



Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesfEffects of different solutions consumed during exercise on cognitive function of male college soccer players[☆]Feng-Hua Sun^{a,*}, Simon B. Cooper^b, Frank Chak-Fung Tse^a^a Department of Health and Physical Education, The Education University of Hong Kong, Hong Kong SAR, China^b Department of Sport Science, Sport Health and Performance Enhancement (SHAPE) Research Centre, School of Science and Technology, Nottingham Trent University, Nottingham, UK

ARTICLE INFO

Article history:

Received 26 May 2020

Received in revised form

15 June 2020

Accepted 16 June 2020

Available online 20 June 2020

Keywords:

Loughborough intermittent shuttle test

Carbohydrate

Protein

Dehydration

Performance

Sports drink

ABSTRACT

Background/Objectives: The present study aimed to investigate the effects of three solutions, i.e. carbohydrate-electrolyte-solution (CES), carbohydrate-electrolyte-protein-solution (CEPS), and placebo (PLA), on cognitive function of college soccer players.

Methods: Sixteen male college soccer players completed three main trials in a randomized cross-over study design. In each main trial, participants completed 90 min Loughborough Intermittent Shuttle Test (LIST) protocol and consumed one of three solutions. The cognitive function tests were performed; blood glucose and lactate concentrations, and several subjective measurements were also recorded in each trial.

Results: Compared with pre-exercise level, the accuracy of Rapid Visual Information Processing test (RVIPT) and the response time in Visual Search Test (VST, complex level) after LIST improved in CES and CEPS trials, but not in PLA trial. However, the accuracy of VST (complex level) decreased in both CES and CEPS trials, compared with PLA trial. CEPS consumption improved accuracy in VST (simple level), compared with CES consumption. Blood glucose concentrations were well maintained in CEPS trial, but not in CES and PLA trials.

Conclusion: It seems that both CES and CEPS consumption show certain benefits on some aspects of cognitive function in male college soccer players in Hong Kong. However, these effects may be specific to the cognitive domain tested.

© 2020 The Society of Chinese Scholars on Exercise Physiology and Fitness. Published by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

There are many physically demanding activities such as sprinting, running, jumping, and tackles in soccer. At the same time, soccer also involves many technical actions including dribbling, shooting, and passing.¹ It is notable for frequent high-intensity

intermittent exercises, and the performance rely on complex characteristics such as tactical, technical, physiological and psychological variables.² Among these variables, psychological factors such as cognitive function have been used to predict soccer performance.^{3,4} Cognitive function describes processes in which humans perceive, evaluate, store, manipulate and respond appropriately to internal and external information.⁵ As soccer players need to respond continuously to a changing and relatively unpredictable situation in the field, cognitive function has been suggested to predict performance of soccer players.³ Also, perceptual and cognitive skills,⁴ inhibitory control, cognitive flexibility, and metacognition⁶ were all superior in elite compared to non-elite players. Therefore, it is necessary to investigate whether there are strategies those can be applied to maintain the cognitive function of soccer players, which typically deteriorate when fatigue ensues towards the end of a game and thus provide a direct intervention to enhance soccer performance.

Abbreviations: CES, Carbohydrate-electrolyte solution; CEPS, Carbohydrate-electrolyte-protein solution; LIST, Loughborough Intermittent Shuttle Test; BM, Body mass; RPE, Rating of perceived exertion; PT, Perceived thirst; AD, Abdominal discomfort; HR, Heart rate; VST, Visual search test; ST, Stroop test; RVIPT, Rapid visual information processing test; BCAA, Branched chain amino acids; 5-HT, 5-hydroxytryptophan.

* This study was supported by Internal Research Grant (ref.: RG 33/2017-2018R) of the Education University of Hong Kong.

* Corresponding author. Rm D4-2F-25, Department of Health and Physical Education, The Education University of Hong Kong, Tai Po, Hong Kong SAR, China.

E-mail address: fhsun@eduhk.hk (F.-H. Sun).

<https://doi.org/10.1016/j.jesf.2020.06.003>

1728-869X/© 2020 The Society of Chinese Scholars on Exercise Physiology and Fitness. Published by Elsevier (Singapore) Pte Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Dehydration (of ~2% body mass loss) is commonly observed in soccer training and match play,^{7,8} with evidence also suggesting that this dehydration impairs soccer performance.⁹ Cognitive function may also be negatively influenced by dehydration caused by exercise.¹⁰ The consumption of traditional carbohydrate-electrolyte solutions (CES) may offset the effect of dehydration on soccer performance.^{11,12} CES consumption has also been suggested as a way to improve cognitive function after submaximal endurance exercise, compared with placebo consumption.^{13,14} Co-ingestion of CHO and protein (carbohydrate-electrolyte-protein solution, CEPS) during endurance exercise was shown to improve endurance exercise capacity and prevent muscle damage, when compared with CHO alone.^{15,16} One recent study found that, compared with distilled water, CEPS but not CES may enhance visual motor speed in female recreational runners.¹⁷ Another study suggested that CEPS consumption decreased the perception of effort and enhanced affective responses during 90 min of strenuous running, compared with traditional CES.¹⁸ However, to date, few studies have been conducted to investigate the potential beneficial effect of CES or CEPS consumption on the cognitive function of soccer players.

Therefore, the purpose of the present study was to investigate the effects of three different solutions, i.e., CES, CEPS, and placebo (PLA), consumed during soccer specific exercise protocol on cognitive function in male college soccer players in Hong Kong. The hypothesis is that both CES and CEPS consumption will enhance cognitive function compared with PLA. Furthermore, a secondary hypothesis is that CEPS will confer additional benefits on cognitive function of participants when compared with CES.

Materials and methods

Participants

Overall, 16 male college soccer players were recruited to participate the present study. Their age, height, weight, and maximal oxygen consumption (VO_{2max}) were 21 ± 1 yr, 174.9 ± 4.4 cm, 68.6 ± 7.7 kg, and 52.0 ± 6.1 mL/kg/min, respectively. Participants were fully informed of the whole procedure and the potential discomfort before they signed a written consent. Ethical approval of the present study was obtained from the University Research Ethical Committee, The Education University of Hong Kong. The study has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

The sample size was calculated using F tests ANOVA repeat measures (within factors) with G*Power software (Version 3.1, Germany). When adopting a two-tailed probability level of 0.05, an effect size of 0.23¹⁹, a conservative correlation between repeated measures of 0.50 and power of 80%, the sample size should be 16 participants in each main trial.

Preliminary tests

One week prior to the main experimental trial, participants were required to undergo a series of preliminary tests to measure basic physiological characteristics, including the VO_{2max} test and oxygen uptake (VO_2)-speed relationship test on a treadmill. These two tests have been used in previous study.²⁰ In brief, participants were required to complete four stages, each of 4 min duration, at four different speeds in the VO_2 -speed test. Expired air samples were collected continuously (Cortex Metalyzer® 3B, Germany) in the test. The data during the last minute of each stage were analyzed to determine the relationship between the speed and VO_2 using linear regression. In the VO_{2max} test, participants completed a continual, incremental graded uphill running. The submaximal

running speed was maintained throughout the test, whereas the gradient of the treadmill was set at 3.5% initially and was increased by 2% per 3-min until volitional exhaustion. The purposes of these preliminary tests were to determine the individual VO_{2max} , as well as speed equivalent to 55% and 95% of the individual VO_{2max} . Participants also completed one pilot trial to become familiar with all the procedures and requirements in the main trials, especially the Loughborough Intermittent Shuttle Test (LIST) protocol and cognitive function tests. The LIST was designed to simulate the exercise pattern and physiological demands of intermittent sports such as soccer, and it has been shown to have good test-retest reliability.²¹ The design of the LIST is shown in Fig. 1. The whole protocol consists of six 15-min blocks separated by 3-min rest. In each block, there were 10–12 cycles of different activities. Each cycle involves 3 × 20-m walk, 1 × 20-m maximal sprint, 4s standing rest, 3 × 20-m run at around 55% VO_{2max} pace, and 3 × 20-m run at around 95% VO_{2max} pace.

Study design and protocol

Participants completed three main experimental trials in a randomized cross-over design with a wash out period of around 7 days. They were asked to record their food and drink consumption for 2 d before the first trial and follow the same diet before each subsequent trial. All participants were required to refrain from alcohol consumption and vigorous physical activity 24 h before each trial. In addition, participants were instructed to ingest approximately 500 mL of water 2 h before arriving at the laboratory to maintain euhydration condition.

In each main trial, the participants arrived at the laboratory 2 h after a standardized meal, which was the same for all experimental trials. Upon arrival, the participants rested for around 20 min. Then the baseline level of body mass (BM), rating of perceived exertion (RPE), perceived thirst (PT), abdominal discomfort (AD), and heart rate (HR) were recorded. Baseline finger capillary blood sample (BS) were also be collected to test blood glucose and blood lactate concentrations. The baseline performance of cognitive function was also evaluated. After baseline data collection, participants performed a standardized 5-min warm-up including jogging, skipping, jumping, walking, and stretching. Then they completed the LIST protocol. The experimental protocol is shown in Fig. 1.

One of three taste-matched solutions was provided to the participants immediately before warming up (5 mL/kg BM) and every 15 min thereafter (during resting period, 2 mL/kg BM).¹⁹ The drinking patters were shown in Fig. 1. The three solutions were CES, CEPS, and taste- and color-matched PLA, separately. The three solutions were formulated based on a local commercial sports drink (Aquarius, Coca-Cola, HK), and were used in previous study¹⁷ which demonstrated that participants could not distinguish between the solutions. All these solutions contain the same electrolyte profile (Sodium, 7 mg/100 mL; Potassium, 7 mg/100 mL; Magnesium, 1.1 mg/100 mL; Calcium, 0.7 mg/100 mL), and a flavor was used to mask any potential difference in taste. The CES contained 6% CHO in the form of sucrose, CEPS contained 4% CHO in the form of sucrose plus 2% whey PRO (bcshop, HK), and the total energy was matched between CES and CEPS. The PLA is a non-caloric artificially sweetened solution (Aquarius Zero, Coca-Cola, HK).

Outcome measures

Cognitive function

Cognitive function was examined using a testing battery and administered via a laptop computer. This test took approximately 15 min to complete. The battery of tests includes a Visual Search

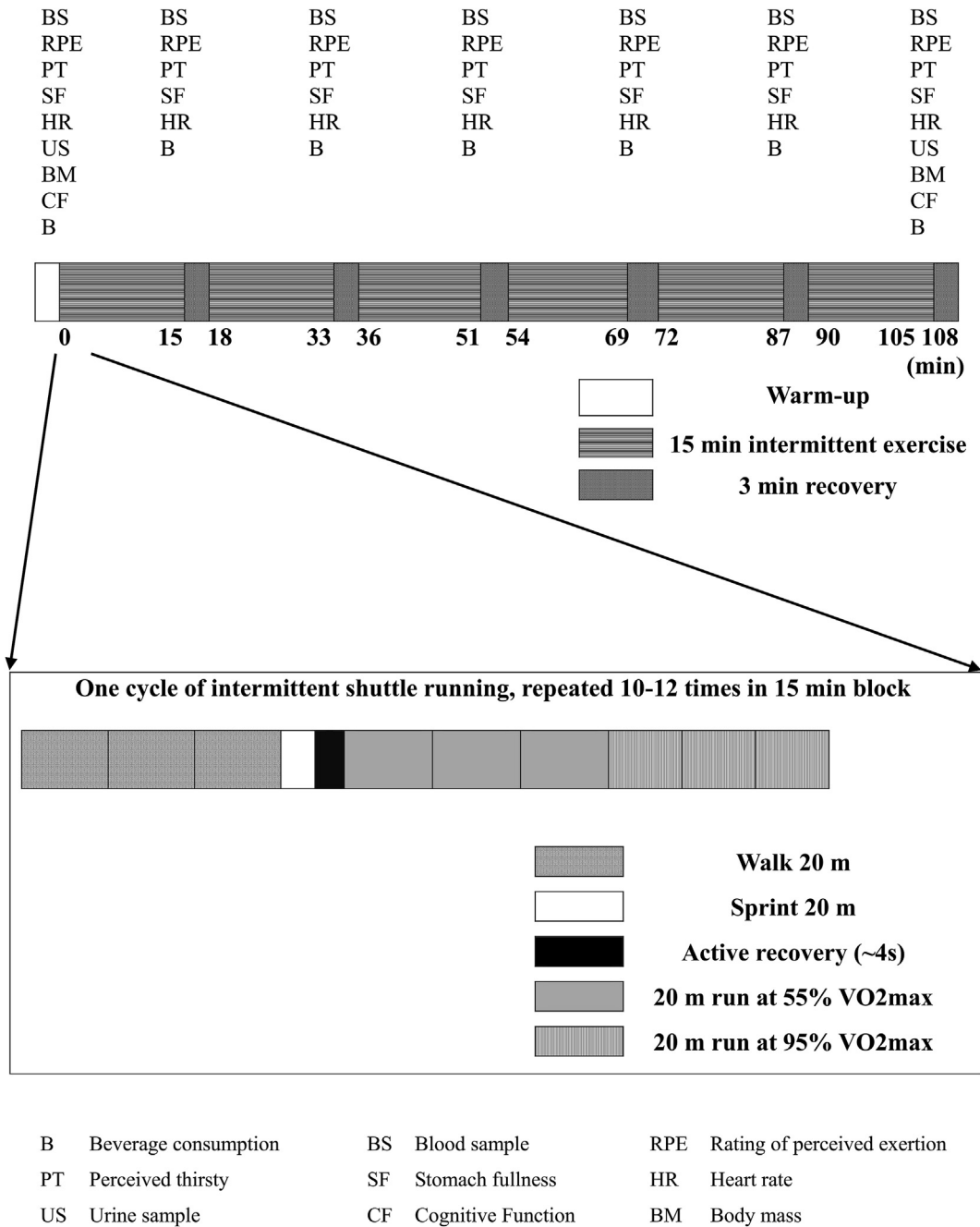


Fig. 1. Representation of the LIST, adopted from Nicholas et al., 2000.

Test (VST, assessing perception), the Stroop Test (ST, assessing attention and executive function), and the Rapid Visual Information Processing Test (RVIPT, assessing sustained attention and vigilance). This battery allows a range of domains of cognitive function to be examined, and has been successfully used in a number of previous studies examining the effects of exercise and nutrition on sporting performance.²²

Demographic and individual information

All participants self-reported their demographic information regarding age, gender, years of soccer experience. Body height and weight were measured using height and weight scales (Body Weight Precisa, DPS-Promaticsrl, Italy).

Blood biomarkers

Capillary blood samples were collected to determine blood lactate concentration using a portable blood lactate analyzer (Nova Lactate Plus, USA). Blood glucose concentration was also determined (YSI1502, YSI, USA).

Heart rate (HR)

The HR was measured throughout each main experimental trial using a HR monitor (Polar Team System, Polar Electro, Finland), to provide a measure of exercise intensity.

Subjective measures

The RPE is ranked from 6 to 20.²³ The score of PT and AD are scaled from 0 to 10, where 0 means “not so much” and 10 means “very much”.¹⁹ These subjective measures helped to understand the different physiological responses to the interventions adopted in the present study.

Statistics

Statistical analyses were performed using SPSS software and R software. Data were presented as mean \pm standard deviation (SD). Two-factor (treatment and time) analysis of variance (ANOVA) with repeated measures were used to test the physiological outcome measures, including blood glucose and lactate concentrations, as well as RPE and PT. A Bonferroni stepwise correction was applied to determine the location of the variance where necessary. Cognitive function data were analyzed using R 3.5.1 (www.r-project.org). Analyses were performed using a two-way repeated measures ANOVA (trial \times time), separately for each test level. Separate analyses for each test level were performed due to the simple and complex levels of each test requiring different cognitive processes. Where a significant overall trial \times time interaction was identified, further analysis were run separately to compare the trials to elucidate where the differences occurred. The statistical significance was accepted as $P < 0.05$.

Results

Cognitive function

The data for each of the cognitive function tests at each time point across all trials can be found in [Supplementary Table 1](#).

Visual search test

Response times. On the complex level of the VST, there was a significant trial \times time interaction ($F_{(2,30)} = 6.2$, $P = 0.002$, [Fig. 2](#)). Specifically, response times improved from pre- to post-exercise on both the CES and CEPS trials, whilst they were maintained on the PLA trial (trial \times time interactions: CES vs. PLA, $F_{(1,15)} = 7.1$, $P = 0.008$; CEPS vs. PLA, $F_{(1,15)} = 10.2$, $P = 0.002$; [Fig. 2](#)). There was no difference in the change from pre- to post-exercise between the CES and CEPS trials (trial \times time interaction, $p = 0.457$).

Accuracy. On the simple level of the VST, there was a significant trial \times time interaction for accuracy ($F_{(2,30)} = 4.0$, $p = 0.018$, [Fig. 3a](#)). Specifically, whilst accuracy decreased from pre- to post-exercise

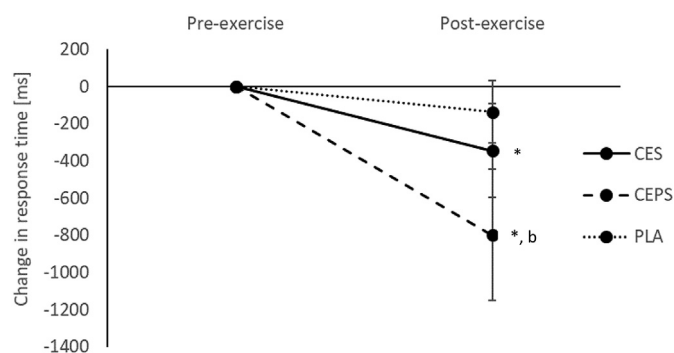


Fig. 2. Change in response times from pre- to post-exercise on the complex level of the visual search test on the CES, CEPS and PLA trials. Data are mean \pm SD. *: $P < 0.05$, vs. Pre-exercise; b: $P < 0.05$, CEPS vs. PLA.

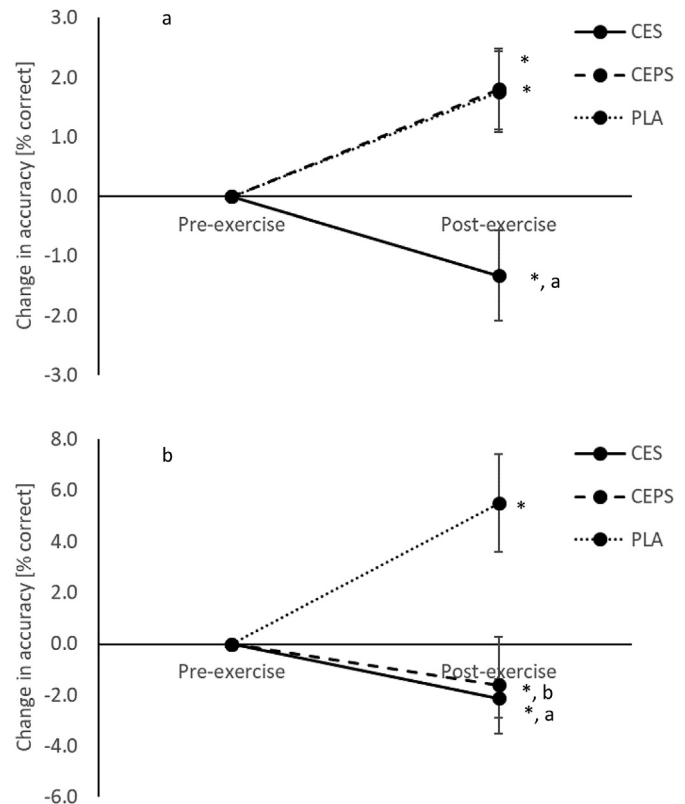


Fig. 3. Change in the percentage of correct responses from pre- to post-exercise on the simple ([Fig. 3a](#)) and complex ([Fig. 3b](#)) levels of the visual search test on the CES, CEPS and PLA trials. Data are mean \pm SD. *: $P < 0.05$, vs. Pre-exercise; a: $P < 0.05$, CES vs. PLA; b: $P < 0.05$, CEPS vs. PLA.

on the CES trial, accuracy improved on both the CEPS and PLA trials (trial \times time interactions: CES vs. CEPS, $F_{(1,15)} = 6.7$, $p = 0.010$; CES vs. PLA, $F_{(1,15)} = 5.2$, $p = 0.023$; [Fig. 3a](#)). On the complex level of the VST, there was also a significant trial \times time interaction for accuracy ($F_{(2,30)} = 20.1$, $p < 0.001$; [Fig. 3b](#)). Upon further inspection, whilst there was a slight decrease in accuracy from pre- to post-exercise on the CES and CEPS trials, accuracy improved on the PLA trial (trial \times time interactions, CES vs. PLA, $F_{(1,15)} = 24.2$, $p < 0.001$; CEPS vs. PLA, $F_{(1,15)} = 29.7$, $p < 0.001$; [Fig. 3b](#)).

Stroop Test

Response times. On the complex level of the ST, there was a significant trial \times time interaction ($F_{(2,30)} = 4.4$, $P = 0.013$, [Fig. 4](#)). Specifically, upon further analysis it was revealed that whilst response times slowed from pre- to post-exercise on the PLA trial, response times improved from pre- to post-exercise on the CES trial ($F_{(1,15)} = 9.1$, $P = 0.003$, [Fig. 4](#)). There was no difference in the change in response times from pre- to post-exercise between the other trials (CES vs. CEPS, $p = 0.124$; CEPS vs. PLA, $p = 0.169$).

Accuracy. There was no difference in the pattern of change in accuracy from pre- to post-exercise between any of the trials on either the simple or complex level of the ST (trial \times time interactions: simple, $p = 0.890$; complex, $p = 0.417$).

Rapid Visual Information Processing Test

Response times. There was a significant trial \times time interaction for response times on the RVIPT ($F_{(2,30)} = 3.6$, $p = 0.028$; [Fig. 5a](#)). Specifically, whilst response times remained similar from pre- to post-exercise on the PLA trial, they improved from pre- to post-

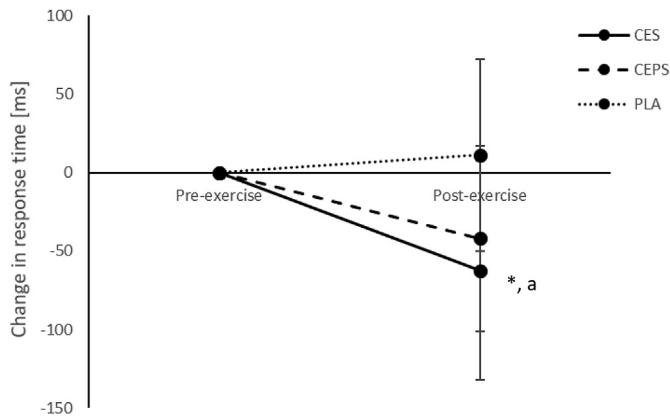


Fig. 4. Change in response times from pre- to post-exercise on the complex level of the Stroop test on the CES, CEPS and PLA trials. Data are mean \pm SD. *: $P < 0.05$, vs. Pre-exercise; a: $P < 0.05$, CES vs. PLA.

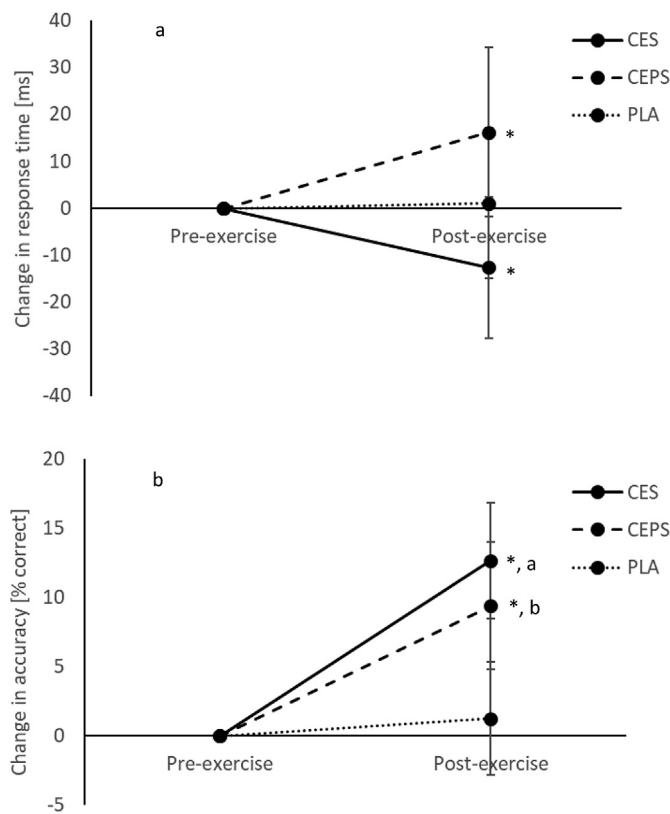


Fig. 5. Change in response times (Fig. 5a) and correct responses (Fig. 5b) from pre- to post-exercise on the RVIP test on the CES, CEPS and PLA trials. Data are mean \pm SD. *: $P < 0.05$, vs. Pre-exercise; a: $P < 0.05$, CES vs. PLA; b: $P < 0.05$, CEPS vs. PLA.

exercise on the CES trial (trial \times time interaction, $F_{(1,15)} = 6.3$, $p = 0.012$; Fig. 5a) but slowed on the CEPS trial (trial \times time interaction, $F_{(1,15)} = 4.2$, $p = 0.041$; Fig. 5a).

Accuracy. There was a significant trial \times time interaction for accuracy on the RVIP ($F_{(2,30)} = 6.7$, $p = 0.001$; Fig. 5b). Specifically, whilst accuracy was maintained from pre- to post-exercise on the PLA trial, it increased from pre- to post-exercise by a similar magnitude on both the CES and CEPS trials (trial \times time interactions, CES vs. PLA, $F_{(1,15)} = 5.9$, $p = 0.015$; CEPS vs. PLA, $F_{(1,15)} = 12.9$, $p < 0.001$; Fig. 5b).

Physiological data and subjective measures

The data for each of the physiological tests and subjective measures at each time point across all trials can be found in Table 1.

Glucose and lactate

There was no difference in blood glucose concentration among the three trials. However, it was found that blood glucose concentration was higher in CEPS trial than that in PLA trial at 33 min, 51 min and 87 min (Table 1). Blood glucose concentration was also higher in CEPS trial than that in CES trial after the whole LIST protocol (Table 1). A significant time effect was observed ($F_{(6,20)} = 4.712$, $P = 0.016$). In PLA trial, blood glucose concentrations were lower than resting value at most of time points, whereas they were maintained in both CES and CEPS trials at most of time points (Table 1). There was no difference in blood lactate concentration among three trials and among different time points.

Abdominal discomfort and perceived thirst

There was no difference in AD scores among three trials and among different time points. There was also no difference in PT scores among three trials. However, a significant time effect was observed ($F_{(6,20)} = 14.398$, $P < 0.001$). In general, the PT scores increased gradually in all three trials (Table 1).

Rating of perceived exertion and heart rate

There was no difference in RPE scores among three trials. A significant time effect was observed ($F_{(6,20)} = 19.668$, $P < 0.001$). In general, the RPE scores increased gradually in all three trials (Table 1). There was also no difference in HR among three trials. However, it was found that HR after session 1 and session 2 in CEPS trial were lower than those in CES trial. A significant time effect was observed ($F_{(6,20)} = 15.674$, $P < 0.001$). In general, HR was higher after each session than resting (Table 1).

Discussion

To the best of our knowledge, the present study was the first study to investigate the effects of three different solutions, i.e. CES, CEPS, and PLA, consumed during soccer specific exercise protocol on cognitive function in male college soccer players. The key findings were that both CES and CEPS consumption showed certain benefits on some aspects of cognitive function.

Acute administration of CHO can facilitate cognitive performance, yet the effect of CES consumption on the cognitive function of soccer players has not been studied to date. In the present study, we found that, compared with PLA, CES improved response time in several tests including VST (complex level), ST (complex level), and RVIPT. For the accuracy, it seems that CES improved RVIPT performance than PLA. However, it should be noted that CES consumption seems to decrease accuracy in VST. Therefore, the findings of the present study suggest that, during high intensity intermittent exercise, the effects of CES on cognitive performance may be domain dependent. For example, as VST is usually used to assess perception, and RVIPT is generally used to assess sustained attention and vigilance,²² the results indicate that CES may have different effects on different aspects of cognitive function. According to previous studies, elite soccer players elicited better perceptual and cognitive skills,⁴ inhibitory control, cognitive flexibility, and metacognition⁶ than non-elite players. Therefore, the results indicated that short-term CES consumption may not benefit all these domains of cognitive function for soccer players. Furthermore, although traditionally CES has been suggested to affect decision-making and technical proficiency (e.g., soccer skills or techniques), one recent review also suggested a non-significant relationship between

Table 1
Physiological data in three trials (Mean \pm SD, n = 16).

| Indicators | Trial | Resting | 15-18' | 33-36' | 51-54' | 69-72' | 87-90' | 105-108' |
|-----------------------------|-------|-----------------|------------------------------|--------------------------------|--------------------------------|----------------------------------|------------------------------------|--------------------------------------|
| Blood Glucose Concentration | CES | 6.09 \pm 1.13 | 4.93 \pm 1.00 ^a | 5.84 \pm 0.63 ^b | 5.76 \pm 0.57 ^b | 5.76 \pm 0.40 ^b | 5.39 \pm 0.81 | 4.95 \pm 1.19 ^{a,c,d,e,f} |
| | PLA | 6.36 \pm 1.22 | 4.77 \pm 0.94 ^a | 5.31 \pm 0.71 ^{a,b} | 5.06 \pm 1.38 ^a | 5.47 \pm 0.81 ^{a,b} | 5.24 \pm 0.97 ^{a,b} | 5.29 \pm 1.41 ^b |
| | CEPS | 6.23 \pm 1.28 | 5.31 \pm 1.56 | 5.85 \pm 0.64 [#] | 5.94 \pm 0.90 [#] | 5.58 \pm 0.50 ^{a,c} | 5.78 \pm 0.50 [#] | 5.78 \pm 0.44 [*] |
| Blood Lactate Concentration | CES | 1.5 \pm 0.8 | 1.4 \pm 0.5 | 1.4 \pm 0.7 | 2.1 \pm 1.5 ^c | 1.6 \pm 1.1 | 2.3 \pm 1.6 ^{b,c,e} | 2.5 \pm 1.6 ^{b,c} |
| | PLA | 1.5 \pm 1.0 | 1.6 \pm 0.8 | 2.1 \pm 1.2 [*] | 1.4 \pm 1.1 ^{*,c} | 1.7 \pm 0.8 | 1.5 \pm 0.8 | 1.7 \pm 1.6 |
| | CEPS | 1.4 \pm 0.8 | 1.5 \pm 0.8 | 1.4 \pm 0.6 | 1.6 \pm 0.7 | 2.3 \pm 1.2 ^{a,c,d} | 1.6 \pm 0.6 ^e | 2.0 \pm 0.9 ^a |
| AD | CES | 0.1 \pm 0.3 | 0.3 \pm 0.6 ^a | 0.5 \pm 0.8 ^a | 0.9 \pm 1.3 ^a | 0.7 \pm 1.0 ^a | 0.8 \pm 1.1 ^a | 0.9 \pm 1.1 ^{a,b} |
| | PLA | 0.1 \pm 0.3 | 0.3 \pm 0.6 ^a | 0.4 \pm 0.7 | 0.6 \pm 1.0 ^a | 0.7 \pm 1.2 | 0.9 \pm 1.3 ^{a,c} | 1.2 \pm 1.7 ^{a,b,c,d,e} |
| | CEPS | 0.2 \pm 0.4 | 0.6 \pm 0.8 ^a | 0.6 \pm 0.9 ^a | 0.9 \pm 1.1 ^a | 1.0 \pm 1.1 ^{a,b,c} | 1.1 \pm 1.0 ^{a,b,c} | 1.2 \pm 1.2 ^{a,b,c} |
| PT | CES | 0.4 \pm 0.5 | 1.3 \pm 0.9 ^a | 1.9 \pm 1.2 ^{a,b} | 2.4 \pm 1.5 ^{a,b} | 2.4 \pm 1.7 ^{a,b} | 2.9 \pm 1.9 ^{a,b,c,d,e} | 2.8 \pm 1.8 ^{a,b,c} |
| | PLA | 0.4 \pm 0.8 | 1.5 \pm 1.5 ^a | 1.8 \pm 1.6 ^a | 2.3 \pm 1.7 ^{a,b,c} | 2.7 \pm 1.8 ^{a,b,c,d} | 2.9 \pm 2.0 ^{a,b,c,d} | 3.0 \pm 2.0 ^{a,b,c,d} |
| | CEPS | 0.3 \pm 0.6 | 1.3 \pm 1.0 ^a | 2.0 \pm 1.4 ^{a,b} | 2.3 \pm 1.5 ^{a,b} | 2.3 \pm 1.6 ^{a,b} | 2.4 \pm 1.8 ^{a,b} | 2.5 \pm 1.8 ^{a,b} |
| RPE | CES | 0.0 \pm 0.0 | 2.0 \pm 0.8 ^a | 2.4 \pm 1.2 ^{a,b} | 3.3 \pm 1.5 ^{a,b,c} | 3.8 \pm 1.4 ^{a,b,c,d} | 4.3 \pm 1.7 ^{a,b,c,d,e} | 4.8 \pm 1.8 ^{a,b,c,d,e,f} |
| | PLA | 0.0 \pm 0.0 | 1.5 \pm 0.7 ^{*,a} | 2.1 \pm 0.8 ^{a,b} | 2.9 \pm 1.1 ^{a,b,c} | 3.3 \pm 1.4 ^{a,b,c,d} | 4.0 \pm 1.7 ^{a,b,c,d,e} | 4.3 \pm 1.8 ^{a,b,c,d,e} |
| | CEPS | 0.0 \pm 0.0 | 1.8 \pm 1.2 ^a | 2.3 \pm 1.4 ^{a,b} | 2.9 \pm 1.5 ^{a,b,c} | 3.2 \pm 1.5 ^{a,b,c} | 3.8 \pm 1.4 ^{a,b,c,d,e} | 4.0 \pm 1.5 ^{a,b,c,d,e,f} |
| HR | CES | 82 \pm 7 | 127 \pm 19 ^a | 125 \pm 17 ^a | 123 \pm 15 ^a | 120 \pm 14 ^{a,b} | 120 \pm 14 ^a | 119 \pm 16 ^{a,b} |
| | PLA | 80 \pm 7 | 122 \pm 21 ^a | 120 \pm 14 ^a | 119 \pm 15 ^a | 119 \pm 12 ^a | 120 \pm 12 ^a | 125 \pm 28 ^a |
| | CEPS | 82 \pm 9 | 118 \pm 13 ^{*,a} | 119 \pm 13 ^{*,a} | 120 \pm 13 ^a | 123 \pm 27 ^a | 116 \pm 13 ^{a,d} | 117 \pm 13 ^{a,d} |

CES: Carbohydrate-electrolyte solution; CEPS: Carbohydrate-electrolyte and protein solution; PLA: placebo; AD: Abdominal Discomfort; PT: Perceived Thirst; RPE: Rating of Perceived Exertion; HR: Heart Rate.

*, P < 0.05 vs. CES; #, P < 0.05 vs. PLA.

a, P < 0.05 vs. Resting; b, P < 0.05 vs. Session 1; c, P < 0.05 vs. Session 2; d, P < 0.05 vs. Session 3; e, P < 0.05 vs. Session 4; f, P < 0.05 vs. Session 5.

cognitive function and acute CHO intake.²⁴ The present study adds to the existing evidence base by demonstrating that CES consumption, when compared to a PLA, enhances perception, executive function and sustained attention; three important domains of cognition that may contribute to successful soccer performance.

Previous evidence has shown that CHO consumption enhances a number of cognitive domains, such as executive function, as measured by the Trail Making Test²⁵ and short-term memory.²⁶ Previous studies have also found that CES consumption may delay the onset of fatigue,²⁷ enhance working memory,¹⁴ reduce RPE and improve choice reaction time¹³ during and/or after endurance exercise. The potential mechanism may be that the increased plasma glucose concentrations after CHO administration leads to alterations in glucose uptake and utilization by the brain, and ultimately causes an increase in glucose-mediated synthesis of acetylcholine in the hippocampus region.²⁸ Another potential explanation is the improved insulin responses after CHO ingestion, which may be responsible for the improved effects of glucose on memory.²⁹

In addition to the beneficial effects of CHO on cognition, protein may also facilitate cognitive performance. In the present study, we found that, compared with PLA, the CEPS consumption improved accuracy in RVIPT, although the response time slowed. On the other hand, although the response time decreased in CEPS trial than PLA trial in VST (complex level), the accuracy also decreased. The results indicated that CEPS consumption may benefit sustained attention and vigilance, potentially contributing to successful soccer performance, but did not affect perception. However, the decreased response time in VST indicated that the changes in the function of perception domain were complicated after CEPS consumption. Given that the present study is the first to examine the effect of CES and CEPS on cognition in soccer players, is difficult to draw definitive conclusions and further research is warranted. However, the suggestion that CEPS may be beneficial for cognition is in line with previous findings demonstrating that protein can reduce the rate of forgetting on a paragraph recall task in healthy older adults,²⁵ as

well as result in better attention and efficiency of tasks concomitant with a higher metabolic activation in young adults.²⁶ The potential mechanism may be that branched chain amino acids (BCAA) decomposed from protein can lower the ratio of plasma f-Tryptophan (TRP)-to-BCAA, which decreases the amount of f-TRP being transported across the blood-brain barrier. This inhibits the synthesis of 5-hydroxytryptophan (5-HT), while 5-HT play an important role in central fatigue.³⁰ Several studies conducted by our research group have indicated the CEPS consumption during endurance exercise may provide certain more benefits than traditional CES on cognitive function,¹⁷ and the sense of effort, as well as affective responses.¹⁸ However, to the best of our knowledge, the present study is the first to assess the effects of CEPS and CES on cognitive function in soccer players. As soccer players have to anticipate and react continuously in the field, it is reasonable to speculate that the findings of the present study may provide valuable information regarding the domains of cognition affected by CES and CEPS consumption during soccer; and given the importance of cognition for soccer performance,³ this has implications for successful performance.

Although CES and CEPS showed similar effects in the present study, we also found some differences between CES and CEPS trials. For example, CEPS consumption improved the accuracy of VST (simple level), compare with CES consumption. In the present study, blood glucose were well maintained in CEPS trial but not in CES and PLA trials (Table 1). This may be part of reason that CEPS consumption may have more beneficial effect on cognitive function. In one previous study using similar three treatments,¹⁷ blood glucose concentration was found to be higher in CES trial than PLA trial during a 21-km run. The inconsistent result may come from different exercise protocol and participants in these two studies. However, only small differences were observed in blood glucose concentrations among the three trials in the present study; therefore the physiological significance of such small changes in blood glucose concentration should be discussed cautiously. It should be noted that types of protein may be one important factor in affecting

the potential benefits of CEPS. One previous study found that increasing the availability of tyrosine may improve cognitive function during soccer-specific exercise in a warm environment.³¹ Several previous studies also suggested that co-ingestion of CHO and alpha-lactalbumin may attenuate feeling of muscle pain and fatigue, as well as cortisol responses during or after endurance exercise, compared with co-ingestion of CHO and whey protein.^{18,32,33} Therefore, further research is warranted to investigate the optimal consumption of a sports drink for cognitive function for soccer players; which may ultimately enhance overall soccer performance.

Whilst the present study provides important novel findings regarding the effects of CES and CEPS on cognitive performance in soccer players, there are a number of limitations that should be noted. Firstly, urine or blood samples were not collected to test hydration status prior to each main trial. However, participants were required to consume water 2 h before they arrived at the lab to ensure they did not arrive in a dehydrated state. Secondly, we did not record the sprint performance during the LIST protocol. The addition of this measure to future studies may provide additional valuable information regarding the potential effects of different solutions on physical performance, as well as cognitive performance, to provide a more holistic overview of the effects on soccer performance.

Conclusion

In conclusion, both CES and CEPS consumption during soccer specific exercise protocol showed certain benefits on some aspects of cognitive function (particularly sustained attention and vigilance) in male college soccer players in Hong Kong. However, these effects may be specific to the cognitive domain tested, with some domains more preferentially affected by CEPS than CES.

CRedit authorship contribution statement

Feng-Hua Sun: Conceptualization, Methodology, Supervision, Data curation, Writing - review & editing. **Simon B. Cooper:** Data curation, Writing - review & editing. **Frank Chak-Fung Tse:** Investigation, Project administration, Writing - original draft.

Declaration of competing interest

This manuscript is original and not previously published, nor is it being considered elsewhere.

There are no conflict of interest those should be disclosed here.

Acknowledgements

The authors would like to thank all the participants for their hard work in this research. This study was partly supported by Internal Research Grant (RG 33/2017-2018R), The Education University of Hong Kong. No conflict of interests should be disclosed here.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jesf.2020.06.003>.

References

1. Nédélec M, McCall A, Carling C, et al. Recovery in soccer. *Sports Med.* 2012;42:997–1015.

2. Stølen T, Chamari K, Castagna C, et al. Physiology of soccer. *Sports Med.* 2005;35:501–536.
3. Vestberg T, Gustafson R, Maurex L, et al. Executive functions predict the success of top-soccer players. *PLoS One.* 2012;7, e34731.
4. Ward P, Williams AM. Perceptual and cognitive skill development in soccer: the multidimensional nature of expert performance. *J Sport Exerc Psychol.* 2003;25:93–111.
5. Attuquayefio T, Stevenson RJ. A systematic review of longer-term dietary interventions on human cognitive function: emerging patterns and future directions. *Appetite.* 2015;95:554–570.
6. Huijgen BC, Leemhuis S, Kok NM, et al. Cognitive functions in elite and sub-elite youth soccer players aged 13 to 17 years. *PLoS One.* 2015;10, e144580.
7. Bangsbo J, Mohr M, Krstrup P. Physical and metabolic demands of training and match-play in the elite football player. *J Sports Sci.* 2006;24:665–674.
8. Maughan RJ, Watson P, Evans GH, et al. Water balance and salt losses in competitive football. *Int J Sport Nutr Exerc Metabol.* 2007;17:583–594.
9. Aragón-Vargas LF, Moncada-Jiménez J, Hernández-Elizondo J, et al. Evaluation of pre-game hydration status, heat stress, and fluid balance during professional soccer competition in the heat. *Eur J Sport Sci.* 2009;9:269–276.
10. Meeusen R. Exercise, nutrition and the brain. *Sports Med.* 2014;44:47–56.
11. Nicholas CW, Williams C, Lakomy HK, et al. Influence of ingesting a carbohydrate-electrolyte solution on endurance capacity during intermittent, high-intensity shuttle running. *J Sports Sci.* 1995;13:283–290.
12. Welsh RS, Davis JM, Burke JR, et al. Carbohydrates and physical/mental performance during intermittent exercise to fatigue. *Med Sci Sports Exerc.* 2002;34:723–731.
13. Collardeau M, Brisswalter J, Vercauysen F, et al. Single and choice reaction time during prolonged exercise in trained subjects: influence of carbohydrate availability. *Eur J Appl Physiol.* 2001;86:150–156.
14. Wong SH, Sun F, Huang WY, et al. Effects of beverages with variable nutrients on rehydration and cognitive function. *Int J Sports Med.* 2014;35:1208–1215.
15. Saunders MJ, Luden ND, Herrick JE. Consumption of an oral carbohydrate-protein gel improves cycling endurance and prevents postexercise muscle damage. *J Strength Condit Res.* 2007;21:678–684.
16. Saunders MJ, Moore RW, Kies AK, et al. Carbohydrate and protein hydrolysate coingestion 's improvement of late-exercise time-trial performance. *Int J Sport Nutr Exerc.* 2009;19:136–149.
17. Gui Z, Sun F, Si G, et al. Effect of protein and carbohydrate solutions on running performance and cognitive function in female recreational runners. *PLoS One.* 2017;12, e185982.
18. Qin L, Wong SH, Sun FH, et al. The effect of carbohydrate and protein co-ingestion on energy substrate metabolism, sense of effort, and affective responses during prolonged strenuous endurance exercise. *Physiol Behav.* 2017;174:170–177.
19. Ali A, Williams C, Nicholas CW, et al. The influence of carbohydrate-electrolyte ingestion on soccer skill performance. *Med Sci Sports Exerc.* 2007;39:1969–1976.
20. Sun F, Wong SH, Huang Y, et al. Substrate utilization during brisk walking is affected by glycemic index and fructose content of a pre-exercise meal. *Eur J Appl Physiol.* 2012;112:2565–2574.
21. Nicholas CW, Nuttall FE, Williams C. The Loughborough Intermittent Shuttle Test: a field test that simulates the activity pattern of soccer. *J Sports Sci.* 2000;18:97–104.
22. Hogervorst E, Bandelow S, Schmitt J, et al. Caffeine improves physical and cognitive performance during exhaustive exercise. *Med Sci Sports Exerc.* 2008;40:1841–1851.
23. Borg G. Perceived exertion. *Med Sci Sports.* 1973;5:90–93.
24. Hawkins N, Keirns N, Helms Z. Carbohydrate and cognitive function. *Curr Opin Clin Nutr Metab Care.* 2018;21:302–307.
25. Kaplan RJ, Greenwood CE, Winocur G, et al. Dietary protein, carbohydrate, and fat enhance memory performance in the healthy elderly. *Am J Clin Nutr.* 2001;74:687–693.
26. Fischer K, Colombani PC, Langhans W, et al. Cognitive performance and its relationship with postprandial metabolic changes after ingestion of different macronutrients in the morning. *Br J Nutr.* 2001;85:393–405.
27. Coyle EF. Fluid and fuel intake during exercise. *J Sports Sci.* 2004;22:39–55.
28. Gold PE, Stone WS. Neuroendocrine effects on memory in aged rodents and humans. *Neurobiol Aging.* 1988;9:709–717.
29. Craft S, Asthana S, Newcomer JW, et al. Enhancement of memory in Alzheimer disease with insulin and somatostatin, but not glucose. *Arch Gen Psychiatr.* 1999;56:1135–1140.
30. Davis JM, Alderson NL, Welsh RS. Serotonin and central nervous system fatigue: nutritional considerations. *Am J Clin Nutr.* 2000;72:573S–578S.
31. Coull NA, Watkins SL, Aldous JWF, et al. Effect of tyrosine ingestion on cognitive and physical performance utilising an intermittent soccer performance test (iSPT) in a warm environment. *Eur J Appl Physiol.* 2015;115:373–386.
32. Qin L, Wong SH, Sun FH, et al. Effects of alpha-lactalbumin or whey protein isolate on muscle damage, muscle pain, and mood states following prolonged strenuous endurance exercise. *Front Physiol.* 2017;8:754.
33. Qin L, Sun FH, Huang Y, et al. Effect of pre-exercise ingestion of α -lactalbumin on subsequent endurance exercise performance and mood states. *Br J Nutr.* 2019;121:22–29.