Effects of acute supplementation of caffeine on cardiorespiratory responses during endurance running in a hot & humid climate

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Background & objectives: Athletes in Malaysia need to perform in a hot and humid climate. Chronic supplementation of caffeine on endurance performance have been studied extensively in different populations. However, concurrent research on the effects of acute supplementation of caffeine on cardiorespiratory responses during endurance exercise in the Malaysian context especially in a hot and humid environment is unavailable.

Methods: Nine heat adapted recreational Malaysian male runners (aged: 25.4 ± 6.9 yr) who were nonusers of caffeine (23.7 ± 12.6 mg per day) were recruited in this placebo-controlled double-blind randomized study. Caffeine (5 mg per kg of body weight) or placebo was ingested in the form of a capsule one hour prior to the running exercise trial at 70 per cent of VO2max on a motorised treadmill in a heat-controlled laboratory (31°C, 70% relative humidity). Subjects drank 3 ml of cool water per kg of body weight every 20 min during the running trials to avoid the adverse effects of dehydration. Heart rate, core body temperature and rate of perceived exertion (RPE) were recorded at intervals of 10 min, while oxygen consumption was measured at intervals of 20 min.

Results: Running time to exhaustion was significantly (P<0.05) higher in the caffeine trial compared to the placebo trial. Heart rate, core body temperature, oxygen uptake and RPE did not show any significant variation between the trials but it increased significantly during exercise from their respective resting values in both trials (P< 0.001).

Interpretation & conclusion: Our study showed that ingestion of 5 mg of caffeine per kg of body weight improved the endurance running performance but did not impose any significant effect on other individual cardiorespiratory parameters of heat-acclimated recreational runners in hot and humid conditions.

Key words Acute supplementation - caffeine - endurance - heart rate - RPE - VO2

Nutritional ergogenic aids are substances which enhance the athletic performance by influencing physiological as well as psychological process. Caffeine is one of the most common ergogenic supplements in endurance sports1.

In a prevalence survey2, 89 per cent of the athletes were found to use a caffeinated substance in the 2005 Triathlon World Championships. Desbrow and Leveritt3 reported that 73 per cent of the 140 athletes at the 2005 Ironman Triathlon World Championships
believed that caffeine is an ergogenic aid that enhanced their endurance performance.

Ingestion of 3-6 mg of caffeine per kg of body weight exerts an equivalent ergogenic effect to its higher doses. A dose of 5 mg caffeine per kg of body weight has been shown to provide most consistent effect to improve endurance performance. According to the Medical Council of International Olympic Committee (IOC), caffeine is allowed in sports as long as its urinary excretion level is below 12 µg/ml. Thus, it has been recommended that caffeine dose should be limited to 7 mg per kg of body weight or less to avoid a positive drug test because there may be individual variations in caffeine clearance.

Though, various studies have demonstrated the ergogenic effects of caffeine on endurance performance, data on the effect of acute supplementation of caffeine on endurance performance, especially in the heat are lacking. Moreover, study on the efficacy of acute caffeine supplementations on Malaysian population under a hot and humid environment has not been reported. Therefore, the present study was conducted to find out the effect of acute supplementation of caffeine on cardiorespiratory responses during endurance running of male recreational runners in a hot and humid environment.

Material & Methods

Selection of subjects: Nine (9) male Malaysian recreational runners (aged: 25.4 ± 6.9 yr) were recruited in this randomized double-blind, placebo-controlled cross-over study. The study was conducted at the Sprot Science Unit Laboratory, Universiti Sains Malaysia, Kelantan, Malaysia. All the subjects were categorized as nonusers of caffeine (23.7 ± 12.6 mg/day). Subjects with hypertension, asthma, diabetes, bronchitis, anaemia, heart problems, kidney or liver diseases and or any other major diseases were excluded from the study. Written informed consent was taken from each subject. The experiment protocol was approved by the Research and Human Ethics Committee of Universiti Sains Malaysia.

Test procedure:

Preparation of subjects - To minimise variation in pre-exercise muscle glycogen status, subjects were requested to record their food intake for 3 consecutive days prior to the first trial and repeat the same diet over 3 days prior to consecutive trials. Subjects were asked to refrain from heavy exercise for 24 h before all the experimental trials.

Pre-trial and trial procedure - Each subject came to the laboratory five times, first 3 visits for pre-trial tests and remaining 2 visits for experimental trials, respectively (Fig.). First pre-trial visit involved the measurement of oxygen consumption at various sub-maximal running speeds while the second pre-trial visit involved the measurement of VO\(_{2}\text{max}\). These two trials were conducted to determine the exact treadmill speed that corresponded to the 70 per cent of the subject’s VO\(_{2}\text{max}\) which was set as the exercise trial speed. Subjects were familiarized with the endurance testing protocol in the heat (31°C, 70% relative humidity) on their third pre-trial visit. At least 3 days gap was maintained between the consecutive trials. For the experimental trials, each subject visited the laboratory twice with at least seven days gap to nullify the effect of the supplement, i.e., caffeine. Subjects reported to the laboratory after an overnight fast of 10 h. All the experimental trials were conducted at 0800 h.

Measurement of oxygen uptake at submaximal running speeds - After the warm up, subject was asked to wear a mouthpiece, a nose clip and heart rate sensor (Sport Tester PE3000, Polar, Finland). A head gear was fitted to support a two-way non-re-breathing valve (Hans Rudolph 2700 series, USA) attached to the mouthpiece. The subjects ran on a motorized treadmill (Quinton 18-60, USA) for four minutes each at four different speeds (7, 8, 9 and 10 km/h). The speed was increased by 1 km/h after every 4 min. Expired air during the test was passed through a mixing chamber where sensors to the pre-calibrated paramagnetic oxygen and infrared carbon dioxide analyzers (Sensormedic 2900, USA) were used to determine the percentages of oxygen and carbon dioxide respectively in the expired air. Both analysers were calibrated using two nitrogen based calibration gases (26% oxygen in nitrogen
mixture, and 4 per cent carbon dioxide and 16 per cent oxygen in nitrogen mixture). The outputs from the gas analyser were processed using a computer for the calculation of oxygen consumption (VO\textsubscript{2max}) and carbon dioxide production (VCO\textsubscript{2}). Expired gas was measured every twenty seconds by the analyser. Heart rate and rate of perceived exertion (RPE) were measured during the final min of each 4 min of the speed increment.

Measurement of maximum oxygen uptake (VO\textsubscript{2max}) - Maximum oxygen uptake was determined by using a modified Astrand protocol\textsuperscript{15}. This test required the subjects to run to volitional exhaustion during a continuous incremental run on a motorized treadmill. Subjects were initially allowed to warm up for 5 min at a low speed (6-7 km/h). After the warm up, the subjects were fitted with the headgear, mouthpiece, nose clip and heart rate sensor as in the sub-maximal test. An appropriate speed (8-12 km/h) was selected and the test began with a grade of 0 per cent for 3 min. Thereafter, the grade was increased by 2½ per cent every 2 min and the subject was encouraged to run until exhaustion.

Expired air samples and heart rate responses were measured at the end of each 2 min stage. The maximum oxygen uptake (VO\textsubscript{2max}) value was accepted when three of the following criteria were met\textsuperscript{16}:

(i) A plateau in oxygen uptake despite increasing workload.

(ii) A heart beat within 10 beats/min of age-predicted maximum heart rate: 220 beats/min - age.

(iii) A respiratory exchange ratio of > 1.15.

The 1\textsuperscript{st} pre-trial visit was conducted to determine the association between oxygen uptake and running speed. The VO\textsubscript{2max} was determined in the 2\textsuperscript{nd} pre-trial visit. The data from these 2 trials were used to determine the running speed that would elicit 70 per cent of their respective VO\textsubscript{2max} during the experimental trials.

**Experimental trial protocol:**

On arrival to laboratory - Subject’s body weight (after emptying their bladder), body height, and pre-exercise heart rate were measured. Body fat percentage was also determined by bio-electrical impedance analysis. A rectal probe was inserted to a depth of 10 cm beyond the anal sphincter for the determination of core body temperature that was recorded on a temperature monitor (Libra Medical ET 300R, USA) throughout the trial.

A heart rate monitor (Sport Tester PE3000, Polar, Finland) was placed on the subject’s chest to monitor the heart rate. Water (500 ml) and a piece of bread (89 kcal) was given to the subject in comfortable sitting posture 1 h before starting the exercise trial. Subject ingested capsule containing caffeine or placebo in random sampling and double blinded method. Fredholm et al\textsuperscript{17} established that caffeine concentration in the blood reached its maximum level after one hour of the caffeine ingestion. That is why, in the present study, caffeine was supplemented one hour before the exercise trials to find out the optimum effect of the ingested caffeine.

During the trials - Heart rate, core body temperature, room temperature, relative humidity and rate of perceived exertion or RPE\textsuperscript{18} were monitored at intervals of 10 min. Subjects were allowed to drink cool water (4-8°C) at the rate of 3 ml per kg of body weight at an interval of 20 min to avoid the adverse effects of dehydration\textsuperscript{19,20}. Subjects ran on the treadmill at 70% of VO\textsubscript{2max} “to voluntary exhaustion” that was determined as the point when they indicated that they could no longer run at the required speed\textsuperscript{4}. At the point of exhaustion and to ensure that the subjects were truly fatigued, the running speed was reduced to elicit 60 per cent VO\textsubscript{2max} for 2 min. Thereafter, the speed was returned to the prescribed speed (70% VO\textsubscript{2max}) and the subjects were encouraged to run as long as possible.

**Statistical analyses:** Statistical Package for Social Sciences (SPSS) version 14.0 (SPSS Incorp, United States) was used for statistical analysis of the data. Shapiro-Wilk Test was used to check the normality of the population. Repeated measure ANOVA was used followed by Bonferroni post-hoc analysis to observe the significant difference at P<0.05 level in heart rate, oxygen uptake and core body temperature. Paired-t test was used to compare the difference between means of endurance time in two trials. Ratings of perceived exertion (RPE) were analysed using Wilcoxon signed rank test.

**Results & Discussion**

The mean body mass index (20.2 ± 1.9 kg/m\textsuperscript{2}) and body fat percentage (15.6 ± 2.8 %) indicated that the subjects were non-obese and non-overweight. Mean VO\textsubscript{2max} (51.0 ± 8.2 ml/kg/min) reflected that the subjects had good cardiorespiratory fitness (Table I).

Average room temperature and relative humidity in the two trials (placebo and caffeine) were 31 ±
0.1 °C; 68.0 ± 1.4 per cent; and 31.0 ± 0.2 °C; 70.0 ± 0.8 per cent; respectively. Mean exhaustion time for placebo (P) and caffeine (C) trials were 83.6 ± 21.4 min and 110.1 ± 29.6 min, respectively. Exhaustion time for C was 31.6 per cent higher than that of the P trial (P<0.05). This finding indicated that the acute supplementation of 5 mg of caffeine per kg of body weight has an ergogenic effect among nonusers of caffeine and heat-acclimatized recreational runners in a hot and humid environment. The findings corroborated with previous studies on sportspersons and sedentary individuals. Caffeine trial demonstrated significant improvement in endurance time among rowers, well trained runners, recreational runners, as well as in 70 yr old male subjects.

There was a gradual increase in heart rate during exercise in both the trials. The exercise heart rates did not show any significant variation between the trails. However, in both the trials the peak heart rate was significantly higher (P<0.001) than the corresponding resting heart rate (Table II). Such gradual increase in heart rate over time was to meet the increasing requirement of the body during the endurance exercise. There was no significant difference in the working heart rate between the two running trials.

The oxygen uptake was gradually increased in both the trials. Oxygen uptake increased significantly (P<0.001) from 10 min to the end of test during the exercise (Table III). There was no significant difference in the oxygen uptake during the exercise between the two trials. This finding corroborated with previous finding that caffeine sustains the cardiovascular and respiratory function during cycling in hot and humid environment.

Core body temperature increased significantly (P<0.001) after the exercise than the corresponding resting values in both the trials. However, no significant difference was observed in the core body temperature between the placebo and experimental trials (Table III). There was no significant association between the time and supplements on core body temperature during the trials. This finding was in agreement with Roti et al who reported insignificant alteration in body’s thermoregulatory responses during endurance exercise following chronic supplementation of caffeine in a hot and humid environment. Millard-Stafford et al concluded that caffeine or caffeinated sports drink maintains hydration during endurance performance in the heat. Similar studies with 10mg/kg body weight of caffeine intake did not impose any significant effect on VO2peak, heart rate, sweat rate and rectal temperature during an exercise heat tolerance test in hot and humid environmental condition.

During the exercise, subjects expressed their feelings on a numerical scale i.e., Borg’s scale to indicate the fatigue level or RPE (Table IV). C trial helped the subjects to sustain the exercise with lesser exertion. There was significant difference in RPE between two trials (P<0.05) as also previously reported among swimmers and recreational college runners. Rate of perceived exertion increased significantly (P<0.001) from 10 min to the end of test in the two trials, respectively. The lower RPE during C trial was probably due to the effect of caffeine ingestion towards exertion of positive influence on nerve impulse transmission as well as analgesic effect and psychological effect. This was perhaps the reason why subjects could sustain the treadmill

### Table I. Anthropometric and physical characteristics of subjects

| Age (yr) | 25.4 ± 6.9 |
| Body mass (kg) | 57.6 ± 8.4 |
| Height (cm) | 168.3 ± 7.6 |
| Body fat (%) | 15.6 ± 2.8 |
| Body mass index (BMI) (kg/m²) | 20.2 ± 1.9 |
| Heart rate max (beats/min) | 197 ± 6.5 |
| VO2max (ml/kg/min) | 51.0 ± 8.3 |

Values are means ± SD (n=9)

### Table II. Heart rate of the subjects in placebo and caffeine trials

<table>
<thead>
<tr>
<th>Trial</th>
<th>Heart rate (beats/min)</th>
<th>Exercise (min)</th>
<th>Exhaustion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Placebo</td>
<td>67 ± 5.7</td>
<td>157</td>
<td>162</td>
</tr>
<tr>
<td>Caffeine</td>
<td>68 ± 5.0</td>
<td>158</td>
<td>164</td>
</tr>
</tbody>
</table>

Value are mean ± SD (n=9)

*P<0.001 between resting and exhaustion values in the respective trial
Table III. Physiological parameters of the subjects in placebo and caffeine trials

<table>
<thead>
<tr>
<th>Trial</th>
<th>VO₂ (ml/kg/min)</th>
<th>Core body temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resting</td>
<td>Peak</td>
</tr>
<tr>
<td>Placebo</td>
<td>7.3 ± 1.3</td>
<td>35.8 ± 5.0</td>
</tr>
<tr>
<td>Caffeine</td>
<td>7.5 ± 1.5</td>
<td>36.9 ± 3.8</td>
</tr>
</tbody>
</table>

Value are mean ± SD (n=9)

# P<0.001 between resting and peak values in the same trial

Table IV. Rate of perceived exertion of the subjects during exercise in both the trial

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Placebo</th>
<th>Caffeine</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10.6 ± 2.4</td>
<td>9.6 ± 2.0</td>
</tr>
<tr>
<td>20</td>
<td>12.0 ± 2.3</td>
<td>11.0 ± 2.2</td>
</tr>
<tr>
<td>30</td>
<td>13.0 ± 2.6</td>
<td>11.7 ± 2.1 *</td>
</tr>
<tr>
<td>40</td>
<td>14.2 ± 2.5</td>
<td>12.4 ± 1.1 *</td>
</tr>
<tr>
<td>50</td>
<td>15.3 ± 2.7</td>
<td>13.5 ± 1.8 *</td>
</tr>
<tr>
<td>60</td>
<td>16.7 ± 2.6</td>
<td>14.1 ± 2.2 *</td>
</tr>
<tr>
<td>End of the trial</td>
<td>19.6 ± 0.5 *</td>
<td>19.6 ± 0.2 *</td>
</tr>
</tbody>
</table>

* P<0.05 between trials

# P<0.001 between resting and peak values in the same trial

running for significantly (P<0.05) longer duration in the C trial in comparison with P trial.

In conclusion, our results showed that ingestion of 5 mg of caffeine per kg of body weight one hour before the exercise improved the endurance running performance among non-users of caffeine in a hot and humid condition but did not impose any significant effect on other individual cardiorespiratory parameters in heat-adapted recreational runners.

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References


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