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PLACEBO EFFECTS OF CAFFEINE ON MAXIMAL VOLUNTARY CONCENTRIC FORCE OF THE KNEE FLEXORS & EXTENSORS

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ABSTRACT

Introduction: We examined the placebo effect of caffeine and the combined effect of caffeine and caffeine expectancy on maximal voluntary strength. *Methods:* Fourteen men completed 4 randomized single-blind experimental trials: 1) Told caffeine, given caffeine (5mg.kg) (CC); 2) Told caffeine, given placebo (CP); 3) Told placebo, given placebo (PP); 4) Told placebo, given caffeine (PC). Maximal voluntary concentric force and fatigue resistance of the knee flexors and extensors was measured using isokinetic dynamometry. *Results:* A significant and equal improvement in peak concentric force was found in the CC and PC trials. Despite participants believing caffeine would evoke a performance benefit, there was no effect of CP. *Conclusion:* Caffeine caused an improvement in some aspects of muscle strength, however there was no additional effect of expectancy. Performance was poorer in participants who believed caffeine would have the largest benefit, which highlights a link between expected ergogenicity, motivation, and personality characteristics.

KEY WORDS: Strength, Isokinetic Dynamometry, Ergogenic Aids, Deception, Caffeine, Placebo.

INTRODUCTION

The popularity of caffeine as an ergogenic aid is supported by a growing body of literature that demonstrates its performance-enhancing effects across a range of sporting activities and exercise intensities (See reviews [1-4]) Recently, a relatively small number of studies have shown that the expectation of caffeine is sufficient to elicit a performance-enhancing response, when in fact a placebo was consumed [5-9]. Such findings highlight an important additional mechanism underpinning the performance-enhancing effect of caffeine. To date, placebo effects of caffeine have only been examined using a limited range of exercise modes and intensities. Consequently, there is a need for additional studies on this topic to better elucidate the extent to which the expectancy of performance-enhancement of caffeine or the actual effect of caffeine ingestion contribute to improved exercise performance.

The placebo effect is a favorable outcome arising purely from the belief that one has received a beneficial treatment [10]. Although not a particularly new concept, the placebo effect has been demonstrated to be a powerful tool for manipulating physiological, psychological, and behavioral variables, [11] and its positive effects in medicine are widely appreciated [12]. A recent meta-analysis considered that, although only a relatively small number of studies have examined the placebo effect on sports performance, different forms of placebo may evoke substantial performance enhancement [13].

Likely due to its widespread use and well documented effects as an ergogenic aid [1], a relatively small number of research papers have examined the placebo effect on sports performance in relation to caffeine (see review [14]). Beedie *et al.* [5] reported that a caffeine placebo caused increased mean power during 10km time trial performance in well trained cyclists, which was greatest when participants believed they had ingested a higher concentration of caffeine. This was later supported by Foad, Beedie, and Coleman [6], who demonstrated that caffeine, and the perception of consuming caffeine, caused small improvements in 40km cycling performance. Work by Foad, Beedie, and Coleman [6] and Duncan [9] represent only a small number of research papers that have used a double dissociation protocol to assess the placebo effect of caffeine. This design allows the assessment of independent effects of placebo, the pharmacological effects of the treatment, and their interaction, and is considered

to be a more robust measure of placebo effects [12]. Duncan [9] demonstrated a significant increase in mean and peak Wingate power when participants consumed placebo that they believed to be caffeine, and a further improvement was seen when participants consumed caffeine that they perceived to be caffeine. This indicates that the expectation of caffeine could be an ecologically valid mechanism for the caffeine effect in sport and exercise, but this has still to be measured in relation to maximal muscle strength.

Using a more traditional protocol of deception, Pollo *et al.* [7] demonstrated that when compared to a non-ergogenic placebo, there was a significant increase in the mean work of the quadriceps muscle during a 60% 1RM (Rep Max) protocol to voluntary exhaustion in participants who believed they had consumed a high dose of caffeine. Interestingly, the placebo-induced increase in work was greater when a conditioning procedure, consisting of a pre-test lifting protocol which was surreptitiously lowered to 45% 1RM, was used to reinforce the placebo effect. This result was later confirmed by Duncan *et al.* [8] who reported a significant increase in the number of knee extensions until failure, using a similar 60% 1RM protocol, when participants perceived they had consumed caffeine. These results further demonstrated that the increase in performance was associated with a reduction in Rating of Perceived Exertion (RPE), indicating that a caffeine-induced reduction in the perception of effort may mechanistically contribute to the demonstrated improvement in performance.

The majority of studies of the effect of caffeine on exercise performance have implemented a placebo controlled double blind experimental protocol [15-18], and although this is considered the most robust way of examining the effect of caffeine on performance, such products are purchased by consumers with the expectancy of an improvement in performance which may pose additional benefits to the typical cognitive and physiological changes evoked by caffeine consumption [19, 20]. Beedie [21] considered that such placebo controlled trials may mask the true caffeine effect. The pharmacologically and mechanistically inert placebo may evoke psychological responses, as participants expect to consume caffeine at some point during the experiment.

The study we report here looks to build on previous work by investigating the placebo effect of caffeine on maximal voluntary peak and average concentric force of the knee flexor and extensor

muscles at two different angular velocities. A double deception protocol, as in Beadie and Foad [12], was implemented to assess the placebo effect of caffeine and the effect of caffeine expectancy on maximal voluntary force production of skeletal muscle. Furthermore this study investigated the placebo effect of caffeine and the effect of caffeine expectancy on the ability to produce maximal voluntary concentric force over 40 repeated contractions. Gains in maximal muscle strength and the ability to sustain this improvement over time would be desirable across a range of sport and exercise activities. In addition, improved maximal voluntary force production may translate to improved performance across a range of contractile intensities, as skeletal muscle will theoretically be able to produce the desired force at lower intensities with a smaller number of recruited fibers.

METHODS

Participants

Following ethical approval from the host institute (Coventry University) and obtaining informed consent, 14 apparently healthy men (mean ± SE = age 21 ± 0.7 years; height 177 ± 1.3 cm; body mass 76 ± 2.2 kg) agreed to take part in the study. Participants were told that they would be taking part in a study examining the repeatability of the effects of caffeine on maximal muscular strength and fatigability of maximal voluntary force production. Over the duration of the experiment, 3 participants had to withdraw from the study due to injuries that were not associated with the experimental procedure. The participants who completed the tests were naive to strength training and habitually consumed caffeine, but were not heavy caffeine users (91.8 ± 16.1 mg/day). Caffeine intake was measured using a 24 hour recall questionnaire [22].

All experiments took place at the same time of day to avoid circadian variation [23], and participants were asked to abstain from high intensity activity and caffeine 48 hours prior to each visit to the laboratory. Participants visited the laboratory at Coventry University on 5 occasions, and each visit was separated by at least 48 hours.

Familiarization

In the first visit heavy clothing and shoes were removed, and measures of height (cm) and mass (kg) were taken to the nearest cm and 100g, using a stadiometer (SECA Instruments Ltd., Germany) and electronic weighing scales (SECA Instruments Ltd., Germany). Participants were then familiarized with isokinetic dynamometry (Kin-com 125 AP, Chattanooga, Tennessee, USA) and the experimental procedure.

Similar to the study by Green *et al.* [24], participants completed a 5 minute warm-up on a cycle ergometer (Monark 857E, United States) at 70 rpm (unloaded cradle), followed by 5 minutes of static and dynamic stretches of the muscle groups involved (gastrocnemius, soleus, hamstrings, and

quadriceps). Participants then used the warm-up feature on the isokinetic dynamometer and were instructed to perform concentric extension and flexion of the knee at a moderate intensity. The isokinetic dynamometer was set up in accordance with the manufacturer's instructions, and the lateral femoral epicondyle and lateral malleolus were used as the anatomical reference points for the knee and ankle [25]. Dynamometer head and seat position for each individual were stored and recalled for each subsequent visit. Maximal voluntary peak and average concentric force during knee flexion and extension of the dominant leg were reordered through a range of motion of 80^0-10°, at velocities of 30^0 and 120°/second. Each velocity was separated by 60 seconds recovery. Maximal voluntary force was achieved with 2-3 attempts, which is common for this type of testing [25]. Following a 10 minute rest period, participants then performed a bout of 40 repetitions of knee extension and flexion of the dominant leg at a velocity of 120°/second in the same manner as previously described. Peak and average force for knee extension and flexion were recorded for each repetition.

Experimental Procedure

Prior to participation, and before each trial where participants believed caffeine would be consumed, a brief synopsis of the performance-enhancing effects of caffeine on measures of maximal strength was provided verbally. Participants completed 4 experimental trials in a counterbalanced, randomized format using a single blind, double-disassociation procedure. This has previously been used in studies of the placebo effect on sports performance [12]. The experimental conditions were as follows: 1) Told caffeine, given caffeine (CC); 2) Told caffeine, given placebo (CP); 3) Told placebo, given placebo (PP); 4) Told placebo, given caffeine (PC). Caffeine drinks contained 5 mg/kg body mass of caffeine (Myprotein, UK) diluted in 4 ml/kg water and 1ml/kg double concentrate sugar free orange cordial (Sainsbury's, UK), and were artificially sweetened with 3mg/kg sucralose (Myprotein, UK). Five mg/kg represents a moderate caffeine dose and is regularly used in studies examining its ergogenic effect on sports performance [15, 17, 18]. Placebo drinks were prepared in the same way with the absence of caffeine. Following a 10 minute rest period and resting measures of Heart Rate (HR; measured in bpm) and Blood Lactate (BLa; measured in mmol/l), drinks were presented to participants in an opaque sports bottle and were asked to consume the contents within 5 minutes. HR was assessed using heart rate telemetry (Polar Electro, Finland), and BLa was measured from a finger prick sample using a

Lactate Pro (Akray, Japan). The participants then rested for 45 minutes, and resting HR and BLa measures were taken. Following this, the participants completed the warm up procedure as previously described. The strength assessments began 60 minutes post-ingestion in line with previous evidence that demonstrates maximal blood plasma concentration of caffeine occurs 1 hour post-consumption (Graham *et al.* 2001). The strength assessments were carried out using the isokinetic dynamometer in the same manner as previously described. Further HR and BLa measures were taken prior to the 40 repeated contractions, on completion of the exercise protocol, and 5 minutes post-recovery. Pain perception was recorded immediately after assessment of maximal voluntary force at both 30^0 and 120°/second and again immediately after the 40 contractions using the pain perception scale [(26)].

Perception of Caffeine as a Performance Enhancer

Prior to the experimental protocol, participants were asked to rate the extent to which they believed caffeine would affect their performance on a scale from -5, a very negative effect, to +5, a very positive effect. Following the experimental trials, but prior to debriefing, participants were asked to rate their belief about caffeine for a second time to see if the experimental protocol affected the participants' perception of caffeine as a performance enhancer. At no point during any of the experimental trials did participants correctly identify the test substance consumed or the true nature of the study.

Statistical Method

Normality and homogeneity of variance were tested using Shapiro–Wilk and Mauchly tests respectively. A series of Treatment (4) X Speed (2) repeated measures ANOVAs were used to examine statistical differences in peak and average concentric force of the knee flexors and extensors, and the perception of pain following the measurement of contractile force. Similarly, Treatment (4) x Rep (40) repeated measures ANOVAs were used to assess potential treatment-induced changes in peak and average force produced during the repeated 40 contraction protocol. A further series of Treatment (4) x Time (4) repeated measures ANOVAs were used to assess changes in HR and BLa at rest and during exercise. Finally, single factor repeated measures ANOVA was used to examine main effects for perception of pain. Pairwise comparisons were used for treatment where appropriate. Partial eta

squared (η2) was used as a measure of effect size. Partial η2 is commonly used in analysis of variance and provides a measure of the variance in the dependant variable attributable to the factor in question [27].

A paired *t*-test was used to examine if the perception of caffeine as a performance enhancer changed significantly post-completion of the experimental trials. Following the debriefing session, no participant confessed to have predicted the true nature of the experiment. Considering that the perception of a performance-enhancing benefit underpins the nature of the placebo effect, it was considered important to examine these results on an individual level. The percentage change in maximal peak and average force from the PP trial to the CP trial was calculated and a series of Pearson correlations were used to examine the relationship between maximal voluntary strength and the score given on the post-experimental caffeine perception questionnaire.

Data are presented as mean ± SE. Statistical analysis was performed using SPSS 22.0 (Chicago, IL, USA). Statistical significance was set at a level of $P<0.05$.

RESULTS

Maximal Peak & Average Force

There was no significant treatment*speed interaction for peak and average knee flexor and extensor force in any of the statistical tests (Fig 1; ANOVA $F<1.4$; $P>0.27$; $P\eta2<0.12$ in each case). Peak and average concentric force production of the knee flexors and extensors was significantly reduced at 120^0/s compared to 30^0/s (Figure 1 A-D; ANOVA $F>20$; $P<0.001$; $P\eta2>0.66$ in all cases).

Peak concentric force of the knee extensors was significantly affected by treatment (Figure 1 A; ANOVA $F=8.3$; $P<0.01$; $P\eta2=0.454$). Peak force produced during the PC and CC trial was significantly greater than the PP trial (by 12.8% and 15.8% respectively at 30°/second and 6.8% and 11.2% respectively at 120°/second; Figure 1 A, pairwise $P<0.05$ in both cases), but the given increase in force was not different between PC and CC trials (Figure 1 A, *t*-test $P>0.6$ for both speeds). Average force was also significantly affected by treatment (Figure 1 B, ANOVA $F=5.8$; $P=0.003$; $P\eta2=0.37$), with that produced in the CC trial being significantly greater than PP (by 18.0% and 14.4% at 30° and 120°/second; Figure 1 B; pairwise $P=0.02$). Peak and average force of the hamstrings was not significantly affected by treatment (Figure 1 C,D; $F<0.17$; $P>0.74$; $P\eta2<0.04$ in both cases).

There was no significant effect of treatment, speed, or interaction of these factors for measurements of pain perception (Table 1; ANOVA $F<2.4$; $P>0.08$; $P\eta2<0.2$ in each case).

*** Figure 1 and Table 1 around here ***

Repeated Maximal Voluntary Contractions

Both peak and average force of the knee extensors and flexors was significantly reduced over the course of the 40 repeated contraction protocol (Figures 2&3; $F>51.5$; $P<0.001$; $P\eta2>0.83$ in all cases), however there was no significant effect of treatment (Figures 2&3; $F<1.05$; $P>0.38$; $P\eta2<0.095$ in all

cases). Furthermore there was no significant treatment*rep interaction in all cases (Figures 2&3; F<1.3; *P*>0.06; Pη2<0.12).

** *Figure 2 & 3 around here* **

Although HR and BLa were both significantly affected by time (Table 2; ANOVA F>36.7; p<0.001; Pη2>0.78 in each case), no effects of treatment were found (Table 2: ANOVA F<0.3; p>0.83; Pη2<0.03 in each case). There was no significant Treatment*Time interaction (Table 2; ANOVA F<1.3; p>0.27; Pη2<0.11). Furthermore the perception of pain was not significantly affected by treatment (Table 1; ANOVA F=1.01; p=3.99; Pη2=0.092).

** *Table 2 around here* **

The Effect of Caffeine Perception on Performance.

Prior to participating in the experimental protocol, all participants believed that the consumption of caffeine would result in improved exercise performance (mean +3.09 ± 0.435), which had not significantly changed at the end of the protocol (mean +3.18 ± 0.423, paired samples *t*-test t=-1.00 *P*=0.341). Table 3 demonstrates that when participants considered caffeine to be more beneficial to performance, there was a negative association with performance in the CP trial, although this was only significant in peak force of the knee extensors measured at 120°/second.

** *Table 3 around here* **

DISCUSSION

Regardless of expectation, caffeine treatment caused a significant increase in peak concentric force of the knee extensors. There were no caffeine or caffeine placebo effects on maximal peak and average force of the knee flexors, or the ability of the knee flexors and extensors to maintain peak and average force over 40 repeated contractions. These findings add further weight to the evidence which suggests that caffeine may be used as an ergogenic aid in events requiring acute maximal strength, but they demonstrate that the perception of caffeine is not sufficient to elicit a performance-enhancing effect in this mode of exercise. As such these results provide an important insight into the relationship between physiological and psychological effects of caffeine as a performance enhancer for skeletal muscle contractility

Placebo Effect of Caffeine

The findings contradict the previous evidence that a caffeine placebo can cause a significant increase in exercise performance [6-9, 21]. More specifically, these results directly contradict the findings of Pollo *et al.* [7] and Duncan [8], who reported a caffeine placebo caused significant improvements in measures of muscle work and repetitions until failure using a 60% 1RM protocol. Initially this may indicate that the mechanism by which a placebo elicits its effect is in some way limited during activities requiring sustained maximal effort. Although few studies have examined a placebo effect on measures of maximal strength, there is some evidence that a performance benefit can be elicited following acute and chronic supplementation of different placebos, where an increased performance is expected [28, 29].

Beyond the work of Kalasountas *et al.* [29] there is a distinct lack of evidence investigative the effect of an acute placebo on maximal strength. Furthermore, a number of methodological discrepancies should be considered when comparing the present findings to the positive effect demonstrated in previous studies examining placebo effects on measures of muscular strength [7, 8, 28, 29]. Most notably a number of studies use submaximal measures of strength, and the use of free weights is mechanically different for assessing strength at a fixed velocity. Additionally, differences occur in the nature and duration of the placebo and the ability of the participants, cumulatively making comparisons between these studies

problematic. Furthermore an experimental effect is more likely in open-ended tests of muscle strength (as in [7, 9]) compared to the fixed-end test we used[30].

The effectiveness of the placebo to elicit a performance-enhancing effect is attributed to the perception that one believes that a performance-enhancing benefit will occur [10]. Geers *et al.* [31] concluded that personality and situational variables interact to determine the response to a placebo, and that perceived optimism or pessimism will result in a positive or negative placebo response. When the results are explored on an individual level, all participants believed that caffeine would cause a performance-enhancing effect, however this did not result in a significant change in maximal voluntary strength when the CP trial was compared to the PP trial. Interestingly, these results infer that when the benefit is perceived to be small, the placebo effect is greater, and when the benefit is perceived to be large, the placebo effect is smaller. This may appear to contradict the underpinning theory that supports the placebo effect, and although the rationale for this is not clear, we speculate that this finding may relate to individual motivation to complete the task. For example, the belief that the consumed substance will cause a significant improvement in maximal voluntary strength may result in reduced effort, as a high performance is expected. In light of these findings, more should be made of the reinforcement approach introduced by Pollo *et al.* [7], as having a physical demonstration of the effectiveness of the treatment, albeit false, may more strongly manipulate the power of perception.

Mechanistically, the placebo effect can in part be attributed to its effect on modulating pain perception [5, 9]. In support of this, some previous studies have demonstrated positive effects of a caffeine placebo on RPE in relation to improvements in exercise performance that may underpin this as a mechanism for the placebo effect in sporting activities. Contradictory findings in our study demonstrate that the perception of pain is unchanged when a perceived performance-enhancing placebo is administered. This may not be particularly surprising, since there was no effect of placebo on exercise performance, but it may leave one to speculate that the lack of effect may be attributed to a lack of change in this measure.

The Effect of Caffeine on Maximal Strength

The only significant effect of treatment found in this study was a caffeine-induced improvement in peak and average concentric force of the knee flexors. Interestingly, even when the participants believed they were completing a placebo trial, caffeine still caused a significant and equal increase in maximal concentric force of the quadriceps. This result in particular supports the value of caffeine in improving maximal voluntary force; however this effect cannot be maintained during repeated contractions. Furthermore, the results demonstrate that this effect is not uniform across all skeletal muscle.

Unlike the research investigating the performance enhancing effect of caffeine on endurance exercise, the body of work exploring the ergogenic effect of caffeine on measures of muscle strength are much more equivocal, with evidence of both substantial strength gains [32-34] and no effect [35-37]. The nature of these discrepancies has largely been attributed to methodological differences, including participant training status, assessment methods, muscle groups tested, and concentration of caffeine. Although it is generally considered that caffeine elicits greater effects in trained athletes [4], our study further demonstrates the value for untrained participants.

Although not statistically significant, Timmins and Saunders [38] suggested that the benefit of caffeine on muscle strength may relate to muscle size. This may partially be why there was no effect of caffeine on the knee flexors, although Timmins and Saunders [38] demonstrated performance-enhancing benefits in muscles much smaller than the hamstrings. Furthermore, studies using isolated muscle have demonstrated fiber type specific effects on contractility following direct caffeine treatment [39] which may have also caused the varying effect. It may also be that the action of producing maximal voluntary concentric force of the hamstrings is a more irregular muscle action, and hence the repeatability of maximal force between trials may influence the results.

There is a distinct lack of studies of the effects of caffeine on the ability to sustain force over repeated contractions. Although our findings infer that there is no additional caffeine benefit, caffeine-induced increases in maximal voluntary force production may translate into improved resistance to fatigue at submaximal exercise intensities, as theoretically the muscle will be able to produce greater work with a smaller number of recruited fibers.

The hydrophobic nature of caffeine allows it to pass across all biological membranes [19], and as such, caffeine may elicit a performance-enhancing effect by a number of mechanisms. Most commonly reported, and aligned to the mode of exercise used in this study, is the action of caffeine as a central nervous system stimulant. Caffeine has been demonstrated to act as a central adenosine receptor antagonist, particularly on A1 and A2a receptors, promoting an elevated release of neurotransmitters [40-42]. The subsequent reduction in the adenosine-induced suppression of dopamine release [43, 44] is believed to contribute to the commonly reported increased alertness and arousal [20]. In addition, a recent review [39] has indicated that caffeine may work directly to increase the force-producing capacity of skeletal muscle. A reduction in pain perception has also been attributed to the performance gains demonstrated in previous studies of caffeine-induced improvements in muscle strength [3, 45, 46]. However, our findings add to the growing body of evidence indicating that modulation of pain perception is not a primary mechanism causing performance-enhancement in muscle strength [47, 48].

An additional aim of this work was to examine whether caffeine expectancy caused a further enhancement in performance. This is considered a more ecologically valid method of testing the caffeine effect on sports performance, as caffeine-containing products are purchased with the intention of seeking an improvement in exercise performance. As no significant difference was found in the improvement in the concentric action of knee flexors and extensors between the CC and PC trials, or in any of the placebo trials, we believe that caffeine expectancy does not further augment the physiological and psychological benefits provided by caffeine alone.

Conclusion

In contrast to previous studies using different modes of exercise, the present work demonstrates that a caffeine placebo fails to elicit a performance enhancing effect on measures of maximal voluntary strength. These findings are particularly interesting, since all participants believed that caffeine treatment would lead to a substantial improvement in performance. Uniquely, we found that participants who perceived the performance effect to be greater demonstrated the smallest change in performance in the exercise trial, which potentially highlights a link between expected ergogenicity, motivation to perform high intensity fatiguing exercise, and personality characteristics. These findings

450 further demonstrate that caffeine treatment caused significant improvement in some aspects of acute
451 maximal voluntary strength. When caffeine treatment and caffeine expectancy were combined, there
452 was no additional benefit. These findings highlight the importance of the mechanistic changes caused
453 by caffeine to evoke an improvement in performance, however when a perceived treatment-induced
454 enhancement of performance is expected, this does not necessarily translate to improved exercise
455 performance. Future research examining the placebo effect should look to further investigate the
456 relationship between the magnitude of the perceived benefit and exercise performance.
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ABBREVIATIONS

η2	Partial eta squared
°	Degrees
ANOVA	Analysis of Variance
BLa	Blood Lactate
CC	Told Caffeine, Given Caffeine
Cm	Centimetres
CP	Told Caffeine, Given Placebo
Fig	Figure
HR	Heart Rate
Km	Kilometres
Mg	Milligrams
ml	Millilitre
mmol/l	milllimole per litre
PC	Told Placebo, Given Caffeine
PP	Told Placebo, Given Placebo
RM	Rep Max
RPE	Rating of Perceived Exertion
SE	Standard Error of the Mean
SPSS	Statistical Package for the Social Science

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FIGURES

Figure 1. The placebo effect of caffeine on peak and average maximal voluntary concentric contractile force of the knee extensor (A & B) and flexor muscles (C & D) at 30^0 and $120\ ^0$/s [Data are represented as mean ± SE; n=11 in each case; matching symbols indicate statistically significant differences]

Figure 2. The placebo effect of caffeine on peak (A) and average (B) concentric force of the knee extensors over 40 repeated maximal voluntary contractions. [Data represented as mean ± SE; n=11 in each case]

Figure 3. The placebo effect of caffeine on peak (A) and average (B) concentric force of the knee flexors over 40 repeated maximal voluntary contractions. [Data represented as mean ± SE; n=11 in each case]

699 **TABLES**

Table 1. The placebo effect of caffeine on pain perception following maximal voluntary isokinetic force of the knee flexors and extensors measured at 30, 120, and 40 repeated contractions

	30°/s	120°/s	Post 40
PP	2.5±0.6	2.1±0.6	6±0.6
CP	2.3±0.4	1.7±0.5	7±0.6
PC	2.1±0.5	2.5±0.6	6±0.6
CC	1.8±0.4	2.5±0.5	6±0.6

700 [Data represented as mean ± SE; n=11 in each case]

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Table 2. The placebo effect of caffeine on resting and post exercise measures of HR and BLa

	Pre-Ing	Post-Ing	Pre 40 reps	Post 40 reps	5 min post
			HR (BPM)		
PP	71±5	75±6	89±5	147±7	101±6
CP	69±4	73±4	85±5	151±7	105±6
PC	71±4	70±4	90±6	155±7	103±6
CC	69±4	73±5	83±5	156±7	105±4
			Bla (mmol/l)		
PP	2.3±0.4	2.0±0.2	2.8±0.8	6.4±1.2	6.0±0.9
CP	2.9±0.5	1.8±0.1	2.5±0.4	5.5±0.8	5.7±0.8
PC	1.9±0.3	2.0±0.2	2.5±0.3	6.8±1.1	6.2±2.1
CC	1.9±0.2	3.1±0.8	2.8±0.4	5.6±0.5	7.3±1.2

[Data represented as mean ± SE; n=11 in each case]

Table 3. Individual percentage difference in maximal voluntary muscle strength between PP and CP trial correlated against the perceived benefit of caffeine

Test	R	*P*
KE Peak 30°/s	-0.03	0.93
KE Peak 120°/s	-0.62	0.04
KE Average 30°/s	-0.014	0.967
KE Average120°/s	-0.487	0.129
KF Peak 30°/s	-0.375	0.255
KF Peak 120°/s	-0.147	0.666
KF Average 30°/s	-0.438	0.666
KF Average120°/s	-0.44	0.899

738 [KE: Knee Extensor; KF: Knee Flexor; n=11 in each case]

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