



## Acute Effects of Caffeine on Strength Performance in Trained and Untrained Individuals

Joseph H Brooks<sup>1</sup>, Kevin Wyld<sup>1</sup> and Bryna CR Chrismas<sup>2\*</sup>

### Abstract

**Objective:** The primary aim of this study was to compare the acute effects of a caffeine based supplement on the strength performance of trained and untrained individuals with a secondary investigation into the effects of a placebo.

**Method:** Seven resistance trained (>6 months) and seven untrained (<6 months) males (mean  $\pm$  SD: age: 21  $\pm$  3 y, mass: 75.2  $\pm$  11.3 kg, height: 176  $\pm$  6 cm) consumed either caffeine (CAF) (5 mg.kg.bw<sup>-1</sup>), placebo (PLA) or nothing (CON) 60 minutes prior to 1 RM squat measurements in a double-blinded, repeated measures design. A two way repeated measures ANOVA was applied to test for the main effects of condition (CAF, PLA, CON) and group (Trained, Untrained), and the interaction effect (condition x group).

**Results:** A significant interaction effect ( $F_{(2,11)}=4.38$ ,  $p=0.024$ ) for 1 RM was observed. In the untrained group there was significant difference between CON and PLA ( $p<0.001$ ). On average 1 RM in the untrained group was 12% lower in the CON trial (92.1 kg) compared to the PLA (102.9 kg; 95% CI=-5.3 to -16.1 kg), and 9% lower compared to CAF ( $p=0.005$ ; 95% CI=-2.7 to 14.5 kg). There was no significant difference in 1 RM in the untrained group between PLA and CAF ( $p=0.87$ , 95% CI -3.2 to 7.5 kg). Additionally, there were no significant differences for the trained group between conditions. There was also a significant main effect for condition for 1 RM ( $F_{(2,11)}=12.81$ ,  $p<0.001$ ). Overall the CON trial was 6% lower ( $p=0.001$ , 95% CI=-3.0 to -10.6 kg) than the PLA trial (117.9 kg; 95% CI 97.6 to 124.6 kg), and 5% lower ( $p=0.12$ , 95% CI=-1.2 to -9.5 kg) than the CAF trial (116.4 kg; 95% CI 105.0 to 127.8 kg). There was no significant difference between PLA and CAF ( $p=0.951$ ). Finally, there was a significant main effect for group ( $F_{(1,12)}=8.79$ ,  $p=0.12$ ). On average 1 RM was 25% higher in the trained group (131.7 kg; 95% CI=114.5 to 148.9 kg) compared to the untrained group (98.6 kg; 95% CI=81.4 to 115.8 kg).

**Conclusion:** These findings suggest that both a caffeine supplementation and placebo improve 1 RM in untrained individuals but do not improve performance in resistance trained athletes. No significant differences between caffeine and placebo, suggests placebo induced mechanisms also need to be considered.

### Keywords

One repetition maximum; Squat; Placebo; Force; Muscle activation; Supplementation

### Introduction

Caffeine is one of the highest consumed drugs in the world with 74% of elite athletes now consuming it prior to competition [1]. Caffeine antagonises adenosine by binding to its receptors, reducing its ability to slow neural activity, reduce arousal, and induce sleep [2]. Additionally, altering of metabolic substrate utilisation may occur when caffeine is present, with increased fat oxidation and glycogen sparing equating to increased endurance performance [3]. Enhanced secretion of  $\beta$ -endorphins has also been documented, allowing for prolonged performance as a result of reduced pain perception [4]. Mechanisms of action in terms of strength performance are still not clear, however, theories for both central and peripheral factors have been postulated [5]. Possible mechanisms may include increased muscle activation, motor unit recruitment [6,7], and enhanced excitation contraction coupling [6]. The effect of caffeine as an adenosine antagonist may also increase maximal voluntary contraction through increased neurotransmitter release, increased firing rates, and increased spontaneous and evoked potentials [8].

Support for the benefits of caffeine is plentiful when investigating endurance based performance [9-11]. Significant enhancements in cycling [12-14], swimming [15] and rowing [16] have been reported following caffeine ingestion. A plethora of research also highlights the use of caffeine to improve muscular endurance; with regards to greater repetitions to failure [17], lower ratings of perceived exertion [18] and reduced fatigue [17]. However, reports of increased muscular strength performance are less established, and often more equivocal. In one study [19], a 5 mg.kg.bw<sup>-1</sup> caffeine dose significantly enhanced bench press 1 RM in resistance trained females. Furthermore, 201 mg of caffeine significantly increased bench press 1 RM in trained men [20] but had no effect on leg extension 1 RM. In untrained men, a similar caffeine dose had no effect on bench press 1 RM [21]. Hendrix et al. [22] also showed no increase in bench press 1 RM or leg extension 1 RM in untrained individuals following 400 mg of caffeine. Similarly, no improvement in trained men was shown for bench press or lat pull down 1 RM following 300 mg caffeine [23]. Eckerson et al. [24] also showed no significant increase in bench press 1 RM in trained individuals following 160mg of caffeine vs. placebo. Furthermore, no increase in bench press or leg press 1 RM compared to placebo was shown in resistance trained men [25]. Consequently, it appears that training status, and exercise type may help explain the equivocal effects of caffeine. Despite this, the effects of training status have only been researched directly in endurance tasks. For example, Collomp et al. [15] displayed a significant reduction in swimming time trials of elite swimmers, with no significant improvement in recreational swimmers, following 250 mg caffeine supplementation. However, these results are not transferable to strength tasks revealing a distinct need for further research in this area.

In terms of studies that have investigated the mechanisms associated with enhanced performance during strength based exercise, contradicting results have been published in terms of muscle activation. Multiple studies have shown significant increases in healthy individuals [26-28] however no significant difference was produced in high level runners [29]. None of these studies have however employed dynamic compound movements and/or utilised

\*Corresponding author: Dr Bryna Chrismas, Sport Science Program, College of Arts and Sciences, Qatar University, Doha, Qatar, Tel: +974 7056 7602; E-mail: [bchrismas@qu.edu.qa](mailto:bchrismas@qu.edu.qa)

Received: October 28, 2015 Accepted: December 14, 2015 Published: December 20, 2015

muscle activation measurements during movements used by elite athletes in training and competition, which have been shown to increase performance [30]. Subsequently, more applicable research in this area is clearly warranted.

Interestingly caffeine placebos have been shown to significantly increase the performance of both endurance and muscular endurance based tasks, often to a similar degree to real caffeine supplements [31-33]. Enhanced muscular work output [33] and reports of caffeine-related symptoms post placebo ingestion have been shown [31]. In addition, improved repetitions to failure and reduced RPE [32] have also been documented. The side effects of caffeine have been well documented [34] and common symptoms for example sleep deprivation [35] may inhibit an athlete's ability to recover effectively. If caffeine-related benefits can be replicated via placebo ingestion, removing the negative side effects, then this may offer an interesting insight for coaches. Research has currently failed to measure the possible magnitude of improvement from a caffeine placebo during 1 RM lifts although they have been shown to increase sporting performance [36]. Research into the effects of a placebo on this type of muscular action would allow for better application of research into both training and competition.

The aim of the current study was to therefore investigate whether acute consumption of a caffeine based supplement (5 mg.kg.bw<sup>-1</sup>) would significantly improve strength performance in trained and untrained individuals. An additional goal was to investigate the caffeine placebo effects on strength based tasks. It was hypothesised that both caffeine and a placebo would significantly increase 1 RM performance trained subjects but have no effect on untrained.

## Methodology

### Experimental approach to the problem

A double-blind, repeated-measures, cross over design was applied. Treatment order (CAF, PLA, CON) was randomly assigned and counterbalanced. Trials were performed at the same time of day (9:00-12:00) to avoid diurnal variation [37]. Subjects attended the laboratory on four separate occasions (Preliminary Measures/Familiarisation, Condition 1, Condition 2 and Condition 3) all separated by 1 week. A smith machine (Pullum: Pullum Pro) was used to assess 1 RM measurements for the barbell back squat on all occasions. Electromyography (vastus lateralis) and vertical force production were assessed during the lift to measure for muscle activation and peak force production. A maximal isometric contraction on a fixed barbell was then performed to normalise EMG data and calculate a percentage of muscle activity. Statistical tests were conducted to test a trained group (n=7) and untrained group (n=7).

### Subjects

Seven resistance trained and seven non-resistance trained male subjects (white, British, age: 21 ± 3 y, mass: 75.2 ± 11.3 kg, height: 176 ± 6 cm) volunteered to be included in this experiment. All subjects categorised themselves as healthy and free from injury or illness. Only male subjects were recruited to remove potential variability caused by a menstrual cycle influence when measuring caffeine response in a female population [38]. Only non-smoking individuals of a normal body weight (BMI=18-29) were enlisted to avoid the increased rate of caffeine degradation [39]. Inclusion criteria stipulated that subjects had been either resistance training at least 3 days a week for the past 6 months (trained) or had not partaken in regular resistance training

for the past 6 months (untrained). Typical training for the "trained" group included both upper and lower body resistance training at a moderate to high repetition range [6-12] and intensity (70-90% 1RM). All testing procedures were verbally explained and a written information sheet was given to all subjects. Informed consent and a physical activity readiness questionnaire was completed prior to participation. A preliminary blood pressure test (Omron, M5-I) was carried out prior to any testing as well as a pre-test questionnaire. If resting blood pressure was ≥ 140/90 mmHg the subject was removed from the study. All subjects had a resting blood pressure less than this cut off, and therefore, no subjects were removed. Subjects were advised to maintain their normal lifestyle patterns apart from being instructed to not participate in vigorous activity 48 hours prior to testing. Subjects were also required to abstain from consuming any other caffeine throughout testing. Additionally, no caffeine was to be consumed within 5 days of starting the experiment to allow for caffeine withdrawal to potentiate effects of acute ingestion [40]. Ethical approval was gained from the University of Bedfordshire prior to any data collection.

### Familiarisation/Preliminary measures

Preliminary measurements for age, height (Stadiometer, Harpendon: HAR-98.602), mass (Tanita: BWB0800) and blood pressure were obtained in the first laboratory visit. Familiarisation processes were instructed by a level 3 personal trainer in which the correct technique for the barbell squat was taught [41]. Subjects were trained to squat to a knee angle of 90° for standardisation. Preliminary 1 RM squats were performed on the smith machine to familiarise the subjects with the 1 RM protocol as well as exercise technique. One repetition maximum measurements were recorded as the maximum amount of weight lifted in which the correct technique was maintained [41]. All 1 RM tests began with a 5 minute warm up on a cycle ergometer (Monark, 824e) at 100 W followed by dynamic stretches (2x15 leg swings each leg) and body weight squats (2 x 12 repetitions). Dynamic stretches were used rather than static due to potential loss of power and strength [42]. A 5 minute cool down was performed on a cycle ergometer (Monark, 824e) at 100 W followed by static stretches for the lower body post testing. All results from the preliminary 1 RM were discarded and not included in the analysis. Subjects returned to the lab 7 days later for the first session of testing.

### Testing protocol

Subjects were randomly allocated in the second visit to consume either a caffeine (CAF) supplement (5 mg.kg.bw<sup>-1</sup>) a placebo (PLA) (Dextrose, 5 mg.kg.bw<sup>-1</sup>) or nothing (CON). Supplements were administered in capsule form and taken with 300 ml of water allowing for decreased discomfort and taste. One hour post consumption, 1 RM back squat was performed on a smith machine (Pullum, Luton, UK) following an identical protocol as the preliminary tests. The squat was performed whilst standing on a force plate (Kistler, Type 9281) to measure peak vertical force (PVF) throughout the movement. Electromyography (EMG) was used to measure peak contraction (PC) using Kendall ARBO EMG electrodes and recorded using Powerlab software (Version 5) with RMS smoothed data being analysed. Immediately following the 1 RM test, a 5 second maximal isometric contraction was performed against a fixed smith machine barbell at a knee angle of 135° to normalise EMG readings [43]. A peak value from the 5 seconds was used to determine an isometric maximal voluntary contraction (IMVC). Electromyography activity was recorded in the vastus lateralis with a ground electrode placed on

the knee. Electrodes were placed according to SENIAM instructions and recommendations (SENIAM, <http://www.seniam.org>). Location preparation included the shaving and cleaning of the skin using an alcohol solution. Identical testing protocols including warm up and cool down were applied for all subjects, for all three conditions.

### Statistical analysis

Data was analysed using SPSS 19 from SPSS Inc. (SPSS 19.0 for Windows, SPSS, Chicago, IL). All data was deemed to be normally distributed by observation of quantile-quantile (Q-Q) plots. Descriptive statistics were obtained for age, height, mass and blood pressure. To determine muscle activation, an EMG percentage was calculated by dividing peak contraction by IMVC and multiplying by 100 [43]. One repetition maximum, EMG % and PVF were all analysed using a two way repeated measures analysis of variance (ANOVA) to test for significant differences between condition (CAF, PLA CON) and group (trained, untrained), and the interaction effect (condition x group). If Mauchly's test of sphericity was observed as non-significant ( $p > 0.05$ ) then sphericity assumed results were reported. In the case of Mauchly's test being deemed as significant ( $p < 0.05$ ), then results derived from a Greenhouse-Geisser test were reported. Following a significant F value, direction and magnitude of difference amongst means were determined using a Bonferroni post hoc test. Significance level was set at  $p < 0.05$ . All results are presented as mean  $\pm$  standard deviation (Table 1).

## Results

### One repetition maximum

A significant interaction effect ( $F = 4.38, p = 0.024$ ) for 1 RM was observed. In the untrained group there was significant difference between CON and PLA ( $p < 0.001$ ). On average 1 RM in the untrained group was 12% lower in the CON trial (92.1 kg) compared to the PLA (102.9 kg; 95% CI = -5.3 to -16.1 kg), and 9% lower compared to CAF ( $p = 0.005$ ; 95% CI = -2.7 to 14.5 kg). There was no significant difference in 1 RM in the untrained group between PLA and CAF ( $p = 0.87$ , 95% CI -3.2 to 7.5 kg) (Figure 1). Additionally, there were no significant differences for the trained group between conditions. There was also a significant main effect for condition for 1 RM ( $F_{(2,11)} = 12.81, p < 0.001$ ). Overall the CON trial was 6% lower ( $p = 0.001$ , 95% CI = -3.0 to -10.6 kg) than the PLA trial (117.9 kg; 95% CI 97.6 to 124.6 kg), and 5% lower ( $p = 0.12$ , 95% CI = -1.2 to -9.5 kg) than the CAF trial (116.4 kg; 95% CI 105.0 to 127.8 kg) (Figure 2). There was no significant difference between PLA and CAF ( $p = 0.951$ ). Finally, there was a significant main effect for group ( $F_{(1,12)} = 8.79, p = 0.12$ ). On average 1 RM was 25% higher in the trained group (131.7 kg; 95% CI = 114.5 to 148.9 kg) compared to the untrained group (98.6 kg; 95% CI = 81.4 to 115.8 kg).

### Muscle activation

No significant interaction effect for muscle activation was revealed ( $F_{(2,11)} = 0.386, p = 0.684$ ). There was also no significant main effect for condition ( $F_{(2,11)} = 0.51, p = 0.61$ ) or group ( $F_{(1,12)} = 1.69, p = 0.22$ , 95% CI = -11.86 to 46.98%).

### Force production

A significant main effect was revealed for group ( $F_{(1,12)} = 8.91, p = 0.01$ ) with average MVF 53% higher in the trained group (2474.98 N; 95% CI = 2029.94 to 2920.03 N) compared to the untrained group (1612.68 N; 95% CI = 1167.64 to 2057.73 N). No significant interaction

effect was observed ( $F_{(2,11)} = 0.311, p = 0.735$ ). There was also no significant main effect for condition ( $F_{(2,11)} = 2.63, p = 0.12$ ).

## Discussion

Both acute caffeine and placebo supplementation significantly increased back squat 1 RM measurements in untrained individuals averaging increases of 11% and 9% respectively. To the authors' knowledge, this is the first study to report significant increases of 1 RM squat measurements in untrained individuals following caffeine supplementation. Results found therefore contradict those previously reported on untrained individuals when no significant increase was observed [21,22]. In terms of placebo ingestion, this study was the first to investigate the effect of a caffeine placebo on 1 RM strength performance. Results found do however coincide with those previous reported in muscular endurance [31-33].

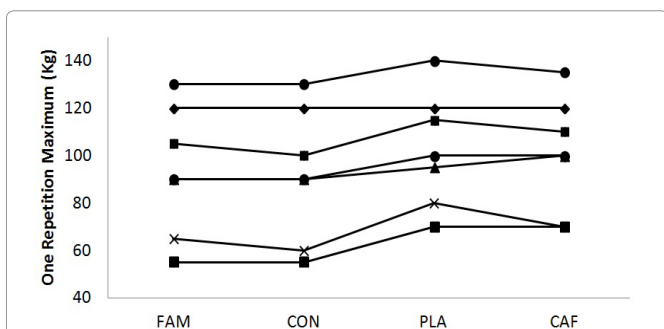
No significant difference was found for trained individuals following caffeine ingestion although a mean increase of 2% was observed. This supports the collection of previous research documenting no significant increase [20,23-25]. It does however contradict the research reporting significant increases of 1 RM bench press in resistance trained women [19] and men [20] although non-significant percentage increases of a similar degree were observed. Different muscle groups tested may have influence on degree of variation observed which may explain the results presented. A placebo supplement failed to significantly increase 1 RM in trained individuals. As mentioned, this study was the first to investigate the effect of a caffeine placebo on 1 RM strength. However, in comparison to research obtained measuring muscular endurance [31-33] these findings did not support those previously published.

Although placebo ingestion failed to significantly increase performance in trained individuals, caffeine did not vary significantly from placebo in all performance measures taken from both groups. Therefore, the hypothesis that placebo would produce a similar response to caffeine was met and supports previous research into caffeine placebos [28,31,32]. Muscle activation and force production did not significantly increase in either trained or untrained individuals supporting some previously published research [6,29] and contradicting others [27,28]. The lack of significant increase in muscle activation and force production, in either group, suggests that previously devised mechanisms of neurotransmitter release and firing rates were either not increased through the antagonising of adenosine or were increased but had no effect on strength performance. Unfortunately, the measuring of these mechanisms was out of the scope of this study. A probable cause is the lower dosage of

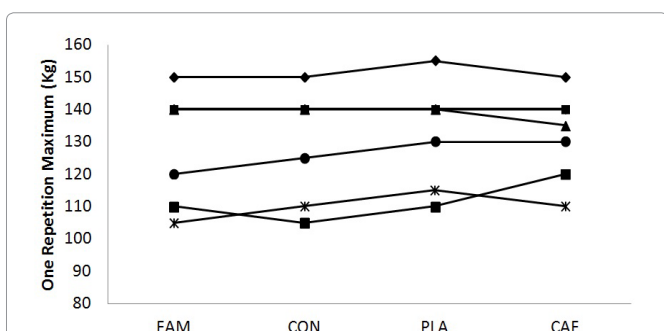
	Control	Placebo	Caffeine
<b>1 RM (KG)</b>			
Trained	130 $\pm$ 17.1	132.1 $\pm$ 13.5	132.9 $\pm$ 13.1
Untrained	92.1 $\pm$ 27.9	100.7 $\pm$ 24.2*	102.8 $\pm$ 24.1*
<b>EMG Percentage (%)</b>			
Trained	120.9 $\pm$ 34.5	130.1 $\pm$ 43.9	124.9 $\pm$ 29.2
Untrained	105.8 $\pm$ 21.4	105.5 $\pm$ 14.2	111.9 $\pm$ 24
<b>Force Production (N)</b>			
Trained	2407.4 $\pm$ 614.3	2324.6 $\pm$ 798.5	2692.8 $\pm$ 525.9
Untrained	1431.1 $\pm$ 594	1586.9 $\pm$ 617.8	1819.9 $\pm$ 608.4

\* Significantly greater than control.

**Table 1:** Descriptive statistics for Trained (n=7) and Untrained (n=7) groups within Control, Placebo and Caffeine conditions. All values are mean  $\pm$  standard deviation.



**Figure 1:** Individual one repetition maximum measurements for untrained individuals within Familiarization (FAM), Control (CON), Placebo (PLA) and Caffeine (CAF) conditions. N=7.



**Figure 2:** Individual one repetition maximum measurements for trained individuals within Familiarization (FAM), Control (CON), Placebo (PLA) and Caffeine (CAF) conditions. N=7.

caffeine administered ( $5 \text{ mg} \cdot \text{kg} \cdot \text{bw}^{-1}$ ) within this study in comparison to previous research which has shown a significant increase in muscle activation [27,28].

No distinct disparity between caffeine and placebo conditions, even when significant increases were observed, suggests placebo induced mechanisms also need to be considered. Increased expectancy and belief in caffeine supplements has previously been shown to increase their ergogenic properties [44]. This effect has also been previously imitated through placebo consumption [45]. Increased expectancy in a performance enhancing supplement can provide an athlete with greater arousal levels [46] which can in turn increase performance, especially in open, simple tasks [47]. However, this phenomenon does not explain the variation in results observed in the present study between trained and untrained individuals, suggesting the cause for disparity may be more complex. Further research aimed at elucidating the main mechanisms involved in the variability between individuals has been previously reported [19,20]. This research provides the understanding that neither training status nor placebo effects are complex enough explanations for the continuing disparity in data.

### Practical Applications

Compared to a control condition, a caffeine supplement did not significantly increase 1 RM squat measurements of trained athletes. There was no significant effect observed in either force production or muscle activity throughout the maximal lift. This evidence therefore suggests that a caffeine supplement may not be an appropriate ergogenic aid when strength based movements are the main focus. Improved performance was however observed in

untrained individuals meaning caffeine or placebo administration may be beneficial for improving performance in the initial uptake of resistance training.

### Conclusion

The ingestion of caffeine can be utilised by an athlete when endurance and muscular endurance performance is the priority. In terms of muscular strength this piece of research adds to a compilation of work suggesting that caffeine may not provide an ergogenic benefit. Any benefit seen in strength and power based movements is likely to be caused by a degree of expectation and belief when ingesting a substance. It is also understood that the magnitude of effect may be determined on an individual basis for which training status may be a factor.

### Acknowledgements

The authors would like to thank the subjects for their participation in this research. A special mention would also like to be made to the laboratory staff at the University of Bedfordshire for their hard work and patience during the collection of data.

### References

- Del Coso J, Munoz G, Munoz-Guerra J (2011) 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.
- Cronin J, Hansen K (2005) Strength and power predictors of sports speed. *J Strength Cond Res* 19: 349-357.
- Graham TE, Battram DS, Dela F, El-Sohemy A, Thong FS (2008) Does caffeine alter muscle carbohydrate and fat metabolism during exercise? *Appl Physiol Nutr Met* 33: 1311-1318.
- Fredholm B (2014) Adenosine-a physiological or pathophysiological agent? *J Mol Med* 92: 201-206.
- Mccormack W, Hoffman J (2012) Caffeine, Energy drink and Strength-Power Performance. *J Strength Cond Res* 34: 11-16.
- Tarnopolsky M, Atkinson S, Maccougall J, Sale D, Sutton J (1989) Physiological responses to caffeine during endurance running in habitual caffeine users. *Med Sci Sport Exer* 21: 418-424.
- Warren G, Park N, Maresca R, Mckibans K, Millard-Stafford M (2010) Effect of caffeine ingestion on muscular strength and endurance: A meta-analysis. *Med Sci Sports Exer* 42: 1375-1387.
- Kalmar JM (2005) Influence of caffeine on voluntary muscle activation. *Med Sci Sports Exerc* 37: 2113-2119.
- Burke L (2008) Caffeine and sports performance. *Appl Physiol Nutr Me* 33: 1319-1334.
- Cox G, Desbrow B, Montgomery P, Anderson M, Bruce C, et al. (2002) Effect of different protocols of caffeine intake on metabolism and endurance performance. *J Appl Physiol* 93: 990-999.
- Glaister M, Howatson G, Abraham CS, Lockey RA, Goodwin JE, et al. (2008) Caffeine Supplementation and Multiple Sprint Running Performance. *Med Sci Sports Exer* 40: 1835-1840.
- Doherty M, Smith PM (2005) Effects of caffeine ingestion on rating of perceived exertion during and after exercise: A meta- analysis. *Scand J Med Sci Sports* 15: 69-78.
- Hoffman JR, Kang J, Ratamess NA, Jennings PF, Mangine GT, et al. (2007) Effect of nutritionally enriched coffee consumption on aerobic and anaerobic exercise performance. *J Strength Cond Res* 21: 456-459.
- Mcnaughton L, Lovell R, Siegler J, Midgley A, Moore, L, et al. (2008) The effects of caffeine ingestion on time trial cycling performance. *Int J Sports Physiol Perform* 3: 157-163.
- Collomp K, Ahmaidi S, Chatard JC, Audran M, Prefaut C (1992) Benefits of caffeine ingestion on sprint performance in trained and untrained swimmers. *Eur J Appl Physiol Occup Physiol* 64: 377-380.

16. Bruce C, Anderson M, Fraser S, Nigel K, Klein, et al. (2000) Enhancement of 2000-m rowing performance after caffeine ingestion. *Med Sci Sport Exer* 32: 1958-1963.
17. Duncan MJ, Lyons M, Hankey J (2009) Placebo effects of caffeine on short-term resistance exercise to failure. *Int J Sports Physiol Perform* 4: 244-253.
18. Duncan MJ, Smith M, Cook K, James RS (2012) The acute effect of a caffeine-containing energy drink on mood state, readiness to invest effort and resistance exercise to failure. *J Strength Cond Res* 26: 2858-2865.
19. Goldstein E, Jacobs P, Whitehurst M, Penhollow T, Antonio J (2010) Caffeine enhances strength in resistance-trained women. *J Inter Soc Sports Nutri* 7: 18-23.
20. Beck TW, Housh TJ, Schmidt RJ, Johnson GO, Housh DJ, et al. (2006) The acute effects of a caffeine-containing supplement on strength, muscular endurance, and anaerobic capabilities. *J Strength Cond Res* 20: 506-510.
21. Beck TW, Housh TJ, Malek MH, Mielke M, Hendrix R (2008) The Acute Effects of a Caffeine-Containing Supplement on Bench Press Strength and Time to Running Exhaustion. *J Strength Cond Res* 22: 1654-1658.
22. Hendrix CR, Housh TJ, Mielke M, Zuniga JM, Camic CL, et al. (2010) Acute effects of a caffeine-containing supplement on bench press and leg extension strength and time to exhaustion during cycle ergometry. *J Strength Cond Res* 24: 859-865.
23. Williams A, Cribb P, Cooke M, Hayes A (2008) The effect of ephedra and caffeine on maximal strength and power in resistance-trained athletes. *J Strength Cond Res* 22: 464-470.
24. Eckerson J, Beachle T, Fischer C, O'Brien D, Moore G, et al. (2013) Acute ingestion of sugar-free red bull energy drink has no effect on upper body strength and muscular endurance in resistance trained men. *J Strength Cond Res* 27: 2248-2254.
25. Astorino TA, Rohmann RL, Firth (2008) Effect of caffeine ingestion on one-repetition maximum muscular strength. *Eur J Appl Physiol* 102: 127-132.
26. Bazzucchi I, Felici F, Montini M, Figura F, Sacchetti M (2011) Caffeine improves neuromuscular function during maximal dynamic exercise. *Muscle Nerve* 43: 839-844.
27. Kalmar J, Cafarelli E (1999) Effects of caffeine on neuromuscular function. *J Appl Physiol* 87: 801-808.
28. Oei A, Hartley L (2005) The effects of caffeine and expectancy on attention and memory. *Hum Psychopharmacol* 20: 193-202.
29. Tamopolsky M (2008) Effect of caffeine on the neuromuscular system - potential as an ergogenic aid. *Appl Physiol Nutr Metab* 33: 1284-1289.
30. Wisloff U, Castagna C, Helgerud J, Jones, R, Hoff J (2004) Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sport Med* 38: 285-288.
31. Beedie C (2010) All in the mind? Pain, placebo effect, and ergogenic effect of caffeine in sports performance. *Open Access J Sports Med* 1: 87-94.
32. Duncan MJ, Oxford S (2011) The effect of caffeine ingestion on mood state and bench press performance to failure. *J Strength Cond Res* 25: 178-185.
33. Pollo A, Carlino E, Benedetti F (2008) The top-down influence of ergogenic placebos on muscle work and fatigue. *Eur J Neurosci* 28: 379-388.
34. Park ND, Maresca RD, Mckibans KI, Morgan DR, Allen TS, et al. (2008) Caffeine's enhancement of maximal voluntary strength and activation in uninjured but not injured muscle. *Inter J Sport Nutr Exer Met* 18: 639-652.
35. Skein M, Duffield R, Minett G, Snape A, Murphy A (2013) The effect of overnight sleep deprivation after competitive rugby league matches on post match physiological and perceptual recovery. *Int J Sports Physiol Perform* 8: 556-564.
36. Davis J, Green J (2009) Caffeine and anaerobic performance: ergogenic value and mechanisms of action. *Sport Med* 39: 813-832.
37. Drust B, Waterhouse J, Atkinson G, Edwards B, Reilly T (2009) Circadian rhythms in sports performance--an update. *Chronobiol Int* 38: 21-44.
38. Lane JD, Steege JF, Rupp SL, Kuhn CM (1992) Menstrual cycle effects on caffeine elimination in the human female. *Eur J Clin Pharmacol* 43: 543-546.
39. Magkos F, Kavouras S (2005) Caffeine use in sports, pharmacokinetics in man, and cellular mechanisms of action. *Crit Rev Food Sci Nutr* 45: 535-562.
40. Bangsbo J, Jacobsen K, Nordberg J, Christensen N, Graham T (1992) Acute and habitual caffeine ingestion and metabolic responses to steady-state exercise. *J Appl Physiol* 72: 1297-1303.
41. Baechle TR, Earle RW (2004) *NSCA Essentials of Personal Training*. Leeds, Human Kinetics, UK.
42. Turki O, Chaouachi A, Drinkwater E, Chtara M, Chamari K, et al. (2011) Ten minutes of dynamic stretching is sufficient to potentiate vertical jump performance characteristics. *J Strength Cond Res* 25: 2453-2463.
43. Burden AM, Trew M, Baltzopoulos V (2003) Normalisation of gait EMGs: A re-examination. *J Electromyogr Kinesiol* 13: 519-532.
44. Mora-Rodriguez R, Pallares JG (2014) Performance outcomes and unwanted side effects with energy drinks. *Nutr Rev* 72: 108-120.
45. Beedie CJ, Stuart EM, Coleman DA, Foad AJ (2006) Placebo effects of caffeine on cycling performance. *Med Sci Sports Exerc* 38: 2159-2164.
46. Schneider R, Gruner M, Heiland A, Keller M, Kujanova Z, et al. (2006) Effects of expectation and caffeine on arousal, well-being, and reaction time. *Inter J Behav Med* 13: 330-339.
47. Beh HC, Hirst R (1999) Performance on driving-related tasks during music. *Ergonomics* 42: 1087-1098.

## Author Affiliation

Top

<sup>1</sup>Department of Sport and Exercise Science, Institute of Sport and Physical Activity Research, (ISPAR), University of Bedfordshire, Bedford, UK

<sup>2</sup>Sport Science Program, College of Arts and Sciences, Qatar University, Doha, Qatar

### Submit your next manuscript and get advantages of SciTechnol submissions

- ❖ 50 Journals
- ❖ 21 Day rapid review process
- ❖ 1000 Editorial team
- ❖ 2 Million readers
- ❖ Publication immediately after acceptance
- ❖ Quality and quick editorial, review processing

Submit your next manuscript at ● [www.scitechnol.com/submission](http://www.scitechnol.com/submission)