# Effect of caffeinated coffee on running speed, respiratory factors, blood lactate and perceived exertion during 1500-m treadmill running

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**Using a motorized treadmill the study investigated the effects of the ingestion of 3 g of caffeinated coffee on: the time taken to run 1500 m; the selected speed with which athletes completed a 1-min 'finishing burst' at the end of a high-intensity run; and respiratory factors, perceived exertion and blood lactate levels during a high intensity 1500-m run. In all testing protocols decaffeinated coffee (3 g) was used as a placebo and a double-blind experimental design was used throughout. The participants in the study were middle distance athletes of club, county and national standard. The results showed that ingestion of caffeinated coffee: decreases the time taken to run 1500 m ($P < 0.005$); increases the speed of the 'finishing burst' ($P < 0.005$); and increases $\dot{V}O_2$ during the high-intensity 1500-m run ($P < 0.025$). The study concluded that under these laboratory conditions, the ingestion of caffeinated coffee could enhance the performance of sustained high-intensity exercise.**

**Keywords: Caffeine, ergogenic acid, $\dot{V}O_2$, blood lactate**

Caffeine has long been considered as a substance capable of enhancing performance or physiological functions[1] and as a result of its reported ergogenic effects, the International Olympic Committee (IOC) have banned the use of high levels of caffeine. However, since caffeine is commonly found in many foods that are taken as part of the 'normal' diet, when testing for the drug the banned level is set above $15\,\mu g\,ml^{-1}$ urine which is reported to represent the ingestion of 500–600 mg of caffeine (five to six cups of coffee) in a 1–2 h period[2]. Therefore in practical terms this dosage is only likely to be exceeded through the use of tablets, injections, suppositories or the deliberate ingestion of large amounts[3].

However, there is some evidence to suggest that the amount of caffeine found in a strong cup of coffee, while not exceeding the limits set by the IOC, may be more than enough to enable an athlete to experience the physiological benefits available from caffeine. The reported ergogenic actions of caffeine have been reviewed in a number of articles[1,2,4] and include stimulation of: the central nervous system; the heart and skeletal muscles; the kidneys including diuresis; respiratory rate and depth; the adrenal medulla increasing the secretion of catecholamines; the release of calcium ions from the sarcoplasmic reticulum; and the oxidation of free fatty acids which would produce a glycogen-sparing effect during prolonged exercise.

Research into the effects of caffeine has tended to concentrate upon endurance activities such as marathon running or prolonged cycling[5–7], with other investigations studying its effects upon maximal strength and power[8,9]. However, relatively little research has looked at the effects of caffeine upon high-intensity prolonged exercise, where the relative importance of the different physiological parameters required to produce a high level of performance and the physiological causes of fatigue can differ from those of endurance and short-term high-intensity exercise.

The aim of this investigation was therefore to study the effect(s) of low doses of caffeine (approximately equivalent to the amount found in two strong cups of coffee) on a number of factors during prolonged high-intensity exercise. The study utilized doses of caffeine that would realistically be ingested by a sports performer before exercise as part of their 'normal' dietary habits without contravening the doping control regulations.

## Materials and methods

Three different exercise testing Protocols were used in the investigation:

1. time trials to assess whether the time taken to complete 1500 m was affected by the ingestion of caffeinated coffee;
2. high-intensity runs during which the first 1100 m were completed at a predetermined speed and the run completed with a final 1-min maximum 'finishing burst' at a speed determined by the athlete;
3. high-intensity 1500 m runs at a speed which was $0.5\,km\,h^{-1}$ slower than the athlete's fastest pace for the course in Protocol 1. This was used to assess whether caffeine had any effect upon respiratory factors, blood lactate or perceived exertion during prolonged high-intensity running on a treadmill.

### General methods

Throughout the investigation all subjects were requested to maintain consistent dietary habits,

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including adherence to the carbohydrate exchange diet (A. E. Hardman, personal communication). They were also asked to abstain from caffeinated foods or beverages and alcohol for a period of at least 24 h before the assessment sessions. Each subject's average daily caffeine consumption was estimated[10] using a questionnaire, since it has been reported that the habitual ingestion of caffeine can result in a tolerance to it and could therefore influence the results of the study[11].

Previous studies investigating the effects of caffeine have used doses of caffeine of 250–800 mg. The amounts used in this investigation were selected primarily because 3 g of coffee (containing approximately 150–200 mg caffeine) realistically represented what an athlete might consume before an event.

One hour before each assessment run the subjects ingested either 3 g instant caffeinated coffee in 350 ml hot water (C), or 3 g instant decaffeinated coffee in 350 ml hot water (D). All coffee was weighed to the nearest 50 mg, using an Oertling HB 63 electronic balance, Oertling, Warley, UK, and a double-blind experimental procedure was used in all three protocols. Pilot studies have shown decaffeinated coffee to be a suitable placebo since subjects were unable to distinguish between it and caffeinated coffee. Decaffeinated coffee has also been shown not to affect oxygen uptake (*R*), perceived exertion or blood lactate levels, and not to affect performance detrimentally when compared with the ingestion of water before the 1500-m runs. The coffee was ingested 1 h before exercise as this time period has been shown to be optimal for the peak absorption of caffeine[1,11].

A motorized treadmill (Powerjog E10, Sport Engineering, Birmingham, UK) set at a 0% gradient was used in all three sections of the investigation. Before testing the subjects declared themselves fit, free from injury and illness, and not to have recently undertaken strenuous exercise that could affect their performance. To minimize any potential effects of circadian rhythm[12,13] each subject fasted overnight and was tested at the same time each morning. All assessment sessions were preceded by a standardized warm up during which the athletes ran on the treadmill for 7–10 min at self selected speeds, this was then followed with 5–10 min of stretching and loosening exercises, with duration and intensity of the warm up being kept consistent for each athlete throughout.

Throughout the study all expired air samples were collected in 2001 Douglas bags (W. E. Collins, Mississippi, USA) using low resistance SRI (Scientific Research Instruments, Edenbridge, UK) mouthpieces and triple head valves. Expired air samples were analysed using separate oxygen and carbon dioxide analysers (Sybron/Taylor Servomex, Crowborough, UK) which had been calibrated using certified gas mixtures (British Oxygen, London, UK) and the volume of expired air assessed using an SRI dry gas meter. Additional data, including the temperature and barometric pressure, were also recorded and used in the calculations. The $\dot{V}O_2$ and *R* values were calculated from these data using a BBC microcomputer (Acorn Computers, Cambridge, UK) program based upon the calculations given by MacDougall *et al*[14]. The coefficients of variation for $\dot{V}O_2$ and *R* were calculated to be 2.2 and 2.5% respectively[15]. Immediately upon completion of each run the subjects were asked to rate their perceived exertion on a scale of 1–5 (*Table 1*). This enabled a comparison of the subjects' perception of fatigue while exercising at or close to their $\dot{V}O_{2max}$.

**Table 1.** Scale of perceived exertion

| | |
|---|---|
| 5 | Absolute maximum/overstretched |
| 4 | Tough maximum |
| 3 | Maximum |
| 2 | Tolerable maximum |
| 1 | Comfortable maximum |

Upon completion of each run the athletes completed a standardized cool down which consisted of a 2-min walk on the treadmill at a speed of 3 km h$^{-1}$ before sitting for a further 3 min. In Protocols 2 and 3 a blood sample was then taken from a finger (5 min after the cessation of the run) using a 'monojector lancet device' and capillary lysing tubes (Analox Instruments, London, UK). A recovery time of 5 min was selected as various studies have indicated peak blood lactate levels to be recorded at this time[16]. The blood sample was then analysed for blood lactate using a 'Champion P-LM5' Blood Lactate analyser (Analox Instruments, UK). The coefficient of variation for the blood lactate measurements was calculated to be 7.8%[15].

## Protocol 1 – 1500-m time trials

Eighteen male athletes participated in this section of the investigation. All were local middle distance athletes or fit Sports Science students. The subjects' ages ranged from 18 to 29 (mean 21.8) years and in preliminary sessions the subjects recorded $\dot{V}O_{2max}$ values of 46–75 (mean(s.d.) 62.5(5.13)) ml kg$^{-1}$ min$^{-1}$.

Each subject completed their standardized warm up with 1 min running on the treadmill at an exercise intensity of approximately 60% of their maximum 1500-m speed followed by 10 s at 90%, 20 s at 60%, 10 s at 90% and 20 s at 60%. They were then given a rest of 1 min before commencing the test.

Each time trial commenced with a 30-s rolling start at a speed corresponding to approximately 60% of the athlete's maximum 1500-m speed. The rolling start helped to minimize any inconsistencies and difficulties that could be encountered when rapidly accelerating the treadmill from a standstill to the athlete's desired speed. At the end of the rolling start the treadmill's speed indicator was concealed from the athlete's view and the athlete given a 5-s countdown into the 1500 m. The treadmill distance indicator was then zeroed at which time the athlete would increase the speed of the treadmill up to the desired level. Since the speed indicator was concealed from view this speed was determined by their own perceived exertion of the intensity of the exercise and their subjective feelings of their running capabilities. The athletes were allowed to adjust the speed of the treadmill throughout the 1500 m and were given verbal information on the distance covered at intervals of 150 m.

All subjects had some experience of treadmill running before the investigation commenced and had undertaken at least one $\dot{V}O_{2\,max}$ assessment. The subjects completed a total of nine time trials. The first three of these were used as familiarization sessions with the remaining six constituting the assessment sessions – three following the ingestion of caffeinated coffee (C) and three following the ingestion of decaffeinated coffee (D) – which were administered in a paired random order. The time taken to complete the distance was recorded in seconds using a stop watch and the data analysed using analysis of variance tests.

### Protocol 2 – high-intensity run plus 1 min 'finishing burst'

Ten subjects participated in this section of the investigation – all were local athletes of club, county or national standard with $\dot{V}O_{2\,max}$ values of 63.9–88.1 $ml\,kg^{-1}\,min^{-1}$. Of this group four had already participated in Protocol 1. The other six underwent an initial $\dot{V}O_{2\,max}$ test and three preliminary 1500-m time trials (using Protocol 1) during the first of which their personal best time for 1500 m on the track was used as an initial indicator of their potential running speed on the treadmill. These preliminary sessions familiarized the athletes with treadmill running and produced the required information on their 1500-m running time on the treadmill.

Based upon the results obtained from Protocol 1 it was possible to calculate each athlete's average fastest running speed for the 1500-m time trial. The second stage of the investigation required the athletes to run for 1100 m at a speed 1 $km\,h^{-1}$ slower than this pace but then required them to complete one final minute as fast as possible, simulating a final 'finishing burst' of approximately 400 m.

Following the standardized warm up the athletes commenced the run with a 30-s rolling start at 60% of the speed at which the athlete would complete the first 1100 m. The assessor then gradually increased the speed of the treadmill to the desired level, the distance indicator of the treadmill was set to zero and the assessment run commenced. Just before completing 1100 m the speed indicator was concealed from the athlete and upon completing 1100 m the athlete accelerated up to the maximum pace which they felt that they could maintain for one further minute. Having attained this pace they indicated to the assessor that they were ready and the final minute was started, during which a 60-s expired air sample was collected and the speed of the treadmill was recorded and kept constant. Upon completion of the run the athletes performed the standardized cool down and blood samples were taken 5 min after completion of the run.

### Protocol 3 – high-intensity 1500-m run at a predetermined speed

To investigate the effects of caffeinated coffee upon sustained high-intensity exercise the subjects performed runs at a speed 0.5 $km\,h^{-1}$ slower than the average speed of their fastest recorded 1500-m treadmill run (Protocol 1). This produced high-intensity exercise which could be reproduced and attained by the subjects at all assessment sessions.

Subjects were six male middle distance athletes of club, county or national standard aged between 17 and 32 years, with $\dot{V}O_{2\,max}$ values of 63.9–88.1 (mean 75.5) $ml\,kg^{-1}\,min^{-1}$. All subjects had already participated in Protocol 2 of the investigation.

Each subject completed a total of nine runs, three familiarization runs and six assessment sessions (three following the ingestion of caffeinated coffee and three following the ingestion of decaffeinated coffee). A double-blind research design was utilized with the caffeinated and decaffeinated coffee being administered in a paired random order.

The basic protocol for this section was similar to the previous ones, with all athletes completing a standardized warm up and the run commencing with a 30-s rolling start at a speed corresponding to 60% of the speed at which they would run the 1500 m. The speed of the treadmill was then gradually increased to the desired speed whereupon the distance register was set to zero and the athlete commenced the 1500-m run. During the run a 60-s expired air sample was collected 2.5–3.5 min into the run.

Immediately upon completion of the run the athletes rated their perceived exertion using the five-point scale (*Table 1*) and began the standardized cool down, after which a blood sample was taken.

## Results

The results of Protocols 1, 2 and 3 are summarized in *Tables 2, 3* and *4* respectively. Where appropriate the

**Table 2.** Results from Protocol 1 – mean time taken by each subject to complete 1500 m following the ingestion of caffeinated or decaffeinated coffee

| *Subject* | *Time to run 1500 m (s)* | | | *Rank order of habitual caffeine ingestion* |
|---|---|---|---|---|
| | *C* | *D* | *D–C* | |
| 1 | 322.9(24.1) | 339.9(26.3) | 17.0 | 4 |
| 2 | 330.9(4.7) | 341.7(19.8) | 10.8 | 6 |
| 3 | 275.7(8.2) | 284.3(4.5) | 8.6 | 14 |
| 4 | 303.8(4.8) | 311.6(10.6) | 7.8 | 17 |
| 5 | 291.5(3.5) | 298.9(2.8) | 7.4 | 1 |
| 6 | 236.1(4.8) | 242.7(1.9) | 6.6 | 11 |
| 7 | 256.4(1.0) | 262.3(4.8) | 5.9 | 13 |
| 8 | 266.8(8.5) | 270.7(5.5) | 3.9 | 7 |
| 9 | 337.3(1.7) | 340.7(13.7) | 3.4 | 16 |
| 10 | 282.1(2.6) | 285.1(0.9) | 3.0 | 5 |
| 11 | 315.6(17.3) | 318.0(9.9) | 2.4 | 15 |
| 12 | 268.9(15.0) | 271.2(9.5) | 2.3 | 10 |
| 13 | 300.5(9.6) | 302.2(7.0) | 1.7 | 2 |
| 14 | 295.5(10.8) | 297.0(5.1) | 1.5 | 12 |
| 15 | 239.1(1.3) | 238.5(2.7) | –0.5 | 17 |
| 16 | 310.9(12.9) | 309.7(12.8) | –1.2 | 3 |
| 17 | 242.5(2.4) | 241.0(2.0) | –1.5 | 9 |
| 18 | 272.2(13.9) | 268.6(9.1) | –3.6 | 8 |
| $\bar{x}$ | 286.0 | 290.2 | +4.2 | |

Values are mean(s.d.) of three runs. C, caffeinated coffee ingested; D, decaffeinated coffee. $F = 12.6$, $P < 0.005$ (analysis of variance C *versus* D)

**Table 3.** Results from Protocol 2

| Subject | Speed of initial 1100 m ($km\ h^{-1}$) | Speed of final min ($km\ h^{-1}$)* | | | $\dot{V}O_2$ ($ml\ kg^{-1}\ min^{-1}$)† | | R‡ | | Blood lactate (mmol)§ | | Perceived exertion | | Rank order of habitual caffeine ingestion |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C | D | C–D | C | D | C | D | C | D | C | D | |
| 1 | 22.0 | 25.7(1.07) | 25.6(0.42) | 0.1 | 85.9(3.31) | 81.6(0.55) | 0.93(0.04) | 0.96(0.04) | 10.2(1.40) | 10.7(0.92) | 4.3 | 5.0 | 8.5 |
| 2 | 21.5 | 24.1(1.40) | 23.7(0.75) | 0.4 | 73.8(3.57) | 72.8(1.44) | 1.04(0.02) | 1.02(0.02) | 14.4(2.23) | 13.7(0.70) | 4.7 | 4.7 | 8.5 |
| 3 | 19.9 | 21.5(0.30) | 21.2(0.29) | 0.3 | 68.5(1.17) | 67.0(2.00) | 0.96(0.04) | 0.97(0.02) | 11.6(0.87) | 12.0(0.72) | 4.0 | 4.0 | 5 |
| 4 | 18.2 | 20.4(0.55) | 20.1(0.32) | 0.3 | 66.9(0.21) | 64.3(0.90) | 0.92(0.02) | 0.93(0.05) | 12.1(0.70) | 13.0(0.35) | 5.0 | 5.0 | 4 |
| 5 | 18.0 | 23.6(0.40) | 22.1(0.67) | 1.5 | 63.8(2.24) | 62.2(0.36) | 1.03(0.02) | 1.05(0.02) | 15.7(0.70) | 13.5(1.53) | 5.0 | 4.7 | 8.5 |
| 6 | 22.0 | 25.9(0.12) | 24.7(0.46) | 1.2 | 75.7(2.30) | 75.8(1.83) | 1.01(0.04) | 1.00(0.04) | 12.7(0.64) | 11.1(1.33) | 4.7 | 4.0 | 3 |
| 7 | 19.0 | 21.9(1.45) | 21.7(0.90) | 0.2 | 64.7(0.17) | 63.5(1.94) | 0.99(0.02) | 1.01(0.02) | 12.1(0.70) | 11.0(0.40) | 4.7 | 4.3 | 1 |
| 8 | 19.4 | 21.7(0.49) | 21.3(0.06) | 0.4 | 65.3(1.02) | 63.7(0.74) | 0.97(0.02) | 0.99(0.06) | 13.0(0.72) | 13.2(0.72) | 5.0 | 5.0 | 8.5 |
| 9 | 21.4 | 24.3(0.70) | 23.0(0.40) | 1.3 | 77.9(0.98) | 77.4(0.95) | 0.94(0.04) | 0.97(0.02) | 9.1(1.01) | 8.6(1.73) | 4.7 | 4.7 | 6 |
| 10 | 21.5 | 26.0(0.06) | 25.9(0.12) | 0.1 | 67.5(0.86) | 68.5(0.70) | 1.02(0.02) | 1.04(0.02) | 14.5(0.76) | 15.4(1.31) | 4.7 | 4.7 | 2 |
| $\bar{x}$ | 20.3 | 23.5 | 22.9 | 0.6 | 71.0 | 69.7 | 0.98 | 0.99 | 12.5 | 12.2 | 4.7 | 4.6 | |

Values are mean(s.d.) of three runs. C, caffeinated coffee; D, decaffeinated coffee. *$F$ 15.55, $P < 0.05$; †$F$ 8.30, $P < 0.005$; ‡$F$ 6.31, $P < 0.05$; §$F$ 0.80, not significant (C *versus* D, analysis of variance)

**Table 4.** Results from Protocol 3

| Subject | Speed ($km\ h^{-1}$) | $\dot{V}O_2$ ($ml\ kg^{-1}\ min^{-1}$)* | | R† | | Blood lactate (mmol)‡ | | Perceived exertion | | Rank order of habitual ingestion |
|---|---|---|---|---|---|---|---|---|---|---|
| | | C | D | C | D | C | D | C | D | |
| 1 | 23.0 | 81.6(1.51) | 78.5(2.93) | 0.91(0.03) | 0.95(0.02) | 9.7(2.23) | 9.2(1.97) | 2.0 | 2.0 | 1.5 |
| 2 | 22.5 | 83.0(2.86) | 81.1(2.34) | 0.87(0.04) | 0.92(0.04) | 7.7(0.30) | 7.7(0.64) | 1.7 | 1.7 | 5.0 |
| 3 | 22.5 | 80.3(1.45) | 79.3(2.45) | 0.90(0.02) | 0.91(0.02) | 7.7(0.58) | 7.8(0.87) | 1.3 | 1.3 | 1.5 |
| 4 | 20.4 | 67.5(1.96) | 67.1(2.43) | 0.93(0.02) | 0.91(0.00) | 11.8(1.25) | 12.0(0.49) | 3.7 | 3.7 | 4.0 |
| 5 | 18.7 | 64.2(1.37) | 63.8(1.40) | 0.91(0.04) | 0.91(0.00) | 11.1(0.64) | 10.6(1.22) | 4.0 | 4.0 | 3.0 |
| 6 | 18.5 | 64.0(1.00) | 62.3(1.68) | 0.92(0.02) | 0.93(0.04) | 8.5(1.03) | 9.4(0.60) | 2.7 | 3.7 | 6.0 |
| $\bar{x}$ | 20.9 | 73.4 | 72.0 | 0.91 | 0.92 | 9.4 | 9.5 | 2.6 | 2.7 | |

Values are mean(s.d.) of three runs. C, caffeinated coffee; D, decaffeinated coffee. *$F$ 11.17, $P < 0.025$; †$F$ 2.02, not significant; ‡$F$ 0.03, not significant (C *versus* D, analysis of variance)

data were analysed using analysis of variance tests for correlated data[16] and a summary of the findings is included within each table.

## Discussion

Protocol 1 showed a statistically significant ($P < 0.005$) difference in the group means for the time taken to complete the 1500-m run following the two regimens C and D. Overall the average mean time to complete the run was 4.2 s faster following the ingestion of caffeinated coffee. Further analysis of the data revealed that 14 of the 18 subjects had faster mean times for the run after the ingestion of caffeinated coffee.

Protocol 2 results supported those from Protocol 1, with all ten of the subjects recording faster speeds (mean of three replicate runs) during the final minute of their run after ingesting caffeinated coffee. An analysis of variance test showed this to be statistically significant with the mean difference in speed for the group being 0.6 (range 0.1–1.5) $km\ h^{-1}$. Over a period of 1 min an increase in speed of 0.6 $km\ h^{-1}$ would correspond to a distance of about 10 m. Analysis of the $\dot{V}O_2$ data showed that eight of the ten subjects recorded higher $\dot{V}O_2$ values during the C runs. This was statistically significant ($P < 0.025$) and is likely to be associated with the faster running speeds attained following the caffeinated coffee (C). In addition to this, eight of the ten subjects recorded lower mean $R$ values for the caffeinated (C) regimen. While this was statistically significant ($P < 0.05$), the basis for this difference is unclear. Statistical analysis of the blood lactate data and perceived exertion ratings revealed no statistically significant differences. However this was not unexpected since all subjects were attempting to run at their maximum perceived exertion in all runs and the level of blood lactate is likely to be associated with this.

In Protocol 3 all six subjects produced a higher mean $\dot{V}O_2$ during the C runs and an analysis of variance test showed this to be statistically significant ($P < 0.025$). However, no other factors were found to be statistically significant in this section.

In all three protocols factors such as the subjects' average running speed and their habitual caffeine intake did not appear to influence the results or the magnitude of any observed improvement. Indeed, the recorded differences between the C and D runs were observed in members of the group of all running standards from club to national level and among those who had a relatively high habitual caffeine intake as well as those with a relatively low habitual caffeine intake.

Overall, the results indicate that, under these controlled laboratory conditions and following an overnight fast, ingestion of 3 g of caffeinated coffee could enhance oxygen uptake and running performance in sustained high-intensity exercise on a motorized treadmill. Since the subjects' choice of speed with which to complete the final 1 min in Protocol 2 was influenced by their perceived exertion of the intensity of the exercise, it is also possible to suggest that the ingestion of caffeine reduced their sensation of fatigue which caused them to select a faster running speed. This suggestion would be in keeping with the results from Protocol 1 where an overall decrease in the time taken to run 1500 m was recorded.

In conclusion, the study found that under laboratory conditions small doses of caffeinated coffee (3 g) had an ergogenic effect upon sustained high-intensity exercise. However, when considering the implications of these findings upon the competitive middle distance athlete it should be remembered that few athletes will compete in a race following an overnight fast, and that the effects of food ingested during the day could influence the effects of caffeinated coffee. Other factors which could also have implications for the findings were the use of a motorized treadmill which required a slightly modified running style and the individual's choice of 'tactics' when in a competitive race. Therefore further research is required to clarify the implications of these findings upon athletes competing in 1500-m races on the track.

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