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Energy drink doses of caffeine and taurine have a null or negative effect on sprint performance.

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Running head: Energy drinks no effect on repeated sprints

ABSTRACT

This study investigated the effects of caffeine and taurine co-ingestion on repeat-sprint cycling performance and associated physiological and perceptual responses. In a double blind, cross-over, repeated measures study, 11 male participants (age 21 ± 2 years; stature 178 ± 7 cm; body mass 80 ± 13 kg) completed 10 x 6-s sprints on a cycle ergometer, each separated by 24-s, an hour after ingesting: caffeine (80 mg) and taurine (1 g), equivalent to the amount observed in popular commercial energy drinks, or placebo (maltodextrin ~1 g) in a gelatine capsule. Performance was measured on a cycle ergometer, whilst blood lactate concentration (B[la]), rating of perceived exertion (RPE) and heart rate (HR) were measured at baseline (pre-exercise) and after sprints 5 and 10. Magnitude-based inferences revealed *likely, trivial* differences in peak power and *unclear, trivial* inter-sprint fatigue index after ingestion of the caffeine and taurine supplement. Intra-sprint fatigue was greater in the caffeine and taurine condition at sprint 10 (*likely, small*) and *possibly smaller* in sprints 6-9. The caffeine and taurine supplement had a *likely large* effect on HR at baseline (ES = 0.94) and increases in B[la] after sprint 5 (*likely small*) and 10 (*possibly small*). There was no effect of the supplement on RPE (*unclear, trivial*). Administration of caffeine and taurine at doses equivalent to commercial energy drinks did not improve repeat-sprint cycling performance and appeared to induce greater fatigue within selected sprints, particularly at the end of the trial. This undesirable performance effect occurs in parallel with increased HR and glycolytic metabolic bi-products.

Key Words:

Ergogenic aids; stimulants; cycling; fatigue

INTRODUCTION

Popular energy drinks such as ‘Monster’, ‘Red Bull’, ‘No Fear’ and ‘Rockstar’ (44) are purported to boost energy and, therefore, enhance exercise performance (42). They are often synthesized as a combination of ingredients to provide a synergistic effect, thereby increasing ergogenic potential. Two key ingredients present in such energy drinks are caffeine and taurine but research examining their isolated effects on sports performance is lacking.

Caffeine (1,3,7-trimethylxanthine) is one of the most popular legal ergogenic aids consumed prior to competition, with approximately 3 out of 4 athletes observed use caffeine for its ergogenic potential (17). Taurine, (2-aminoethanesulfonic acid), is a non-essential amino acid that is abundantly present in the human body, particularly in the brain, heart and skeletal muscle (40). However, the ergogenic potential of taurine is less well described. Popular energy drinks contain 80 mg of caffeine and 1g of taurine in a 250 mL can (providing a dose of ~1 mg/kg caffeine and ~ 12.5 mg/kg taurine, in a 80 kg person) (42). Energy drinks are one of the most popular supplements among athletes (15,49) with a consumption prevalence of 73% in American college athletes (25) and 42% in British elite athletes (37). Many of these athletes take part in multiple sprint sports and will consume energy drinks based on their purported ergogenic effects (49).

Caffeine and taurine act as ergogenic aids via numerous mechanisms, some of which are shared. Caffeine acts on the CNS via adenosine receptor antagonism and subsequent inhibition of various neurotransmitters in the brain (24). Caffeine’s ergogenic effects might also be mediated by increases in Ca^{2+} from the sarcoplasmic reticulum, thereby facilitating skeletal muscle contraction (53). Taurine is also thought to regulate intracellular Ca^{2+} handling to modulate skeletal muscle contractile function (8,26,35), amongst numerous other physiological functions, such as bile acid conjugation, neuromodulation, metabolic effects, and antioxidant and anti-inflammatory properties (43). Together, *in vitro* studies have demonstrated that physiological concentrations of taurine can improve muscle

force (~29 %) and the rate of force development (~28 %) in the presence of caffeine in skinned skeletal muscle fibres (8). Furthermore, both can play a role in controlling cardiovascular responses (11,19,34) and act on the central nervous system (24), which could potentially enhance high intensity repeated efforts.

Recent work from our own laboratory suggests that caffeine and taurine co-ingestion can improve peak and mean power output during repeated Wingate tasks in comparison to placebo (56); however, the doses used are much higher than those contained in current energy drinks. In addition, we showed that the co-ingestion of caffeine with taurine attenuated the ergogenic effect of isolated taurine, thus indicating a potential negative performance consequence to their interaction *in vivo*. A number of studies have investigated the benefits of these drinks on exercise performance, with mixed results. Caffeine and taurine co-ingestion, in the doses observed in energy drinks, have improved reaction time, alertness, upper body muscular power, aerobic and anaerobic performance, as well as simulated soccer performance (1,18,23,46,48), whilst others have failed to improve repeated sprint running ability (5,33), time to exhaustion (16), or enhance peak power during repeated Wingate tests (23,36). However, many of these studies have not used isolated doses of the purported ergogenic ingredients (caffeine and taurine), thus discounting the contribution of other ingredients. Furthermore, there has been no investigation of prolonged repetitive sprinting protocols, interspersed by brief recovery periods using a mode of ergometry that permits a detailed investigation of power output profiles. This is important as the maintenance of power output during match sprinting on a track has been shown to differentiate international from domestic-level cyclists (28).

Therefore, the aim of this study was to investigate the effect of caffeine and taurine co-ingestion, in the doses found in commercially available energy drinks, on repeated sprint exercise. It was hypothesised that caffeine and taurine would enhance performance compared to placebo.

METHODS

Experimental Approach to the Problem

Using a randomised, double blind, cross-over, repeated measures study, male participants visited the laboratory on three separate occasions, each separated by one week. During visit one, participants conducted preliminary testing consisting of anthropometric measurements and familiarisation with equipment. On visits two and three, participants were administered capsules containing either caffeine and taurine or placebo (maltodextrin) 1-h before testing. Following a warm-up, participants performed a repeated-sprint test that consisted of ten, 6-s maximal sprints, separated by a 24-s complete static rest (45). All of their trials were conducted at the same time of day (± 30 -min). Laboratory conditions were 20 ± 1 °C, 51 ± 8 % relative humidity and atmospheric pressure 768 ± 8 mmHg, across all trials.

Subjects

Eleven physically active university males volunteered to participate (mean \pm SD: age 21 ± 2 years; stature 178 ± 7 cm; body mass 80 ± 13 kg; body fat 14 ± 4 %). Participants were not currently taking any supplements and were accustomed to performing repeated sprint protocols and exercised at least 4-h per week. Participants recorded food dairies 48-h before the first visit and were asked to replicate on the second visit. They were a mix of regular caffeine users. Participants were instructed to avoid consumption of alcohol or caffeinated products for 24-h before each visit, as well as strenuous exercise 48-h before testing. They were instructed not to eat within 3-h of testing and to arrive fully hydrated. Ethical approval was provided by St Mary's University ethics committee, which was conducted in accordance with the 1964 Helsinki declaration. Participants were informed of the benefits and risks of the investigation and provided written informed consent prior to testing.

Procedures

Repeated-sprint protocol. All sprints were conducted with resistance set at a torque factor of 0.75 $\text{N}\cdot\text{m}\cdot\text{kg}^{-1}$, equating to an applied torque of 60 ± 10 $\text{N}\cdot\text{m}$ on an electronically-braked cycle ergometer

(Lode Excalibur Sport, The Netherlands). Cycling position was established during visit 1 and replicated on subsequent visits. The protocol consisted of a 5-min warm-up at 100 W cycling at 80 r/min, followed by two 6-sec practice sprints, the first at 70% perceived maximal effort and the second at 100% perceived maximal effort with 1-min rest between. A 2-min rest period followed this. The repeated-sprint test consisted of ten, 6-s maximal sprints separated by a 24-s rest period with complete static rest. Time, power output, and cadence were concealed from the participant's view during all trials. Toe clips were used to secure the feet to the pedals and each sprint was performed seated with the dominant leg pedal orientated at 45 degrees when preparing for each sprint. Participants were given a 5-s countdown to each sprint and strongly encouraged for the duration of all sprints. Rating of perceived effort (RPE, 6 - 20) (12) and heart rate (HR) was recorded immediately following each sprint. Capillary blood was taken from the earlobe at rest prior to the warm up and following sprint 5 and 10. Measures recorded were: peak power, intra-sprint fatigue calculated using equation 1 and inter-sprint fatigue calculated using equation 2 (22).

1. Intra-sprint fatigue % = $[(\text{Peak Power} - \text{Minimum Power}) / \text{Peak Power}] \times 100$
2. Inter-sprint fatigue % = $100 - [(\text{Total power output} / \text{Ideal power output}) \times 100]$

Where:

Total power output = sum of peak power values from all sprints

Ideal power output = the number of sprints \times peak power maximum.

Supplement. All supplements were prepared in a powder form, which were measured using an analytical balance (Precisa 125A, Precisa Gravimetrics AG, Moosmattstrasse 32, Switzerland) and ingested in a gelatine capsule. The capsules contained either caffeine (80 mg) and taurine (1000 mg) or a placebo (1080mg maltodextrin) matched for colour, number of capsules and ingested with 250 ml water, 1-h prior to repeated-sprint testing. The dose of caffeine and taurine selected was chosen as representative of the dose present in energy drinks currently on the market. The 1-h timing was chosen as this accounted for the peak plasma availability of both taurine (30) and caffeine (3,47) after oral administration. All supplements were sourced from the same company (My Protein, Manchester, UK). Randomisation was conducted by generating random numbers for each condition for all

participants using online software, (Research Randomizer, Pennsylvania, USA) (54). Participants were asked if they could distinguish between the two supplements, and if so, to identify the basis of that decision. Five out of eleven participants correctly identified the caffeine/taurine trial *post hoc*. No participants reported any side effects resulting from supplementation.

Physiological measures. The right ear lobe was cleaned using an alcohol swab and punctured using an automated lancet. Blood was taken from the earlobe using 20 µl capillary tube (EKF Diagnostics, Barleben, Germany). The sample was hemolysed in a pre-filled micro test tube and analysed using a blood lactate analyser (Biosen C_Line, EKF Diagnostics, Barleben, Germany). Body mass (kg) was recorded using a Portable Scale (MPMS-230, Marsden Weighing Group, Oxfordshire, UK). Percent body fat was calculated by measuring skinfold thickness across four sites according to Durnin and Wormersley: Biceps, Triceps, Subscapular and Iliac Crest (sum of which = SF). Measures were taken in duplicate to the nearest 0.1 mm using skinfold calipers (Harpندن, Burgess Hill, UK) and calculated using the following equations (3 and 4) (21):

$$3. \quad BD = 1.1631 - 0.0632 \log (SF)$$

$$4. \quad \% \text{ Body Fat} = 495/BD - 450$$

Heart rate was monitored continuously during each test using heart rate monitors (Polar S610; Polar Electro Oy, Kempele, Finland).

Statistical analysis

Hopkins' method was used (39) to estimate sample size for magnitude-based inferences, based on peak sprint power reliability data from our laboratory. A sample size of 5 participants was generated based on a smallest important change of 43 W ($0.2 \times$ between subject SD) during the trial and a typical error of 20 W. The chances of type I and II errors were deemed to be 5 %. Based on best-practice recommendations for research in sports nutrition (14), effect sizes (ES) and magnitude-based inferences (MBIs) were used to identify mechanistic differences in the dependent variables between the two experimental conditions (caffeine & taurine or placebo) at baseline, sprint 1, 5 and 10, of the repeat-sprint protocol. Effect sizes were defined as; trivial = 0.2; small = 0.21–0.6; moderate = 0.61–

1.2; large = 1.21–1.99; very large > 2.0 (10). Raw data were log-transformed to account for non-uniformity of effects. Threshold probabilities for a substantial effect based on the 90% confidence limits were: <0.5% *most unlikely*, 0.5–5% *very unlikely*, 5–25% *unlikely*, 25–75% *possibly*, 75–95% *likely*, 95–99.5% *very likely*, 99.5% *most likely*. Thresholds for the magnitude of the observed change in the dependent variables were determined as the within-participant standard deviation \times 0.2 (*small*) 0.6 (*moderate*) and 1.2 (*large*). Effects with confidence limits across a *likely small* positive or negative change were classified as *unclear* (38). The uncertainty of effects was based on 90% confidence limits for all variables. A custom spreadsheet designed for cross-over trials was used to perform all of the calculations (<http://www.sportsci.org/>).

RESULTS

Average peak power achieved during the first sprint was 1167 ± 215 W and 1165 ± 192 W for the caffeine/taurine and placebo groups, respectively. There were *likely, trivial* differences in peak power across the 10 sprints (C/T: 1011 ± 87 ; P: 1006 ± 84 W) in both conditions (Figure 1).

*****Insert figure 1 here*****

The rate of fatigue intra-sprint 10 was *likely, smaller* (ES = 0.43; Beneficial/Trivial/Harmful: 83 / 16 / 1 %) in the placebo condition (C/T: 44 ± 19 %; P: 35 ± 13 %), with *possibly, smaller* reductions in sprints 6-9 (Figure 2). 8 out of the 11 participants demonstrated a consistent trend for a worse maintenance of power in the final sprint of the caffeine/taurine condition v.s. placebo, with marginal differences in the other 3 participants. The inter-sprint fatigue index was similar between the two conditions (*unclear, trivial*) (C/T: 14 ± 3 ; P: 16 ± 5.1 %) (Figure 3).

*****Insert figures 2 and 3 here*****

There was a *likely, large* increase in heart rate at baseline for the caffeine and taurine condition (C/T: 140 ± 16 bpm) vs. placebo (P: 127 ± 20 bpm) (ES = 0.94; Beneficial/Trivial/Harmful: 92 / 6 / 2 %), which was *unclear and small* by sprint 5 (C/T: 173 ± 10 ; P: 170 ± 9 bpm) (ES = 0.31) and *unclear and trivial* by sprint 10 (C/T: 174 ± 10 ; P: 174 ± 10 bpm) (ES = 0.01) (Figure 4). RPE was similar between conditions at baseline (CT: 10 ± 4 ; P: 10 ± 3) (ES = 0.03), sprint 5 (C/T: 16 ± 3 ; P: 15 ± 2) (ES = 0.21) and 10 (C/T: 19 ± 1 ; P: 19 ± 1) (ES = 0.06) (*unclear, trivial*) (Figure 5).

*****Insert figures 4 and 5 here*****

There were *likely, small* increases in B[la] after sprint 5 (C/T: 6.7 ± 1.0 ; P: 6.0 ± 0.7 mmol⁻¹) (ES = 0.50; Beneficial/Trivial/Harmful: 89 / 11 / 1 %) and *possibly, small* increases after sprint 10 (C/T:

10.8 ± 1.4 ; P: $10.2 \pm 1.2 \text{ mmol}^{-1}$) (ES = 0.35; Beneficial/Trivial/Harmful: 70 / 26 / 4 %) in the taurine and caffeine condition. However, the increase in B[la] was *unclear, small* prior to exercise (C/T: 1.1 ± 0.3 ; P: $1.0 \pm 0.2 \text{ mmol}^{-1}$) (ES = 0.28) (Figure 6).

*****Insert figure 6 here*****

DISCUSSION

The main findings of this study were that oral ingestion of caffeine and taurine at commensurate doses to popular commercial energy drinks did not improve repeat-sprint cycling performance. These findings are inconsistent with our hypothesis and further question the proposed ergogenic efficacy of caffeine and taurine-containing energy drinks for those competing in multiple-sprint sports. In addition, analysis of intra-sprint fatigue revealed that power output was maintained more effectively in the placebo condition throughout selected sprints compared to the caffeine and taurine condition, suggesting potential negative effects of these supplements at the given doses. These negative effects were observed alongside an increased HR prior to performance (baseline) and raised B[la] during performance.

Commercial energy drinks, such as Red Bull, have been reported to increase cycling time to exhaustion at 70 % $\dot{V}O_{2\max}$ (29) and time-trial performance of approximately 1-h (41). Del Coso et al. (18) also found that high intensity distance covered and sprinting frequency were improved during a simulated soccer match after consumption of a sugar-free Red Bull beverage. However, whilst performance improvements are apparent in endurance-based protocols, this has not been reported during shorter, intermittent exercise bouts (5,23,33,36). The protocol used in the current study, comprising short sprints with brief recovery periods of 10 repetitions, was designed to extend upon previous investigations by measuring both maximal intensity performance (i.e. sprints 1-3), as well as tolerance to fatigue in later periods (i.e. sprints 7-10). Our analysis of performance also extended upon previous studies by evaluating the intra- and inter-sprint fatigue profiles. The current study has revealed that gross performance (i.e. power output) and inter-sprint fatigue is not improved by caffeine and taurine ingestion and that the maintenance of power within selected sprints is compromised. This was most notable in the latter periods of the protocol, when the effects of fatigue are most apparent. These findings are inconsistent with the theory that energy drinks, and their key constituents, namely caffeine and taurine, exert their effects during periods of fatigue via centrally acting mechanisms (27).

Given the established ergogenic ranges of caffeine (3-6 mg/kg) (32) and taurine (50 mg/kg) (53) in previous studies, it is perhaps unsurprising that performance was not improved using the isolated doses herein (caffeine 0.8-1.2 mg/kg and taurine 11-15 mg/kg). This raises questions over which ingredients are responsible for improving performance in previous investigations and whether they are integral to the composition of commercial energy drinks, particularly at the current low doses. Indeed, the largest reported effects of Red Bull on endurance performance have been found among fasted participants, without iso-caloric placebo control (41). This is in contrast to the current study, whereby participants were not fasted. Ivy et al. (41) also reported a lower RPE in the Red Bull condition, which is consistent with the established effects of carbohydrate ingestion prior to performance (51) but not that previously (4) or currently reported for caffeine. Similarly, the effects of taurine might be dependent on the selected dose and are increased in isolation from caffeine (53). A study using 1 g of isolated taurine (equivalent dose to energy drinks), reported a 1.7 % increase in 3-km running performance, with no effect on RPE (9), and yet others using 1.66 g have not (50). Whilst more work is required to establish the dose-response relationship of taurine and performance, the low dose of taurine, coupled with its co-ingestion with caffeine in commercial energy drinks, appear to limit its capacity to improve performance. Furthermore, assuming that taurine or caffeine exert their ergogenic effects at the site of the skeletal muscle fibre (8), it is possible that the co-ingestion of these ingredients is responsible for the observed ergolytic effects on intra-sprint power profiles.

Heart rate was increased (*likely large*) at the beginning of the study, approximately 1-h after ingestion of caffeine and taurine. This is indicative of the acute effects of caffeine on cardiac frequency at rest, which is partly under the control of circulating catecholamines (55). Catecholamines are released in response to caffeine (2), as well as energy drinks of similar composition to that of the current trial (29). This mechanism might also explain the increases in exercising B[la] observed in latter parts of the current protocol, which are consistent with the reported glycolytic responses to epinephrine release (31). Conversely, taurine has been shown to acutely decrease HR (56) and increase left ventricular contractility (19). These opposing effects could be explained by the different

pharmacokinetics of caffeine and taurine, whereby peak plasma levels of taurine occur approximately 1 to 2.5-h (mean = 1.5-h) after oral ingestion (30), whereas peak plasma caffeine concentration is typically reached between 0.25 to 1-h (mean = 0.5-h) after ingestion (3).

Since both supplements were administered simultaneously in the current study, it is possible that the actions of caffeine on the cardiovascular system dominated the observed physiological responses. It is also possible that the noted increase in heart rate at the beginning of the trial is indicative of an increase in pre-exercise energy expenditure, as a result of caffeine supplementation (7,13). Indeed, increased energy expenditure could be attributed to the myocardial oxygen demand alone. Any increase in metabolic work rate would, therefore, increase the energetic cost associated with sprinting in the caffeine/taurine condition or at least contribute to a reduced net efficiency during the trials. The increases in the B[la] during the trials in the caffeine and taurine condition are an indication of increased glycolytic response and might support this theory. This could partially explain the accelerated decline in intra-sprint power output during the latter stages of the repeated bouts in the caffeine/taurine group. Collectively, our findings indicate that an increased resting HR is the only notable acute effect of ingesting caffeine and taurine. Further research is warranted to establish if these results are replicable across other high intensity exercise modalities. The rating of perceived exertion (RPE) is an indicator of consciously perceived psycho-physical strain (12). RPE did not change between conditions but did increase with sprint number over time. Whilst reductions in RPE have been noted following caffeine supplementation, these are usually associated with prolonged exercise (6,20). Determination of differences in psycho-physical strain during brief (< 6 s) maximal intensity sprints might be more difficult (6) and might explain the lack of difference in the current study.

This study is not without limitations. Despite double blinding procedures, 5 out of 11 correctly guessed that they were in the caffeine/taurine condition, which could have had an effect on perceived performance or the elevated heart rate data measured. Participants were also not in a fasted state, which has been shown to modulate caffeine metabolism (52). Finally, testing was conducted 1-h after

consumption of the supplement but with peak plasma caffeine occurring at 0.25-1-h (3) and taurine at 1-2.5-h (30), it is possible that taurine was not at its peak ergogenic potency. However, given the intra-individual variation in the both caffeine and taurine peak plasma availability, this is a common limitation of studies in this area.

PRACTICAL APPLICATIONS

Athletes who are required to perform multiple sprints as part of their sport should not consider the use of commercial energy drinks containing caffeine and taurine primarily for their ergogenic potential, to improve performance. Ingesting caffeine and taurine at these doses might increase the resting HR of users but this will not confer a performance benefit and, based on the current data, could have deleterious effects on the maintenance of power output during the latter periods of repeated sprinting.

REFERENCES

1. Alford, C, Cox, H, and Wescott, R. The effects of red bull energy drink on human performance and mood. *Amino Acids* 21: 139–150, 2001.
2. Anderson, DE and Hickey, MS. Effects of caffeine on the metabolic and catecholamine responses to exercise in 5 and 28 degrees C. *Med Sci Sports Exerc* 26: 453–458, 1994.
3. Arnaud, MJ and Welsch, C. Theophylline and caffeine metabolism in man. Zurich: Friedr.: Vieweg and Sons, 1982.
4. Astorino, TA, Cottrell, T, Talhami Lozano, A, Aburto-Pratt, K, and Duhon, J. Effect of caffeine on RPE and perceptions of pain, arousal, and pleasure/displeasure during a cycling time trial in endurance trained and active men. *Physiol Behav* 106: 211–217, 2012.
5. Astorino, TA, Matera, AJ, Basinger, J, Evans, M, Schurman, T, and Marquez, R. Effects of red bull energy drink on repeated sprint performance in women athletes. *Amino Acids* 42: 1803–1808, 2012.
6. Astorino, TA and Roberson, DW. Efficacy of acute caffeine ingestion for short-term high-intensity exercise performance: a systematic review. *J Strength Cond Res* 24: 257–265, 2010.
7. Astrup, A, Toubro, S, Cannon, S, Hein, P, Breum, L, and Madsen, J. Caffeine: a double-blind, placebo-controlled study of its thermogenic, metabolic, and cardiovascular effects in healthy volunteers. *Am J Clin Nutr* 51: 759–767, 1990.
8. Bakker, AJ and Berg, HM. Effect of taurine on sarcoplasmic reticulum function and force in skinned fast-twitch skeletal muscle fibres of the rat. *J Physiol* 538: 185–194, 2002.
9. Balshaw, TG, Bampouras, TM, Barry, TJ, and Sparks, SA. The effect of acute taurine ingestion on 3-km running performance in trained middle-distance runners. *Amino Acids* 44: 555–561, 2013.
10. Batterham, AM and Hopkins, WG. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform* 1: 50–57, 2006.
11. Bichler, A, Swenson, A, and Harris, MA. A combination of caffeine and taurine has no effect on short term memory but induces changes in heart rate and mean arterial blood pressure. *Amino Acids* 31: 471–476, 2006.

12. Borg, GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 14: 377–381, 1982.
13. Bracco, D, Ferrarra, JM, Arnaud, MJ, Jequier, E, and Schutz, Y. Effects of caffeine on energy metabolism, heart rate, and methylxanthine metabolism in lean and obese women. *Am J Physiol* 269: E671–8, 1995.
14. Burke, LM. Caffeine and sports performance. *Appl Physiol Nutr Metab* 33: 1319–1334, 2008.
15. Campbell, B, Wilborn, C, La Bounty, P, Taylor, L, Nelson, MT, Greenwood, M, et al. International Society of Sports Nutrition position stand: energy drinks. *J Int Soc Sports Nutr* 10: 1, 2013.
16. Candow, DG, Kleisinger, AK, Grenier, S, and Dorsch, KD. Effect of sugar-free Red Bull energy drink on high-intensity run time-to-exhaustion in young adults. *J Strength Cond Res* 23: 1271–1275, 2009.
17. Del Coso, J, Munoz, G, and Munoz-Guerra, J. Prevalence of caffeine use in elite athletes following its removal from the World Anti-Doping Agency list of banned substances. *Appl Physiol Nutr Metab* 36: 555–561, 2011.
18. Del Coso, J, Munoz-Fernandez, VE, Munoz, G, Fernandez-Elias, VE, Ortega, JF, Hamouti, N, et al. Effects of a caffeine-containing energy drink on simulated soccer performance. *PLoS One* 7: e31380, 2012.
19. Doerner, JM, Kuetting, DL, Luetkens, JA, Naehle, CP, Dabir, D, Homsy, R, et al. Caffeine and taurine containing energy drink increases left ventricular contractility in healthy volunteers. *Int J Cardiovasc Imaging* 31: 595–601, 2015.
20. Doherty, M and Smith, PM. Effects of caffeine ingestion on rating of perceived exertion during and after exercise: a meta-analysis. *Scand J Med Sci Sports* 15: 69–78, 2005.
21. Durnin, JV and Womersley, J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Br J Nutr* 32: 77–97, 1974.
22. Fitzsimons, M, Dawson, B, Ward, D, and Wilkinson, A. Cycling and running tests of repeated sprint ability. *Aust J Sci Med Sport* 25: 82–87, 1993.

23. Forbes, SC, Candow, DG, Little, JP, Magnus, C, and Chilibeck, PD. Effect of Red Bull energy drink on repeated Wingate cycle performance and bench-press muscle endurance. *Int J Sport Nutr Exerc Metab* 17: 433–444, 2007.
24. Fredholm, BB, Battig, K, Holmen, J, Nehlig, A, and Zvartau, EE. Actions of caffeine in the brain with special reference to factors that contribute to its widespread use. *Pharmacol Rev* 51: 83–133, 1999.
25. Froiland, K, Koszewski, W, Hingst, J, and Kopecky, L. Nutritional supplement use among college athletes and their sources of information. *Int J Sport Nutr Exerc Metab* 14: 104–120, 2004.
26. Galler, S, Hutzler, C, and Haller, T. Effects of taurine on Ca²⁺(+)-dependent force development of skinned muscle fibre preparations. *J Exp Biol* 152: 255–264, 1990.
27. Ganio, MS, Klau, JF, Lee, EC, Yeargin, SW, McDermott, BP, Buyckx, M, et al. Effect of various carbohydrate-electrolyte fluids on cycling performance and maximal voluntary contraction. *Int J Sport Nutr Exerc Metab* 20: 104–114, 2010.
28. Gardner, AS, Martin, DT, Barras, M, Jenkins, DG, and Hahn, AG. Power output demands of elite track sprint cycling. *Int J Perform Anal Sport* 5: 149–154, 2005.
29. Geiss, KR, Jester, I, Falke, W, Hamm, M, and Waag, KL. The effect of a taurine-containing drink on performance in 10 endurance-athletes. *Amino Acids* 7: 45–56, 1994.
30. Ghandforoush-Sattari, M, Mashayekhi, S, Krishna, C V, Thompson, JP, and Routledge, PA. Pharmacokinetics of oral taurine in healthy volunteers. *J Amino Acids* 2010: 346237, 2010.
31. Gjedsted, J, Buhl, M, Nielsen, S, Schmitz, O, Vestergaard, ET, Tonnesen, E, et al. Effects of adrenaline on lactate, glucose, lipid and protein metabolism in the placebo controlled bilaterally perfused human leg. *Acta Physiol (Oxf)* 202: 641–648, 2011.
32. Graham, TE and Spriet, LL. Metabolic, catecholamine, and exercise performance responses to various doses of caffeine. *J Appl Physiol* 78: 867–874, 1995.
33. Gwacham, N and Wagner, DR. Acute effects of a caffeine-aurine energy drink on repeated sprint performance of American college football players. *Int J Sport Nutr Exerc Metab* 22: 109–116, 2012.

34. Hajsadeghi, S, Mohammadpour, F, Manteghi, MJ, Kordshakeri, K, Tokazebani, M, Rahmani, E, et al. Effects of energy drinks on blood pressure, heart rate, and electrocardiographic parameters: An experimental study on healthy young adults. *Anatol J Cardiol* 16: 94–99, 2016.
35. Hamilton, EJ, Berg, HM, Easton, CJ, and Bakker, AJ. The effect of taurine depletion on the contractile properties and fatigue in fast-twitch skeletal muscle of the mouse. *Amino Acids* 31: 273–278, 2006.
36. Hoffman, JR, Kang, J, Ratamess, NA, Hoffman, MW, Tranchina, CP, and Faigenbaum, AD. Examination of a pre-exercise, high energy supplement on exercise performance. *J Int Soc Sports Nutr* 6: 2, 2009.
37. Hoffman, JR. Caffeine and energy drinks. *Strength Cond J* 32: 15–20, 2010.
38. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3–13, 2009.
39. Hopkins, WG. Estimating sample size for magnitude-based inferences. *Sportscience*. 10: 63–70, 2006. Available from: sportsci.org/2006/wghss.htm
40. Huxtable, RJ. Physiological actions of taurine. *Physiol Rev* 72: 101–163, 1992.
41. Ivy, JL, Kammer, L, Ding, Z, Wang, B, Bernard, JR, Liao, Y-H, et al. Improved cycling time-trial performance after ingestion of a caffeine energy drink. *Int J Sport Nutr Exerc Metab* 19: 61–78, 2009.
42. Laquale, KM. Red Bull: The other energy drink and its effect on performance. *Athl Ther Today* 12: 43–45, 2007.
43. Lourenco, R and Camilo, ME. Taurine: a conditionally essential amino acid in humans? An overview in health and disease. *Nutr Hosp* 17: 262–270, 2002.
44. McLellan, TM and Lieberman, HR. Do energy drinks contain active components other than caffeine? *Nutr Rev* 70: 730–744, 2012.
45. La Monica, MB, Fukuda, DH, Beyer, KS, Hoffman, MW, Miramonti, AA, Riffe, JJ, et al. Altering work to rest ratios differentially influences fatigue indices during repeated sprint ability testing. *J Strength Cond Res* 30: 400–406, 2016.

46. Prins, PJ, Goss, FL, Nagle, EF, Beals, K, Robertson, RJ, Lovalekar, MT, et al. Energy drinks improve five-kilometer running performance in recreational endurance runners. *J Strength Cond Res* 30: 2979–2990, 2016.
47. Quinlan, P, Lane, J, and Aspinall, L. Effects of hot tea, coffee and water ingestion on physiological responses and mood: the role of caffeine, water and beverage type. *Psychopharmacology (Berl)* 134: 164–173, 1997.
48. Quinlivan, A, Irwin, C, Grant, GD, Anoopkumar-Dukie, S, Skinner, T, Leveritt, M, et al. The effects of Red Bull energy drink compared with caffeine on cycling time-trial performance. *Int J Sports Physiol Perform* 10: 897–901, 2015.
49. Rosenbloom, C. Energy drinks, caffeine, and athletes. *Nutr Today* 49: 49–54, 2014.
50. Rutherford, JA, Spriet, LL, and Stellingwerff, T. The effect of acute taurine ingestion on endurance performance and metabolism in well-trained cyclists. *Int J Sport Nutr Exerc Metab* 20: 322–329, 2010.
51. Sherman, WM, Peden, MC, and Wright, DA. Carbohydrate feedings 1 h before exercise improves cycling performance. *Am J Clin Nutr* 54: 866–870, 1991.
52. Skinner, TL, Jenkins, DG, Folling, J, Leveritt, MD, Coombes, JS, and Taaffe, DR. Influence of carbohydrate on serum caffeine concentrations following caffeine ingestion. *J Sci Med Sport* 16: 343–347, 2013.
53. Tarnopolsky, M and Cupido, C. Caffeine potentiates low frequency skeletal muscle force in habitual and nonhabitual caffeine consumers. *J Appl Physiol* 89: 1719–1724, 2000.
54. Urbaniak, GC and Plous, S. Research randomizer (version 4.0) [computer software]. , 2015. Available from: <http://www.randomizer.org/>
55. Waldhauen, JA, Kilman, JW, and Abel, F. Effects of catecholamines on the heart. Myocardial contractility, cardiac efficiency, and total peripheral resistance. *Arch Surg* 91: 86–91, 1965.
56. Warnock, R, Jeffries, O, Patterson, S, and Waldron, M. The effects of caffeine, taurine or caffeine-aurine co-ingestion on repeat-sprint cycling performance and physiological responses. *Int J Sports Physiol Perform* 1–24, 2017.

FIGURES

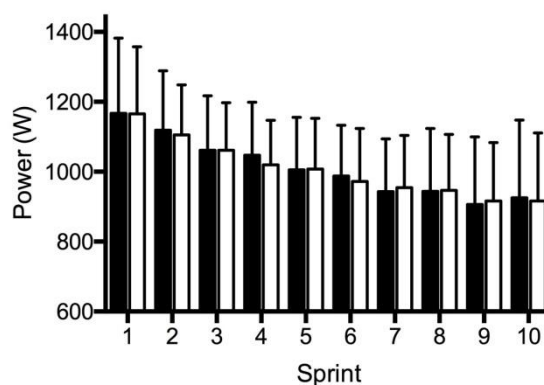


Figure 1 Mean \pm SD for peak power (PP) across repeated sprint performance between condition. Black bars indicate caffeine & taurine condition and white bars indicate placebo ($n = 11$). There were trivial differences between condition.

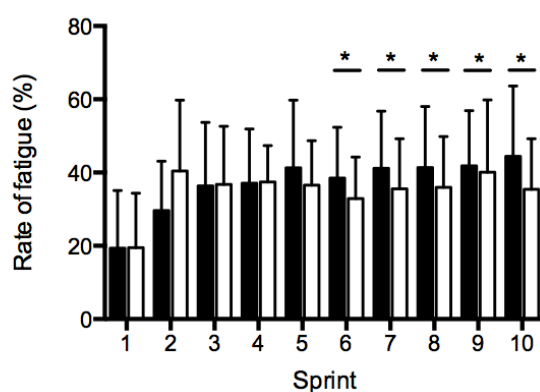


Figure 2 Mean \pm SD for intra-sprint fatigue between condition. Black bars indicate caffeine & taurine condition and white bars indicate placebo ($n = 11$), * indicates *possibly, smaller* reductions in sprints 6-10 between condition.

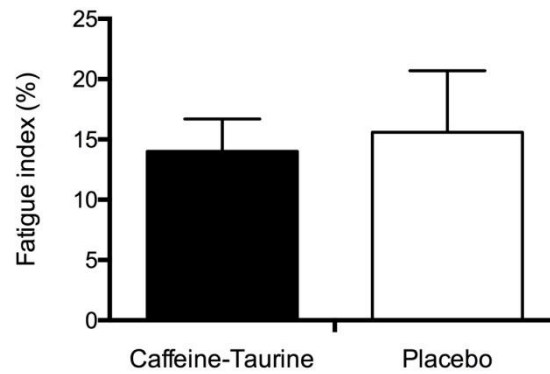


Figure 3 Mean \pm SD for inter-sprint fatigue index between condition. Black bars indicate caffeine & taurine condition and white bars indicate placebo ($n = 11$). There were trivial differences between condition.

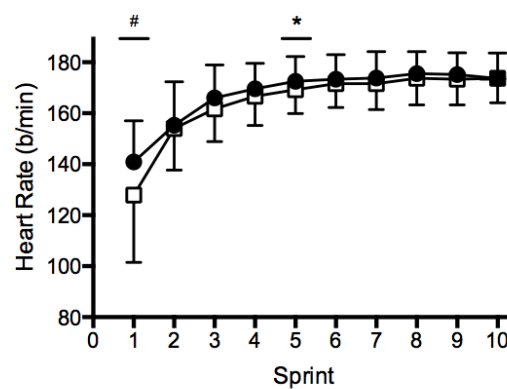


Figure 4 Mean \pm SD for heart rate between condition. Black circles indicate caffeine taurine condition and white squares indicate placebo ($n = 11$), * indicates an *unclear and small* effect between condition, # indicates a *likely, large* increase in heart rate at baseline between condition.

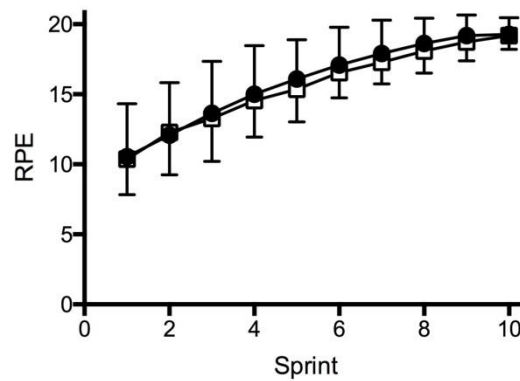


Figure 5 Mean \pm SD for RPE between condition. Black circles indicate caffeine taurine condition and white squares indicate placebo ($n = 11$). There were trivial differences between condition.

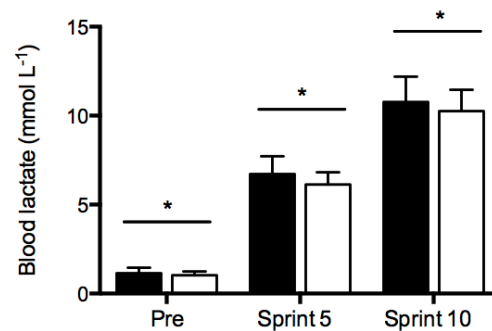


Figure 6 Mean \pm SD for blood lactate between condition. Black bars indicate caffeine taurine condition and white bars indicate placebo ($n = 11$). * indicates *unclear, small* differences prior to exercise, *likely, small* increases at sprint 5, and *possibly, small* increases at sprint 10, between conditions.