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Acute Caffeine Ingestion Increases Velocity and Power in Upper and Lower Body Free-Weight Resistance Exercises

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ABSTRACT

International Journal of Exercise Science 12(2): 1280-1289, 2019. The purpose of this study was to examine the acute effects of caffeine supplementation on velocity and power output during bench press and back squat exercises. Resistance trained males (n = 12) consuming less than 300 mg of caffeine daily, were recruited for this study. In a blinded crossover study design, participants supplemented with 6 $mg \cdot kg^{-1}$ caffeine or placebo (placebo, gluten-free cornstarch) 60 min prior to exercise. Participants completed 3 × 1 repetition with maximum explosive intent at 80% of their 1-RM for bench and squat exercises with two minute rest periods between each repetition. A linear position transducer was used to measure power and velocity of barbell movement. Each trial was separated by a 72 h washout period. Results indicated that mean velocity (p = 0.027; ES = 1.04) and mean power (p = 0.008; ES = 0.24) were higher during bench press exercise with caffeine versus placebo. Furthermore, mean velocity (p = 0.005; ES=1.06) and mean power (p = 0.020; ES = 0.71) values were higher for back squat exercise with caffeine versus placebo. This study suggests that caffeine ingestion imposes ergogenic benefits by increasing velocity and power in both upper and lower body resistance exercises. However, caffeine had a larger effect on lower body power output versus upper body exercise. Results may hold important implications for using caffeine during training.

KEY WORDS: Bench press, squat, ergogenic aid, weight training, concentric velocity, power output

INTRODUCTION

Caffeine is one of the most widely used psychoactive substances in the world, due to its ability to increase neural drive, arousal, and alertness (8). Since its removal from the banned drug list by the World Anti-Doping Agency (WADA) in 2004, it is estimated that approximately 73.8% of elite athletes consume caffeine prior to competition (11). Many investigations have reported ergogenic benefits of caffeine use in various types of exercise including endurance and resistance/strength based activities (14, 19, 36), although some literature is conflicting (1, 7, 10). These conflicts may be due to differences in dosage, type of exercise, timing of ingestion before exercise, and load lifted during exercise. For strength and power training, the physiological mechanisms responsible for ergogenic properties are not fully understood. Previous evidence has suggested that caffeine may increase motor unit recruitment, muscle activation, and firing rates of motor neurons (25). Given this information, caffeine and caffeine -containing supplements have become increasingly popular when paired with resistance exercise as enhancement of motor unit recruitment and muscle activation may lead to greater performance and adaptation (34). Since the evidence supporting performance enhancement during resistance training is equivocal, further study is warranted.

The effects of caffeine and caffeine -containing supplements on resistance exercise performance have largely been studied through both muscular endurance and strength (1, 3, 7, 14, 19). Green et al. (19) reported that caffeine ingestion led to increased leg press repetitions during repeated sets to failure despite no differences in rate of perceived exertion (RPE) suggesting caffeine may alter pain responses thereby delaying fatigue. However, other studies have shown no practical differences in muscular endurance or have reported a placebo effect accompanying supplementation leaving the exact contribution to performance enhancement equivocal (1, 7). In regards to strength, multiple groups have reported increases in upper body strength in particular with caffeine ingestion (3, 7, 17). Beck et al. (3) reported increases in bench press one-repetition maximum (1-RM) with caffeine supplementation in males. However, similar to findings measuring muscular endurance with caffeine, there have also been multiple reports that have reported no changes in strength with supplementation (1, 2).

Previous studies have shown caffeine to have an ergogenic effect on power during Wingate anaerobic testing (WaNT) (20) and seated medicine ball throws (21), as well as an increase in jump height (6). The effects of caffeine supplementation on power and velocity during traditional resistance exercise has been comparatively less studied. Mora-Rodriguez et al. showed that caffeine ingestion can attenuate time-of-day declines in velocity during resistance based exercise (29). However, a carbohydrate rich meal was ingested with the caffeine. Given that previous evidence has shown that carbohydrate ingestion can acutely improve muscle force output and impact caffeine absorption (35, 38), power and velocity changes may have been impacted. In a follow-up study, Mora-Rodriguez et al. showed that caffeine increased propulsive velocity during Smith machine exercises (30). However, velocity measurements may have been altered due to the fact that Smith machine exercises have no horizontal component compared to free-weight exercise. Given this information, more study is warranted on caffeine ingestion and velocity during free-weight resistance exercise. Recently, a meta-analysis reviewing the effects of caffeine on power output and strength suggested that caffeine might impose greater ergogenic benefit in upper body exercise versus lower body exercise and suggested further study (22). Thus, the following study sought to investigate the efficacy an effects of caffeine on power output and velocity during free-weight back squat and bench press exercises. We hypothesized that acute caffeine ingesting would increase power and velocity in upper and lower body barbell exercises. We also hypothesized that the upper body performance would be affected to a greater extent when compared to lower body performance.

METHODS

The following investigation used a randomized, counterbalanced, crossover study design to investigate the effects of caffeine ingestion on velocity and power output during resistance exercise. Resistance-trained, college-aged males volunteered to participate and participated in 3 visits. For the first visit, participant's one repetition maximum (1-RM) was obtained for bench press and back squat. For the following 2 trials, participants were randomly grouped and consumed caffeine or placebo and completed 3 sets × 1 repetition as explosively as possible. Comparisons were drawn between caffeine and placebo for mean velocity and power during back squat and bench press exercises averaged over the 3 sets. Visits were separated by a 72 hour washout period.

Participants

Resistance-trained males (n = 12) between the ages of 18-24 were recruited for this investigation. Descriptive characteristics are presented in (Table 1). Resistance-trained was defined as participating in resistance exercise training a minimum of 2-3 days a week (27). Participant suitability for exercise was determined using a modified physical activity readiness questionnaire (PAR-Q) which excluded participants who reported upper or lower body injuries in the past six months, metabolic disease, cardiovascular disease, musculoskeletal disease, or other health problems. A caffeine consumption questionnaire was used to approximate daily caffeine consumption. To avoid heavy caffeine users, participants were excluded if they reported consuming greater than a moderate amount of caffeine daily (>300 mg) (28). All participants had previous experience performing back squat and bench press exercises in particular. Informed consent was obtained from each participant prior to data collection and all experimental procedures were approved by the Samford University Institutional Review Board (IRB). This research was carried out in accordance to the ethical standards of the International Journal of Exercise Science (31).

Table 1. Descriptive characteristics (n = 12).

Characteristics	Mean ± SD
Age (yrs)	20.0 ± 1.7
Body mass (kg)	83.9 ± 13.0
Bench press 1-RM (kg)	92.4 ± 24.6
Back squat 1-RM (kg)	121.4 ± 24.8
Relative bench press [1-RM (kg)/ BM (kg)]	1.1 ± 0.1
Relative back squat [1-RM (kg)/ BM (kg)]	1.4 ± 0.1
Supplement amount (mg)	504.0± 78.7

Protocol

Supplementation: Participants supplemented with either pure caffeine anhydrous (Dual health Body & Mind, USA) or placebo (gluten-free cornstarch) at a dosage of 6 $mg \cdot kg^{-1}$ prior to each testing session after a 4 hour fast. Caffeine and placebo were administered to the participants 60 minutes before each exercise trial (15, 16). Both caffeine and placebo were dissolved in approximately 500 mL of water with a commercially available sugar-free drink mix to mask taste. Participants were instructed to consume the entirety of the supplement within 5 minutes. Prior to each session, participants were instructed to abstain from any caffeine, nicotine, and alcohol for a minimum of 24 hours.

One-repetition Maximum (1-RM) Testing and Familiarization: For the first session, a light warm-up was performed prior to each 1-RM test. Briefly, participants completed 5 reps of 50% and 3 reps at 70% of their perceived 1-RM with 3 minutes of rest in between sets. Following the warm-up, barbell load was increased by 2.0 - 20.0 kg for each attempt until the participant could not complete the lift. The 1-RM weight was determined within four attempts with three- to five-min rest periods between each attempt (27). This protocol was used for both bench press and back squat exercises in that order. A rest period of 10 min separated the completion of the bench 1-RM assessment and the beginning of the back squat 1-RM assessment. Following 1-RM testing, participants were familiarized with the protocol of lifting with maximum explosive intent for each exercise. Participants lifted a standard 20-kg Olympic barbell as fast and explosively as possible for a total of three repetitions which was repeated for a total of three sets.

Exercise Testing: Following the ingestion of the supplement, participants began with a brief warm up consisting of 3 repetitions of an unloaded standard 20-kg Olympic bar, 2 repetitions at 40% of 1-RM, and 1 repetition at 65% of 1-RM. Each set was separated by a 2-min rest period and warm ups were identical between bench press and back squat. Following the bench press warm up, participants bench pressed 80% of 1-RM for one repetition as explosively as possible for a total of three sets with 2-min rest periods between. After 5-min of rest, participants completed the subsequently mentioned warm up for back squat and squatted 80% of 1-RM for one repetition as explosively as possible for a total of three sets with 2-min rest periods between. 80% of 1-RM was chosen based off evidence that weights greater than 75% 1-RM are needed to elicit maximal strength adaptations (26). During all exercises, a linear position transducer (GymAware, Kinetitech Performance Technology, Australia) was attached to the barbell to obtain velocity and power measurements. This device has been previously validated for velocity and power measurements (24, 32). In addition, it has shown excellent test-retest reliability in our laboratory (ICC (3,1) = 0.932; SEM = 0.019; MD = 0.054; n = 12). The device was used according to manufacturer's instructions such that the device was attached to the barbell with a perpendicular angle being achieved throughout the entirety of lifts (23). Although some participants completed their trials in the morning and some in the evening, each participant completed all trails within 2 hours of the same time of day.

Statistical Analysis

All data were analyzed using SPSS 25 (IBM, Armonk, NY). All performance variables were averaged over all three repetitions and analyzed using a paired samples t-test. Cohen's d effect sizes were calculated for all performance variables as caffeine minus placebo divided by the pooled standard deviation with the following interpretation: 0.2 – small, 0.5 – moderate, and 0.8 large (9). All data are presented as mean ± standard deviation (SD). Significance was set at $p \leq 0.05$ a priori.

RESULTS

Bench press and back squat mean velocity ($m \cdot s^{-1}$) are shown in (Figure 1). Mean velocity during the bench press exercise was significantly higher with caffeine than placebo (placebo = 0.50 $m \cdot s^{-1}$ ± 0.05, caffeine = 0.56 $m \cdot s^{-1}$ ± 0.06; p = 0.027; ES = 1.04). Similarly, mean velocity during the back squat exercise was significantly higher with caffeine than placebo (placebo = 0.57 $m \cdot s^{-1}$ ± 0.06, caffeine = 0.63 $m \cdot s^{-1}$ ± 0.04; $p = 0.005$; ES = 1.06). Mean power (W) during the bench press and back squat are shown in (Figure 2). For bench press, was significantly higher with caffeine than placebo (placebo = 371.0 watts ± 107.1, caffeine = 398.3 watts ± 109.5; $p = 0.008$; ES = 0.24). Also, mean power was significantly higher during back squat exercise with caffeine versus placebo (placebo = 1,042.4 watts ± 157.0, caffeine = 1,172.0 watts ± 210.6; $p = 0.020$; ES = 0.71).

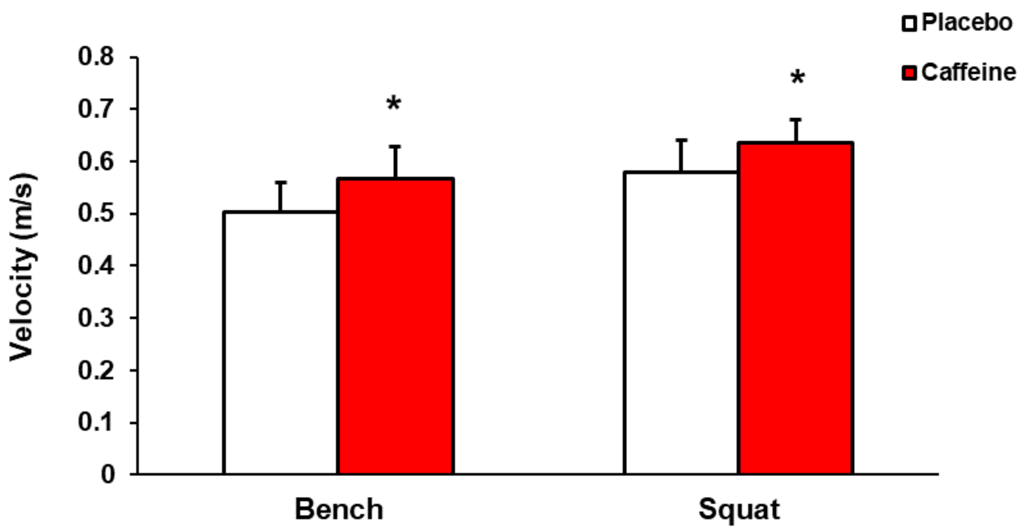

Figure 1. Mean velocity during bench press and back squat exercise. Data are presented at mean ± SD. * indicates significantly different from placebo ($p < 0.05$).

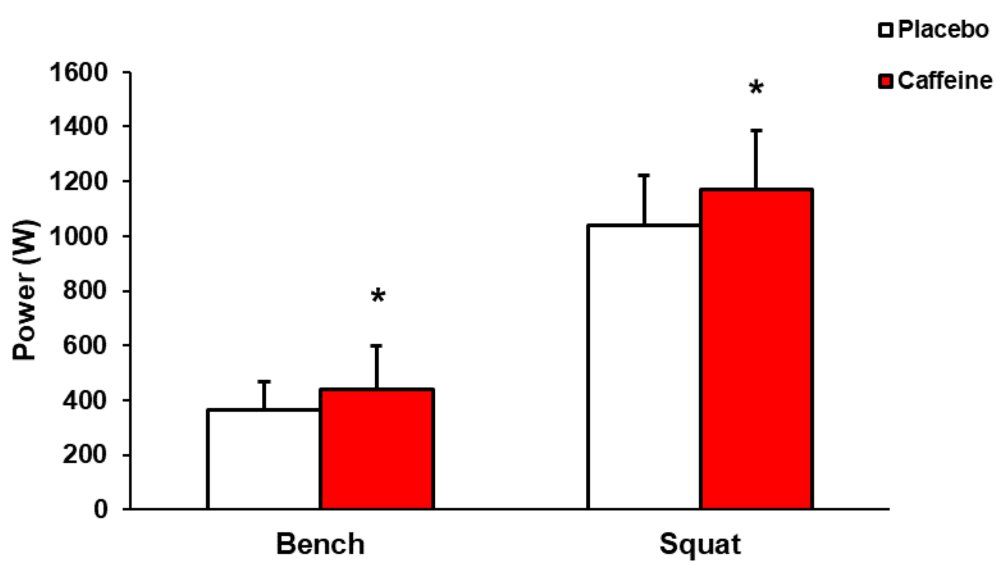

Figure 2. Mean power output during bench press and back squat exercise. Data are presented at mean ± SD. * indicates significantly different from placebo ($p < 0.05$).

DISCUSSION

Caffeine has been repeatedly reported to have ergogenic properties in both endurance and resistance exercise. Few investigations have examined the effects of caffeine, velocity, and power output during resistance training. There is some evidence that caffeine supplementation may attenuate declines in velocity due to time-of-day and that caffeine may improve power output during bench press repetitions to failure (12, 29). However, previously mentioned limitations have made it difficult to make a conclusion on how caffeine influences velocity and power during free-weight resistance exercise. Thus, the current study sought to investigate the effects of caffeine supplementation on velocity and power output during the back squat and bench press exercises further. Findings from this study reveal that caffeine ingestion increases velocity and power output in both free weight bench press and back squat exercises. Counter to our hypothesis, caffeine ingestion had a larger effect on power output during lower body versus upper body exercise. While precise mechanisms for these improvements are not fully clear at this time, these findings hold important implications for the use of caffeine to increase performance in explosive resistance exercise.

Previous research has provided evidence that caffeine enhances power output during lower body and upper body power-based assessments and explosive movements (6, 20, 21). Our results support these findings in that the current data suggests that caffeine improves performance in both upper and lower body multi-joint barbell exercises. Interestingly however, our results showed that caffeine ingestion only had a small effect on increasing bench press power and a moderate effect on back squat power. This is in contrast with previous studies suggesting that acute caffeine ingestion may improve upper body exercises to a greater degree (22). Differences in these results may be due to the modality of exercise used to measure power output of the lower body. The current study used 80% of 1-RM back squat, while previous investigations used body weight or low-load exercises such as the counter movement jump and squat jump (Grgic et al. 2018). Mora-Rodriguez et al. reported that caffeine reversed declines in velocity of barbell movement due to time-of-day influences after standardization (29). Given that the current study standardized for time of day, our results confirm these findings. Of particular note, our results also further support Mora-Rodriguez et al.'s reported ergogenic effects of using a caffeine dose of 6 $mg \cdot kg^{-1}$. Our findings of increased power also support previous research that showed increases in power output during bench press repetitions to failure in Brazilian Jiu-jitsu athletes (12). However, Diaz-Lara et al. used a considerably lighter load (~45% of 1-RM) and lower dose of caffeine (3 $mg \cdot kg^{-1}$) than that used in the current study. Thus, our results suggest that caffeine also imparts ergogenic benefit even at heavier loads albeit with a higher dosage. From our data alone, it is unknown whether lower doses of caffeine impart benefits to velocity and power during resistance exercise at heavy loads. Future research is needed to determine if caffeine can concurrently increase power and velocity of barbell movements at lower doses and what threshold dose is needed to see improvements in performance.

The physiological mechanisms responsible for increased power and velocity are not fully known. As previously mentioned, caffeine has previously been reported to increase muscle activation and motor unit recruitment (25). While not confirmatory in current experiment, our results support this notion in that increased muscle activation and recruitment of motor units lead to greater power output and velocity (34). Thus, the increases in mean velocity and power output during the caffeine trial may be due to modulation of muscle activity. Our results are further supported by previous evidence showing that caffeine can enhance force production and performance during ballistic movements (5). However, how our results translate to changes in performance such as muscular strength and endurance are not currently clear. caffeine in particular is also known for its ability to increase alertness and arousal (8). Another possible explanation for the increases in mean velocity and power output in the current study may be due to increased arousal thereby modifying effort and focus. This is bolstered by previous evidence of various factors which increase arousal leading to increases in exercise performance (4, 13). More particularly, evidence has suggested that increasing arousal enhances muscular force production (37). To our knowledge, it is not fully clear how arousal contributes to changes in power and velocity during resistance exercise. Thus, future studies are needed to determine the contribution of arousal in particular with caffeine and resistance exercise.

The novelty of our results show that mean power and velocity is increased during lower body and upper body multi-joint free-weight barbell exercises. The back squat and bench press exercises are commonly used by athletes to develop muscular strength and power to enhance sport-specific performance. A study by Pareja-Blanco et al. (33) demonstrated that training at higher concentric velocities in the back squat was more effective at increasing lower body maximum strength and CMJ height. Furthermore, a group that trained at higher concentric velocity in the bench press achieved greater increases in bench press strength than a group training at 50% lower velocity (18). While these studies purposefully had one group train at a slower velocity, these findings suggest that greater adaptations occur when higher concentric velocities are achieved for a given relative intensity. The results of our study demonstrate that caffeine significantly increases concentric velocity in an acute exercise bout. Thus, the acute increases in concentric velocity following caffeine supplementation may lead to greater long-term adaptations to training. Future studies should investigate chronic caffeine consumption prior to training and whether it leads greater long-term enhancements in muscular strength and power.

While the current study presents new information regarding caffeine supplementation and resistance exercise performance, there were several limitations to the study. The current study did not elucidate a physiological mechanism for improvements in performance. Thus, it is still unknown what physiological factors contribute to the changes in velocity and power output and warrants further study. Also, only one load was used for testing (80% 1-RM). While this load is commonly used by athletes training to increase strength and hypertrophy, it is unknown whether our supplementation protocol translates to lighter or heavier loads. The participants for the current study were resistance trained college males. Thus, it is unknown if different ages or populations would be impacted differently. Lastly, only a single-time dosage of 6 $mg \cdot kg^{-1}$ was used prior to exercise. Thus, it remains unknown how long-term supplementation impacts performance and adaptations.

In conclusion, the results from the current study show that acute caffeine ingestion enhances velocity and power output during both upper and lower body resistance exercises. Future study is needed to describe the physiological mechanisms responsible for increases in velocity and power output with caffeine supplementation. Given that acute supplementation increased concentric velocity and previous evidence suggests this may lead to greater adaptation, this study holds important implications for use of caffeine to enhance training adaptations during resistance exercise.

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REFERENCES

1. Astorino TA, Rohmann RL, Firth K. Effect of caffeine ingestion on one-repetition maximum muscular strength. Eur J Appl Physiol 102(2): 127-132, 2008.

2. Beck TW, Housh TJ, Malek MH, Mielke M, Hendrix R. The acute effects of a caffeine-containing supplement on bench press strength and time to running exhaustion. J Strength Cond Res 22(5): 1654-1658, 2008.

3. Beck TW, Housh TJ, Schmidt RJ, Johnson GO, Housh DJ, Coburn JW, Malek MH. The acute effects of a caffeine-containing supplement on strength, muscular endurance, and anaerobic capabilities. J Strength Cond Res 20(3): 506-510, 2006.

4. Bell DG, Jacobs I, Ellerington K. Effect of caffeine and ephedrine ingestion on anaerobic exercise performance. Med Sci Sports Exerc 33(8): 1399-1403, 2001.

5. Bloms LP, Fitzgerald JS, Short MW, Whitehead JR. The effects of caffeine on vertical jump height and execution in collegiate athletes. J Strength Cond Res 30(7): 1855-1861, 2016.

6. Bloms LP, Fitzgerald JS, Short MW, Whitehead JR. The effects of caffeine on vertical jump height and execution in collegiate athletes. J Strength Cond Res 30(7): 1855-1861, 2016.

7. Brooks JH, Wyld K, Chrismas BC. Acute effects of caffeine on strength performance in trained and untrained individuals. J Athl Enhancement 4(6), 2015.

8. Chawla J, Suleman A. Neurologic effects of caffeine. Medscape Reference. Retrieved February 2013.

9. Cohen J. Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale: Erlbaum Associates; 1988.

10. Crowe MJ, Leicht AS, Spinks WL. Physiological and cognitive responses to caffeine during repeated, high-intensity exercise. Int J Sport Nutr Exerc Metab 16(5): 528-544, 2006.

11. Del Coso J, Muñoz G, Muñoz-Guerra J. 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(4): 555-561, 2011.

12. Diaz-Lara FJ, Del Coso J, Garcia JM, Portillo LJ, Areces F, Abian-Vicen J. Caffeine improves muscular performance in elite Brazilian jiu-jitsu athletes. Eur J Sport Sci 16(8): 1079-1086, 2016.

13. Dillman Carpentier FR, Potter RF. Effects of music on physiological arousal: Explorations into tempo and genre. Media Psychol 10(3):339-363, 2007.

14. Duncan MJ, Stanley M, Parkhouse N, Cook K, Smith M. Acute caffeine ingestion enhances strength performance and reduces perceived exertion and muscle pain perception during resistance exercise. Eur J Sport Sci 13(4): 392-399, 2013.

15. Duncan MJ, Stanley M, Parkhouse N, Cook K, Smith M. Acute caffeine ingestion enhances strength performance and reduces perceived exertion and muscle pain perception during resistance exercise. Eur J Sport Sci 13(4): 392-399, 2013.

16. Goldstein E, Jacobs PL, Whitehurst M, Penhollow T, Antonio J. Caffeine enhances upper body strength in resistance-trained women. J Int Soc Sports Nutr 7(1): 18, 2010.

17. Goldstein E, Jacobs PL, Whitehurst M, Penhollow T, Antonio J. Caffeine enhances upper body strength in resistance-trained women. J Int Soc Sports Nutr 7: 18, 2010.

18. Gonzalez-Badillo JJ, Rodriguez-Rosell D, Sanchez-Medina L, Gorostiaga EM, Pareja-Blanco F. Maximal intended velocity training induces greater gains in bench press performance than deliberately slower half-velocity training. Eur J Sport Sci 14(8): 772-781, 2014.

19. Green JM, Wickwire PJ, McLester JR, Gendle S, Hudson G, Pritchett RC, Laurent CM. Effects of caffeine on repetitions to failure and ratings of perceived exertion during resistance training. Int J Sports Physiol Perform 2(3): 250-259, 2007.

20. Grgic J. Caffeine ingestion enhances Wingate performance: A meta-analysis. Eur J Sport Sci 18(2): 219-225, 2018.

21. Grgic J, Mikulic P. Caffeine ingestion acutely enhances muscular strength and power but not muscular endurance in resistance-trained men. Eur J Sport Sci 17(8): 1029-1036, 2017.

22. Grgic J, Trexler ET, Lazinica B, Pedisic Z. Effects of caffeine intake on muscle strength and power: A systematic review and meta-analysis. J Int Soc Sports Nutr 15: 11, 2018.

23. Helms ER, Storey A, Cross MR, Brown SR, Lenetsky S, Ramsay H, Dillen C, Zourdos MC. Rpe and velocity relationships for the back squat, bench press, and deadlift in powerlifters. J Strength Cond Res 31(2): 292-297, 2017.

24. Hori N, Andrews W. Reliability of velocity, force and power obtained from the GymAware optical encoder during countermovement jump with and without external loads. J Aust Strength Cond 17(1): 12-17, 2009.

25. Kalmar JM. The influence of caffeine on voluntary muscle activation. Med Sci Sports Exerc 37(12): 2113-2119, 2005.

26. Medicine ACoS. American college of sports medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 41(3): 687, 2009.

27. Medicine ACoS. ACSM's exercise testing and prescription (10th ed.). Philadelphia: Lippincott Williams & Wilkins; 2017.

28. Mitchell DC, Knight CA, Hockenberry J, Teplansky R, Hartman TJ. Beverage caffeine intakes in the U.S. Food Chem Toxicol 63: 136-142, 2014.

29. Mora-Rodriguez R, Garcia Pallares J, Lopez-Samanes A, Ortega JF, Fernandez-Elias VE. Caffeine ingestion reverses the circadian rhythm effects on neuromuscular performance in highly resistance-trained men. PLoS One 7(4): e33807, 2012.

30. Mora-Rodriguez R, Pallares JG, Lopez-Gullon JM, Lopez-Samanes A, Fernandez-Elias VE, Ortega JF. Improvements on neuromuscular performance with caffeine ingestion depend on the time-of-day. J Sci Med Sport 18(3): 338-342, 2015.

31. Navalta JW, Stone WJ, Lyons S. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

32. Orange ST, Metcalfe JW, Marshall P, Vince RV, Madden LA, Liefeith A. Test-retest reliability of a commercial linear position transducer (GymAware PowerTool) to measure velocity and power in the back squat and bench press. J Strength Cond Res, 2018.

33. Pareja-Blanco F, Rodriguez-Rosell D, Sanchez-Medina L, Gorostiaga EM, Gonzalez-Badillo JJ. Effect of movement velocity during resistance training on neuromuscular performance. Int J Sports Med 35(11): 916-924, 2014.

34. Powers SK, Howley ET. Exercise physiology: Theory and application to fitness and performance. New York City: McGraw-Hill Education; 2014.

35. Skinner TL, Jenkins DG, Folling J, Leveritt MD, Coombes JS, Taaffe DR. Influence of carbohydrate on serum caffeine concentrations following caffeine ingestion. J Sci Med Sport 16(4): 343-347, 2013.

36. Southward K, Rutherfurd-Markwick KJ, Ali A. The effect of acute caffeine ingestion on endurance performance: A systematic review and meta–analysis. Sports Med 48(8): 1913-1928, 2018.

37. Tod D, Iredale F, Gill N. 'Psyching-up'and muscular force production. Sports Med 33(1): 47-58, 2003.

38. Wax B, Brown SP, Webb HE, Kavazis AN. Effects of carbohydrate supplementation on force output and time to exhaustion during static leg contractions superimposed with electromyostimulation. J Strength Cond Res 26(6): 1717-1723, 2012.