Journal of Science and Medicine in Sport xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Review

Caffeine and diuresis during rest and exercise: A meta-analysis

Yang Zhang[a,*], Aitor Coca[b], Douglas J. Casa[c], Jose Antonio[d], James M. Green[e], Phillip A. Bishop[f]

[a] Chinese Badminton Association, Zhejiang Jiaxing Branch, People's Republic of China
[b] National Personal Protective Technology Laboratory, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, United States
[c] Korey Stringer Institute, Department of Kinesiology, University of Connecticut, United States
[d] Farquhar College of Arts and Sciences, Exercise and Sports Science, Nova Southeastern University, United States
[e] Department of Health, Physical Education and Recreation, University of North Alabama, United States
[f] Department of Kinesiology, University of Alabama, United States

ARTICLE INFO

Article history:
Received 15 February 2014
Received in revised form 7 May 2014
Accepted 31 July 2014
Available online xxx

Keywords:
Methylxanthine
Coffee
Diuretic
Fluid balance
Dehydration

ABSTRACT

Objectives: Although ergogenic, acute caffeine ingestion may increase urine volume, prompting concerns about fluid balance during exercise and sport events. This meta-analysis evaluated caffeine induced diuresis in adults during rest and exercise.
Design: Meta-analysis.
Methods: A search of three databases was completed on November 1, 2013. Only studies that involved healthy adults and provided sufficient information concerning the effect size (ES) of caffeine ingestion on urine volume were included. Sixteen studies met the inclusion criteria, providing a total of 28 ESs for the meta-analysis. Heterogeneity was assessed using a random-effects model.
Results: The median caffeine dosage was 300 mg. The overall ES of 0.29 (95% confidence interval (CI) = 0.11–0.48, $p = 0.001$) corresponds to an increase in urine volume of 109 ± 195 mL or 16.0 ± 19.2% for caffeine ingestion vs. non-caffeine conditions. Subgroup meta-analysis confirmed exercise as a strong moderator: active ES = 0.10, 95% CI = −0.07 to 0.27, $p = 0.248$ vs. resting ES = 0.54, 95% CI = 0.22–0.85, $p = 0.001$ (Cochran's *Q*, $p = 0.019$). Females (ES = 0.75, 95% CI = 0.38–1.13, $p < 0.001$) were more susceptible to diuretic effects than males (ES = 0.13, 95% CI = −0.05 to 0.31, $p = 0.158$) (Cochran's *Q*, $p = 0.003$).
Conclusions: Caffeine exerted a minor diuretic effect which was negated by exercise. Concerns regarding unwanted fluid loss associated with caffeine consumption are unwarranted particularly when ingestion precedes exercise.

1. Introduction

Despite its popularity and ergogenic properties during sports performance,[1,2] caffeine is generally recognized as having a mild diuretic effect.[3,4] The U.S. Food and Drug Administration purports caffeine has diuretic properties and advises its users to drink extra water to avoid dehydration during exercise in the heat.[4] Considering caffeine is often used to enhance endurance performance[5] and endurance events sometimes occur in high ambient conditions, these situations prompt concerns about excessive fluid loss and impaired endurance performance. During post-exercise rehydration, ingestion of caffeinated beverage has also been shown to increase urine volume and thus the fluid requirement.[6] In certain occupations where maintaining fluid balance is essential, extra cautions have been suggested regarding drinking coffee. Industrial workers performing prolonged labor in hot climates are advised to avoid caffeinated beverages in the workplace.[7] Military personnel often engage in sustained operations with limited fluid supply; therefore, current military doctrine recommends closely monitoring caffeine ingestion.[8]

The underlining mechanism of caffeine induced diuresis is not yet clear. It has been postulated, methylxanthines such as caffeine can inhibit phosphodiesterases in the proximal tubule of the kidneys, which may contribute to the diuretic effect.[9] Antagonism of adenosine receptors may also mediate caffeine induced diuresis and natriuresis.[10] Because caffeine does not increase the kidneys' glomerular filtration rate,[11] the diuretic effect is more likely to be related to its natriuretic effect following adenosine receptor blockade. Evidence shows that caffeine acts on the kidneys by inhibiting sodium reabsorption in the proximal and distal tubules,[11] thus

* Corresponding author.
E-mail address: dr.zhang.yang@qq.com (Y. Zhang).

http://dx.doi.org/10.1016/j.jsams.2014.07.017
1440-2440/

increases the solute excretion and consequently free water excretion.

Concerns about fluid deficit associated with caffeine ingestion is highly relevant to sports, health and fitness, industry, and military, where exercise is often accompanied with caffeine ingestion. Caffeine is commonly used as an ergogenic aid in ultra-endurance and multi-day sports events.[5] Likewise, coffee and energy drinks are popular beverages for health and fitness, the military, as well as for workplace productivity.[8] Whether performing prolonged labor or exercising in hot climates with limited access to fluid replacement, hydration is a challenging issue. Consuming caffeine potentially increases the risks of fluid deficits for athletes, fitness enthusiasts, industrial workers, and military personnel if a diuretic effect exists.

Several studies have challenged the assertion that caffeine could contribute to a severe fluid deficit.[12,13] The question still remains concerning the magnitude, significance, and moderators of the diuretic effect. Therefore, the objective of this meta-analysis was to quantify caffeine induced diuresis in adults during rest and exercise. The results can be used to guide caffeine use in sports and exercise in hot conditions during which fluid balance is always a concern for optimal health and performance.

2. Methods

A literature search was performed using the PubMed, Web of Science, and ProQuest Dissertation and Theses. Only English literatures and full length publications were considered. No publication date restriction was imposed. Using a Boolean search, the keywords used were: "caffeine", "coffee", "tea", and "cola", in conjunction with, "fluid balance", "diuresis", "diuretic", "hydration", "rehydration", "dehydration", and "urine volume". All of the studies that were located during online searches were then manually cross-referenced for additional studies. Moreover, searches were refined by cross-referencing relevant reviews[14–16] to supply studies missed during the online searches. After these processes no longer yielded new citations, a list of potential studies was summarized.

Studies which involved healthy adults regardless of their level of participation in exercise and sports were included. This review was limited to studies identifying urine volume as the primary outcome variable following caffeine ingestion. The sources of caffeine included pills, tea, coffee, and caffeinated beverages. Studies must have included sufficient information for calculating the effect sizes (ESs). If it was not possible to accurately estimate the ES, we contacted the listed corresponding author, or the study was excluded. The final list of studies meeting the above criteria was assessed for risk of bias using the Physiotherapy Evidenced-Based Database Scale (PEDro).[17]

Data were extracted to a spreadsheet by one investigator initially and were cross-compared by another investigator independently to avoid errors. The extracted data were sample size, mean, and standard deviation (SD) of urine volume for caffeine ingestion and non-caffeine conditions. SD was converted by multiplying SE by the square root of the sample size in those reporting SE only. A number of studies employed multiple treatment conditions, therefore the extracted data were treated as "independent" investigations for the meta-analysis. Extracted data were subsequently coded based on potential moderators. Moderators were categorized: continuous moderators included caffeine dosages and investigation durations; discrete moderators included activity state at time of observation and sex. The coding procedure was performed independently by two investigators and any differences were resolved before the meta-analysis.

Caffeine induced diuresis was quantified by calculating the ES, as well as the absolute and relative change in urine volume between caffeine ingestion and non-caffeine conditions. ES was calculated as the standardized mean difference. There was one study[18] that reported a pooled SE only; the ES in this case was calculated by subtracting the mean of non-caffeine conditions from the mean of caffeine ingestion, divided by the pooled SD.[19] The SE, variance, and weighting (inverse of the variance of ES) of each investigation were calculated along with the ES. Absolute mean change was calculated by subtracting the mean of non-caffeine conditions from that of caffeine ingestion; relative mean change was calculated as absolute mean change divided by the mean of non-caffeine conditions, multiplied by 100. Obligatory urine volume was not considered, as it arguably introduced minimal differences between caffeine ingestion and non-caffeine conditions particularly in crossover designs.

Both Cochran's Q statistics and measure I^2 were calculated to assess the heterogeneity.[20] I^2 of 25%, 50%, and 75% were interpreted as low, moderate, and high levels of heterogeneity, respectively.[21] A random-effects model was chosen for the meta-analysis to compensate for methodological and biological diversities in studies.[21] Subgroup meta-analyses and meta-regressions using method-of-moments were performed to reveal moderators. Orwin's fail-safe N[22] was used to determine the effect of publication bias on the primary meta-analysis. This meta-analysis included many crossover studies, therefore a sensitivity analysis[23] was introduced to assess whether the primary result would have changed due to missing information about the inter-trial correlations in crossover studies.

Data were analyzed using the Comprehensive Meta-Analysis Software (Version 2.2; Biostat, Inc., USA). ES was interpreted as follows: <0.2 as a trivial effect, 0.2–0.49 as a small effect, 0.50–0.79 as a moderate effect, and ≥0.80 as a large effect.[24] Subgroup meta-analysis with more than 2 levels, was adjusted by the Bonferroni correction for the alpha inflation. An alpha ≤ 0.05 was considered to be significant.

3. Results

The literature search was completed on November 1, 2013 with a total of 78 initial studies being identified via titles found in the databases. Following review of the titles and abstracts, twenty five studies were retrieved as full text and assessed for eligibility. Of those, nine were excluded on the basis of failure to satisfy the pre-established inclusion criteria. Sixteen studies providing a total of 28 usable investigations were included for the quantitative synthesis. The PEDro quality scores for the studies ranged from 7 to 11.

This meta-analysis represented data from 379 participants, of which 246 were males and 133 were females. Ten studies recruited male participants exclusively, with the remaining recruiting either female participants exclusively ($n = 2$) or mixed groups ($n = 4$). Except for one study,[18] most studies recruited young participants with a median age of 27 yr (min–max: 22–36). Most studies ($n = 13$) employed crossover designs. Median caffeine dosage was 300 mg (min–max: 114–741). Half of the studies monitored treatment effect over 12 h, and the remaining half explored acute treatment effect (mode = 3 h). Participants were either in free living,[12,25–27] free living plus exercise,[28] exercise,[29,30] or rest[6,13,18,31–36] conditions for the duration of the main data collection period.

A summary of the 28 investigations from the 16 studies is presented in Fig. 1. Considerable dispersion in the ESs was observed. Of the 28 investigations, six ESs were negative, four ESs were trivial (<0.2), ten ESs were small (0.2–0.49), three ESs were moderate (0.50–0.79), and five ESs were large (≥0.80). Primary meta-analysis yielded a small but significant overall ES: ES = 0.29, 95% CI = 0.11–0.48, $p = 0.001$. This overall ES represented an increase in urine volume of 109 ± 195 mL or 16.0 ± 19.2% for caffeine ingestion vs. non-caffeine conditions.

Please cite this article in press as: Zhang Y, et al. Caffeine and diuresis during rest and exercise: A meta-analysis. *J Sci Med Sport* (2014), http://dx.doi.org/10.1016/j.jsams.2014.07.017