

Effects of Carbohydrate Mouth Rinse on Performance in Elite Rhythmic Gymnasts Under Mental Fatigue

Bochecho de carboidrato e desempenho de ginastas rítmicas de elite submetidas à fadiga mental

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ABSTRACT

Introduction: The effect of carbohydrate (CHO) mouth rinsing on the performance of Brazilian National Team rhythmic gymnasts subjected to mental fatigue (MF) was evaluated. The objective was to determine whether CHO mouth rinsing would attenuate the negative impacts of MF on performance. **Methods:** Twelve rhythmic gymnasts from the Brazilian National Team participated in a randomized, double-blind, crossover experimental study. Mental fatigue was induced using personalized cognitive tasks (Stroop and n-back) maintained until a subjective fatigue level of 60% was reached, as measured by a visual analog scale (VAS), reaction time, and blink frequency. Participants performed 10-second mouth rinses with a 7% CHO solution or a placebo, followed by a simulated rhythmic gymnastics routine and three “risk” movements, which were evaluated by experienced coaches. Statistical analysis was conducted using a linear mixed model. **Results:** The protocol effectively induced mental fatigue over an average duration of 1 hour and 26 minutes, characterized by increased perceived fatigue (VAS), reaction time, and blink frequency, as well as a reduction in correct responses on cognitive tasks. The CHO group achieved a significantly higher mean score on risk movements (4.72 ± 2.55) compared to the placebo group (4.17 ± 2.41) ($p = 0.0402$). **Conclusion:** CHO mouth rinsing attenuates the negative effects of mental fatigue on the performance of elite rhythmic gymnasts. This non-metabolic benefit—possibly mediated by the activation of brain areas related to motor planning and reward—suggests a relevant ergogenic strategy for maintaining cognitive and motor performance without caloric intake.

Keywords: mental fatigue; gymnastics; carbohydrate; oral rinsing

RESUMO

Introdução: Foi avaliado o efeito do bochecho com carboidrato (CHO) no desempenho de ginastas rítmicas da Seleção Brasileira submetidas à fadiga mental (FM). O objetivo foi verificar se o bochecho com CHO atenuaria impactos negativos da FM na performance. **Métodos:** Participaram doze ginastas rítmicas da Seleção Brasileira, em delineamento experimental crossover, randomizado e duplo-cego. A fadiga mental foi induzida através de tarefas cognitivas personalizadas (Stroop e n-back), mantidas até o alcance de 60% de fadiga subjetiva, mensurada por escala visual analógica (EVA), tempo de reação e frequência de piscadas. As participantes realizaram bochechos de 10 segundos com solução contendo 7% de CHO ou placebo, seguidos de simulação de série de GR seguida de três movimentos de risco, avaliados por treinadores experientes. A análise estatística foi conduzida através de modelo linear misto. **Resultados:** O protocolo induziu efetivamente fadiga mental por um tempo médio de 1h26min, caracterizada pelo aumento da fadiga percebida (EVA), do tempo de reação e da frequência de piscadas, além da redução de acertos nas tarefas cognitivas. O grupo CHO apresentou escore médio significativamente maior nos movimentos de risco ($4,72 \pm 2,55$) em comparação ao grupo placebo ($4,17 \pm 2,41$) ($p = 0,0402$). **Conclusão:** O bochecho com CHO atenua efeitos negativos da fadiga mental no desempenho de ginastas rítmicas de elite. Esse benefício não metabólico, possivelmente mediado pela ativação de áreas cerebrais relacionadas ao planejamento motor e à recompensa, sugere uma estratégia ergogênica relevante para a manutenção do desempenho cognitivo e motor sem ingestão calórica.

Palavras-chave: fadiga mental; ginástica; carboidrato; enxague

Introduction

The carbohydrate (CHO) mouthwash strategy has been investigated as an ergogenic aid for physical performance, especially in high-intensity endurance exercises such as cycling and running [1–6]. The proposed mechanism for this improvement is predominantly non-metabolic, involving the activation of carbohydrate receptors in the mouth that modulate central pathways associated with motivation and brain activity, rather than relying on carbohydrate oxidation [5–9].

At the same time, mental fatigue (MF), a psychobiological state induced by prolonged periods of demanding cognitive activity, has been widely recognized for its negative impact on physical performance [5,8,10–14]. MF can impair several sports, such as cycling, running and swimming, mainly through an increase in the perception of effort and changes in brain activity [8,10–14]. Interventions using carbohydrate mouthwash have been investigated to mitigate the deleterious effects of MF [7,8,11,14,15].

Despite the growing body of evidence on CHO mouthwash and FM in endurance athletes, the literature on their combined effects in complex sports such as Rhythmic Gymnastics (RG) is scarce. RG is an artistic and aesthetic sport that demands high levels of physical and psychological stress, with the execution of complex technical elements and the need for physical capabilities such as speed, strength, jumping ability, explosive power, and flexibility [16–21].

However, studies on RG tend to be descriptive, focusing on physiological, anthropometric, technical, and psychological aspects, without addressing nutritional interventions such as CHO mouthwash to optimize performance under FM conditions [16,18,21]. No studies were found that specifically evaluated the effect of carbohydrate mouthwash in gymnasts, only in endurance and cycling athletes [5,6] and many of the available studies are not of sufficient quality to warrant their application to elite athletes [22].

Therefore, the objective of this study is to evaluate the effect of carbohydrate mouthwash on the performance of rhythmic gymnasts from the Brazilian National Team, subjected to mental fatigue, thus filling an important gap in the sports literature.

Methods

Participants

The study included 12 adult rhythmic gymnasts from the Brazilian National Team, representing the entire census of the ensemble team qualified for the Paris Olympic Games. Inclusion criteria were being an active member of the national team and not using medications that could influence mental fatigue. Participants were excluded for: (a) missed training; (b) injury or motor impairment preventing physical testing; (c) cardiovascular, metabolic, or neurological diseases; (d) performance-e-

enhancing drug use; or (e) ergogenic supplement use (e.g., caffeine, creatine, beta-alanine, nitrate, bicarbonates) during the experiment.

No sample size calculation was performed as the study used the total available population of elite athletes in this category.

Procedure

The research utilized a randomized, double-blind, placebo-controlled crossover design, incorporating one between-participant factor (group: carbohydrate or placebo) and three within-participant factors (duration of fatigue tests, maximum heart rate, and subjective perception of effort). The number of trials, experiment day, and participants were all considered random factors.

The order of treatment exposure (CHO or PLA) was randomized via a draw conducted by an independent researcher to ensure allocation concealment. The experiment took place over three Saturdays. The first Saturday established a baseline fatigue test. On the second and third Saturdays, participants were randomized into carbohydrate or placebo groups, undergoing a fatigue test, followed by the assigned mouthwash, and then a physical test. Groups were switched on the third Saturday.

Participants had a familiarization session for the mental fatigue task (first Saturday or baseline) and were instructed to maintain consistent sleep, training, and similar dietary intake in the week leading up to the experiments. Breakfast on experiment days was standardized at 300 calories (30% protein, 25% fat, 45% carbs).

During the familiarization session, participants were provided with a standardized definition of mental fatigue as a 'psychobiological state characterized by feelings of tiredness and lack of energy resulting from prolonged demanding cognitive activity'. To ensure a robust induction of fatigue in this elite cohort, a threshold of 60% on the Visual Analogue Scale (VAS-MF) [23] was established as the criterion for starting the physical tests, notably, participants were not informed of this specific threshold.

Subsequently, computer-based Stroop and N-back tasks were presented, and participants were instructed to complete as many trials as possible. After each set of tasks, participants completed the VAS-MF. If their perceived mental fatigue was below the defined threshold, the session ended and the number of repetitions was recorded as their baseline duration; otherwise, another repetition of the Stroop and N-back tasks was initiated.

On the second and third Saturdays, participants first completed the mental fatigue task, which was customized to their baseline duration. Then, they used either the carbohydrate or placebo mouthwash before performing the physical test. (see a scheme with the data collection on Fig. 1).

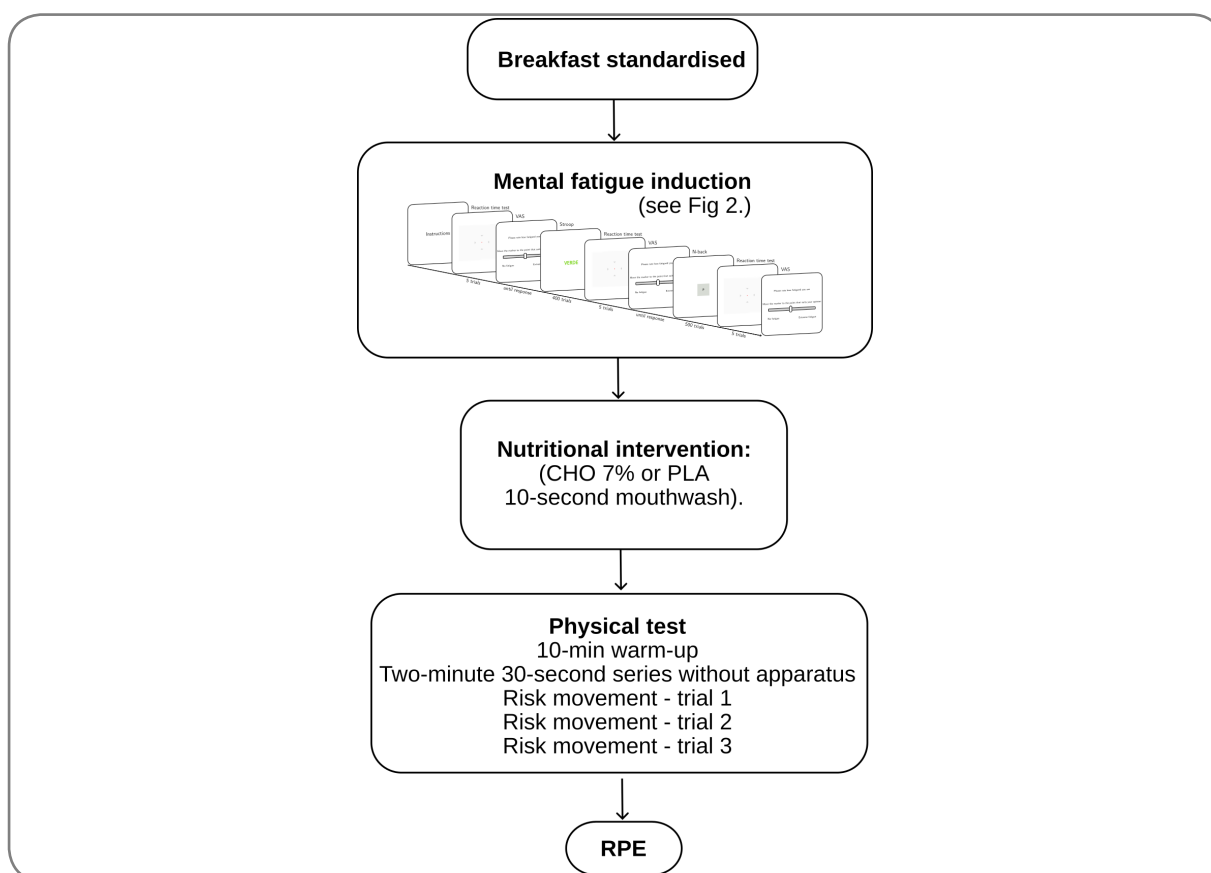


Figure 1 – Data collection flowchart of the second and third Saturdays

Mental fatigue task

Participants completed computer-based Stroop and n-back tasks to induce mental fatigue. The Stroop task (ST) involved identifying the font color of one of four words (black, green, purple, beige) by pressing the corresponding key, ignoring the word's meaning. A 500 ms feedback was provided after each keypress. Each trial lasted approximately 5 minutes.

The n-back task (NBT) consists of a sequence of capital letters that appear briefly (2000 ms) one at a time in the center of the computer screen. The participant was required to press the spacebar if the current letter matched the letter two screens prior. Feedback (1000 ms) confirmed correct/incorrect responses. All procedures are repeated for 5 min; approximately 500 times (see Fig. 2).

The combination of the Stroop and n-back tasks was utilized to ensure a comprehensive depletion of executive resources, specifically targeting response inhibition and working memory simultaneously. This multi-task protocol is supported by previous research [23] suggesting that engaging varied cognitive domains prevents task-specific adaptation and more effectively induces a global state of mental fatigue in high-performance athletes.

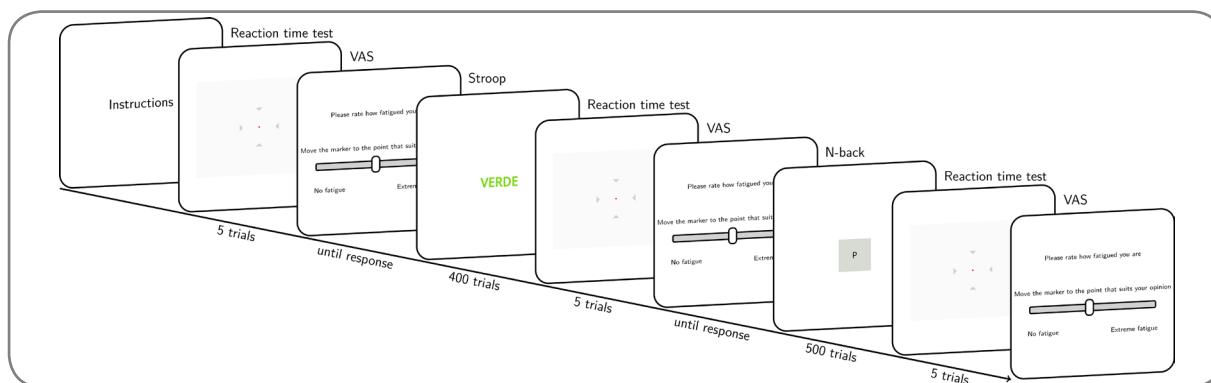


Figure 2 – Schematic representation of an experimental block, which consists of an alternating sequence of mental fatigue tasks and fatigue ratings

Mental fatigue ratings

Mental fatigue was assessed using three methods: a Visual Analog Scale (VAS), a horizontal rectangle filled with red. The rectangle is numbered from 0 to 100, with higher numbers and more color indicating greater fatigue. The second was a five-trial reaction time task (RTT). In each trial, participants pressed the spacebar as quickly as possible after a black circle appeared on the computer screen. The final was determined by measuring the frequency with which participants blinked during the task.

The mental fatigue tasks (ST and NBT), as well as the VAS and RTT, were programmed using OpenSesame software [24] version 4.0 and executed on laptop computers. In all cases, reaction time and number of correct responses were recorded for each participant.

Blinks detection

OpenFace software [25–28] analyzed video recordings of participants' faces to identify eye positions, determine when the eyes were closed, and estimate blink frequency and duration. Blinks that lasted longer than half a second were excluded from the analysis.

Treatment

All participants completed mental fatigue tasks (ST, RT, NBT) and fatigue rankings (VAS) in a consistent order: ST, RT, VAS, NBT, RT, VAS. Fatigue rankings followed each task. This block was repeated 3-8 times, based on baseline data. Before the first block, participants completed VAS and RT.

Physical task

A technical committee of three expert coaches from one of the world's top-ranked rhythmic gymnastics (RG) teams designed the physical task circuit. Following a specific 10-minute warm-up, athletes performed an apparatus-free hoop series simulation before attempting three trials of a 'risk' movement (see Fig. 3). In RG, a risk is defined as a high apparatus throw combined with two or more dynamic rotations under its flight, followed by recovery.



Figure 3 – Schematic representation of the physical task. (1) Starting position with the hoop held in front of the body. (2) Hop while passing through the hoop. (3) Throw of the hoop to initiate the risk element. (4) Three chaîné turns with the arms overhead. (5) Catching the hoop during an illusion turn while passing through it, without visual control. Figure generated using Gemini 3.1 with iterative prompt refinement

To ensure objectivity and adherence to the Fédération Internationale de Gymnastique (FIG) Code of Points, performance was evaluated by the same two blinded, experienced coaches (20+ years of experience), who were unaware of the nutritional intervention. They assigned scores using a 0–5–10 system developed to reflect the ‘all-or-nothing’ nature of risk elements: 10 for perfect execution; 5 for completed movements with technical faults (imperfect catch); and 0 for a loss of apparatus (drop), which constitutes a major competitive deduction.

Physical task intensity was estimated via heart rate (Polar Team Pro, Kempele, Finland) and classified using ACSM criteria [29]: very light (< 57% max HR), light (57–63% max HR), moderate (64–76% max HR), vigorous (77–95% max HR), and close to maximum (> 96% max HR).

After completing the task, athletes completed the CR10 RPE scale, answering: “How hard do you think the exercise was?”

Nutritional intervention

The nutritional intervention utilized a commercial orange-flavored isotonic drink (Gatorade) as the carbohydrate (CHO) solution, providing a 7% concentration following Brietzke *et al.* [9]. Its composition includes water, sucrose, glucose, sodium chloride, sodium citrate, monobasic potassium phosphate, citric acid, flavoring, and artificial colors (tartrazine and sunset yellow).

The placebo (PLA) was a commercial sugar-free orange-flavored powdered drink (Clight), match-controlled for color, temperature, and taste. The PLA composition consists of vitamins (C, A, B1), dehydrated orange juice, citric acid, sodium citrate, and the sweeteners aspartame and acesulfame potassium.

To ensure the integrity of the double-blind protocol, an independent researcher prepared the solutions in identical glasses, and the sensory similarity between the two brands was previously validated through a taste test with nutrition students.

Participants were instructed to swish the liquid in their mouths for 10 seconds without swallowing, and then expel it.

Statistical analysis

The analysis had two stages: first, determining if athletes reached high mental fatigue, then assessing carbohydrate mouth rinsing's impact on physical tasks after mental fatigue. The initial stage began with scatter plots and linear trend lines to compare reactions time and hits with VAS and blinking frequency.

The second stage used a linear mixed model to analyze average risk scores. Fixed factors included group (CHO or PLA), computer-assisted cognitive task duration (DU_PSI), max HR (HR_MAX), and the rating of perceived exertion (RPE). Random factors were the number of fatigue task blocks (BLs), experiment day (Day), and participant identification (ID).

$$\text{average_risk} \sim \text{GROUP} * \text{DU_PSI} * \text{HR_MAX} * \text{RPE} + (1 | \text{BLs}) + (1 | \text{Day}) + (1 | \text{ID})$$

Interaction effects within the linear mixed model, such as GROUP * HR_MAX, were included based on the hypothesis that the ergogenic benefits of carbohydrate mouthwash are more pronounced during periods of higher physiological stress [9]. To address the risk of overfitting inherent in a small, elite sample size ($n = 12$), we used a stepwise backward selection process to retain only the most parsimonious model.

Furthermore, multicollinearity was assessed using Variance Inflation Factors (VIF); RPE and HR_MAX were found to be independent predictors, representing subjective effort and physiological intensity respectively.

Post hoc tests used Holm adjustment (multcomp library). All analyses were in R/RStudio using lmerTest and lme4 libraries. Normality and homoscedasticity were checked before model selection using the performance package.

Ethics approval

This study was approved by Brazil's National Council for Ethics in Research (Conselho Nacional de Ética em Pesquisa [CONEP]) protocol n.º 92652418.0.0000.5546. All participants provided voluntary informed consent before their enrollment.

Results

Mental fatigue test

Participants experienced similar mental fatigue across three sessions. This was achieved through 3–8 repetitions (average 5.25 ± 1.36) of a task block (ST + RT + VAS + NBT + RT + VAS), lasting 1 hour and 26 minutes on average. Mental fatigue, measured by VAS and reaction time (Fig. 4A-B), increased over time but remained consistent across the three sessions, as indicated by a similar trend on the first Saturday (Fig. 4A) and the trend lines of subsequent Saturdays (Fig. 4B).

Another indicator of mental fatigue is fewer hits on the attention test as the fatigue perception (VAS) increases. Figures 4C and 4D show that as perceived mental fatigue rose across conditions, Stroop test hits declined.

Increased blinking during the test, shown in Figure 4E, indicates mental fatigue, aligning with the hypothesis that the tasks caused increased blinking, reaction times, and perceived fatigue. Mental fatigue levels were consistent across all experimental days.

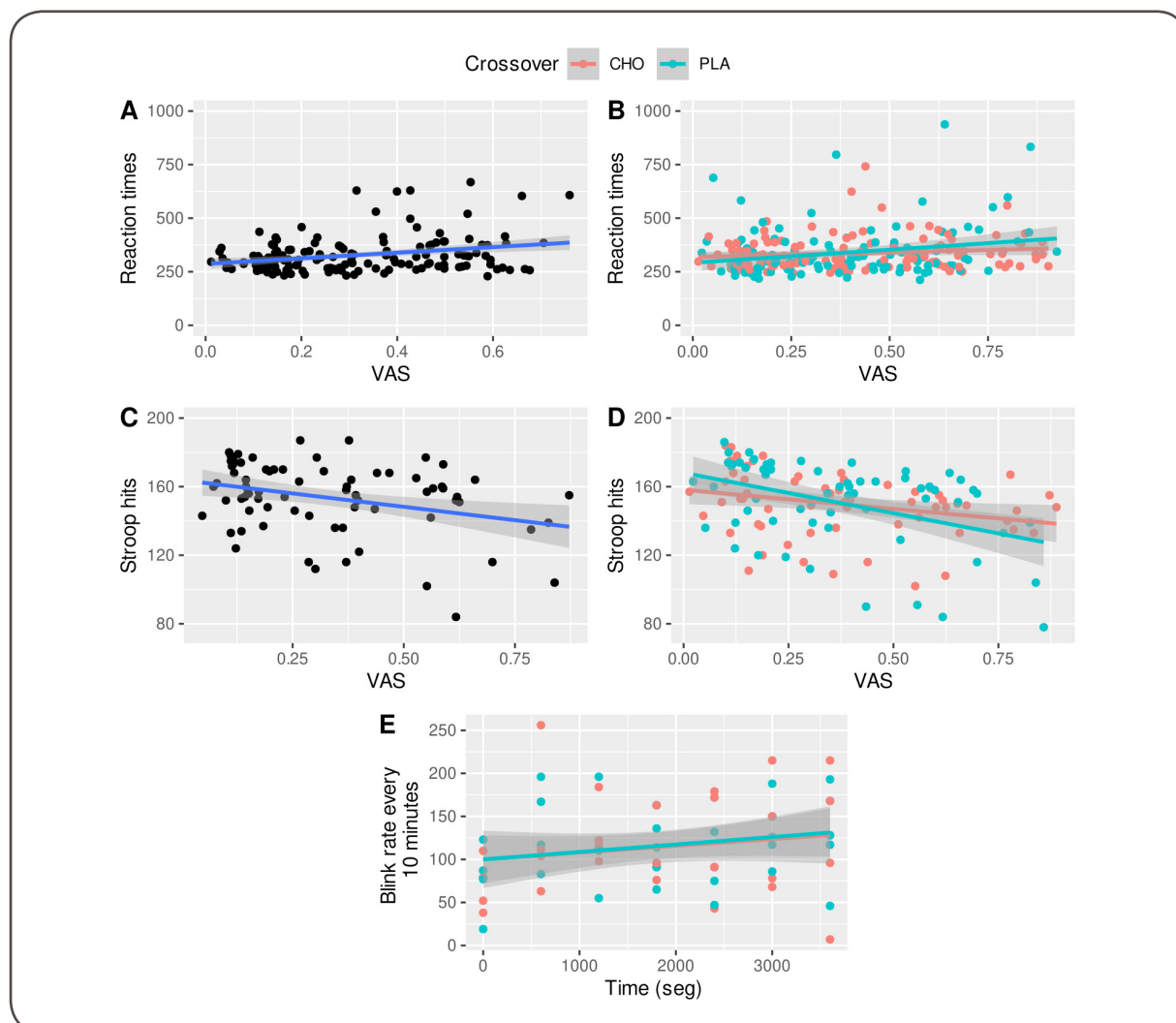


Figure 4 – Scatter plots compare VAS values (x-axis) with the reaction time of a reaction time task (y-axis of panels A and B) for the first (A) and second and third sessions (B). Panels C and D illustrate scatter plots comparing VAS values (x-axis) and frequency of hits on the Stroop test for the first (C) and second and third sessions (D). Finally, Panel E shows the scatter plot of blinks' frequency across the attentional tasks

Physical tests

The physical tests, which lasted on average 13 minutes, were of vigorous intensity, according to HR and CR10. The mean HR was 76.99 ± 10.71 bpm for the CHO group and 80.00 ± 6.89 bpm for the PLA group. The mean RPE was 7.25 ± 1.06 for the CHO group and 7.42 ± 1.31 for the PLA group. Finally, the average score for the risk task was 4.72 ± 2.55 for the CHO group and 4.17 ± 2.41 for the PLA group. Table I summarizes the results of mental fatigue and physical tests.

Table 1 – Number of blocks and duration of the mental fatigue tests and physical performance indicators of the athletes in each group (CHO and PLA) (mean $\pm$ SD)

Variables	CARB	PLA
Mean number of blocks of mental fatigue task	5.25 $\pm$ 1.36	5.25 $\pm$ 1.36
Mean duration of mental fatigue task (min)	86.58 $\pm$ 21.26	86.58 $\pm$ 21.26
Mean Duration of physical task (warm-up + series + 3 risk) (min)	13.12 $\pm$ 0.01	13.07 $\pm$ 0.02
Risk 1 score (a.u.)	5.00 $\pm$ 3.69	4.17 $\pm$ 2.89
Risk 2 score (a.u.)	5.42 $\pm$ 3.34	4.16 $\pm$ 3.59
Risk 3 score (a.u.)	3.75 $\pm$ 3.11	4.17 $\pm$ 2.87
Risks average score (a.u.)	4.72 $\pm$ 2.55	4.17 $\pm$ 2.41
Average HR during physical task (bpm)	76.99 $\pm$ 10.71	80.00 $\pm$ 6.89
RPE (a.u)	7.25 $\pm$ 1.06	7.42 $\pm$ 1.31

a.u. = arbitrary unit; RPE = Rating of Perceived Exertion

Linear mixed model

The resulting model after the stepwise backward model/variable selection was:

average_risk ~ GROUP + DU_PSI + HR_MAX + RPE + (1 | BLs) + GROUP:HR_MAX + DU_PSI:HR_MAX + DU_PSI:RPE + HR_MAX:RPE

The numerical variables were rescaled using R's scale function. Tests for normality and homoscedasticity demonstrated that the model exhibited a normal distribution and homogeneous variance. The $R^2(\text{marginal}) = 0.33$ indicated that the model could explain a significant amount of variance.

Table II presents the results of the ANOVA for the linear mixed model. The ANOVA results indicate differences in the performance of the risk sequences for the main factors of GROUP, HR_MAX, and RPE, as well as for the interactions between GROUP:HR_MAX, DU_PSI:HR_MAX, DU_PSI:RPE, and HR_MAX:RPE. A post-hoc analysis using the emmeans package comparing the variable GROUP showed significant differences (tratio = 2.283, df = 12.8, $p = 0.0402$), with a higher mean risk score in the CHO group. Figure 5 shows a comparison of the average risk scores of the two groups.

Table II – ANOVA table (type III) for the resulting model after stepwise backward model/variable selection. Asterisks represent significant levels lower than: ‘***’0.001, or ‘**’0.01, or ‘*’0.05

	Chisq	Df	Pr(>Chisq)
Intercept	1.6866	1	0.194047
GROUP	5.2921	1	0.021422 *
DU_PSI	2.3945	1	0.121760
HR_MAX	3.0865	1	0.078946 *
RPE	23.7162	1	1.116e-06 ***
GROUP:HR_MAX	10.7137	1	0.001063 ***
DU_PSI:HR_MAX	4.9080	1	0.026733 *
DU_PSI:RPE	10.1416	1	0.001450 **
HR_MAX:RPE	19.809	1	1.253e-05 ***

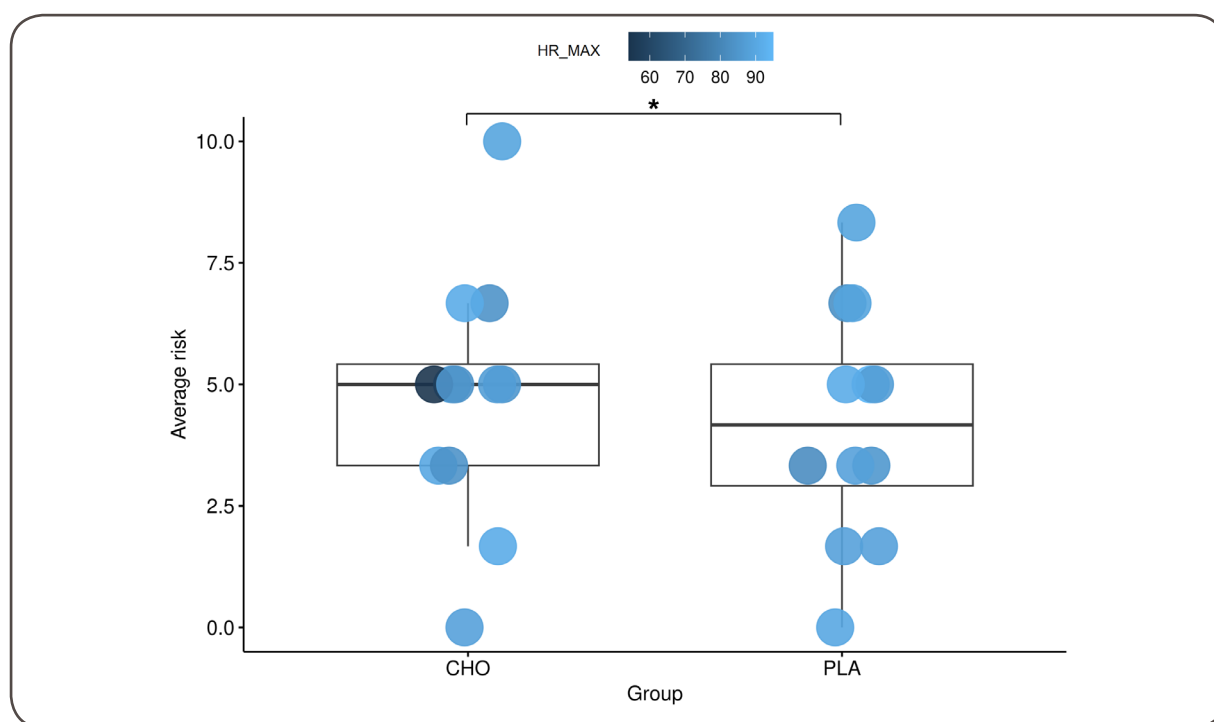


Figure 5 – Box plots of the average risk scores for the groups CHO and PLA, showing the HR mean through the point colors. Each point represents an athlete score

Discussion

The present study investigated the impact of carbohydrate (CHO) mouthwash on the performance of elite rhythmic gymnasts subjected to acute mental fatigue. The findings demonstrate that the mental fatigue induction protocol was effective and consistent, revealing an increase in perceived fatigue and a reduction in cognitive performance, as in other studies [9,12,14,30–37].

The combined use of self-report (VAS-MF), behavioral (reaction times), and physiological measures (blink frequency) enabled the attainment of a high and sustained level of fatigue, despite the marked resilience of this group of athletes. This multimodal approach represents a principal contribution of the present study, offering a robust protocol for the induction of mental fatigue. In this context, our findings indicate a substantial divergence in mental fatigue (MF) thresholds relative to the existing literature. Whereas standard protocols typically induce cognitive exhaustion within approximately 30 minutes in recreational or less specialized populations [31–33,38,39], the elite gymnasts examined here maintained intensive cognitive performance for an average of 86.58 ± 21.26 minutes before reaching the fatigue criterion. This duration is comparable to the longest induction times reported by Van Cutsum *et al.* [37], who similarly employed a combination of the Stroop task and additional attentional tasks. Notably, the Stroop task remains one of the most widely used paradigms for inducing mental fatigue [8,34,37], thereby further supporting the validity of our approach.

The heightened resilience observed in rhythmic gymnastics athletes suggests the presence of a specialized cognitive profile, potentially shaped by the distinctive attentional demands of the discipline, which entails the simultaneous coordination of apparatus manipulation and technical precision under strict musical synchronization. This profile may be considered comparatively more robust than that observed in other sport modalities, such as soccer players [33] or road cyclists [40], for whom approximately 30 minutes of mental fatigue induction were sufficient to elicit comparable levels of mental fatigue. Furthermore, this resistance to MF likely stems from chronic adaptation to the sport's rigorous ecological routine [20], where pre-competition warm-ups alone typically last three to four hours [19]. Such high-volume training necessitates sustained mental focus and may foster superior neuro-psychological endurance compared to other athletic populations.

The results of the study corroborate the understanding that mental fatigue has a negative impact on cognitive performance [9,31–37], particularly manifesting itself in tasks that require attention and quick reaction [9,31–34,37]. Notably, the group that performed the CHO mouthwash showed significantly higher performance in movements with a high level of risk of losing the device compared to the placebo group, which suggests a complex interaction between nutritional strategies, mental fatigue state and decision-making processes in high-performance athletes [8,9,14,31,33,34,37].

This finding is particularly relevant as the literature suggests that CHO mouthwash can modulate brain responses [1,3–6,8]. CHO mouthwash is believed to stimulate oral receptors that activate brain areas related to motor planning and emotional responses, such as the prefrontal cortex (PFC), and reward circuits in the brain, even without ingestion [1,5,6,8,9,35,37]. While the precise neurobiological pathways remain to be fully elucidated through direct imaging, we hypothesize that the observed improvements in risk execution are mediated by the activation of oral

carbohydrate receptors. This non-metabolic mechanism likely modulates brain areas associated with motor planning and reward, such as the prefrontal cortex. Activation of these reward centers can generate positive cognitive, emotional, and behavioral responses [6,9], which, in turn, can influence the willingness to take risks or the perception of the outcomes associated with those risks [6,12,14,33,35,37].

In the context of Rhythmic Gymnastics, this may improve the quality of movement execution and spatial awareness during high-pressure ‘risk’ moments, even when the athlete is in a state of cognitive depletion.

Although previous studies have examined the effects of CHO mouthwash on endurance and cycling performance [5,6,8,9,11], its direct influence on performance in tasks characterized by a high risk of apparatus loss under conditions of mental fatigue has not been previously investigated. This represents one of the principal strengths of the present study, together with the inclusion of the entire census of the Brazilian National Ensemble Team, thereby conferring high ecological validity within an elite sport context. Furthermore, the individualized fatigue-induction protocol ensured that each gymnast reached her specific cognitive threshold prior to the physical task, mitigating the bias associated with fixed-duration protocols reported in earlier research [34].

Clinical implications

For rhythmic gymnasts, a sport that demands perfection of technical gestures, well-developed physical and artistic abilities, and high levels of physical and psychological stress [19,21,41], mental fatigue can be a limiting factor [14,34,37]. The ability to make ideal decisions, especially in risk situations inherent to performance (e.g., elements of difficulty, interaction with apparatus) [19,21], is vital. In this context, CHO mouthwash can be a valuable tool to combat mental fatigue, helping to maintain cognitive and motor performance during intense training sessions and competitions [4,8,9,12,37]. CHO mouthwash offers an ergogenic benefit without caloric intake, minimizing potential gastrointestinal discomfort and supporting the maintenance of athletes’ performance [1,3,4,6,8].

Limitations

It is important to acknowledge some limitations of this study. Although the study’s relevance is justified by the lack of research on CHO mouthwash in rhythmic gymnasts, the sample size may suggest a small sample size ($n = 12$). Despite revealing statistical significance, it may impact the robustness and generalizability of the results. Furthermore, it is important to highlight that the study was conducted with gymnasts from the Brazilian National Team, an elite population with highly specific physiological and psychological characteristics. The findings may not be directly applicable to recreational athletes or athletes from other sports. Finally, although the findings suggest that central nervous system (CNS) mechanisms play a role in modulating performance, future studies should incorporate direct neuroimaging te-

chniques to corroborate and elucidate the hypothesised neural activation patterns.

Conclusion

Carbohydrate mouthwash significantly improved the performance of elite rhythmic gymnasts in risk movements when subjected to mental fatigue. This strategy highlights the importance of targeted nutritional interventions in aesthetic sports to mitigate the negative impacts of cognitive exhaustion on technical execution.

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Competing interests

The authors declare no competing interests.

Data sharing statement

The R scripts and data are accessible on Zenodo at <https://zenodo.org/records/17194718>.

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None

Authors' contribution

Conceptualization, Writing–original draft, Investigation: Nascimento IO; Conceptualization, Methodology: Gomes JH, Martins B, Coradine J, Rezende C, Fernandes I, Fortes LS, Fiorese L; Writing–reviewed draft, Writing–review & editing: Oliveira JVC, Investigation: Andrade R; Conceptualization, Writing–review & editing, Formal Analysis, Methodology: Tejada J; Conceptualization, Writing–review & editing, Methodology: Mendes RR

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