Sex Differences on the Acute Effects of Caffeine on Maximal Strength and Muscular Endurance

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Running Header: Effects of Caffeine on Strength Performance

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Abstract

The aim of this study was to look at the effects of caffeine on strength performance and to examine any differences between sexes. Sixteen moderately active, resistance-trained individuals (10 males and 8 females) performed 2 trials (excluding a familiarisation trial). The effect of 5mg·kg⁻¹ body mass (BM) caffeine or a placebo on bench press (BP) one repetition maximum (1RM), squat 1RM, the number of BP reps to failure at 40% 1RM (total weight lifted; TWL), pain rating (0-10) were recorded after each final successful lift.

BP 1RM was significantly greater (p=0.016), with an increase of 5.91% for males and an increase of 10.69% for females. However, there was no sex difference in squat 1RM with males producing 130.3±27.8 and 134.0±28.9kg and females producing 66.9±6.2 and 65.3±7.0kg for placebo and caffeine respectively. TWL tended to increase with caffeine for males from 1246.8±704.9 to 1545.5±920.3kg; with females having no effect of caffeine (397.8±245.1 to 398.8±182.7kg; p=0.06). Caffeine had no effect on pain perception.

This study found that 5mg·kg⁻¹BM caffeine improved BP 1RM in resistance-trained males and females. However, for TWL there was a tendency towards improvement in males only, suggesting a sex difference to caffeine ingestion for TWL.

Key Words: ergogenic aid, strength training, pain perception

Introduction

Caffeine is a psychoactive alkaloid, typically found in foods and beverages such as chocolate, tea, cola, energy drinks and coffee (Astorino and Roberson, 2010; Davis and Green, 2009; Goldstein *et al.,* 2010; Penolazzi *et al.*, 2012; Sokmen *et al.,* 2008*;* Woolf *et al.*, 2008). Caffeine use amongst strength and power athletes has been habitual with those attempting to achieve an ergogenic effect (Jacobson *et al.*, 1992; Sokmen *et al.,* 2008). However, the research supporting caffeine's ergogenic effect for resistance training is equivocal (Davis and Green, 2009). Caffeine has been found to have hypoalgesic effects and as such caffeine may alter pain perception (PP) allowing athletes to train harder beyond their previously perceived capacity (Astorino *et al*., 2011a; Davis and Green, 2009; Warren *et al*., 2010).

It is suggested (Davis and Green, 2009; Goldstein *et al.*, 2011; Woolf *et al.*, 2008) that the hypoalgesic effect works as caffeine affects the adenosine receptors within the brain and skeletal muscles. Adenosine prevents the release of neurotransmitters, such as dopamine and serotonin, in the brain (Astorino and Roberson, 2010; Woolf *et al.*, 2008). Consequently, adenosine increases the magnitude of PP and fatigue, thus reducing sympathetic activity and motor unit recruitment (Beck *et al.*, 2008; Bellar *et al.*, 2011; Woolf *et al.*, 2008). However, caffeine inhibits the effect of adenosine (adenosine antagonism), causing a reduction in PP, which results in a greater time to fatigue and exhaustion (Astorino *et al*., 2011a; Bruce *et al.*, 2000; Davis and Green, 2009). This may explain the mechanism behind caffeine's ability to improve maximal strength and muscular endurance, although the literature is unclear (Warren *et al*., 2010).

Various studies state that caffeine is an ergogenic aid and improves performance (Astorino and Roberson, 2010; Beck *et al*., 2008; Davis and Green, 2009; Goldstein *et al*., 2011). The optimal caffeine dose appears to be between 3 and 6 mg·kg^{-1}BM (Davis and Green, 2009). ==Although caffeine ingestion has elicited mixed results for maximal strength, similar doses have been utilised (range 4-6mg·kg^{-1}BM) suggesting this is not the main reason for differences in results.== Studies have found bench press 1RM to increase with caffeine (Beck *et al*., 2006; Goldstein *et al*., 2010), whereas other studies have found no difference (Astorino *et al.*, 2008; Beck *et al*., 2008; Hendrix *et al*., 2010; Warren *et al*., 2010). Similarly, Jacobson *et al.* (1992) found that with caffeine leg press 1RM increased, whereas two studies found no difference (Astorino *et al.*, 2008; Warren *et al*., 2010). Likewise, muscular endurance and TWL have increased with caffeine (Duncan and Oxford, 2010; Duncan *et al.*, 2013; Woolf *et al.*, 2008), although other studies have found no difference (Astorino *et al.*, 2008; Astorino *et al*., 2011a; Goldstein *et al*., 2011; Spradley *et al.*, 2012).

There are very few studies which include female participants, and thus comparing the literature in order to identify any sex differences becomes rather difficult. However, two studies in particular highlight that there may be a difference in sex reaction to caffeine ingestion, albeit using a 2000m rowing protocol. Bruce *et al.* (2000) and Anderson *et al.* (2000) conducted very similar studies on 8 men and 8 women respectively. The athletes consumed 6mg·kg^{-1}BM and 9mg·kg^{-1}BM caffeine. It was concluded that the females seemed to be more responsive to 9mg·kg^{-1}BM caffeine, whilst males were more responsive to 6mg·kg^{-1}BM. Despite these studies being on rowing performance and not resistance training, it may highlight a difference in caffeine sensitivities depending on sex. The reason for a potential difference in sex response to caffeine remains unclear and could potentially be due to physiological differences such as testosterone levels (Davis and Green, 2009), or differences in muscle fibre type (Jacobson *et al*., 1992). However, there is no categorical evidence for neither testosterone nor muscle fibre composition to affect caffeine response. Therefore, further research needs to be undertaken to

determine whether there is a difference in sex response to caffeine. The main aim of this study was to investigate the effects of caffeine on bench press and squat 1RM and muscular endurance performance; to identify the effect of pain perception and to examine any sex related differences. <mark>The hypotheses of the study were that a) caffeine would improve bench press and squat 1RM as well as muscular endurance, b) there would be no differences between sexes and c) there would be a lower pain perception when ingesting caffeine.</mark>

Methods

Participants
10 moderately active <mark>(trained at least 3-5 hours per week)</mark>, resistance-trained males (age 24.4 ± 3.2years; stature 178.19 ± 7.68cm; body mass 80.92 ± 10.36kg; mean ± SD) and 8 females (age 27.9 ± 6.13 years; stature 164.94 ± 3.54cm; body mass 61.38 ± 6.91kg) volunteered. Participants were injury free at the time of data collection and provided written informed consent. University Ethics Committee approval for the study's experimental procedures was obtained and followed the principles outlined in the Declaration of Helsinki. The participants had more than 1 year of resistance training.

Procedure
The study was a crossover, single blind, randomised, placebo-controlled study with 7 days between trials. Participants were required to fast overnight <mark>(from 11pm until 8am)</mark>, and to abstain from caffeine consumption for at least 24 hours prior to each trial. <mark>This is a sufficient period of abstention from caffeine for this participant cohort (Van Soeren & Graham, 1998). All trials were performed in the morning and all participants were habitual caffeine drinkers.</mark> Participants consumed either a caffeine ($5mg \cdot kg^{-1}BM$ of dry anhydrous caffeine, mixed with 300ml water and sugar free peach squash) or placebo solution (300ml water and sugar free peach squash) one hour before the exercise protocols began to allow caffeine to reach peak plasma levels (Sokmen *et al.*, 2008). This dose ($5mg \cdot kg^{-1}BM$) of caffeine was used as it was within the optimal range of $3-6mg \cdot kg^{-1}BM$ (Davis and Green, 2009).

Participants began with a familiarisation session (FAM), followed by randomised caffeine ($5mg \cdot kg^{-1}BM$) and placebo sessions. Sessions were one week apart. FAM consisted of collecting 1RM data, anthropometric data, resting heart rate (HR) and resting blood pressure (Omron, M3(HEM-7200-e8), UK). This was followed by a 5minute warm up on an elliptical trainer (Matrix, Elliptical Trainer E7XC, UK), followed by dynamic leg and upper body stretches. The participants were taught the correct technique for BP and back squat (Technogym, 2SC Multipower, UK). Resting HR was recorded at the start of each session. Order of testing was bench press 1RM, squat 1RM then bench press endurance. This was followed by a cool down on the elliptical trainer and full body, static stretches.

1RM Protocol
The 1RM protocol consisted of a warm up with 25% of their previously determined 1RM, performing 10 reps, followed by rest. Each participant performed one rep at 80% of their 1RM, increasing incrementally by 5kg following the completion of each rep, their 1RM was accurate to 1.25kg. Spotters were used for all exercises. This protocol was used for both the BP and squat.

Muscular Endurance Protocol

The exercise used to assess muscular endurance was a BP at 40% of 1RM, performing repetitions to failure. The number of reps and total weight lifted (40% 1RM x Reps) were recorded.

Pain Rating Scale
The 11 point scale by Ferrira-Valente *et al.* (2011) was used to quantify pain when performing each exercise protocol. Participants were issued with a pain rating scale following the completion of a rep and exercise; the results were recorded for each exercise.

Statistical Analyses
Descriptive statistics (mean ± standard deviation) were calculated for all variables. To examine any effects of caffeine on performance, pain ratings, number of reps between sexes, mixed factorial 2 x 2 (condition x sex) ANOVAs were conducted with significance accepted at the $p \leq 0.05$ level. Effect sizes for F-statistics were expressed as eta-squared (η^2). All statistical procedures were conducted using SPSS 20.0 (SPSS Inc., Chicago, IL).

Results

Heart Rate

HR was significantly higher with caffeine compared to placebo ($F_{(1,16)}=12.682$; $p=0.003$; $\eta^2=0.442$) for both males (11.95% increase; 66 ±10 to 74 ±10 beats.min^{-1}) and females (5.61% increase; 65 ±8 to 68 ±11 beats.min^{-1}). There were no sex differences ($F_{(1,16)}=1.745$; $p=0.205$; $\eta^2=0.098$).

Bench Press 1RM

***** Figure 1 here *****
Figure 1: Bench press 1RM performance for males and females, with caffeine and a placebo. * denotes significant difference between sexes (P<0.05).

Figure 1 shows that BP 1RM was significantly greater with caffeine ($F_{(1,16)}=7.293$; $p=0.016$; $\eta^2=0.313$); an increase of 5.91% for males from 101.5±28.9 to 107.5±30.5kg and an increase of 10.69% from 32.2±9.0 to 35.3±7.3kg for females. There was no sex difference ($F_{(1,16)}=0.724$; $p=0.407$; $\eta^2=0.043$).

Squat 1RM

***** Figure 2 here *****
Figure 2: Squat 1RM performance for males and females, with caffeine and placebo

There was no effect of caffeine on squat 1RM ($F_{(1,16)}=0.177$; $p=0.680$; $\eta^2=0.011$; Figure 2) with males producing 130.3±27.8 kg and 134.0±28.9kg and females producing 66.9±6.2 and 65.3±7.0kg for placebo and caffeine respectively. There was no significant sex difference ($F_{(1,16)}=1.041$; $p=0.323$; $\eta^2=0.061$).

Total Weight Lifted

***** Figure 3 here *****

Figure 3: Bench press endurance performance (TWL) for males and females, with caffeine and placebo

Figure 3 shows that caffeine had a tendency to increase TWL (F(1,16)=4.119; p=0.059; η^2=0.205). There was a 23.96% increase for males from 1246.8±704.9 to 1545.5±920.3kg; whilst for females there was no difference 397.8±245.1 to 398.8±182.7kg. There was a tendency for a difference between sexes (F(1,16)=4.067; p=0.061; η^2=0.203).

Pain Perception

***** Figure 4a here *****

***** Figure 4b here *****

Figure 4: a) Male pain ratings for bench press and squat 1RM, and total weight lifted, with caffeine and placebo
   b) Female pain ratings for bench press and squat 1RM, and total weight lifted, with caffeine and placebo

Figure 4a and 4b shows that there were no significant interactions in pain rating between trials and gender for BP 1RM (F(1,16)=0.142; p=0.711; η^2=0.009) as well as squat 1RM (F(1,16)=2.044; p=0.172; η^2=0.113) and BP endurance (F(1,16)=0.918; p=0.352; η^2=0.054).

Discussion

This study found that BP 1RM increased with the ingestion of 5mg·kg^{-1}BM caffeine in both males and females. TWL tended to increase with caffeine (p=0.059), as well as there being a tendency for a difference between sexes (p=0.061) with males producing a greater TWL compared to females. BP endurance weight and reps showed no differences, with caffeine eliciting no difference in PP for any exercise.

Performance measures
In this study, BP 1RM was significantly greater with caffeine (p=0.016), with an increase of 5.91% for males and 10.69% for females. These findings are in accordance with Goldstein *et al.* (2011), as they found 6mg·kg^{-1}BM to significantly increase BP 1RM in 15 resistance-trained females. Conversely, this study does not agree with Walter *et al.* (2009) and Astorino *et al.* (2008) although they used a similar population to this study, resistance-trained males, and found no differences. They found that BP 1RM increased by 1.31%, after the ingestion of 6mg·kg^{-1}BM caffeine in 22 resistance-trained males. In summary, females replicated the findings of Goldstein *et al.* (2011) whereas the males had contrasting results to Walter *et al.* (2009) and Astorino *et al.* (2008). Additionally, there were no differences found in the sex x condition interaction, which would suggest that 5mg·kg^{-1}BM caffeine affected both males and females equally.

Unlike BP 1RM, squat 1RM with caffeine yielded no significant differences. Whilst there are no studies that utilise the back squat, the findings can be compared to leg press or extension protocols. Walter *et al.* (2009) found that leg press decreased slightly by 0.78%. This is similar to the female response in this study, wherein a non-significant decrement of 2.35% was

observed. However, the population used by Walter *et al.* (2009) was 20 recreationally active males with an approximate caffeine consumption of 2.61mg·kg⁻¹BM·day⁻¹.

This study found that caffeine elicited a large, non-significant increase (23.96%) in TWL for males, however for females it effectively stayed the same (0.24% increase). The lighter weight (40% 1RM) may be an important factor in the explanation for an improvement in TWL. This is because the lighter weight pertains more to endurance and caffeine is known to improve performance in endurance-related activities (Davis and Green, 2009). This suggests that there is a sex difference with regards to caffeine's effects on muscular endurance (Anderson *et al.*, 2000). In addition, the difference in responses to TWL may also be due to the sensitivity to caffeine between sexes. As mentioned previously, studies by Bruce *et al.* (2000) and Anderson *et al.* (2000) observed females to respond to 9mg·kg⁻¹BM caffeine rather than 6mg·kg⁻¹BM. Therefore, the dose administered in the present study may not have been sufficient to have an effect on female performance. In future research higher doses should be considered in the research design.

Pain Perception
BP, squat and BP endurance protocols all showed that PP was unaffected by caffeine ingestion (Figure 4a; 4b). Similarly, Astorino *et al.* (2011b) found that leg pain in 15 active males (26.4±3.9 years) was unaffected by 2mg·kg⁻¹BM and 5mg·kg⁻¹BM caffeine. Whilst the protocol was different to this study, the findings seem to be the same; showing that caffeine does not affect PP. However, Duncan *et al.* (2013) found that PP was significantly reduced with caffeine in bench press, squat and deadlift protocols.

5mg·kg⁻¹BM caffeine seemed to improve BP and TWL in males, whereas females only improved in BP. However, as PP was unaltered by caffeine ingestion, the mechanism within which caffeine improves muscular performance was not determined in this study (Hendrix *et al.*, 2010). There are various theories, including: the release of Ca^{2+} from the sarcoplasmic reticulum; decrease in Ca^{2+} uptake; increased intracellular cyclic adenosine 5' monophosphate levels; increased motor unit recruitment; central governor theory and increased pain tolerance rather than a reduction in PP (Beck *et al.*, 2008; Bjørkedal and Flaten, 2011; Bruce *et al.*, 2000; Doherty and Smith, 2005; Jacobson *et al.*, 1992; Noakes, Gibson and Lambert, 2004; Sokmen *et al.*, 2008; Warren *et al.*, 2010). These mechanisms are thought to increase force production and the latter two mechanisms are thought to allow individuals to train beyond their previous capacity. As caffeine is known to affect the CNS, it may blunt the perceptual response (Doherty and Smith, 2005; Hudson *et al.*, 2008). This therefore causes peripheral fatigue signals to the brain to be overridden, which allows the individual to engage in the exercise for longer and would also explain the increase in pain tolerance, whilst PP would not necessarily be affected, as demonstrated by the male BP endurance performance in this study (Astorino *et al.*, 2011a; Bjørkedal and Flaten, 2011; Bruce *et al.*, 2000; Noakes *et al.*, 2004; Warren *et al.*, 2010). Consequently, the participant can perform until their physiological maximum, beyond their psychological threshold; which may also explain why caffeine seems to elicit greater effects on trained participants (Doherty and Smith, 2005; Graham, 2001). With regards to this study, the muscular endurance protocol showed that males experienced no difference in PP with caffeine, however tended to increase TWL (1246.8±704.9 to 1545.5±920.3kg for placebo and caffeine respectively). This could suggest that the participants were able to perform more due to lower pain perception at a lower intensity. However, for females, PP stayed the same, and so did TWL (397.8±245.1 to 398.8±182.7kg respectively). This would suggest that there may be a relationship, which should be explored further using trained participants.

Furthermore, Jacobson *et al.* (1992) state that as caffeine tends to affect type I fibres more so than type II fibres, which explains the equivocal nature of previous findings into caffeine's effects on maximal strength and muscular endurance. This may explain potential sex differences as females have more type 1 fibres, due to a lesser quantity of muscle mass than males (Staron *et al.*, 2000).

A limitation of this study is that hormonal changes, as a result of the menstrual cycle were not controlled for. Motl *et al.* (2006) stated that during the luteal phase, pain sensitivity is found to be greatest, and as such, they conducted their testing during the follicular phase. Additionally, habituation status was not accounted for, which can influence the results. Moreover, performance changes may be explained by experiencing withdrawal after having to abstain from caffeine before trials (Irwin *et al.*, 2011). Therefore, future research should take this into account, as well as, training status, muscle group size, hydration status and diet (Duncan and Oxford, 2010; Warren *et al.*, 2010).

In conclusion, this study has found $5mg \cdot kg^{-1}$BM caffeine to have ergogenic effects on BP 1RM for both resistance-trained males and females. However, it seems that the female reaction is of a lesser magnitude than the males', as shown by a tendency towards improvement in TWL for males, but no difference for females. Overall, caffeine had no effect on PP. The findings from this research may present a basis for resistance trained males and females to use caffeine when performing high weight, low rep upper body exercises, more specifically bench press. Also, males may also benefit from caffeine supplementation when undergoing muscular endurance based training regimes. Further research should take into account caffeine habituation and individual responsiveness. It should also examine the effects of caffeine on a large sample of elite athletes; it could be posited that professional power lifters would make a suitable sample. The mechanisms by which caffeine affects the sexes differently and improves maximal strength should also be ascertained.

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