Liu et al. BMC Sports Science, Medicine and Rehabilitation (2025) 17:98
https://doi.org/10.1186/s13102-025-01144-z

BMC Sports Science, Medicine and Rehabilitation

RESEARCH

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Effects of caffeinated chewing gum-induced sympathetic activation and diuretic effect on the rapid rate of weight loss in bodybuilders: a double-blind crossover study

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Abstract

Background The purpose of this study was to investigate effects of caffeinated chewing gum-induced sympathetic activation and diuretic effect on the rapid rate of weight loss in bodybuilders.

Methods Fourteen current elite natural bodybuilding athletes (age: 26 ± 7 years old; BMI: 26.9 ± 7.1 kg/m^2; muscle mass: 40.4 ± 7.1 kg; %body fat: 15.5 ± 4.4%) were included as participants. After confirming the specific gravity of the urine, the participants chewing either caffeinate Gum containing 3 mg/kg of caffeine (CAF trial) or placebo gum without containing caffeine (PL trial) for 10 min, with a randomized, double-blind, cross-over design. Following a 15-minute period of rest, the participants undergo a weight reduction process by engaging in cycling on a bicycle with an adjustable resistance level. The cycling is performed until the participant has experienced a dehydration state, resulting in a weight reduction of 2% of their initial body weight. Record time, heart rate, heart rate variability (HRV) urination volume and energy expenditure from exercise to completion of dehydration.

Results The urination volume ($P = 0.040$) and sympathetic activation were significantly higher in the CAF trial than in the PL trial during dehydration exercise ($P < 0.05$). Time to dehydration ($P = 0.024$) and the rating of perceived exertion (RPE) score during exercise were significantly lower in the CAF trial than in the PL trial. There were no significant differences in heart rate and energy expenditure during dehydration exercise between the two trials ($P < 0.05$).

Conclusions This study found that chewing caffeinated gum increased sympathetic nerve activity and accelerated dehydration in bodybuilders.

Trial registration This study was registered in ClinicalTrials.gov (Date: 04/08/2024; ID "NCT06431035"; https://register.clinicaltrials.gov).

Keywords Sympathetic nerve activity, Endurance exercise, Diuretic

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Introduction

Natural bodybuilding is rapidly on the rise in popularity. Bodybuilders are judged on their aesthetic appearance, which includes elements such as muscle mass, symmetry, definition, low body fat and stage presentation [1]. Using dehydration to reduce water is a common technique used by bodybuilders to help create more defined muscles. Dehydration is achieved by manipulating water and sodium intake, along with aerobic exercise or diuretics [2]. Despite the fact that some studies have concluded that dehydration does not lead to better muscle definition [2, 3]. However, it is clear from the studies that the majority of athletes still use dehydration to make their muscles more defined before a competition [1]. For bodybuilders, pre-competition dehydration has been widely used by competitors in many international competitions to enhance their defined muscles [3]. One of the most common and rapid methods of weight loss among bodybuilders is the reduction of body water through dehydration, including aerobic exercise or increase urination [4]. In order to achieve these effects, it appears that the stimulation of sympathetic nerves is an effective method for increasing the diuretic effect or the capacity for aerobic exercise, especially when combined with caffeine, which has a diuretic effect [5].

Despite it has been suggested that caffeine supplementation during exercise does not induce a diuretic effect, which can lead to dehydration [6]. However, previous meta-analyses have indicated that the intensity of exercise may be the primary factor contributing to the observed dehydrating effect of caffeine [7], especially the relationship between caffeine and dehydration, which predominantly employs higher-intensity exercise as a model [8]. Therefore, whether caffeine still has diuretic properties or even increases the rate of dehydration at relatively low exercise intensities remains to be investigated.

Another potential mechanism by which caffeine's diuretic effect is induced during exercise may involve sympathetic nerve activity. The administration of caffeine prior to physical exertion has been observed to result in antagonism of adenosine receptors. This phenomenon has been demonstrated to enhance the release of calcium ions and to maintain the activity level of sodium-potassium ATPase, otherwise referred to as Na+/K+-ATPase [9, 10]. In addition, caffeine supplementation has been shown to activity the sympathetic nervous system, which may enhance the efficacy of dehydration [5]. Caffeine supplementation using caffeinated gum (CAF) before exercise has been found to be absorbed through the oral mucosa at a faster rate than caffeine capsules [11]. The previous studies revealed that the consumption of CAF has been demonstrated to significantly increases sympathetic nerve activity [12]. It is possible that the increased sympathetic nerve activity may be followed by an increased diuretic effect and improved aerobic capacity [13]. From this perspective, caffeine supplementation appears to be an effective method for accelerating the dehydration process by increase the exercise capacity or the diuretic effect.

The act of CAF does not necessitate the intake of water, which may contribute to an even greater rate of dehydration. However, it remains unclear whether CAF has the same significant effect on dehydration ability in bodybuilding athletes. Therefore, the purpose of this study was to investigate the effects of caffeinated chewing gum-induced sympathetic activation and diuretic effect on the rapid rate of weight loss in bodybuilders. The hypothesis was that CAF could increase the rate of dehydration by improving aerobic capacity and increasing urinary output.

Methods and materials

Design

This study employed a randomization crossover with a double-blind experimental design. Participants were randomly assigned to either a caffeinated chewing gum trial (CAF) or a placebo trial (PL). Following the initial trial, participants were permitted a washout period of rest and recovery, lasting between 7 and 15 days. All tests were conducted in the morning (around 09:00) and completed within one month. The participants completed a pre-test and two randomized formal tests, for a total of three visits to the laboratory. Throughout the trial period, all participants maintained their normal training status, with no alterations to their training or retraining menus and no over-training or participation in additional competitions. Participants were randomized using Microsoft Office 365 (Microsoft Excel, Microsoft Corp, Bellevue, WA) to randomize the order of experiments. This study was started from 08/04/2024 to 30/06/2024. This is the out-of-season training period for bodybuilders (Fig. 1).

Participants

Seventeen drug-free natural bodybuilders national level bodybuilders were recruited for this study. After deducting one car accident and two injuries, a total of 14 participants (age: 26.2 ± 7.1 years old; BMI: 26.9 ± 7.1 kg/m^2; muscle mass: 40.4 ± 7.1 kg; %body fat: 15.5 ± 4.4%; resting energy expenditure: 3037.3 ± 664.6 kcal) completed the experiment. All participants had more than 6 years of professional bodybuilding training and had participated in national bodybuilding competitions with adequate pre-competition dehydration experience. Inclusion criteria were: (1) having won the top 8 places in a national competition, (2) having no cardiovascular or joint diseases, and (3) being an adult male. Exclusion criteria were: (1) no top 8 finishes at national level; (2) cardiovascular or joint disease, or any other condition

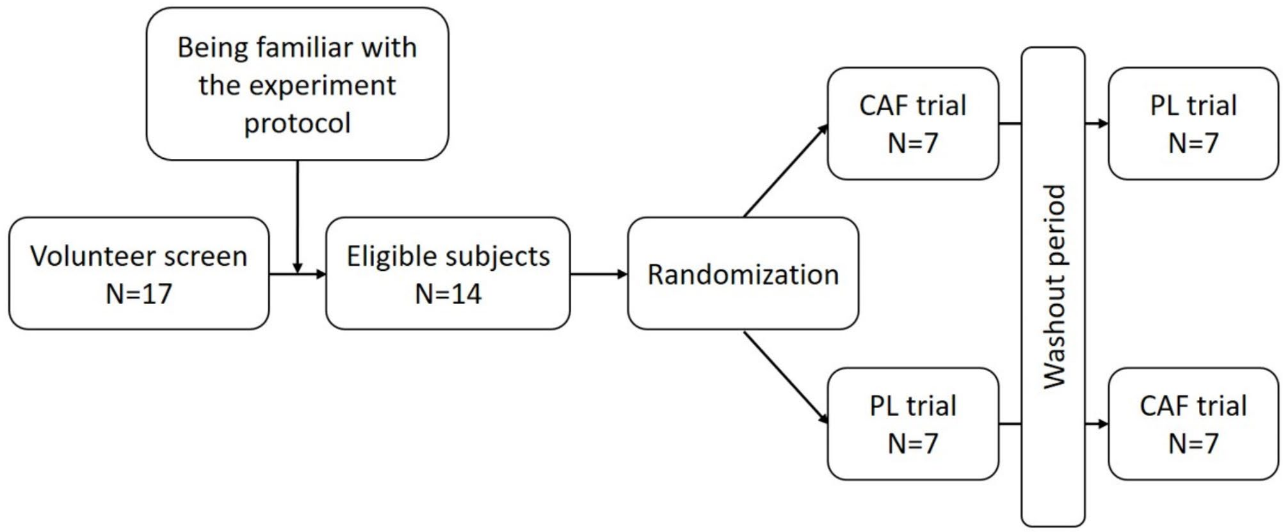

Fig. 1 CONSORT diagram and study design

that could be impaired by exercise; (3) underage participants; (4) previous caffeine allergy. In order to avoid the potentially confounding effects of the female menstrual cycle on weight loss outcomes, female participants were excluded from this study. This study received approval from the Institutional Review Board of Jen-Ai Hospital - Dali Branch (202300071B0) and registered in ClinicalTrials.gov (Date: 04/08/2024; ID "NCT06431035"; https://register.clinicaltrials.gov). This study adheres to CONSORT guidelines. This study was conducted following the Declaration of Helsinki.

Protocol

Pre test

Prior to the commencement of the primary experiment, all participants were required to complete a 12-minute sub-maximal exercise intensity test. The methodology of this pre test has previously been used in the literature [14]. Following the wearing of a heart rate monitor (V800; Polar Electro Oy, Kempele, Finland), participants were asked to rest for a period of 10 min in a standing position, during which time heart rate values were obtained. Subsequently, the participants were positioned on a gas analyser (Vmax Series 29 C, Sensor Medics, CA, USA) and started sub-maximal exercise intensity test on a bicycle with a resistance of 75w at 70–80 rpm. The resistance was increased by 25w every 3 min, 100w, 125w and 150w respectively. Heart rate and energy expenditure during exercise were recorded for subsequent studies. This was undertaken in order to gain a better understanding of the relationship between exercise intensity and a variety of physiological variables, including heart rate and energy expenditure.

Experimental procedure

Three days before the first trial, participants recorded all of their diets and followed the same diet for three days before the second formal trial. Participants were asked to consume at least 30 ml of water per kilogram of body mass in the 24 h prior to the test to achieve adequate hydration. All participants woke up and urinated and arrived at the laboratory after breakfast. The average energy consumption for breakfast include 22.5 ± 9.4 g of protein, 6.8 ± 4.4 g of fat, 40.0 ± 14.1 g of carbohydrates, and 331.5 ± 114.5 total calories. All experiments were scheduled to begin at 9:00 am. To avoid disturbances caused by circadian rhythm effect, all participants arrived at the lab at the same time. Upon arrival at the laboratory, participants will have their urine analysed using a hydrometer (AAnalyst 800, Perkin Elmer, Waltham, MA) to assess their hydration status (specific gravity < 1.020). The urine discarded during the morning is not subject to testing, and the urine that arrives at the laboratory is typically the second or third urination of the day. Participants with a specific gravity value exceeding 1.020 were provided with 500 ml of bottled water to consume for 15 min prior to the beginning of the test, until such time as adequate hydration was achieved. This experimental procedure for inducing dehydration has been employed in previous study [15]. Throughout the experiment, only three participants had an index greater than 1.02 and were therefore hydrated.

When the participants had reached a comparable level of hydration, they were asked to wear a heart rate monitor (V800; Polar Electro Oy, Kempele, Finland) and to chew either caffeine gum (3 mg/kg for 10 min per chew) or a placebo gum (10 min per chew, using placebo gum). A 15-minute rest period was permitted following the chewing phase, during which a brief warm-up and stretching routine was completed. The exercise environment was maintained at 30 °C and 50% humidity using air conditioning. After the warm-up period, participants were permitted to adjust the resistance and speed of the bicycle according to their subjective sensations by engaging in cycling, and they were at liberty to arrange the duration of their rest periods. Following a 30-minute cycling session, the participants' body weight was recorded at 10-minute intervals until they reached a dehydration level of 2% of their original body mass [15]. The time taken for the participants to become dehydrated was recorded, and the energy expenditure was calculated from the regression curve. During the exercise, the participant was also free to go to the toilet and the total amount of urine was recorded.

Outcome measure

A similar procedure of 2% time to complete dehydration has been previously documented in the past study [15]. In order to better match the dehydration of the bodybuilders before the competition, the participants were allowed to freely choose the resistance and speed of the bicycle, and the heart rate was used to record the intensity of the exercise and to calculate the energy expenditure during the exercise. The rating of perceived exertion (RPE) score was recorded using a 1–10 scale [16].

The heart rate variability test used in this study has previously been employed in the literature [17]. A portable heart rate monitor was utilized to record beat-to-beat heart rate at a frequency of 1 millisecond. The percentage of differences between adjacent normal RR intervals of more than 50 ms (pNN50), low-frequency normalized units (LF) and high-frequency normalized units (HF) were calculated.

Caffeine and placebo gum

The caffeinated chewing gum (Military Energy Gum, Arctic Mint flavour; Stay Alert, Chicago, USA) and placebo used in this study were of the same composition as those used in a previous study [18, 19]. All gums were prepared by crushing, grinding, blending, and reshaping them, and flavoring with 0.3 g of peppermint flavoring powder. This process was undertaken to ensure that the appearance, color, taste, weight, and size of the prepared gums were similar to those of the original gum. This method has been employed on numerous occasions in previous studies by our research team. These studies consistently indicated that the participants were unable to differentiate between the experimental trial and the placebo trial [12, 19]. The laboratory researchers were instrumental in the completion of two distinct chewing gum varieties, which they then provided to the site personnel in accordance with a designated numbering system.

Table 1 Baseline parameters

	CAF	PL	*P*
Weight (kg)	83.1 ± 8.6	83.1 ± 8.1	0.983
Urine Specific Gravity	1.006 ± 0.005	1.008 ± 0.006	0.262
RPE	1.35 ± 0.49	1.29 ± 0.47	0.752
Heart Rate (bpm)	73.0 ± 8.9	73.8 ± 9.1	0.620
PNNF50(%)	13.4 ± 12.8	12.5 ± 10.2	0.818
LF (n.u.)	65.5 ± 10.4	65.0 ± 8.1	0.878
HF (n.u.)	22.2 ± 8.9	21.2 ± 10.8	0.801
LF/HF	3.5 ± 1.7	4.5 ± 3.5	0.376

Values are mean SD, $n = 14$. CAF, caffeine trial; PL, placebo trial; pNN50, percentage of differences between adjacent normal RR intervals of more than 50 ms; LF, low-frequency normalized units; HF, high-frequency normalized units; LF/HF; the ratio of LF over HF

Sample size calculation

We employed G*Power 3.1.9.6 [20] to determine the required sample size based on data from a previous investigation [21]. Previous studies have found that caffeine supplementation increases urinary output during prolonged endurance exercise at an intensity of 60% of maximal oxygen intake and has a greater effect size (> 0.8) [21]. These data were analyzed using the paired t-test to obtain a power value of 80% for 12 participants. This calculation assumed an alpha level of 0.05 and a correlation coefficient of 0.8 using a paired t-test for the two trial conditions. Following these calculations, 14 participants were enrolled in this study.

Statistical analysis

The data in this study are presented as mean ± standard deviation. The Shapiro–Wilk test was used to examine the normality of the data. When normality distribution was reached, energy expenditure, dehydration rate, and urine specific gravity between the two trials were analyzed using the paired-sample t-test. Heart rate and RPE values during exercise were analysed using two-way ANOVA with repeated measures. Effect sizes were calculated using Cohen's d to quantify the magnitude of observed effects and defined as trivial (< 0.20), small (0.20–0.40), moderate (0.40–0.80), and large (> 0.8), respectively [22]. The power value of each data set was calculated using G*Power 3.1.9.6 software [20]. Significant levels were set at $\alpha < 0.05$.

Result

Baseline parameters

The values of each item before chewing gum are shown in Table 1. There were no significant differences in body mass, urine specific gravity, RPE, heart rate and heart rate variability between the two trials of participants ($P > 0.05$).

The indicators of heart rate variability during exercise

The indicators of heart rate variability were shown in Table 2. In LF and LF/HF, the CAF trial is significantly higher than the PL trial ($P<0.05$). There is no significant difference between PNNF50 and HF.

Table 2 The indicators of heart rate variability during exercise

	CAF	PLA	*P*	Cohen's d	Actual power
PNNF50(%)	0.83 ± 0.73	1.17 ± 1.49	0.447	0.28	NA
LF (n.u.)	64.30 ± 14.70*	56.08 ± 17.06	0.033	0.52	0.80
HF (n.u.)	25.68 ± 15.43	34.22 ± 24.88	0.053	0.41	NA
LF/HF	3.67 ± 2.43*	2.51 ± 1.93	0.034	0.52	0.81

Values are mean SD, $n=14$. CAF, caffeine trial; PL, placebo trial; pNN50, percentage of differences between adjacent normal RR intervals of more than 50 ms; LF, low-frequency normalized units; HF, high-frequency normalized units; LF/HF; the ratio of LF over HF. *CAF was significantly different than those for the PL

Dehydration time and urination volume

The time to dehydration until 2% of original body mass was significantly lower ($P=0.024$; Cohen's d = 0.54; Power = 0.81) in CAF trial than in PL trail (Fig. 2A). In the CAF trial, 12 out of 14 participants urinated during exercise. In the PL trial, 10 out of 14 participants urinated during exercise. There is no significant difference in the dehydration volume ($P=0.593$) between the two trials (Fig. 2B). Urinary volume (Fig. 2C) was significantly higher in the CAF trial than in the PL trial urination volume ($P=0.040$ Cohen's d = 0.54; Power = 0.82).

Heart rate and energy expenditure during dehydration

The average heart rate of the dehydration exercise between the two trials are shown in Fig. 3A. There was no statistically significant difference in average heart rate between the two trials ($P=0,480$). There was no significant difference in energy expenditure (Fig. 3B) between the two trials during dehydration exercise ($P=0.458$). There were no significant differences in heart rate between the two trials at 25%, 50%, 75%, and at the completion of dehydration (trial*time, $P=0.717$).

Rating of perceived exertion (RPE)

There was a significant interaction (trial*time, $P=0.007$) between the two trials for RPE scores at before, 30 min after exercise and end of exercise (Fig. 4). CAF trial were significantly lower than those of the PL trial at 30 min after exercise ($P=0.008$) and at the end of exercise ($P=0.007$).

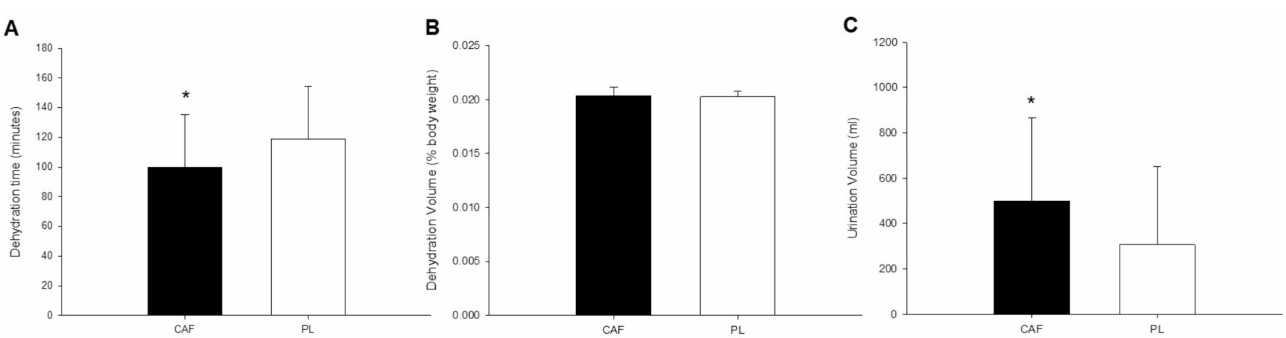

Fig. 2 Dehydration time and urination volume. The time to dehydration (**A**), dehydration volume (**B**), and urinary volume (**C**). * CAF was significantly different than those for the PL

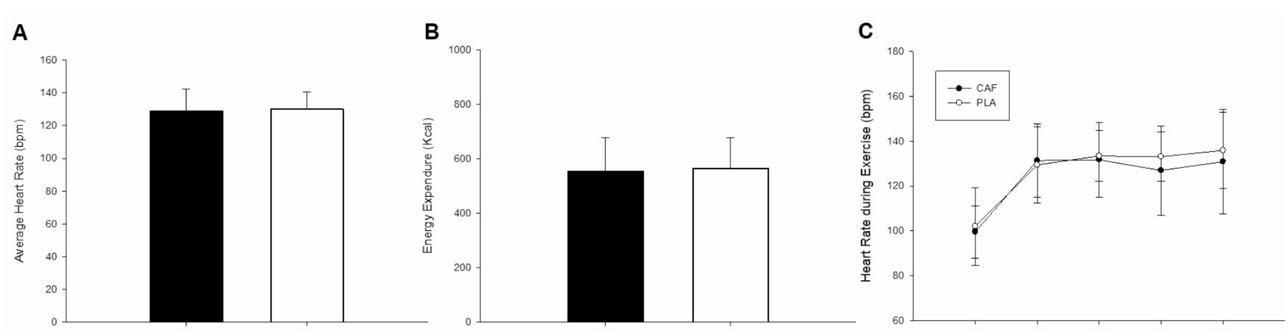

Fig. 3 Heart rate and energy expenditure during dehydration. The average heart rate (**A**), energy expenditure (**B**), and heart rate during dehydration exercise (**C**)

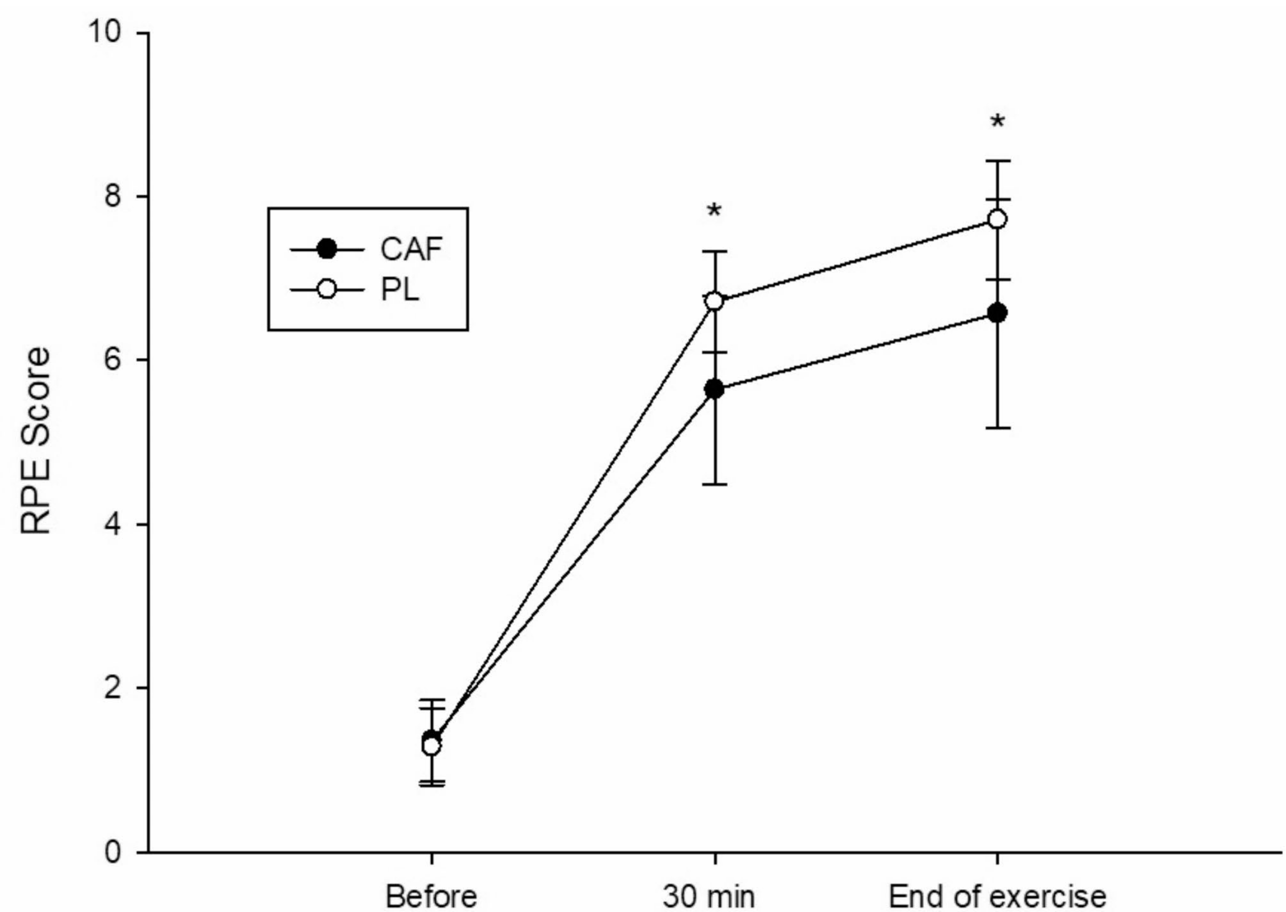

Fig. 4 The rating of perceived exertion (RPE) during dehydration. * CAF was significantly lower than those for the PL

Discussion

This study clearly showed that CAF significantly increase the activity of the sympathetic nervous system, increase the volume of urine during exercise and accelerated dehydration to 2% in bodybuilders using aerobic dehydration exercise. Despite the absence of a statistically significant difference in exercise intensity as heart rate and energy expenditure in the dehydration exercise, the ingestion of caffeinate chewing gum was found to significantly increase the volume of urine during dehydration exercise, thereby accelerating the dehydration process. The primary explanation for this phenomenon may be attributed to an elevated level of sympathetic activation.

Despite the existence of numerous studies that have reached the conclusion that caffeine supplementation prior to exercise does not result in increased dehydration [7]. However, the findings of this study contradicted the conclusions of previous research and demonstrated that exercising at relatively low intensities and supplementing with caffeine in the form of CAF is effective in increasing urination and rate of dehydration during dehydrating exercise. Different to traditional caffeine supplementation methods, this study was the first study to found that using caffeinated gum, the faster absorb caffeine method, which result in increasing sympathetic nerve activation during dehydration, enhances urination and accelerates the rate of dehydration. Indeed, previous study has demonstrated that the supplementation of caffeine by caffeinated chewing gum leads to a substantial enhancement in sympathetic nerve activity [12]. Caffeine-induced diuresis and natriuresis may be mediated by increases the sympathetic nerve activity [5]. In this study, the LF and LF/HF were significantly higher in the CAF trial than in the PL trial. The interpretation of heart rate variability is characterized by higher levels of LF and LF/HF, which represent elevated sympathetic activation [23]. It has been demonstrated in previous research that, in conditions of elevated sympathetic activation, there is a notable increase in urinary output during periods of rest [5]. There is currently no available data that specifically addresses the relationship between sympathetic activation and urinary output during exercise. On the other hand, the values of LF and LF/HF in the present study were the same as those of previous study [17] using the same equipment and the same analytical method, indicating that the equipment used in the present study was effective and successful in analysing the heart rate variability of the participants during exercise. The present study provides valuable data indicating that CAF can increase sympathetic nerve activity during exercise and accelerate the rate of dehydration by increasing urination.

An additional potential explanation for the diuretic impact of caffeine is the intensity of the exercise or the physical characteristics of the participants. In a previous meta-analysis, 28 research papers were examined, and it was determined that caffeine may have an acute diuretic effect on workers who work extended hours [7]. In addition, the diuretic effect of caffeine was found to be significantly influenced by the intensity of the exercise. As the intensity of the exercise increases, the sympathetic effect is amplified, thereby nullifying the diuretic effect of caffeine [7]. In another study, it was found that caffeine supplementation did not increase the diuretic effect when football players performed high-intensity intermittent exercise [8]. In contrast to the present study, previous studies have not recruited bodybuilders, who have higher muscle mass as participants. On the other hand, compared to these studies, the percent of maximal heart rate (%HRmax) of the dehydrating exercise used in the present study was 68.4 ± 7.3% in CAF trial and 70.0 ± 5.5% in PL trial ($P = 0.271$), which is of moderate intensity [24]. It can be suggested that caffeine effective in increase sympathetic nerve activity at moderate intensity and has diuretic effects during dehydration exercise.

For endurance exercise during dehydration, this study found that CAF did not affect heart rate or energy expenditure during exercise. In contrast to the findings of previous studies, caffeine supplementation is frequently employed for the purposes of enhancing endurance performance, calculating cycling time at a consistent intensity, or completing a specified distance as rapidly as possible within a fixed distance [25–27]. In order to more accurately reflect the pre-competition dehydration experienced by bodybuilders engaged in endurance exercise, participants were permitted to select their desired resistance, rotation speed, and rest time in a relatively warm environment. It was found that there was no significant effect on heart rate and energy expenditure during exercise. In the RPE scores, a lower RPE scores at the same exercise intensity means that the athlete feels less fatigue despite maintaining the same exercise intensity. This may also represent the fact that in the real world, bodybuilders can achieve weight loss with a relatively low level of physiological intensity. Furthermore, it is important information for athletes who need to manage dehydration without expending excessive energy, such as those involved in judo, wrestling, boxing, and MMA. Further research could concentrate on the collection of data regarding perspiration, with the objective of deepening the understanding of the principal reason why caffeine can accelerate the rate of dehydration in bodybuilders.

In this study, a variety of data were collected prior to the dehydration exercise that could affect the degree of dehydration. It was found that the indicators were the same between the two trials prior to the start of the dehydration exercise. Furthermore, prior to the experiment, the participants were required to strictly control their training volume, food intake, water intake. In terms of controlling for these exogenous variables, the present study provides a complete control of the relevant variables that affect exercise performance and heart rate variability. In addition, the power values for the rate of dehydration, urinary output, and the significantly different heart rate variability indicators were all greater than 80% in this study, thus providing sufficient reference value for the data. It is therefore reasonable to conclude that the data presented in this study should be considered a valuable academic reference.

The strength of this study was the recruitment of currently active bodybuilders and a variety of data were collected prior to the dehydration exercise that could affect the degree of dehydration. The finding that caffeine chewing gum enhanced sympathetic nerve activity during dehydration exercise and increased urination to achieve faster dehydration, as far as possible under the real dehydration conditions of the athletes. Even though we have tried to control for the relevant variables as much as possible, there are still some research limitations in this study. First, in this study, the sole method employed for investigating the activation level of sympathetic nerves was the use of a heart rate meter, with no related sympathetic activation biochemical indicators, such as α-amylase concentration. However, the heart rate meters used in this study have been shown to have adequate reliability for measuring heart rate variability [28, 29]. Secondly, the study did not analyse the concentration of caffeine in the participants' bodies. Prior research has demonstrated that the CAF can rapidly facilitate the absorption of caffeine into the body [11]. On the other hand, from unpublished data from our research team, 21 participants who were allowed to chew caffeinated gum at 3 mg per kilogram of body mass and rest for 15–20 min were found to significantly elevate the caffeine concentration in saliva for at least 2 h. It can be concluded from the aforementioned results that, despite the aforementioned research limitations, the present study still possesses sufficient value as a reference. Thirdly, the activation of the sympathetic nerves, apart from increasing the amount of urination, may also result in the opening of the calcium channel via the β-adrenergic receptor [30], which subsequently leads to an increase in sweating during exercise, especially when the participant did not drink any water during the exercise [31]. Further research may be conducted to examine the magnitude of sympathetic activation and perspiration during exercise. Also, further investigations are required to investigate whether the fast-absorbing effect of CAF results in a greater increase in sympathetic nerve activity compared to traditional caffeine capsules.

Conclusion

The results of this study indicate that for professional natural bodybuilders, CAF has a significant impact on the activity of the sympathetic nervous system. In addition, it has been observed to increase the volume of urine during exercise and accelerate dehydration to 2% in bodybuilders using aerobic dehydration exercise. The findings of this study may be utilized as a point of reference for natural bodybuilding competitors or coaches when implementing dehydration protocols prior to competition.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-025-01144-z.

Supplementary Material 1

Acknowledgements

Thanks to the National Science and Technology Council in Taiwan, National Taiwan University of Sport and Tungs' Taichung Metroharbor Hospital for providing the equipment for this study.

Author contributions

H.-S. L. (Hou-Shao Liu) and C.-C C. (Chih-Chun Chang) assisted the data collect and manuscript preparation. Takashi Okada and Hiroku Mitsuya assisted the experimental design and assist in editing and revising the manuscript. M.-H. H. (Meng-Hung Hsieh) and C.-W. H. (Chien-Wen Hou) assisted in editing and revising the manuscript. C.-H. C. (Chih-Hui Chiu) carried out the experiment, data analysis and assisted in the manuscript preparation. All authors read and approved the final version of the manuscript.

Funding

This study was not funded by any organization. The publication fees were partly funded by Tungs' Taichung Metroharbor Hospital (TTMHH-R1140007).

Data availability

All relevant materials are presented in the present manuscript.

Declarations

Ethics approval and consent to participate

The study was conducted following the Declaration of Helsinki. We confirm that we obtained informed consent from all participants, and all procedures were conducted in compliance with applicable guidelines and regulations. This study was approved by the Institutional Review Board of Jen-Ai Hospital (202300071B0) in Taiwan.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Competing interests

The authors declare that they have no competing interests.

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Received: 8 November 2024 / Accepted: 3 April 2025
Published online: 26 April 2025

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