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Original research

Effect of caffeine on cycling time-trial performance in the heat

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ABSTRACT

Objectives: The purpose of this investigation was to determine whether a moderate dose of caffeine would improve a laboratory simulated cycling time-trial in the heat.
Methods: Nine well-trained male subjects (VO_2max 64.4 ± 6.8 mL min^{-1} kg^{-1}, peak power output 378 ± 40 W) completed one familiarisation and two experimental laboratory simulated cycling time-trials in environmental conditions of 35 °C and 25% RH 90 min after consuming either caffeine (3 mg kg^{-1} BW) or placebo, in a double blind, cross-over study.
Results: Time-trial performance was faster in the caffeine trial compared with the placebo trial (mean ± SD, 3806 ± 359 s versus 4079 ± 333 s, p = 0.06, 90%CI 42–500 s, 86% likelihood of benefit, d = −0.79). Caffeine ingestion was associated with small to moderate increases in average heart rate (p = 0.178, d = 0.39), VO_2 (p = 0.154, d = 0.45), respiratory exchange ratio (p = 0.292, d = 0.35) and core temperature (p = 0.616, d = 0.22) when compared to placebo, however, these were not statistically significant. Average RPE during the caffeine supplemented time-trial was not significantly different from placebo (p = 0.41, d = −0.13).
Conclusion: Caffeine supplementation at 3 mg kg^{-1} BW resulted in a worthwhile improvement in cycling time-trial performance in the heat.
Design: Double-blind cross-over study.

1. Introduction

Caffeine (1,3,7-trimethylxanthine) is one of the most popular and accepted ergogenic aids used by athletes in endurance sports.[1–3] It has well-documented positive effects on exercise performance in standard ambient temperatures (∼21 °C and 40% RH) particularly in exercise tasks which last 30 min or longer.[4] However, the ergogenic benefits of caffeine consumed before exercise in the heat are much less convincing.[5–7] Del Coso et al.[7] have shown that caffeine can enhance quadriceps force production after 120 min of cycling in the heat. Conversely, caffeine consumed at doses of 6 and 9 mg kg^{-1} BW before cycling time-trials in the heat does not appear to enhance performance,[5,8] nor was there an improvement in 21 km run time in warm field conditions when 5 or 9 mg kg^{-1} BW of caffeine was consumed before exercise.[6] Taken together, these studies suggest that caffeine may not be ergogenic when consumed before exercise performed in the heat.

Although caffeine has well-noted beneficial effects on endurance performance, heat has been shown to have detrimental effects on endurance performance,[9–11] even in heat adapted individuals.[10] Heat increases core temperature[11] and this is thought to be the main limiting factor on endurance performance as increased core temperature increases the thermoregulatory stress placed on the body to maintain a stable internal environment and may lead to reductions in central drive, limiting endurance performance.[11] Exercise in the heat and the increased reliance on evaporative heat loss mechanisms increase core temperature,[10] sweat rate,[9] heat transfer from the skin[9,12] and potentially reduce central drive to continue exercise.[13] Increased sweat rate during exercise in the heat leads to increased fluid loss and reduced blood volume, which has a cascade effect in reducing stroke volume, increasing heart rate and limiting endurance capacity. There is evidence to suggest that caffeine supplementation is associated with increased core temperature, heart rate and sweat rate when compared to a placebo at a set work rate.[5,14,15] Thus plausible reasons for any lack of benefit from high dose caffeine under hot conditions may be due to some of the metabolic effects associated with caffeine such as increased core temperature[8] due to increased work output, or by affecting diuresis or sweat rate.[15,16] Caffeine supplementation has, in some cases, been shown to cause a greater rise in core temperature during steady-state endurance exercise in a hot environment compared with a placebo,[8,16] while other

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studies show only very subtle perturbations in body temperature and heat storage resulting from caffeine ingestion prior to exercise in the heat.[7,17] Nevertheless, it is possible that when exercise is performed in a hot environment, the ergogenic effects of caffeine are negated due to elevations in physiological variables such as body temperature, heart rate and sweat rate.[5,8]

Interestingly, the studies showing no improvement in exercise performance in the heat after caffeine ingestion have used relatively high doses ranging from 5 to 9 mg kg^{-1} BW.[5,6,8] The ergogenic effects of caffeine on endurance time-trial performance in ambient conditions appear to plateau at doses close to 3 mg kg^{-1} BW with no additional benefit from higher doses.[14,18] The effect of a moderate dose (~3 mg kg^{-1} BW) of caffeine on exercise performance in the heat is yet to be investigated.

The purpose of this investigation was to determine the effect of a 3 mg kg^{-1} BW dose of caffeine on cycle time-trial performance in the heat. It was hypothesised that a 3 mg kg^{-1} BW dose of caffeine would enhance performance to a similar extent to what has previously been observed during exercise in standard laboratory temperatures.[14]

2. Methods

Participants were nine highly trained male cyclists (22–42 years, body mass 73.56 ± 8.28 kg, height 176.6 ± 8.7 cm, VO_2max 64.4 ± 6.8 mL min^{-1} kg^{-1} and peak power output 378 ± 40 W). Seven of the nine participants were regular caffeine consumers in the average range of 100–300 mg day^{-1}. The research was conducted according to the National Statement on Ethical Conduct in Human Research (2007) (Australia) and was approved by the Tasmanian Human Research Ethics Committee (approval number H11654). Participants were recruited from cycling clubs around Northern Tasmania and were required to have a minimum of two years cycling experience.

The study was a randomised, counterbalanced, double-blind, placebo-controlled, cross-over design. Cyclists attended the laboratory on four separate occasions including two experimental trials. The first visit involved measurement of VO_2max and peak power output in laboratory conditions of 21 °C and 40% relative humidity (RH). The second visit was a familiarisation session where the cycling time-trial was completed in hot conditions (35 °C and 25% RH) without respiratory measurements or blood sampling. The two experimental trials involved cyclists ingesting either 3 mg kg^{-1} of BW anhydrous caffeine (PCCA, NSW, Australia) or an equivalent amount of placebo (Metamucil™, NSW, Australia) 90 min before completing the cycling time-trial in the climate chamber.

Participants' VO_2max and peak power (W_{max}) were determined using an incremental test to exhaustion on a calibrated cycle ergometer (Lode Excalibur Sport Cycle Ergometer, Groningen, The Netherlands). Participants began cycling at 100 W for 5 min with increases in intensity of 50 W every 2.5 min until exhaustion, as previously described by Desbrow et al.[19] During the VO_2max testing expired air was collected and analysed using a calibrated metabolic cart (ParvoMedics' TrueOne2400). Heart rate (HR) was recorded every 30 s of the test using a heart rate monitor (RS800CX, Polar Instruments Inc., Finland). Rating of perceived exertion (RPE) was recorded at every stage of the test using Borg's 6–20 RPE scale.[20] VO_2max was determined as an average of the two highest 30 s consecutive readings.

Each participant completed one familiarisation of the cycling time-trial in the hot conditions, following the same protocol as the future exercise trials, with the absence of blood sampling and respiratory gas collection. The cycle ergometer was adjusted to cyclists' personal specifications. Seat and bar height and positions were then recorded and replicated in the subsequent exercise trials.

Two experimental trials involving the consumption of either an anhydrous caffeine capsule (3 mg kg^{-1} BW) or a placebo capsule containing psyllium husk (Metamucil ™ P&G Australia Pty Ltd., Sydney, NSW, Australia) 90 min prior to exercise were completed by each participant. All exercise trials were completed at the same time of day (morning) with at least seven days separating each trial. The climate chamber was set at 35 °C and 25% RH.

Prior to each trial, participants were asked to perform no physical activity, aside from activities of daily living, for 24 h before the start of each testing session and were provided with a 24 h prepackaged diet including all food and fluid to be consumed before the trial and a standardised breakfast on the morning of each trial. The standardised diet was designed to minimise dietary differences across participants and between trials to ensure reliability, reproducibility and validity of time-trial results.[21] The pre-packaged diet provided 200 kJ kg^{-1} BW and 7.5 g kg^{-1} BW of carbohydrate for the day preceding the time-trials 40 kJ kg^{-1} BW and 1.5 g kg^{-1} BW of carbohydrate in the breakfast on the morning of time-trials. Participants were required to avoid alcohol for at least 24 h and caffeine for at least 12 h prior to each trial.

Each exercise trial involved participants completing a time-trial on the same calibrated cycle ergometer. The protocol used was similar to that described by Irwin et al.[22] However, the target amount of work was reduced by 20% to ensure that most participants completed the time-trial in approximately 60 min in the hot conditions. The target amount of work was calculated according to the formula:

$$\text{Total work (J)} = 0.75 \times \text{PPO} \times 2880$$

The time-trial was performed with the ergometer set in linear mode. The participants' linear factors were determined on an individual basis (during VO_2max testing) to allow cycling at each participant's preferred cadence. Participants were required to perform the set amount of work as fast as possible.

Throughout the two exercise trials VO_2 was recorded at 25%, 50%, 75% and 90% of time-trial completion (for 90 s with readings taken every 15 s and the final three readings averaged) while rating of perceived exertion (RPE) was recorded at 25%, 50%, 75%, 90% and 100% of time-trial completion. Core temperature was measured continuously throughout the time-trials using Vitalsense (Philips Respironics, Eindhoven, Netherlands) core temperature capsules ingested 4 h prior to the onset of the exercise bout. Heart rate was monitored every 15 s throughout (RS800CX, Polar Instruments Inc., Finland). Participants consumed 3 mL kg^{-1}BW of a carbohydrate electrolyte beverage (Gatorade) every 25% of time-trial completion, provided immediately after VO_2 measurement. On completion of the study cyclists were asked to identify which trial they believed they consumed caffeine pre-exercise.

Blood samples were obtained from the forearm antecubital space of each cyclist 90 min prior to exercise, 5 min pre-exercise and immediately post-exercise for analysis of plasma caffeine concentration. Blood was transferred into lithium heparin collection tubes then centrifuged at 4 °C for 15 min at 2500 rpm. Plasma was then extracted and stored at −80 °C until subsequent analysis. The quantitative analysis of plasma caffeine was performed using an automated reversed-phase high-performance liquid chromatography system, with conditions adapted with subtle modifications from Koch et al.[23] The precise method has been previously described by Desbrow et al.[19]

Before analysis, data was tested for normality using a Kolmogorov–Smirnov test. All data were normally distributed with the exception of HR data expressed at 0%, 25%, 50%, 75%, 90% and 100% time-trial completion which was then log transformed prior to analysis. To determine changes in cycling time-trial time and the trial average of physiological variables a t-test was used while