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The acute effect of a caffeine containing energy drink on mood state, readiness to invest effort and resistance exercise to failure

Running Head: Caffeine and Resistance Exercise

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ABSTRACT

The efficacy of caffeine ingestion in enhancing aerobic performance is well established. The evidence for caffeine's effects on resistance exercise is mixed and has not fully examined the associated psychological and psychophysiological changes. This study examined acute effects of ingesting a caffeine-containing energy drink on repetitions to failure, rating of perceived exertion (RPE) and readiness to invest physical (RTIPE) and mental (RTIME) effort during resistance exercise to failure. Thirteen resistance trained males took part in this double-blind, randomized cross-over experimental study whereby they ingested a caffeinated (179mg) energy drink or placebo solution 60mins before completing a bout of resistance exercise comprising of bench press, deadlift, prone row and back squat exercise to failure at an intensity of 60% 1 repetition maximum. Experimental conditions were separated by at least 48hours. Participants completed significantly greater repetitions to failure, irrespective of exercise, in the energy drink condition ($p = .015$). RPE was significantly higher in the placebo condition ($p = .02$) and was significantly higher during lower body exercises compared to upper body exercises irrespective of substance ingested ($p = .0001$). RTIME was greater with the energy drink ($p = .04$), irrespective of time. A significant time X substance interaction ($p = .036$) for RTIPE indicated that RTIPE increased for both placebo and energy drink conditions pre ingestion to pre exercise, but the magnitude of increase was greater with the energy drink compared to placebo. This resulted in higher RTIPE post exercise for the energy drink condition. These results suggest that acute ingestion of a caffeine containing

energy drink can enhance resistance exercise performance to failure and positively enhances psychophysiological factors related to exertion in trained males.

Keywords: High-intensity exercise; Resistance exercise; Repetitions to failure, Mood, Psychophysiology

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INTRODUCTION

The use of pre-exercise energy drinks is becoming increasingly common in athletic populations. Many such drinks include caffeine as a key ingredient, due to its widely published ergogenic benefits (29). Caffeine is often combined with other ingredients to provide a synergistic effect, thereby increasing ergogenic potential, and increasing the probability of a performance response from energy drinks. A wide range of research has documented enhanced performance in aerobic endurance performance following caffeine ingestion (14). More recently, research has reported enhanced resistance exercise performance in the presence of caffeine (2, 10, 15, 17, 31) using caffeine doses in the range of 5 to 6mg kg⁻¹. However, other studies have reported that acute caffeine ingestion at lower relative (4) and absolute doses (18, 30) does not enhance resistance exercise performance. Consequently, the efficacy of caffeine as an ergogenic aid during anaerobically-based exercise remains uncertain (31).

Recent studies have demonstrated that pre-exercise energy drinks (containing a combination of caffeine, taurine and amino acids amongst other ingredients) can delay fatigue, improve the quality of resistance exercise (13, 16) and significantly improve the volume of training an individual can undertake (16). The data pertaining to psychophysiological responses to such energy drinks pre and post exercise is limited and equivocal. Research has reported no beneficial effect of energy drink ingestion on subjective feelings of 'focus', 'energy' and 'fatigue' pre and post resistance exercise (13). In contrast, during a study on running to exhaustion at 70% VO₂max there were

improved subjective feelings of 'focus' and 'energy' during but not post a treadmill run to exhaustion (29). Caffeine likely plays a key role in any ergogenic effect of such energy drinks (13) with other ingredients, particularly taurine and glucuronolactone, included to form an 'energy matrix'. In combination these ingredients have been shown to enhance aerobic endurance performance but their effect on resistance exercise performance is uncertain (13). It is also unclear whether caffeine containing energy drinks enhance resistance exercise performance (16). Furthermore, the effects of caffeine containing energy drinks, on resistance exercise performance, should not be inferred from research results on the effects of caffeine alone, as such an approach ignores the possibility that caffeine may have synergistic effects with the other ingredients in a given energy mixture.

Moreover, Astorino and Roberson (1) have asserted that the effect of caffeine and caffeine containing supplements on psychological responses to resistance exercise merits further attention. RPE data suggest that acute caffeine ingestion dampens RPE during aerobically-based, exercise (7, 8) but data purporting to resistance exercise are less clear. The sole use of RPE as an indicator of the psychological/perceptual response to exercise has been criticized (24), as perception of effort is multidimensional and factors such as readiness to invest effort may also be important in understanding psychological responses to exercise (24, 27, 28).

During scientific studies on caffeine participants are required to abstain from caffeine prior to experimentation. One hypothesis is that, compared with a placebo, caffeine and caffeine containing supplements may dampen the serious withdrawal effects, such as lethargy, irritability and headaches,

reported with abstention from caffeine. This effect coupled with central nervous system (CNS) changes due to adenosine antagonism (20) may result in caffeine trials causing enhanced mood and/or a greater willingness to invest effort in a given task. Recent research has reported improved mood post resistance exercise (10) and post Wingate test performance (11) with acute caffeine ingestion (5mg kg^{-1}). Conversely, other research (15) has reported no change in mood state following resistance exercise performance in the presence of caffeine (6mg kg^{-1}). However, the experimental designs used in these studies are limited and further research on this topic is needed to address this particular issue (1).

Therefore, the efficacy of ingesting caffeine containing energy drinks on acute, short-term, high-intensity exercise, particularly resistance exercise is unclear. Studies to date have not fully investigated any potential ergogenic effects of such products alongside psychological variables such as mood state and readiness to invest effort. Such energy drinks may directly improve the quality of a given training session, through enhanced resistance exercise performance, or may have indirect effects via psychological changes influencing perceptual responses to exercise. However, research has yet to fully examine this issue.

The aim of the present study was to address these gaps in the literature base by examining the effect of ingesting a caffeine containing energy drink on: 1) resistance exercise to failure, and 2) RPE, readiness to invest effort, and mood state pre to post exercise in a sample of moderately trained males. The study hypothesized that ingestion of a caffeine containing energy drink, in comparison to placebo, would enhance resistance exercise

performance and would positively influence mood states and psychophysiological measures of effort in a sample of resistance trained men.

METHODS

Experimental Approach to the Problem

This study employed a within-subjects, repeated measures, double-blind design whereby 13 resistance trained males consumed a commercially available energy drink Quick Energy™ or a placebo solution diluted into 250ml artificially sweetened water in a randomized manner on two occasions separated by 48-72 hours. One hour following ingestion of each solution, subjects completed as many repetitions to failure as possible on the bench press, deadlift, prone row and back squat, at an intensity of 60% of their one repetition maximum (1RM). Rating of perceived exertion (RPE) was determined for each exercise on task failure. On each occasion measures of mood state and readiness to invest mental effort and physical effort were completed pre ingestion, 60 minutes post ingestion and pre exercise and post exercise. This approach was employed based on criticisms of prior studies that failed to take account of any psychological changes that may have occurred simply from ingesting a possible active substance. The approach used in the present study addresses limitations cited in previous studies (9) and fills gaps in the literature as it allows for identification of any effect of the substance ingested (Independent variable) on repetitions to failure, mood and readiness to invest effort pre and post exercise and RPE (dependent variables). This approach also enabled any additive effect of exercise over

ingestion of the caffeine containing energy drink to be determined alongside any effect on resistance exercise performance. All testing took place within the institution's human performance laboratory.

Subjects

Following institutional ethics approval, briefing regarding the study and provision of written informed consent, 13 males (mean age \pm S.D. = 22.7 \pm 6.0 years) volunteered to participate. All participants had specific experience performing resistance exercise and were free of any musculoskeletal pain or disorders. All participants competed in team games (rugby union, football, basketball) at University level and testing took place during the preparatory period of their periodized training cycle. They were currently participating in > 10 hours week⁻¹ programmed physical activity including strength and endurance based activities. Mean \pm S.D. of years training experience was 9.5 \pm 5.5 years. All participants were asked to refrain from vigorous exercise and maintain normal dietary patterns in the 48h prior to testing and were asked not to consume caffeine after 6:00pm the night before testing to control for the effects of caffeine already consumed (22). From a 24 hour diet recall, average caffeine intake was equal to 211.5 (67.4 mg/day-1 with a range of 120-400 mg/day⁻¹). Subjects were also required to follow the same diet on each day preceding each trial including maintaining adequate hydration levels. They were provided with a list of items that contain caffeine such as coffee, chocolate, soda, etc, as well as over the counter medications to assist in this process. From 24 hour diet and activity recall questionnaires, it was confirmed whether subjects had adhered to these guidelines. If this was not the case,

testing was rescheduled. This questionnaire was also used to confirm that pre trial hydration status and general preparation for the trials (e.g., sleep quality, mental preparedness) was not markedly different across experimental conditions.

Procedure

Each participant attended the human performance laboratory on three occasions. All testing took place between 9.00am and 12.00noon with each condition taking place at the same time for each participant to avoid circadian variation. The first visit to the laboratory involved a briefing session and determination of each participant's one repetition maximum (1RM) on the bench press, deadlift, prone row and back squat. All participants had experience performing resistance exercises in general and these exercises in particular. However, prior to commencing the 1RM testing, each exercise, with proper lifting technique, was demonstrated to each participant. The 1RM was determined according to methods advocated by Kraemer, et al. (21) and was used to set the 60% 1RM intensity undertaken during the proceeding experimental trials.

During each condition participants undertook a 5 minute submaximal warm-up on a cycle ergometer and then completed 1 set of each resistance exercise to failure at 60% 1RM with a 3 minute rest between exercises. Exercises were completed in the following order: bench press, deadlift, prone row, back squat. Conditions, separated by 48-72hours, were randomized and consisted of a caffeinated energy drink condition (where 179mg of caffeine in the form of 'Quick Energy™' [Viva Beverages Ltd, London, UK]) a caffeinated

energy drink (59ml) was diluted into 250ml of artificially sweetened water) and a placebo condition (where 250ml of artificially sweetened water drink were consumed). The energy drink consumed contained 179mg caffeine alongside a matrix of the following ingredients; Vitamins B3, 6, 9, 12, tyrosine, taurine, mallic acid and glucuronolactone in a total volume of 1024mg combined.

Solutions were consumed 60min before each exercise trial as plasma caffeine concentration is maximal 1 hour after ingestion of caffeine (14). Although studies have used different time periods between administration of caffeine containing solutions and the onset of a given exercise task, the 60minute period was chosen in the current study as, in addition to the reason stated above, is the most commonly used time period, from ingestion to onset of exercise task, in prior studies (1, 6, 12). Solutions were presented to participants in an opaque sports bottle to prevent the researchers administering the solutions or the participants from actually seeing the solutions themselves. Prior to exercise testing, body height (m) and mass (kg) were assessed using a Seca stadiometre and weighing scales (Seca Instruments, Hamburg, Germany). Participants were also required to follow the same diet in the 24 hours preceding each exercise trial (based on 24 hour diet and exercise recall) and were required to complete no intense physical exercise in the 48 hours preceding each laboratory visit. In addition, participants were instructed to ingest nothing but water in the 3 hours before each trial. Adherence to these requirements was verified via a brief questionnaire administered prior to each trial.

Lifting Procedures

All exercises were performed using a 20kg Eleiko bar (Eleiko Sport AB, Halmstad, Sweden), Pullum Power Sports lifting cage, Olympic lifting platform and prone row bench (Pullum Power Sports, Luton, UK). All lifts were completed in accordance with protocols previously described, by Earle and Baechle, for the bench press, deadlift, row and back squat (11). The prone row was performed using a barbell with the upward and downward phases of the movement being identical to those previously described for the bent over row (11). The only difference between the two movements was that in the current study, the movement was performed lying prone on a custom made row bench rather than with feet on the floor and in a bent over posture. A trained researcher/spotter was present during all testing sessions to ensure proper range of motion. Any lift that deviated from proper technique was not counted.

During all exercises and across conditions, repetition frequency was paced by a metronome set at 60beats min^{-1} . This cadence resulted in one complete repetition every 4 s with concentric and eccentric phases comprising 2 s each. Feedback related to lifting procedures or the number of repetitions completed was not made available to participants until completion of the whole experimental procedure. Intraclass correlation coefficients were $R = .093$, $.091$, $.092$ and $.93$ for bench press, deadlift, prone row and back squat respectively.

Performance Measures

During each condition and each exercise, repetitions to failure were counted using a hand tally counter (Tamaco Ltd, Tokyo, Japan). Immediately after

each participant had reached failure they were asked to provide ratings of perceived exertion using the Borg 6-20 RPE scale (5). In addition, mood state was assessed before ingestion of any substance or beginning the exercise protocol (i.e., pre caffeine or placebo ingestion), 60 minutes later (post ingestion, pre exercise) and immediately post each experimental condition using the fatigue and vigor subscales of the Brunel Mood State Inventory (BRUMS; 25). This measure of mood is a well established, reliable and valid measure of mood state that has been previously employed to assess the mood state response to various exercise modes (10, 25, 26). The fatigue and vigor subscales were chosen in particular as prior research has identified these dimensions of mood state to be most influenced by caffeine ingestion and exercise (9, 10, 15). In light of criticisms leveled at prior studies employing RPE as the only psychophysiological measure of perceived effort (27, 28), participants also completed measures of readiness to invest physical effort (RTIPE) and readiness to invest mental effort (RTIME) on visual analogue scales ranging from 0-10. This measure was based on recommendations for assessing perceived effort in exercise testing (24) and asked participants to rate how physically and mentally ready they were to invest effort using visual analogue scales incorporating a range of 0-10 with higher scores reflecting greater readiness to invest effort. These measures were completed using the same time pattern as completion of mood state data. Following completion of all conditions participants were thoroughly debriefed.

Statistical Analysis

Any changes in total repetitions completed and RPE were analyzed using a series of 2 (substance ingested) X 4 (exercise) ways, repeated measures analysis of variance (ANOVA). Any changes in BRUMS subscales, readiness to invest physical effort and readiness to invest mental effort were analysed using a series of 3 (time; pre ingestion, post ingestion and pre exercise, post exercise) X 2 (substance ingested) ways repeated measures analysis of variance (ANOVA). Post hoc analysis using Bonferroni adjustments were performed where any significant interactions and main effects were found. Partial η^2 was used as a measure of effect size. The truncated product method (30) was used to combine all the P values in this study to determine whether there was a bias from multiple hypothesis testing. The truncated product method p value was <0.0001 , indicating that the results were not biased by multiple comparisons. A p value of 0.05 was set to establish statistical significance and the Statistical Package for Social Sciences (SPSS, Inc, Chicago, Ill) Version 17.0 was used for all analyses.

RESULTS

Results, in relation to repetitions to failure, indicated significant main effects due to substance ingested ($F_{1,10} = 8.527$, $p = .015$, Partial $\eta^2 = .460$) and across exercises ($F_{3,30} = 4.998$, $p = .006$, Partial $\eta^2 = .333$). Bonferroni post hoc pairwise comparisons indicated that participants completed significantly more repetitions to failure in the energy drink condition compared to placebo (Mean diff = 1.38, $p .015$). Mean \pm SD of repetitions to failure, across all exercise types, was 20.1 ± 6.3 and 18.6 ± 5.6 (Mean Diff = 1.386, $p = .015$)

for energy drink and placebo conditions respectively. Participants also completed significantly lower repetitions in the prone row compared to the bench press (Mean diff = 6.136, $p = .006$). Mean \pm S.D. of repetitions to failure were 22 ± 5.0 , 15.8 ± 4.9 , 17.5 ± 6.2 and 21.9 ± 7.9 for the bench press, prone row, deadlift and back squat respectively.

For RPE there were also significant main effects due to substance ingested ($F_{1,12} = 6.979$, $p = .022$, Partial $\eta^2 = .368$) and exercise ($F_{3,36} = 10.616$, $p = .0001$, Partial $\eta^2 = .469$). Bonferroni post hoc multiple comparisons indicated significantly lower RPE in the energy drink condition compared to placebo (Mean Diff = $-.538$, $p = .022$, See Figure 1). In regard to the exercise main effect post hoc tests indicated that there was significantly lower RPE in the prone row compared to the deadlift (Mean diff = -1.885 , $p = .013$) and the prone row compared to the back squat (Mean diff = -2.346 , $p = .003$). Mean \pm SD of RPE across exercise is presented in Figure 2.

Figure 1 Here

Figure 2 Here

In respect to mood state, results indicated a significant time main effect for the fatigue BRUMS subscale ($F_{2,24} = 82.658$, $p = .0001$, Partial $\eta^2 = .873$). Post hoc tests indicated significantly greater fatigue post exercise when compared to pre ingestion (Mean diff = -21.07 , $p = .0001$) and greater fatigue post exercise compared to post ingestion, pre exercise values (Mean diff = -22.5 , $p = .0001$). Mean \pm S.D. of fatigue scores were 46.5 ± 8.4 , 45.1 ± 8.6 and 67.6 ± 8.6 for pre ingestion, post ingestion pre exercise and post exercise

respectively. Likewise, BRUMS scores for the vigor subscale evidenced a similar main effect for time point ($F_{2, 24} = 24.3, p = .001, \text{Partial } \eta^2 = .670$). Vigor was significantly higher pre ingestion when compared to post exercise (Mean diff = 11.07, $p = .001$) and post ingestion pre exercise when compared to post exercise (Mean diff = 11.154, $p = .0001$). However, vigor scores were also significantly different depending on the substance ingested ($F_{1, 12} = 9.114, p = .011, \text{Partial } \eta^2 = .432$). Mean \pm SD of vigor scores were 46.8 ± 9.3 in the presence of the energy drink compared to 42.3 ± 7.6 with placebo (Mean diff = 4.436, $p = .011$).

Scores for readiness to invest effort revealed a significant substance by time interaction for RTIPE ($F_{2, 24} = 3.833, p = .036, \text{Partial } \eta^2 = .242$; Figure 3), whereby RTIPE increased for both conditions pre ingestion to post ingestion, pre exercise and decreased from post ingestion, pre exercise to post exercise. However, the magnitude of change in both these instances was greater for the energy drink condition compared to placebo. For RTIME, results indicated a significant main effect for substance ($F_{1,12} = 5.294, p .04, \text{Partial } \eta^2 = .306$) and for time ($F_{2,24} = 53.079, p .0001, \text{Partial } \eta^2 = .816$). Bonferroni post hoc pairwise comparisons revealed that RTIME was higher in the energy drink condition across all time points (Mean diff = 1.051, $p = .04$; Figure 4) and that RTIME was significantly lower pre ingestion to post ingestion, pre exercise (Mean diff = -1.377, $p = .0001$) and was significantly higher pre ingestion to post exercise (Mean diff = 2.981, $p = .0001$). RTIME post ingestion, pre exercise was also significantly higher compared to RTIME post exercise (Mean diff = 4.358, $p = .0001$). Mean \pm SD of RTIME across time is presented in Figure 5.

Figure 3 Here

Figure 4 Here

Figure 5 Here

DISCUSSION

The current study examined the acute effect of a caffeine containing energy drink on mood state, readiness to invest effort and resistance exercise to failure and sought to address gaps in the literature by employing a design where multiple resistance exercise were used alongside multidimensional measures of effort (as opposed to only RPE) and mood state assessed pre ingestion, post ingestion but pre exercise and following exercise. The impact of the present study can therefore be seen across a number of the dependant variables examined. For example, the use of repetitions to failure in multiple resistance exercises in the current study resulted in a greater volume of total work completed in the experimental conditions and arguably a greater level of fatigue and discomfort than prior studies examining performance in one exercise. Examination of the effect of caffeine ingestion on multiple resistance exercises has been cited as a research need (10) and the results of this study provide support for prior assertions that caffeine ingestion enhances performance in short-term resistance exercise to failure. This agrees with previous studies (10, 15, 17, 31) and is in contrast to those studies that have reported no significant enhancement of resistance exercise performance following acute caffeine ingestion (4, 30). This also provides evidence that the

ergogenic effect of such energy drinks is not limited to one very short exercise bout and therefore may have potential to enhance the quality of training produced in a particular training session. Furthermore, the results of the present study agree with prior research that has documented enhanced resistance exercise performance following ingestion of an energy drink containing many of the same ingredients as the product examined in the present study (13, 16).

The significant main effect for RPE in this study supports prior research that has reported dampened RPE with caffeine ingestion in aerobically based exercise tasks (7, 8). However, these results also contradict a range of studies that have reported no difference in RPE following caffeine ingestion in resistance exercise (4, 10, 15, 31). One suggestion for the lack of dampening effect of caffeine on resistance exercise RPE has been that the short nature of exercise to failure in one given exercise (e.g., bench press) is insufficient to elicit a perceived difference in exertion between substances consumed (10). It may therefore be that the greater total volume of work employed in the current study enabled a more consistent differentiation between the caffeine containing energy drink and placebo conditions compared to prior studies. This suggestion is however speculative and further research is needed to verify this claim. Likewise, the differences in RPE across exercises, irrespective of substance ingested, are not unexpected as higher RPE values were reported in the exercises using more muscle mass (deadlift and back squat) compared to those using less muscle mass (prone row) and this is congruent with past research documenting higher RPE with exercise involving greater muscle mass.

The results in regard to mood state broadly indicate that there was a positive main effect for the vigor subscale of the BRUMS, with participants reporting that they felt more vigorous in the presence of the caffeinated drink when compared to placebo. Specifically participants reported that they felt more vigorous and less fatigued in the caffeine containing energy drink condition. Prior research examining the impact of caffeine ingestion on mood state has predominantly examined post exercise mood state (15) making it difficult to compare the results of the current study to prior research. More recently, Duncan and Oxford (10) assessed mood state pre ingestion and pre exercise compared with post exercise (i.e., 2 time points) using bench press to failure as their dependant variable. Similar to the present study, they found that after caffeine ingestion participants also reported increased vigor when compared with placebo. However, in the aforementioned study the lack of mood state data pre exercise, but post substance ingestion, limited the ability to make conclusions regarding any additive effect of consuming a caffeinated substance on the mood state response to an acute exercise bout.

The main effect for vigor also indicates that it was the independent variable (energy drink or placebo) which was largely responsible for the change in mood scores rather than the resistance exercise bout itself. To the authors' knowledge this is the first study to report such a finding and as such has added to the literature by employing a design where the effect of the independent variable could be examined on mood state prior to and post exercise allowing any additive effect of exercise to also be considered. Furthermore, in the current study, scores for both vigor and fatigue changed over the time course of the experimental design with significantly lower vigor

and higher fatigue scores post exercise compared to pre ingestion scores and scores obtained post ingestion but pre exercise. Such data are logical given the resistance exercise task employed in the study.

These results also agree with prior research that has assessed mood state responses to resistance exercise following caffeine ingestion (15) and Wingate anaerobic test performance (9). They also support claims made by Walsh et al (29), in respect to the effect of a caffeine containing energy drinks on a treadmill run to failure but disagree with the findings of Gonzalez et al (13) who reported no changes in subjective feelings of energy, focus and fatigue following resistance exercise performance in the presence of a caffeine containing energy drink. Gonzalez et al (13) suggested that one reason why subjective feelings related to mood were not influenced in their study was to do with the mode and duration of exercise used. The results of the current study would clearly contradict their assertion in respect to the impact of caffeine containing energy drinks on mood in general. However, the composition of the substances ingestion in the present study and that of Gonzalez et al (13) does differ and as a result the differences between the two studies may be due to the different ingredients consumed in the energy drinks that were examined. Subsequently, due to the dearth of studies investigating the impact of ingesting caffeine and caffeine containing energy drinks on mood state responses to exercise, further research is needed to fully elucidate the nature of any mood state changes that arise due to caffeinated energy drink ingestion and following short-term, high intensity exercise.

The current study also employed measures of readiness to invest effort, as has been recommended (24), and indicated that participants reported greater readiness to invest both mental and physical effort following ingestion of a caffeine containing energy drink. In the case of RTIPE, the substance X time interaction indicated that the increase in RTIPE pre ingestion to post ingestion (but pre exercise) was greater for the caffeine containing energy drink conditions compared to placebo, with subsequent greater RTIPE post exercise in the caffeine condition. To the authors' knowledge, this is the first study to report readiness to invest effort pre and post exercise in the presence of caffeine. This is despite criticisms of prior exercise based studies in the sole use of RPE as the only psychophysiological measure of effort examined (24, 27, 28) and recommendations that researchers incorporate measures of readiness to invest effort in their designs (24).

It may be that ingestion of caffeinated energy drinks results in psychological changes whereby participants feel more able to provide maximal effort compared to ingestion of placebo, possibly due to dampened RPE and pain perception, as other prior studies have suggested (1). As this is the first study to report readiness to invest effort after caffeine ingestion further research examining this concept is needed. The current study acted on criticisms cited by previous authors and has highlighted that the psychological responses to resistance exercise in the presence of caffeine containing energy drinks is multidimensional and not simply restricted to perception of effort during or immediately following exercise. Practitioners and coaches would therefore benefit from use of a more multidimensional approach to

assessing the psychological responses to resistance exercise following nutritional intervention in future. Moreover, the dose of caffeine utilized in the present study was low in comparison to previous studies. It might therefore be useful for future studies to examine the impact of different doses of caffeine on psychophysiological responses to resistance exercise.

The present study does have a number of limitations. The task used employed one set of 4 exercises to failure and may not be fully representative of the range of resistance exercises undertaken by athletic populations. Prior research has tended to employ very brief resistance exercise tasks such as one set of one exercise (e.g., bench press) to failure (10) or brief bouts of isokinetic dynamometry (18). The present study sought to build on these by employing an increased number of exercises to failure than has been the case in prior studies (2, 4, 9). However, the protocol employed in the present study may not fully address the typical training session undertaken by many recreational exercisers and athletes. Future research might therefore benefit from trying to replicate the typical training undertaken in gym environments (e.g., examining 3 sets of multiple resistance exercises with the final set of each to failure), rather than one set of each exercise to failure as was employed in the current study.

It may also be useful to compare the responses of participants of different training status as this has been suggested as one of the main explanations of the equivocal findings on this topic. In the present study, caffeine intake prior to data collection could have been more stringently controlled. Participants abstained from caffeine from 6.00pm on the night prior to testing rather than the typical 24-48hour period used in other studies. This

procedure was chosen based on recommendations of Marlat & Rosenhow (22) who suggested that studies employing a 24 hour or greater withdrawal period in moderate to heavy caffeine users may actually result in assessing the reversal of withdrawal symptoms rather than the actual effect of caffeine ingestion. This issue has recently been alluded to in work by Astorino et al (3) where the majority of meaningful increases in performance after caffeine administration were found with participants who were the heavier caffeine users. Nevertheless, this issue may be considered a limitation and future research assessing the issue of performance change at different stages of caffeine withdrawal would be useful in elucidating this issue further.

Furthermore, the present study examined one absolute dose of caffeine on performance alongside other ingredients (Taurine, Tyrosine, Vitamin B12, 9, 3, 6 and Glucuronolactone) in a commercially available energy drink. This resulted in participants ingesting doses of caffeine in the range of 2.0-4.2 mg kg⁻¹ in relative terms. Studies have shown lower doses (as low as 1.5mg kg⁻¹) to be ergogenic in aerobic tasks (23) but these have not been examined in relation to acute resistance exercise. The present study sought to examine the effect of a commercially available energy drink on resistance exercise performance as the manufacturer's claim it enhances exercise performance and enhances mood alongside a range of other benefits. An absolute dose of the energy drink was used in the current study, congruent with other studies that have examined similar products (13, 16, 29) as this provides a more ecologically valid examination of how the product would be used by athletes and recreational exercisers. We are also making the assumption that caffeine is likely the most important ingredient in the

energy drink affecting performance as this appears to be the most likely explanation, and is in line with other studies that have investigated the ergogenic effects of similar products (13, 16). The other ingredients within the energy drink may have contributed to the data presented in this study. In particular, many commercially available energy drinks include taurine and glucuronolactone in their products as a form of 'energy matrix' and have been shown to be ergogenic in resistance and aerobic endurance exercise (13, 16, 29). The results reported in the current study cannot therefore be solely attributed to caffeine ingestion and other ingredients within the energy drink may have contributed to the findings presented here. While other studies have also examined the impact of absolute doses of caffeine in other energy drinks (e.g., 4) this obviously results in between-subject variation in the bolus of caffeine ingested and limits the ability of scientists to prescribe a relative dose of caffeine that is likely to enhance exercise performance.

PRACTICAL APPLICATIONS

Considerable attention has been paid to the use of substances purported to enhance sports and exercise performance, including energy drinks. Results of the present study suggest that ingestion of a caffeinated energy drink results in enhanced resistance exercise performance alongside dampened perception of exertion and greater vigor compared to a placebo. No study to date has reported the effect of caffeine or caffeine containing energy drinks on readiness to invest effort pre and post resistance exercise. Increases in readiness to invest physical effort were seen following ingestion of Quick

Energy™ and persisted, post exercise, indicating that subjects felt more able to produce maximal efforts during and after the exercise bout. For coaches and practitioners this is important as the current study suggests the drink Quick Energy™ not only enhanced resistance exercise performance but also prompted positive changes in the willingness to invest maximal effort in a high intensity exercise bout. Therefore, such substances could be used as a pre-exercise strategy to provide a more positive psychological climate before, during and after resistance exercise resulting in athletes and regular exercisers demonstrating greater willingness to undertake more work and invest effort.

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Figure Legends

Figure 1. Mean \pm SD of RPE between caffeinated energy drink and placebo conditions (n = 13), * = $p = .022$.

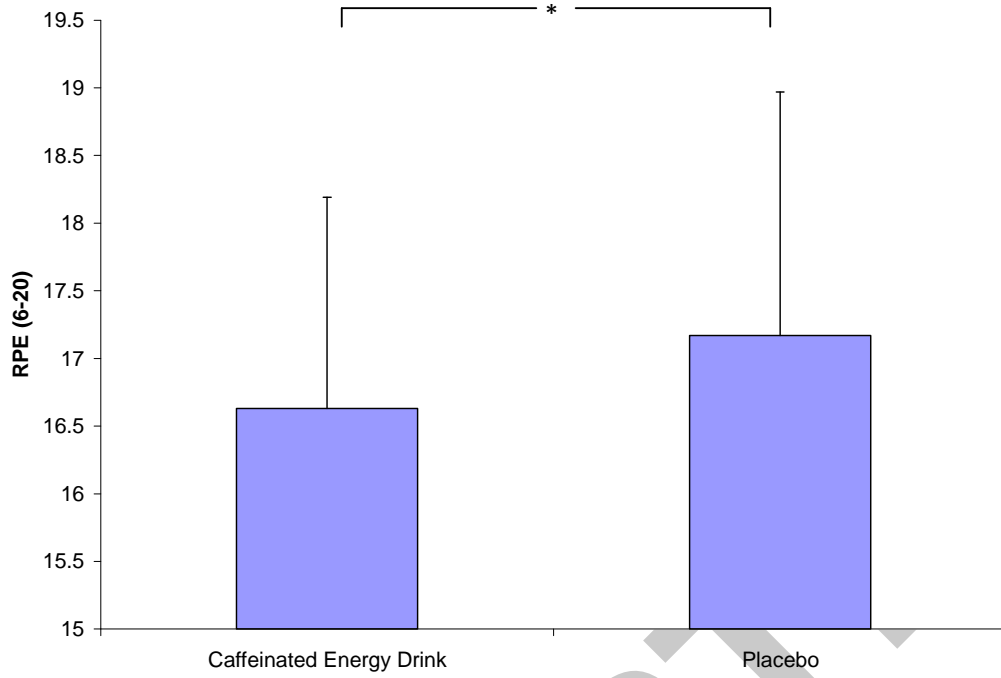
Figure 2. Mean \pm SD of RPE across bench press, prone row, deadlift and back squat exercises (n = 13), * = $p = .013$, § = $p = .003$.

Figure 3. Mean \pm SD of readiness to invest physical effort (RTIPE) across time and between caffeinated energy drink and placebo conditions (n = 13), $p = .03$ between conditions.

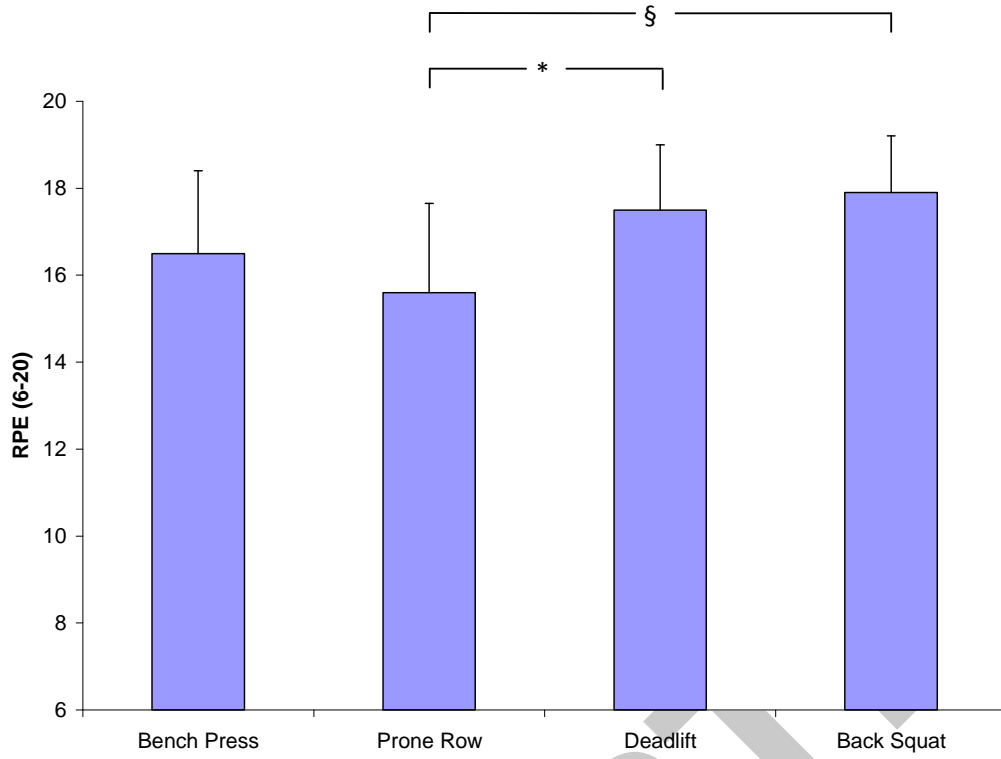
Figure 4. Mean \pm SD of readiness to invest mental effort (RTIME) between caffeinated energy drink and placebo conditions (n = 13), * = $p = .04$.

Figure 5. Mean \pm SD of readiness to invest mental effort across time (RTIME), irrespective of substance ingested (n = 13), * = $p = .0001$.

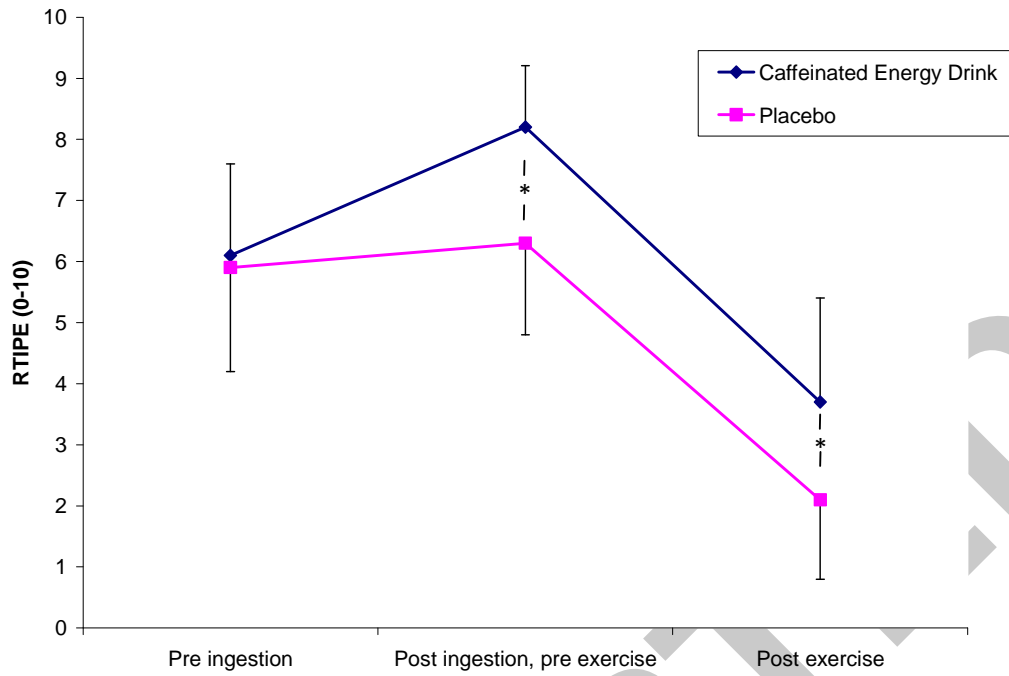
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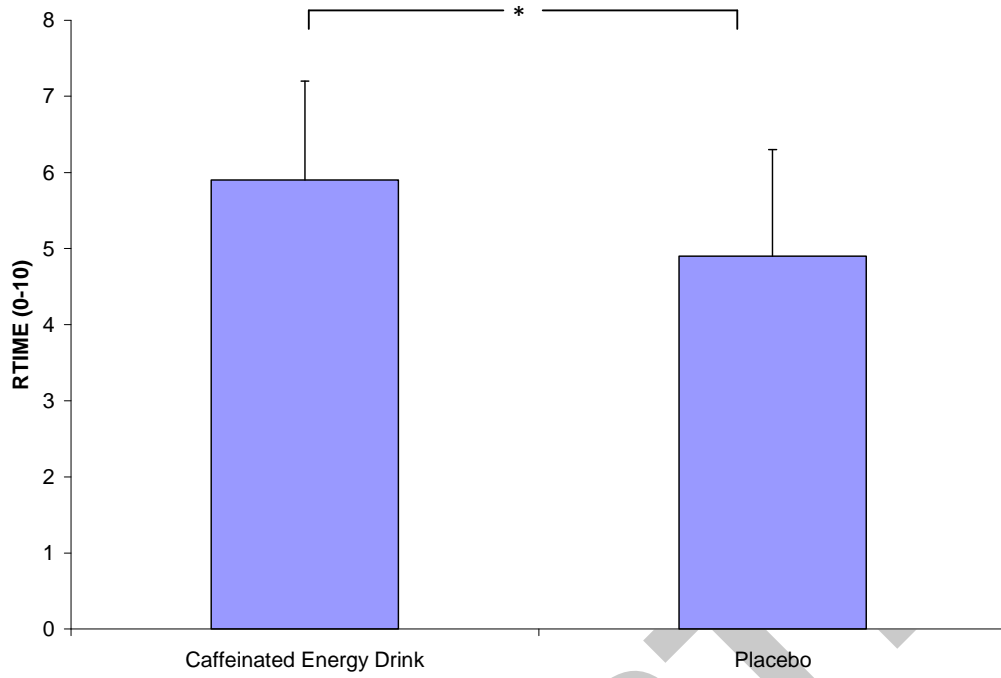
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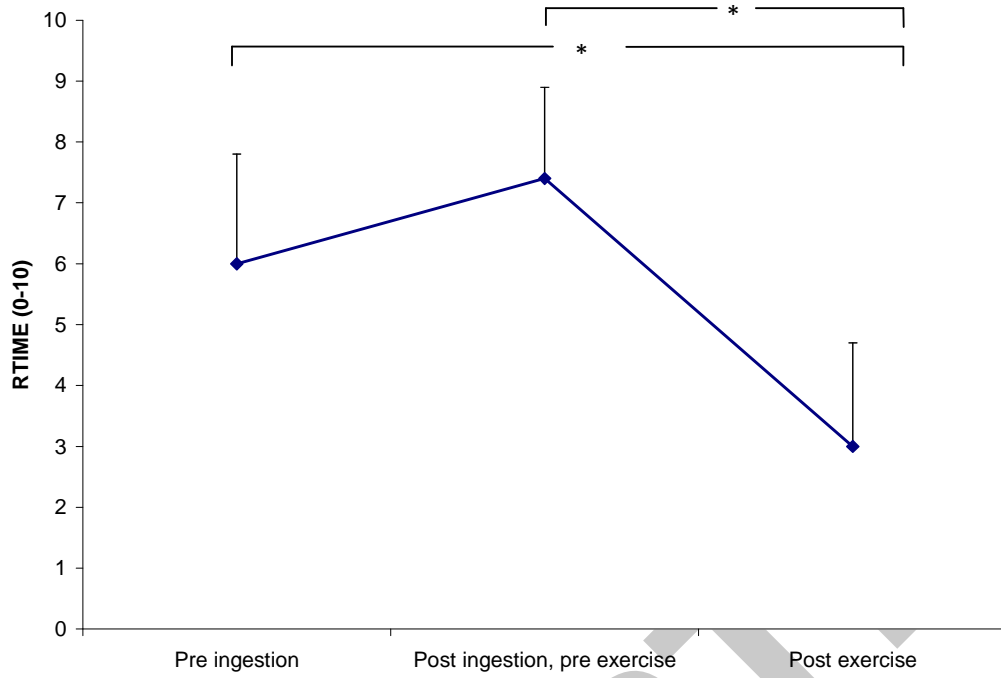
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