quality, and did not consume caffeine containing foods or beverages.

Data Collection Tools

Anthropometric measurements: Anthropometric measurements were taken on the first day of the experiment, in the morning after an overnight fast, and while wearing only shorts, using a professional body composition analysis system (Tanita BC 418, Tanita Corp, Inc., USA).

Caffeine Consumption Questionnaire: The average daily CAF intake of the players was assessed using the CAF Consumption Questionnaire (CCQ) developed by John Preston [22], and the mean intake of the 16 individuals was reported as 168.44 ± 54.55 mg.

Yo-Yo Intermittent Recovery Test (Yo-Yo IRT-1): The Yo-Yo IRT-1 is a widely utilized field test to assess aerobic endurance and anaerobic threshold. It consists of repeated shuttle runs of 20 m, with progressively increasing running speeds and short recovery periods between each shuttle. The test is designed to elicit maximum physiological responses from the participant, making it a valuable tool for assessing fitness levels and monitoring training progress [23].

Rating Scale of Mental Effort (RSME): The mental effort of the athletes was measured using the ME rating scale developed by Zijlstra [24]. The RSME is one of the most frequently used self-assessment scales in the sports performance psychology literature and consists of a vertical axis with a range of 0-150. Immediately after the games, participants marked the amount of ME expended on the game with a point on the scale.

Technical Analysis: The SSGs were recorded using a high-definition video camera (Canon HF R806, Tokyo, Japan). Technical analyses of the SSGs recorded by the camera were performed using eAnalyze Soccer software (Espor software, Ankara, Turkey). Technical analyses examined the total passing, shooting, and tackling activities. An experienced coach with match and performance analysis certificates conducted technical analyses.

Kinematic Profiles: A Polar V800 device with GPS technology was used to analyze the kinematic data. Polar V800 measures 37 mm × 56 mm x 12.7 mm and weighs 79 g. Polar V800 is a reliable device based on SiRFstarIV technology that provides an accuracy of ±2% for distance measurements and ±2 km/h for speed measurements in all outdoor sports [26]. Furthermore, it has a positional update rate of 1 Hz in the high-accuracy mode. For each participant, total distance travelled variables were collected for the speed segments 0.7-7.1 km/h, 7.2-14.3 km/h, 19.8-25.1 km/h and >25 km/h. These variables were recorded using the equipment and used for analysis.

Mouth Rinse Protocol

The single-blind, randomized repeated measures study examined the effects of five different MR conditions on mental effort, technical performance, and kinematic responses during SSGs. There were five MR conditions as follows: i) MR_{CHO} solution only (CHO; 6.4% maltodextrin, 1.6 g per 25 mL, 1.6 g, Protein Ocean, Türkiye), ii) MR_{CAF} solution only (CAF; 1.2% caffeine, 300 mg per 25 mL, 300 mg, Nature's Supreme), and iii) single MR solution combining CHO and CAF (6.4% maltodextrin + 1%. 2% caffeine in 25 mL), where participants were instructed to focus on the sweet taste (CHO) as the predominant perception, iv) the same combined CHO+CAF solution (same as $MR_{CHO+CAF}$), however participants were instructed to focus on the bitter taste (CAF) as the predominant perception, v) the control condition with no MR intervention. The solution combination and total volume were identical under the $MR_{CHO+CAF}$ and $MR_{CAF+CHO}$ conditions (25 mL containing CHO and CAF). Thus, the only difference between these conditions was the pre-rinse verbal instruction to change participants' perceived taste dominance to sweet (CHO) or bitter (CAF). The present study builds on previous findings showing that activating different taste receptors (T1R2/T1R3 for sweet and TAS2R for bitter) can initiate different neural pathways that influence performance and cognitive responses [7,14,21]. MR interventions were performed 10 s before each SSG, during which participants were instructed to rinse the entire volume in their mouths for 10 s and then spit the solution back into the pre-weighed container [26]. To verify compliance and ensure no ingestion, containers were weighed before and after each rinse using a calibrated precision digital scale (Etekcity, USA; accuracy: 1 g / 0.04 oz). No sequential rinses or volumes greater than 25 mL were performed under any condition.

Procedures

All SSG sessions were conducted simultaneously on a standardized turf soccer pitch under controlled environmental conditions (temperature: 27–30°C, humidity: ~40-45%) (17:00-19:00). Players engaged in 4-a-side formats, each comprising four bouts and four-minute halves separated by a 2-minute passive recovery. Pitch dimensions (25 × 32m) remained constant across formats to control for pitch size effects, resulting in a playing area of ~ 100 m2 per player in 4-a-side formats, respectively. Standard 1m x 1.5m goals were used, and players were encouraged verbally via coaches. Each session began with a 15-minute warm-up, which included 5 min of light jogging, dynamic stretches, agility drills, acceleration sprints, and game-based activities. Technical activity and kinematic profile responses were monitored during games, except for RSME, which was only collected after games in five minutes. The two coaches oversaw the game and promptly provided the new balls. The players received standardized instructions to sustain game intensity without specific tactical or technical guidance. The details and instructions for the study design of MR interventions are shown in Figure 1.

Figure 1. Study Design

Analysis of Data

The arithmetic mean and standard deviation values were calculated for descriptive analysis, and the normality of the data was assessed using the Shapiro-Wilk test. For repeated-measures analyses, violations of the sphericity assumption, as determined by Mauchly's test, were corrected using the Greenhouse-Geisser correction. One-way repeated-measures ANOVA was used to compare the five experimental conditions. In contrast, one-way analysis of variance (ANOVA) was used to evaluate differences in the RSME, kinematic profile, and technical activity responses. The assumptions of ANOVA, including normality and homogeneity of variance, were assessed using the Levene's test. Bonferroni post hoc analysis was conducted to determine group-specific differences, and partial eta-squared (ηP^2) values were reported as an indicator of effect size, classified as small (0.01), medium (0.06), or large (0.14) [27]. The significance level was set at $P < 0.05$. All statistical analyses were performed using SPSS 27 software.

RESULTS

In this part of the study, we present the statistical results of the RSME, technical activity, and kinematic profiles in response to MR interventions during 4-a-side SSGs in soccer.

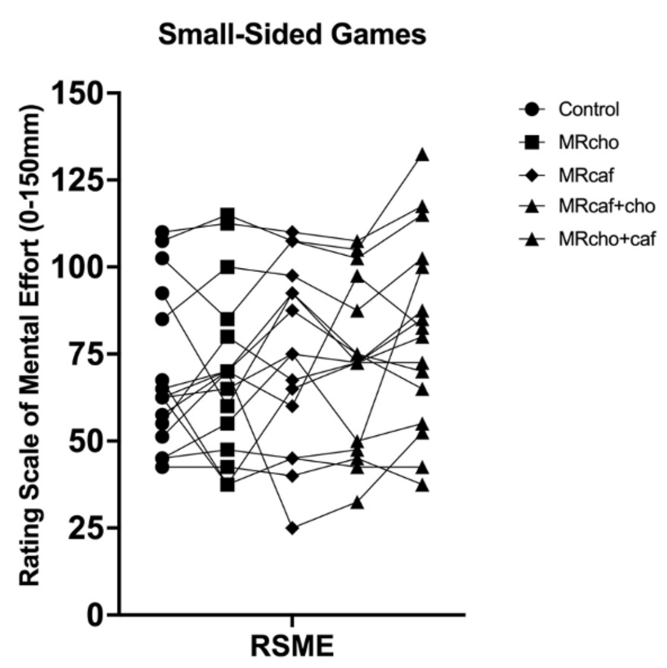

Figure 2. RSME responses to MR interventions

Figure 2 shows the responses regarding the effects of MR interventions on RSME during the SSGs. There was no statistically significant difference in the RSME between the Control (69.61 ± 22.70), MR_{CAF}(69.84 ± 24.19), MR_{CHO} (74.53 ± 26.48), $MR_{CAF+CHO}$ (72.34 ± 23.71) and $MR_{CHO+CAF}$ (81.09 ± 27.49) MR interventions (F = 2.153; p = 0.106; n_p^2 = 0.126).

Table 1. Kinematic profile of different MR intervention during SSGs

SSGs	Walking (0.0–7.1 km · h^{-1})	Jogging (7.2–14.3 km · h^{-1})	Running (14.4–19.7 km · h^{-1})	High-speed running (> 19.8 km · h^{-1})
(1) Control	895.19 ± 42.95	251.69 ± 67.88	4.19 ± 3.92	0.19 ± 0.75
(2) MR_{CAF}	963.38 ± 82.83	321.31 ± 119.26	10.94 ± 21.65	2.50 ± 8.12
(3) MR_{CHO}	958.00 ± 60.20	465.94 ± 141.07	15.88 ± 10.81	0.88 ± 1.89
(4) $MR_{CAF+CHO}$	1065.75 ± 83.51	455.63 ± 123.02	11.19 ± 6.73	0.56 ± 1.55
(5) $MR_{CHO+CAF}$	941.44 ± 167.51	769.63 ± 237.33	49.43 ± 20.43	3.88 ± 4.80
F	7.616	41.567	22.705	1.848
p	0.002*	0.001*	0.001*	0.183
	0.337	0.735	0.602	0.110
Post-hoc	4**1 (0.01); 4**2 (0.04) 4**3 (0.01)	5**1 (0.01); 5**2 (0.01) 5**3 (0.01); 5**4 (0.01)	5**1 (0.01); 5**2 (0.02) 5**3 (0.01); 5**4 (0.01)	-

1: Control; 2: MR_{CAF}; 3: MR_{CHO}; 4: $MR_{CAF+CHO}$; 5: $MR_{CHO+CAF}$; ** Significant differences between SSGs (p < 0.01); * Significant differences between SSGs (p < 0.05).

Table 1 demonstrates the effects of the MR interventions on kinematic performance at different speed zones. The results showed that $MR_{CHO+CAF}$ significantly improved performance at jogging (7.2-14.3 km-h-1) and running (14.4-19.7 km-h-1) speeds ($p < 0.05$). The $MR_{CAF+CHO}$ combination was the most effective intervention for walking (0.0-7.1 km-h-) ($p < 0.05$). However, no significant difference was found between any high-speed running (>19.8 km-h-1) running speed zone intervention.

Table 2. The technical activity of different MR interventions during SSGs

SSGs	Total Pass	Total Shot	Interception
Control	33.81 ± 9.57	2.31 ± 2.18	1.75 ± 1.44
MR_{CAF}	36.06 ± 9.86	2.19 ± 2.07	1.13 ± 0.96
MR_{CHO}	32.06 ± 11.70	3.56 ± 2.16	1.19 ± 1.05
$MR_{CAF+CHO}$	32.06 ± 11.47	4.06 ± 2.64	1.56 ± 1.55
$MR_{CHO+CAF}$	37.00 ± 11.15	3.31 ± 2.33	1.63 ± 1.20
F	0.884	2.680	0.848
p	0.429	0.058	0.500
	0.056	0.152	0.054
Post-hoc	-	-	-

*1: Control; 2: MR_{CAF}; 3: MR_{CHO}; 4: $MR_{CAF+CHO}$; 5: $MR_{CHO+CAF}$; ** Significant differences between SSGs ($p < 0.01$); * Significant differences between SSGs ($p < 0.05$).*

Table 2 depicts the MR interventions' effects on soccer players' technical performance. The results showed no significant differences between the interventions in terms of the total number of passes, shots, or interceptions ($p > 0.05$).

DISCUSSION

This study investigated the effects of MR_{CAF}, MR_{CHO}, $MR_{CAF+CHO}$, and $MR_{CHO+CAF}$ interventions and control conditions on RSME, technical activity, and kinematic profiles of soccer SSGs. The results of the present study showed no statistical difference between the total passing, shooting, and tackling activities in all conditions. Considering the distances covered at different speeds, while $MR_{CHO+CAF}$ significantly improved performance at jogging (7.2-14.3 km-h-1) and running (14.4-19.7 km-h-1) speeds, the $MR_{CAF+CHO}$ combination was the most effective intervention for walking (0.0-7.1 km-h-). However, no significant difference was found between any high-speed running (>19.8 km-h-1) running speed zone intervention. Another finding of the current study was that MR practice had no significant effect on ME. To the best of our knowledge, this literature review shows no other study in which MR_{CAF} and MR_{CHO} practices and a combination of $MR_{CAF+CHO}$ and $MR_{CHO+CAF}$ practices were examined in soccer SSGs.

We found no significant differences in total passes, shots, or interceptions among the various MR interventions during the SSGs. Arlai and Nana [28] examined the effects of MR_{CAF} and MR_{CHO} on soccer performance and found that these interventions did not significantly improve sprinting, passing, or shooting. Our findings align with this, suggesting that MR experiments have a limited effect on the technical parameters. The minimal changes in technical performance indicate that soccer skills are influenced not only by ergogenic aids but also by factors such as player skill levels, tactical decisions, and game dynamics. Although no other study has directly investigated the effect of MR on technical performance in soccer, the impact of different CHO and CAF intake methods has been examined. For example, Ali et al. [29] found that CHO-electrolyte solutions improved shooting performance in players with low glycogen stores, but had little effect on passing. Andrade-Souza et al. [30] investigated the effects of CHO and CAF on soccer passing performance, separately and in combination involving 11 amateur male soccer players who completed the Loughborough Intermittent Shuttle Test followed by the Loughborough Soccer Passing Test and found no significant difference in the total passing time when CHO and CAF were combined. In contrast, Foskett et al. [31] reported that CAF in capsule form improved passing accuracy and overall football skill performance. These conflicting findings suggest that the effects of CAF may vary depending on the method of administration and that physiological differences between the MR method and direct CAF intake could influence the results. Therefore, further research is needed to clarify MR's effects on soccer's technical parameters.

Our findings suggest that carbohydrate and MR_{CAF} protocols have the potential to enhance low-speed kinematic performance; however, their effects on high-speed activities are limited. Although CHO and CAF influence MR mechanisms, they activate different brain regions. MR_{CHO} stimulates motor cortex activation by sending rapid signals regarding energy availability, enhancing motivation, and reducing perceived effort [14,32]. In contrast, the bronchodilator effect of CAFs may support aerobic metabolism by increasing oxygen uptake at low speeds [33]. However, this effect may be insufficient at high speeds, owing to the dominance of anaerobic energy systems. Additionally, CAF can activate bitter taste receptors in the oral cavity, enhancing cognitive alertness through dopamine release and affecting brain regions linked to motor control, attention, and motivation [12,21]. Neuroimaging studies have confirmed increased activity in the prefrontal, orbitofrontal, and dorsolateral cortices following MR_{CAF} [21]. Activation of the sympathetic nervous system via bitter compounds, such as CAF, may contribute to its ergogenic effects [34]. However, because the CAF does not trigger energy signals, its full potential may not be realized. Nevertheless, the strong signals transmitted to the brain via CAF-stimulated TAS2R receptors may optimize motor control, attention, and motivation mechanisms, potentially enabling sustained performance at low speeds.

These findings suggest that CHO and CAF enhance performance through different mechanisms, depending on the order of administration, which could be particularly advantageous in small-sided soccer games.

ME is defined as the cognitive workload required to perform a task and the subjective experience of engaging in the task [35]. SSGs influence athletes' mental states during training, increasing the demand for cognitive processes [36]. Intense ME can lead to mental fatigue by activating inhibition centers in the brain, increasing perceived effort while reducing motivation and willingness to act [37]. Our study suggests that different MR methods do not alter the ME. While previous studies [9,25] have primarily focused on the effects of CHO and CAF consumption on physical performance, recent research [21,31,38] has examined the potential of CHO, CAF, and their combinations to enhance cognitive performance. However, only one study has investigated the effect of MRs on ME in SSGs. Soylu et al. [10] reported that continuous and intermittent SSGs with MRCHO did not significantly affect RSME compared to a placebo. In a study involving professional athletes, Almeida et al. [39] found that acute CAF intake before SSGs had no significant effect on perceived effort. Similarly, Guttierres et al. [40] emphasized that comparing CAF and CHO intake in sports drinks during matches did not significantly impact the perceived effort levels. These findings were consistent with those of the present study. Given the limited number of studies on different MR practices in SSGs, a comprehensive discussion remains challenging. However, based on our results, CAF, CHO, and their combination did not affect ME significantly.

This study on MR effects during SSGs had limitations, including a focus on young amateur male soccer players, limited generalizability to other groups, and a lack of assessment of long-term effects. RSME measures mental effort but does not other psychological factors such as anxiety or stress. Future research could use real-game scenarios to achieve greater ecological validity. A key limitation was the lack of a placebo due to the challenges in creating a taste-matched, non-caloric solution. Including a placebo would have complicated the crossover design, increasing participant burden. The control condition without MR served as the baseline. Although the study was conducted under a single-blind design, complete perceptual blinding was impossible in all conditions because of the distinct taste profiles of CAF (bitter) and CAF (sweet). In $MR_{CHO+CAF}$ and $MR_{CAF+CHO}$, the participants were not informed of the solution content. However, they were given sensory-focus instructions (i.e., to attend to sweet or bitter aspects), which may have influenced their awareness of the condition. This limitation is standard in studies involving oral taste receptor stimulation and should be considered when interpreting the findings. Future studies should explore alternative placebos or controls to isolate MR's effects better. Addressing these limitations will improve our understanding and guide further research on nutritional interventions for sports performance.

CONCLUSION

Using MR_{CAF} and MR_{CHO} separately did not affect technical parameters or ME. However, the $MR_{CHO+CAF}$condition significantly improved performance at jogging and running speeds. Simultaneously, the $MR_{CAF+CHO}$ combination was the most effective intervention for walking speed, with no significant difference between the interventions at high-speed running speeds. These findings suggest that the active compounds used in MR and the order in which they are perceived may influence the psychophysiological responses during intermittent sports activities. However, future research should consider incorporating manipulation checks or alternative perceptual measures to further clarify the role of taste dominance sequencing.

Ethics Committee Approval / Etik Komite Onayı

The Ethics Committee of Tokat Gaziosmanpasa University granted ethical approval (approval number 35711501-68, dated 26/12/2023.

Conflict of Interest / Çıkar Çatışması

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

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Author Contributions / Yazar Katkıları

Concept: YS, UG, EA, BK; Design: YS, UG, EA, BK; Supervision: YS; Materials: YS, UG; Data Collection and Processing: YS, UG; Analysis and Interpretation: YS, UG; Literature Review: UG; Writing Manuscript: YS, UG, EA, BK; Critical Reviews: YS, EA, BK. All authors contributed to the final version of the manuscript and discussed the results and contributed to the final manuscript.

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