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Acute caffeine supplementation promotes small to moderate improvements in performance tests indicative of in-game success in professional female basketball players

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Abstract

The aim of this study was to determine the effect of acute caffeine supplementation on anaerobic performance in professional, female basketball players. A double-blind, placebo-controlled, experimental design was used in a randomized, counterbalanced manner. In separate sessions, 10 professional basketball players ingested caffeine (3 mg/kg body mass) or a placebo (dextrose: 3 mg/kg body mass) 60 min before completing countermovement jumps (CMJ) with and without arm swing, a squat jump (SJ), the Lane Agility Drill, 20-m sprints (with 5-m and 10-m split times recorded) with and without dribbling a ball, and a Suicide Run. Participants provided ratings of perceived exertion (RPE) and ratings of perceived performance 30 min following testing. Data anlayses included the use of effect size (ES) and significance. Caffeine supplementation produced *small*, non-significant ($p > 0.05$) increases in CMJ without arm swing (ES = 0.30), CMJ with arm swing (ES = 0.29), SJ (ES = 0.33), and the Lane Agility Drill (ES = -0.27). Caffeine supplementation produced s*mall* to *moderate*, significant improvments in 10-m (ES = -0.63; $p = 0.05$) and 20-m (ES = -0.41; $p = 0.04$) sprint times without dribbling. Caffeine supplmentation promoted a *moderate*, significant reduction in RPE during the test battery (ES = -1.18; $p = 0.04$) and a *small*, non-significant improvement in perceived performance (ES = 0.23; $p = 0.53$). Acute caffeine supplementation may produce *small* to *moderate* improvements in key performance attritubes required for basketball while reducing RPE.

Key words: jump, sprint, power-based attributes, ergogenic aids, perceived exertion, side-effects

Introduction

During a basketball match, female players spend ~10 min completing high-intensity activities encompassing jumping, sprinting, and shuffling movements with and without the ball (Conte et al. 2015). In addition, 52% of sprinting performed during basketball match-play consists of curved movement paths and changes in direction, emphasizing the importance of non-linear, high-intensity activity (Conte et al. 2015). In this regard, a systematic analysis of basketball match-play demonstrated a pronounced decrease in the time engaged in high-intensity activity towards latter match quarters (Stojanović et al. 2018a). Furthermore, higher level players sustain greater high-intensity and intermittent workloads compared to lower level players during match-play (Abdelkrim et al. 2010), highlighting the importance of targeting change-of-direction (COD), jump, and sprint performance for success in basketball. As such, the efficacy of ergogenic aids, such as caffeine, on anaerobic performance are of interest for basketball coaches and athletes. Namely, anaerobic performance may be improved by ergogenic properties of caffeine such as an increased secretion of β-endorphins (Laurent et al. 2000), mobilization of intracellular calcium (Graham 2001), and adenosine receptor antagonism in the central nervous system (Davis et al. 2003; Sökmen et al. 2008), all of which can aid performance by increasing reaction time, reducing perceived exertion, and delaying fatigue.

Numerous studies have investigated the effects of caffeine on anaerobic performance during jumping (Abian-Vicen et al. 2014; Abian et al. 2015; Coso et al. 2014; Puente et al. 2017b; Tucker et al. 2013), sprinting (Stuart et al. 2005), and COD in team sports (Abian et al. 2015; Coso et al. 2014; Puente et al. 2017b); however, limited research has examined the effects of caffeine supplementation in basketball players. To our knowledge, only three studies (Abian-Vicen et al. 2014; Puente et al. 2017b; Tucker et al. 2013) have examined the effects of caffeine supplementation on anaerobic performance in basketball players. Further, it is difficult to draw conclusions regarding the efficacy of caffeine supplementation to enhance anaerobic performance in basketball players due to methodological differences in the administration of caffeine between studies. More precisely, previous research has used energy drinks (Abian-Vicen et al. 2014) and capsules (Tucker et al. 2013) containing other ingredients to administer caffeine, which introduces a possible synergistic effect of the constituent substances (e.g. taurine, sodium bicarbonate, L-carnitine, maltodextrin, thiamin).

The authors of one study reported caffeine supplementation administered through capsules at a dose of 3 mg/kg body mass yielded a significant positive effect on vertical jump height across female and male professional and semi-professional basketball players (Puente et al. 2017b). Likewise, Abian-Vicen et al. (2014) reported caffeine supplementation consumed in an energy drink at a dose of 3 mg/kg body mass to significantly increase vertical jump height in young, elite, male basketball players. In contrast, Tucker et al. (2013) reported caffeine supplementation at a dose of 3 mg/kg body mass combined with 10 mg of thiamine to induce no significant changes in repeated vertical jump ability in professional male basketball players. However, the lack of an ergogenic effect on vertical jump performance reported by Tucker et al. (2013) may have been due to the small sample size (n = 5) and the non-specific nature of the vertical jump test consisting of 10 sequential jumps, which is not typical of basketball match activities (Wen et al. 2018). Moreover, a higher habitual caffeine consumption was reported in participants examined by Tucker et al. (2013) (< 500 mg per day) compared to participants investigated by Abian-Vicen et al. (2014) and Puente et al. (2017b) (< 100 mg per day). Due to the equivocal findings, methodological differences, disparities in caffeine habituation of the participants examined, and form of caffeine administration between studies (Abian-Vicen et al. 2014; Puente et al. 2017b; Tucker et al. 2013), the effect of caffeine supplementation on vertical jump performance in basketball players remains to be definitively determined.

According to a review of the literature, the effect of caffeine supplementation on linear sprinting and COD speed are still unclear in team sports due to the scarcity of available studies (Chia et al. 2017). Furthermore, only one study has determined the acute effect of caffeine supplementation on COD speed specifically in basketball players, reporting a non-significant effect ($p = 0.338$; -0.2%) (Puente et al. 2017b), while linear sprinting was not investigated. The equivocal findings regarding the influence of caffeine supplementation on anaerobic performance in wider team sports and the limited investigations conducted in basketball players, especially females basketball players, emphasize a need for research in this area. Specifically, only one study (Puente et al. 2017b) has incorporated female basketball players when examining the ergogenic effects of caffeine supplementation using pooled statistical methods across a mixed-sex sample. It is important to examine the ergogenic effect of caffeine supplementation independently in

female and male players given sex-related differences in physiological and performance responses have been reported with caffeine ingestion (Dalbo et al. 2010; Schrader et al. 2013; Temple and Ziegler 2011; Temple et al. 2015). Therefore, the aim of our study was to determine the effect of caffeine supplementation on anaerobic performance in professional, female, basketball players.

Methods

Participants

Professional, female, basketball players (n = 10, age: 20.2 ± 3.9 yr, body mass: 69.2 ± 6.3 kg, height: 175.4 ± 5.9 cm, body fat: 19.7 ± 5.2%) volunteered to participate in this study. All participants were members of the same senior basketball team competing in the first division of the National Serbian League. Participants had 9.4 ± 3.2 yr of basketball experience and were training across 8 x 90-min sessions per week (3 x 90-min sessions in the mornings and 5 x 90-min sessions in the evenings) with a minimum of one competitive match per week during the investigation. All participants were light caffeine consumers (219 ± 141.4 mg/wk, < 100 mg/day) and completed testing in the luteal phase of their menstrual cycle. Participants were free from injury and medical conditions to safely participate in the study. Self-reported data were obtained through structured interviews and a reliable Caffeine Consumption Questionnaire (Shohet and Landrum 2001). All participants were informed of the study procedures and provided written informed consent prior to participation, including guardian consent for participants under 18 yr of age. This study was approved by an institutional Human Research Ethic Committee with all procedures conducted in accordance with the Declaration of Helsinki.

Experimental design

A double blind, placebo-controlled, experimental design was used in a randomized, counterbalanced manner. Each participant completed two experimental trials on an indoor, hardwood basketball court under similar environmental conditions (temperature: 20.0 ± 0.1° humidity: 35.0 ± 1.3%) at the same time of day (19:00-21:00). Experimental trials were separated by 1 week to allow for complete recovery and caffeine wash-out (Kamimori et al. 2002). On one occasion participants ingested powdered caffeine in opaque and unidentifiable

capsules. The caffeine dosage was set at 3 mg/kg body mass for each participant (Lara et al. 2014; Pérez-López et al. 2015). On another occasion, participants ingested an identical capsule filled with 3 mg/kg body mass of the placebo (dextrose). The capsules were ingested with 250 ml of water 60 min prior to testing to allow complete caffeine absorption into circulation (Desbrow et al. 2009). Caffeine and placebo capsules were prepared and coded by the pharmaceutical staff of the Medical Faculty who had no further involvement with the study, to blind participants and investigators to the condition tested. The code to the capsules was unveiled to the experimeters after the analysis of the variables.

Procedures

Participants were instructed to maintain a consistent diet without caffeine consumption in any form 48 h prior to testing and refrain from intense exercise 24 h prior to testing. Participants were also encouraged to have a light meal at least 3 h before testing. Participants were weighed in the nude 2 days before test commencement to calculate caffeine dosages (Inbody 770; Biospace Co. Ltd, Seoul, Korea, nearest 0.1 kg). Height was measured using a portable stadiometer (Seca 220, Seca Corporation, Hamburg, Germany) with a graduation of 0.1 cm.

Participants were familiarized with the testing procedure 1 week before the experimental trials. Upon arrival at the basketball court, before the beginning of each experimental trial, participants ingested the capsules containing individualized caffeine or placebo dosages 60 min prior to testing. Before any performance tests, participants completed a standardized warm-up, consisting of moderate-intensity jogging (5-10 min), static and dynamic stretching (5 min), and brief bouts of high-intensity running with and without dribbling. Performance testing consisted of a countermovement jump (CMJ) with and without arm swing, squat jump (SJ), Lane Agility Drill, 20-m sprints (with 5-m and 10-m split times recorded) with and without dribbling, and a Suicide Run. During each experimental trial players were allowed to consume water during the recovery period between tests (<0.75 L). Participants provided ratings of perceived exertion (RPE) and ratings of perceived performance 30 min following the completion of all tests (Foster et al. 2001) in order to ensure the ratings reflected the entire testing session. RPE and ratings of perceived performance were measured using a 10-point Likert scale (with ´1´ indicating a minimum response and ´10´ indicating a maximum response) and were recorded in arbitrary

units (AU). Participants also completed a questionnaire about sleep quality, nervousness, gastrointestinal problems, and other discomforts in the morning following each experimental trial. The questionnaire consisted of eight items with a yes/no response required for each item and has previously been used to assess the perceptible side-effects of caffeine consumption in sport (Del Coso et al. 2012).

Vertical jump

Vertical jump height (cm) was assessed using a photocell mat (Optojump, Microgate, Bolzano, Italy), which measures flight time taken as the duration between take-off and landing (0.001 s). Players performed three types of vertical jumps including a CMJ with arm swing, CMJ without arm swing, and SJ. These tests are commonly used to assess vertical jump performance in basketball players (Wen et al. 2018). For the CMJ with and without arm swing, participants began in a stationary, upright position with body weight equally distributed over both feet. During the CMJ without arm swing, participants placed their hands on hips to avoid any influence of arm movement, while arms were freely able to be moved during the CMJ with arm swing. Participants then flexed their knees and jumped as high as possible and landed on both feet. Participants performed the SJ from a standing position, bending the knees to 90˚, stopping for 3 s, and then jumping as high as possible to avoid any countermovement of the knee or trunk. Three trials were completed for each jump with 1 min of passive rest between each trial and 3 min of passive rest between jump types. The highest jump heights (cm) recorded for each jump type were taken as outcome measures.

Lane Agility Drill

The Lane Agility Drill test has been used to assess COD speed in basketball players (McGill et al. 2012; Stojanović et al. 2018b). Time was recorded using electronic timing gates (Witty, Microgate, Bolzano, Italy) placed 1 m above the ground at the start line. Participants started at the top left corner of the key, 20 cm behind the free-throw line and ran 5.8 m to the baseline. Participants then side-shuffled 4.9 m to the right across the baseline before running backwards to the top right corner of the key at the free-throw line. Participants then side-shuffled 4.9 m to the left where they touched the floor with their foot at a designated point, and then immediately completed the same circuit in the opposite direction. Three maximal trials were performed with 3

min of passive rest between each trial. Timing commenced and ceased when players triggered the timing gates at the start/end position. The best performance time (s) was taken as the final outcome measure.

20-m sprints with and without dribbling

Sprint speed was evaluated with participants completing maximal running efforts across 20 m from a standing start (with 5-m, 10-m, and 20-m split times recorded). This test has been previously administered to assess sprint speed in basketball players (Delextrat and Cohen 2009). Performance time was recorded using electronic timing gates (Witty, Microgate, Bolzano, Italy) placed 1 m above the ground at the start line, 5-m, 10-m, and 20-m. Participants commenced each sprint 20 cm before the initial timing gate to avoid inadvertent triggering of timing. Three sprints were completed each with and without dribbling a ball (standard size 6, Molten, FIBA approved), with 2 min of passive rest between each trial. The fastest 5-m, 10-m, and 20-m sprint times (s) with and without dribbling were taken as outcome measures.

Suicide Run

The Suicide Run is a test commonly used in basketball in order to assess the anaerobic capacity of players (Delextrat and Cohen 2008). This test consists of a 140-m sprint with several changes of direction. Participants started from a standing position 20 cm behind the baseline and ran at maximal speed to the near free-throw line (5.8 m), half-court line (14 m), far free-throw line (22.2 m), and far baseline (28 m). Once participants arrived at each line, they were required to make foot contact with the line and then immediately sprint back to the original baseline (5). Two participants performed the test at the same time to encourage maximal effort. Total performance time (s) was measured using electronic timing gates (Witty, Microgate, Bolzano, Italy) and taken as the outcome measure.

Statistical analyses

The present study was sufficiently powered given n = 10 was recommended using $\alpha = 0.05$, $\beta = 0.80$, and effect size = 1.0 based on research examining the effect of caffeine on sprint performance in female athletes (G*Power, v3.1.9.3) (Buck et al. 2015). Data analyses were performed using SPSS (v19, SPSS Inc., Chicago, IL). Normality of all data was confirmed with

the Shapiro-Wilk test. Differences between experimental trials in each outcome measure were assessed using paired t-tests. The magnitude of difference between caffeine and placebo conditions was measured with effect size (ES) analyses and interpreted as: *trivial* = < 0.20; *small* = 0.2–0.59; *moderate* = 0.60–1.19; *large* = 1.20–1.99; *very large* = > 2.0 (Hopkins et al. 2009). Individual variability in the adaptive responses to acute caffeine supplementation was also presented, whereby participants were labeled as responders, non-responders, or negative responders. Responders were identified if their performance change was more than the smallest worthwhile change (SWC = 0.2 multiplied by the between-participant deviation) (positive values for jump, and negative values for COD speed, sprint, and repeated sprint performance), non-responders if their performance change was inside the SWC, and negative responders if their performance change was lower than the SWC. Differences in the frequencies of side-effects were analyzed using the McNemar test. All data are presented as mean ± standard deviation (SD) and statistical significance was set at $p \leq 0.05$.

Results

Mean ± SD for each outcome measure in the caffeine and placebo conditions are presented in Table 1. Individual differences in anaerobic performance between caffeine and placebo conditions are shown in Table 2. The effect size analyses for comparisons between the caffeine and placebo conditions in each anaerobic-related outcome measure is shown in Figure 1.

**** Table 1 about here****

**** Table 2 about here****

****Figure 1 about here****

Vertical jump

Caffeine supplementation resulted in *small*, non-significant increases in jump height for CMJ without arm swing (ES = 0.30), CMJ with arm swing (ES = 0.29), and SJ (ES = 0.33). Six participants were identified as positive responders to caffeine during the CMJ with and without arm swing, while 5 participants were indentified as positive responders to caffeine during the SJ.

Lane Agility Drill

Caffeine supplementation resulted in a *small*, non-significant improvement in the Lane Agility Drill (ES = -0.27). Six participants were identified as positive responders to caffeine.

20-m sprints with and without dribbling

Caffeine supplementation resulted in *small* to *moderate*, significantly faster 10-m (ES = -0.63; p = 0.05) and 20-m (ES = -0.41; p = 0.04) sprint times without dribbling. Five participants were identified as positive responders to caffeine supplementation across all sprint times without dribbling. However, a varied number of participants were identified as positive responders to caffeine supplementation while dribbling (5-m: 7 participants; 10-m: 6 participants; 20-m: 4 participants).

Suicide Run

Caffeine supplementation resulted in *small*, non-significant improvements in repeated-sprint performance during the Suicide Run (ES = -0.24; p = 0.28). Six participants were identified as positive responders to caffeine supplementation.

Perceptual measures and side-effects

Caffeine supplementation *moderately* decreased RPE during the test battery (ES = -1.18; p = 0.04) and elicited *small* improvements in perceived performance (ES = 0.23; p = 0.53). Side-effects of caffeine supplementation were low (p > 0.05) in the morning following completion of the test battery (Table 3).

****Table 3 about here****

Discussion

We sought to determine the effects of acute caffeine supplementation (3 mg/kg body mass) on anaerobic performance in professional, female, basketball players. Acute caffeine consumption produced *small* improvements in vertical jump height and COD speed, as well as *small* to *moderate* faster sprint and repeated-sprint times. The positive performance effects of caffeine supplementation were accompanied by *moderately* lower RPE and a *small* increase in perceived

performance. Individual data revealed large variations across participants in response to caffeine supplementation. In fact, many participants displayed meaningful beneficial improvements (greater than the SWC) in performance outcome measures.

At the group level, caffeine supplementation enhanced CMJ height without arm swing by 4.6% (± 7.9%), CMJ height with arm swing by 3.8% (± 7.0%), and SJ height by 4.8% (± 7.3%). Our results are in agreement with previous investigations reporting benefits of caffeine supplementation administered in different forms on vertical jump performance in athletes (Abian-Vicen et al. 2014; Abian et al. 2015; Coso et al. 2014). Specifically, similar vertical jump performance improvements have been obtained following the ingestion of 3 mg/kg body mass of caffeine in the form of an energy drink in collegiate male volleyball players (CMJ: 5.0%; SJ: 5.5%) (Coso et al. 2014), and elite male badminton players (CMJ: 5.0%; SJ: 6.0%) (Abian et al. 2015). However, it must be noted caffeine consumed in energy drinks is not a representation of the sole effects of caffeine on performance but rather the effects of the energy drink containing other potential performance-enhancing ingredients such as carbohydrates, amino acids, and taurine (Souza et al. 2017). To date, only one study has examined the effects of acute caffeine supplementation on CMJ performance in adolescent, male, basketball players (n = 16; 14.9 ± 0.8 yr) (Abian-Vicen et al. 2014). Acute caffeine supplementation at a dose of 3 mg/kg body mass was administered in the form of an energy drink and resulted in a 2.1% improvement in CMJ (Abian-Vicen et al. 2014), which is somewhat lower compared to our data. The ergogenic effect of caffeine may be more noticeable in trained athletes (Davis and Green 2009), therefore the higher training status of the players investigated in our study might underpin the greater ergogenic effect of caffeine we observed compared to the adolescent basketball players examined previously (Abian-Vicen et al. 2014).

In addition to jumping maneuvers, basketball players typically execute many directional changes during match-play (Stojanović et al. 2018a). We reported a *small* (ES= -0.27; -1.74%) reduction in total time to complete the Lane Agility Drill with caffeine supplmentation. However, Puente et al. (2017a) also supplemented players with 3 mg/kg body mass of caffeine and failed to report any difference in total time to complete a COD test compared to a placebo in semi-professional, male and professional, female basketball players pooled together. To replicate the

multidirectional, high-intensity movement distances in a short period of time, Puente et al. (2017b) utilized a COD speed test with and without dribbling (~6 s) which consisted of a linear 5-m sprint, 45° and 90° cuts, 3-m sprints to the left and right, and a linear 10-m sprint (Lockie et al. 2013). Davis and Green (2009) reported the efficacy of caffeine supplementation on anaerobic performance is more favorable when the incorporated testing protocol reflects sport-specific performance demands. In this regard, the demands encountered during basketball game-play are better represented by the Lane Agility Drill test utilized in our study than the COD speed test used by Puente et al. (2017b). Specifically the Lane Agility Drill test incorporates the multidirectional, high-intensity movements contained in the COD speed test used by Puente et al. (2017b), but requires players to cover distances and work for durations indicative of high-intensity movement sequences performed during basketball game-play (Delextrat et al. 2015). Furthermore, shuffling bouts are performed during the Lange Agility Drill test, which are particularly prevalent during basketball game-play when changing direction and moving laterally (Scanlan et al. 2012) and elicit high metabolic stress on players (Williford et al. 1998). Although non-significant results were reported across both studies, percentage variations in study findings may relate to the movement patterns performed in the respective tests examined. In addition, the longer test duration we observed in the Lane Agility Drill (~13 s) compared to the COD speed test (~6 s) used by Puente et al. (2017b) might have magnified the ergogenic effects of caffeine.

We reported the magnitude of the ergogenic effect of acute caffeine supplementation across sprints (5-m, 10-m, and 20-m) with and without dribbling to range from 1.0%-4.8%. Sprint comparisons following caffeine supplementation are difficult to conduct considering the lack of existing studies in basketball players. Namely, the effects of caffeine supplementation on total sprint times have been measured using the Rugby test (consisting of 20-m, 30-m, offensive, defensive, and tackle sprints) in amateur rugby union players (Stuart et al. 2005). The mean percentage improvements of 0.5%-2.9% were recorded across all types of sprints in the Rugby test after consuming 6 mg/kg body mass of caffeine. Variations in sprint outcomes with caffeine supplementation between the rugby players and female basketball players may be due to disparities in training status (amateur vs. professional) and habitual use of caffeine (regular vs. light consumers). Specifically, habitual use of caffeine may reduce performance benefits from acute caffeine supplementation (Beaumont et al. 2017); however, more intervention-based

studies are needed to better understand the influence of habitual caffeine ingestion on the ergogenic responses of caffeine supplementation at varied dosages.

While execution of single sprint bouts are important during basketball match-play, players undergo extensive intermittent activity (Stojanović et al. 2018a), being required to perform sprints in a repeated manner. We reported, *small* (ES = -0.24; -1.2%) improvements in repeated-sprint times following caffeine supplementation. Similar research in female floorball players (Lednický 2014) yielded a 3.6% improvement in a repeated-sprint test longer (6 x 40 m, ~54 s) than we administered in the Suicide Run (140 m, ~32 s). The discrepancy in test design may underpin the greater decrease in total time observed in floorball players (Lednický 2014) compared to our study due to an increased reliance on the glycolytic energy system. The total contribution of glycolysis to ATP resynthesis is nearly double the ATP production from the phosphocreatine energy system during maximal exercise lasting > 30 s (Grenhaff 1998), promoting high muscle lactate concentrations and onset of fatigue. Acting through adenosine receptors in the brain, caffeine may modulate central fatigue and reduce perceived exertion and pain (Davis and Green 2009), which are more pronounced during high-intensity bouts of exercise > 30 s. Collectively, enhanced anaerobic performance with caffeine supplementation might be also associated with the increase motor unit recruitment (Bazzucchi et al. 2011) and muscle activation (Behrens et al. 2015). In addition, caffeine ingestion enhances the force of muscle contraction via increases in calcium release from the sarcoplasmic reticulum (Chia et al. 2017; Magkos and Kavouras 2005). To further confirm these mechanisms, further studies are needed examining neuromuscular responses to acute caffeine supplementation during anaerobic tasks in basketball players.

While the ergogenic effects of caffeine supplementation were evident across the group in the present sample of professional, female basketball players, responses were heterogeneous in magnitude on an individual basis. Our findings suggests some individuals (40-70%) may experience improved anaerobic performance with acute caffeine intake (Table 3). Consequently, individual participant responses demonstrate large variations regarding the ergogenic effect of caffeine supplementation at a dose of 3 mg/kg of body mass, consumed 60 min prior to exercise. In addition to inter-individual variations, disparities in responses were also observed across tests

for the same participant, which may be related to individual differences in time to reach peak plasma caffeine concentrations. A review (Pickering and Kiely 2018) highlighted variations by genetic predispositions whereby polymorphisms in genes affect caffeine metabolism speed and nervous system excitability. However, no study has considered the effect of genotype when examining the influence of caffeine ingestion on anaerobic performance in athletes to confirm this notion.

Perceptual data collected in our study revealed caffeine supplementation *moderately* decreased RPE (ES = 1.18; $p < 0.05$) and produced a *small* enhancement in perceived performance (ES = 0.23; $p > 0.05$) with caffeine. The perceptual benefits of caffeine supplementation may be related to the blockade of central nervous system adenosine receptors dampening pain perception, blunting RPE, and increasing arousal, resulting in the perception of a performance improvment (Davis and Green 2009). In addition, although caffeine produced marginal side-effects ($p > 0.05$), a somewhat higher prevalence of vigor/activeness (placebo = 0% vs. caffeine = 30%) was observed following caffeine ingestion, whereas other negative side-effects of caffeine were kept at a low rate (0-20% difference between placebo and caffeine condition). As the participants were female basketball players tested in the luteal phase of menstrual cycle, it is also important to note that systematic clearance of caffeine might be slower (Lane et al. 1992), increasing the likelihood of experiencing vigor. However, this side-effect could be a positive outcome of caffeine improving mood, reaction time, and alertness (Alford et al. 2001; Seidl et al. 2000). Our findings suggest caffeine supplementation at a dose of 3 mg/kg body mass could provide psychological advantage for various basketball performance tests. Therefore, research exploring the transfer of our findings to actual basketball match-play is encouraged to better understand the potential psychological benefits of acute caffeine supplementation in basketball.

Some limitations of our investigation should be acknowledged. First, we were unable to measure changes in plasma and urine caffeine concentrations in response to caffeine supplmentation. Laboratory measures indicate ergogenic enhancement is related to maintaining adequate concentrations of caffeine in circulation (Bell and McLellan 2002). Second, our sample was limited to a professional, female basketball team and thus only included 10 players. Larger cohort studies are required utilizing female and male players of varying ages and playing levels

to confirm these results across wider player populations. Third, players in the current study were light caffeine users, which may limit generalizability to other players who consume larger habitual dosages of caffeine.

Conclusion

Acute caffeine supplementation may be an effective approach to enhance anaerobic peformance including vertical jumps, COD speed, sprint, and repeated-sprint performance in professional female, basketball players. Although many of the players we investigated displayed meaningful beneficial performance improvements, the ergogenic effects of caffeine varied in magnitude among individuals. Therefore, it is recommended to determine whether pre-exercise caffeine supplementation is ergogenic at the individual level, to avoid unnecessary or detrimental effects of caffeine supplementation. In addition, the performance-enhancing effects of caffeine supplementation were accompanied by a lower RPE and enhanced perceived performance with no adverse side-effects.

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Conflict of interest statement

The authors declare that there are no conflict of interest

References

Abdelkrim, N.B., Castagna, C., El Fazaa, S., and El Ati, J. 2010. The effect of players' standard and tactical strategy on game demands in men's basketball. J. Strength Cond. Res. **24**(10): 2652-2662. DOI: 10.1519/JSC.0b013e3181e2e0a3.

Abian-Vicen, J., Puente, C., Salinero, J.J., González-Millán, C., Areces, F., Muñoz, G., et al. 2014. A caffeinated energy drink improves jump performance in adolescent basketball players. Amino Acids **46**(5): 1333-1341. DOI: 10.1007/s00726-014-1702-6.

Abian, P., Del Coso, J., Salinero, J.J., Gallo-Salazar, C., Areces, F., Ruiz-Vicente, D., et al. 2015. The ingestion of a caffeinated energy drink improves jump performance and activity patterns in elite badminton players. J. Sports Sci. **33**(10): 1042-1050. DOI: 10.1080/02640414.2014.981849.

Alford, C., Cox, H., and Wescott, R. 2001. The effects of red bull energy drink on human performance and mood. Amino Acids **21**(2): 139-150. DOI: 10.1007/s007260170021.

Bazzucchi, I., Felici, F., Montini, M., Figura, F., and Sacchetti, M. 2011. Caffeine improves neuromuscular function during maximal dynamic exercise. Muscle Nerve **43**(6): 839-844. DOI: 10.1002/mus.21995.

Beaumont, R., Cordery, P., Funnell, M., Mears, S., James, L., and Watson, P. 2017. Chronic ingestion of a low dose of caffeine induces tolerance to the performance benefits of caffeine. J. Sports Sci. **35**(19): 1920-1927. DOI: 10.1080/02640414.2016.1241421.

Behrens, M., Mau-Moeller, A., Weippert, M., Fuhrmann, J., Wegner, K., Skripitz, R., et al. 2015. Caffeine-induced increase in voluntary activation and strength of the quadriceps muscle during isometric, concentric and eccentric contractions. Sci. Rep. **5**: 10209. DOI: 10.1038/srep10209.

Bell, D.G., and McLellan, T.M. 2002. Exercise endurance 1, 3, and 6 h after caffeine ingestion in caffeine users and nonusers. J. Appl. Physiol. **93**(4): 1227-1234. DOI: 10.1152/japplphysiol.00187.2002.

Buck, C., Guelfi, K., Dawson, B., McNaughton, L., and Wallman, K. 2015. Effects of sodium phosphate and caffeine loading on repeated-sprint ability. J. Sports Sci. **33**(19): 1971-1979. DOI: 10.1080/02640414.2015.1025235.

Chia, J.S., Barrett, L.A., Chow, J.Y., and Burns, S.F. 2017. Effects of Caffeine Supplementation on Performance in Ball Games. Sports Med. **47**(12): 2453-2471. DOI:10.1007/s40279-017-0763-6.

Conte, D., Favero, T.G., Lupo, C., Francioni, F.M., Capranica, L., and Tessitore, A. 2015. Time-motion analysis of Italian elite women's basketball games: Individual and team analyses. J. Strength Cond. Res. **29**(1): 144-150. DOI: 10.1519/JSC.0000000000000633.

Coso, J.D., Pérez-López, A., Abian-Vicen, J., Salinero, J.J., Lara, B., and Valadés, D. 2014. Enhancing physical performance in male volleyball players with a caffeine-containing energy drink. Int. J. Sports Physiol. Perform. **9**(6): 1013-1018. DOI: 10.1123/ijspp.2013-0448.

Dalbo, V.J., Roberts, M.D., Stout, J.R., and Kerksick, C.M. 2010. Effect of gender on the metabolic impact of a commercially available thermogenic drink. J. Strength Cond. Res. **24**(6): 1633-1642. DOI: 10.1519/JSC.0b013e3181db9bbd.

Davis, J., and Green, J.M. 2009. Caffeine and anaerobic performance. Sports Medicine **39**(10): 813-832.

Davis, J.M., Zhao, Z., Stock, H.S., Mehl, K.A., Buggy, J., and Hand, G.A. 2003. Central nervous system effects of caffeine and adenosine on fatigue. Am. J. Physiol. Regul. Integr. Comp. Physiol. **284**(2): R399-R404. DOI: 10.1152/ajpregu.00386.2002.

Del Coso, J., Salinero, J.J., González-Millán, C., Abián-Vicén, J., and Pérez-González, B. 2012. Dose response effects of a caffeine-containing energy drink on muscle performance: a repeated measures design. J. Int. Soc. Sports Nutr. **9**(1): 21. DOI: 10.1186/1550-2783-9-21.

Delextrat, A., Badiella, A., Saavedra, V., Matthew, D., Schelling, X., Torres-Ronda, L. 2015. Match activity demands of elite Spanish female basketball players by playing position. Int J Perf Anal Spor. 15(2): 687-703. DOI: 10.1080/24748668.2015.11868824.

Delextrat, A., and Cohen, D. 2008. Physiological testing of basketball players: toward a standard evaluation of anaerobic fitness. J. Strength Cond. Res. **22**(4): 1066-1072. DOI: 10.1519/JSC.0b013e3181739d9b.

Delextrat, A., and Cohen, D. 2009. Strength, power, speed, and agility of women basketball players according to playing position. J. Strength Cond. Res. **23**(7): 1974-1981. DOI: 10.1519/JSC.0b013e3181b86a7e.

Desbrow, B., Barrett, C.M., Minahan, C.L., Grant, G.D., and Leveritt, M.D. 2009. Caffeine, cycling performance, and exogenous CHO oxidation: a dose-response study. Med. Sci. Sports Exerc. **41**(9): 1744-1751. DOI: 10.1249/MSS.0b013e3181ae37e7.

Foster, C., Florhaug, J.A., Franklin, J., Gottschall, L., Hrovatin, L.A., Parker, S., et al. 2001. A new approach to monitoring exercise training. J. Strength Cond. Res. **15**(1): 109-115. DOI: 10.1519/00124278-200102000-00019.

Graham, T.E. 2001. Caffeine and exercise. Sports Med. **31**(11): 785-807. DOI: 10.2165/00007256-200131110-00002.

Grenhaff, P. 1998. Interaction between aerobic and anaerobic metabolism during intense muscle exercise. Exerc. Sport Sci. Rev. **26**: 1-30.

Hopkins, W., Marshall, S., Batterham, A., and Hanin, J. 2009. Progressive statistics for studies in sports medicine and exercise science. Med. Sci. Sports Exerc. **41**(1): 3-12. DOI: 10.1249/MSS.0b013e31818cb278.

Kamimori, G.H., Karyekar, C.S., Otterstetter, R., Cox, D.S., Balkin, T.J., Belenky, G.L., et al. 2002. The rate of absorption and relative bioavailability of caffeine administered in chewing gum versus capsules to normal healthy volunteers. Int. J. Pharm. **234**(1): 159-167. DOI: 10.1016/S0378-5173(01)00958-9.

Lane, J., Steege, J., Rupp, S., and Kuhn, C. 1992. Menstrual cycle effects on caffeine elimination in the human female. Eur. J. Clin. Pharmacol. **43**(5): 543-546. DOI: 10.1007/BF02285099.

Lara, B., Gonzalez-Millán, C., Salinero, J.J., Abian-Vicen, J., Areces, F., Barbero-Alvarez, J.C., et al. 2014. Caffeine-containing energy drink improves physical performance in female soccer players. Amino Acids **46**(5): 1385-1392. DOI: 10.1007/s00726-014-1709-z.

Laurent, D., Schneider, K.E., Prusaczyk, W.K., Franklin, C., Vogel, S.M., Krssak, M., et al. 2000. Effects of caffeine on muscle glycogen utilization and the neuroendocrine axis during exercise. J. Clin. Endocrinol. Metab. **85**(6): 2170-2175. DOI: 10.1210/jcem.85.6.6655.

Lednický, I.K.M.S.A. 2014. Effect of caffeine on motoric performance of female floorball players. AFEPUC(1): 21-28.

Lockie, R.G., Schultz, A.B., Callaghan, S.J., Jeffriess, M.D., and Berry, S.P. 2013. Reliability and validity of a new test of change-of-direction speed for field-based sports: the change-of-direction and acceleration test (CODAT). J. Sports Sci. Med. **12**(1): 88-96.

Magkos, F., and Kavouras, S.A. 2005. Caffeine use in sports, pharmacokinetics in man, and cellular mechanisms of action. Crit. Rev. Food Sci. Nutr. **45**(7-8): 535-562. DOI: 10.1080/1040-830491379245.

McGill, S.M., Andersen, J.T., and Horne, A.D. 2012. Predicting performance and injury resilience from movement quality and fitness scores in a basketball team over 2 years. J. Strength Cond. Res. **26**(7): 1731-1739. DOI: 10.1519/JSC.0b013e3182576a76.

Pérez-López, A., Salinero, J.J., Abian-Vicen, J., Valadés, D., Lara, B., Hernandez, C., et al. 2015. Caffeinated energy drinks improve volleyball performance in elite female players. Med. Sci. Sports Exerc. **47**(4): 850-856. DOI: 10.1249/MSS.0000000000000455.

Pickering, C., and Kiely, J. 2018. Are the current guidelines on caffeine use in sport optimal for everyone? Inter-individual variation in caffeine ergogenicity, and a move towards personalised sports nutrition. Sports Med. **48**(1): 7-16. DOI: 10.1007/s40279-017-0776-1.

Puente, C., Abián-Vicén, J., Areces, F., López, R., and Del Coso, J. 2017a. Physical and physiological demands of experienced male basketball players during a competitive game. J. Strength Cond. Res. **31**(4): 956-962. DOI: 10.1519/JSC.0000000000001577.

Puente, C., Abián-Vicén, J., Salinero, J.J., Lara, B., Areces, F., and Del Coso, J. 2017b. Caffeine Improves Basketball Performance in Experienced Basketball Players. Nutrients **9**(9): 1033. DOI: 10.3390/nu9091033.

Scanlan, A.T., Dascombe, B.J., Reaburn, P., and Vincent, D. 2012. The physiological and activity demands experienced by Australian female basketball players during competition. J Sci Med Sport. **15**(4):341-347. DOI: 10.1016/j.jsams.2011.12.008.

Schrader, P., Panek, L.M., and Temple, J.L. 2013. Acute and chronic caffeine administration increases physical activity in sedentary adults. Nutr. Res. **33**(6): 457-463.DOI: 10.1016/j.nutres.2013.04.003.

Seidl, R., Peyrl, A., Nicham, R., and Hauser, E. 2000. A taurine and caffeine-containing drink stimulates cognitive performance and well-being. Amino Acids **19**(3): 635-642. DOI: 10.1007/s007260070013.

Shohet, K.L., and Landrum, R.E. 2001. Caffeine consumption questionnaire: a standardized measure for caffeine consumption in undergraduate students. Psychol. Rep. **89**(3): 521-526. DOI: doi.org/10.2466/pr0.2001.89.3.521.

Sökmen, B., Armstrong, L.E., Kraemer, W.J., Casa, D.J., Dias, J.C., Judelson, D.A., et al. 2008. Caffeine use in sports: considerations for the athlete. J. Strength Cond. Res. **22**(3): 978-986. DOI: 10.1519/JSC.0b013e3181660cec.

Souza, D.B., Del Coso, J., Casonatto, J., and Polito, M.D. 2017. Acute effects of caffeine-containing energy drinks on physical performance: a systematic review and meta-analysis. Eur. J. Nutr. **56**(1): 13-27. DOI: 10.1007/s00394-016-1331-9.

Stojanović, E., Stojiljković, N., Scanlan, A.T., Dalbo, V.J., Berkelmans, D.M., and Milanović, Z. 2018a. The activity demands and physiological responses encountered during basketball match-play: A systematic review. Sports Med. **48**(1): 111-135. DOI: 10.1007/s40279-017-0794-z.

Stojanović, E., Aksović, N., Stojiljković, N., Stanković, R., Scanlan, A.T., and Milanović, Z. 2018b. Reliability, Usefulness, and Factorial Validity of Change-of-direction Speed Tests in Adolescent Basketball Players. J. Strength Cond. Res. ahead of print. DOI: 10.1519/JSC.0000000000002666.

Stuart, G.R., Hopkins, W.G., Cook, C., and Cairns, S.P. 2005. Multiple effects of caffeine on simulated high-intensity team-sport performance. Med. Sci. Sports Exerc. **37**(11): 1998-2005. DOI: 10.1249/01.mss.0000177216.21847.8a.

Temple, J.L., and Ziegler, A.M. 2011. Gender differences in subjective and physiological responses to caffeine and the role of steroid hormones. J. Caffeine Res. **1**(1): 41-48. DOI: 10.1089/jcr.2011.0005.

Temple, J.L., Ziegler, A.M., Martin, C., and de Wit, H. 2015. Subjective responses to caffeine are influenced by caffeine dose, sex, and pubertal stage. J. Caffeine Res. **5**(4): 167-175. DOI: 10.1089/jcr.2015.0022.

Tucker, M.A., Hargreaves, J.M., Clarke, J.C., Dale, D.L., and Blackwell, G.J. 2013. The effect of caffeine on maximal oxygen uptake and vertical jump performance in male basketball players. J. Strength Cond. Res. **27**(2): 382-387. DOI: 10.1519/JSC.0b013e31825922aa.

Wen, N., Dalbo, V.J., Burgos, B., Pyne, D.B., and Scanlan, A.T. 2018. Power Testing in Basketball: Current Practice and Future Recommendations. J. Strength Cond. Res. **32**(9): 2677-2691. DOI: 10.1519/JSC.0000000000002459.

Williford, H.N, Olson, M.S., Gauger, S., Duey W.J., and Blessing, D.L. 1998. Cardiovascular and metabolic costs of forward, backward, and lateral motion. Med Sci Sports Exerc. **30**(9):1419-1423. DOI: 10.1097/00005768-199809000-00011.

TABLE AND FIGURE CAPTIONS

Table 1. Jump height, change-of-direction speed, linear sprint speed, and repeated-sprint performance (mean ± SD) with the ingestion of placebo and caffeine (3 mg/kg body mass) capsules in professional, female basketball players (n = 10).

Table 2. Individual responses in jump height, change-of-direction speed, linear sprint speed, and repeated-sprint performance following the ingestion of placebo and caffeine (3 mg/kg body mass) capsules in professional, female basketball players (n = 10).

Table 3. Prevalence of side-effects (%), rating of perceived exertion (RPE), and perceived performance with caffeine ingestion (3 mg/kg body mass) in professional, female basketball players (n = 10).

Figure 1. Forest plot of the effect sizes (boxes) and 95% confidence intervals (horizontal lines) in each outcome measure following caffeine ingestion. *Note*: comparisons presented as caffeine vs placebo; shaded area represents borders for *trivial* changes; CMJ – countermovement jump; SJ – squat jump; LAD - Lane Agility Drill.

Table 1. Jump height, change-of-direction speed, linear sprint speed, and repeated-sprint performance (mean ± SD) with the ingestion of placebo and caffeine (3 mg/kg body mass) capsules in professional, female basketball players (n = 10).

Outcome measure	Condition		SWC	Δ (%)	p value
	Placebo	*Caffeine*			
Jump height					
CMJ without arm swing (cm)	27.92 ± 4.24	29.20 ± 4.39	0.86	4.58	0.10
CMJ with arm swing (cm)	33.85 ± 3.92	35.14 ± 5.08	0.90	3.81	0.15
Squat jump (cm)	25.97 ± 3.16	27.22 ± 4.37	0.75	4.81	0.08
Change-of-direction speed					
Lane Agility Drill (s)	13.22 ± 0.87	12.99 ± 0.86	0.17	-1.74	0.12
Linear sprint speed					
5-m sprint (s)	1.24 ± 0.15	1.18 ± 0.11	0.03	-4.84	0.13
10-m sprint (s)	2.11 ± 0.18	2.01 ± 0.13*	0.03	-4.74	0.05
20-m sprint (s)	3.59 ± 0.25	3.49 ± 0.23*	0.05	-2.79	0.04
5-m dribbling sprint (s)	1.22 ± 0.08	1.20 ± 0.05	0.01	-1.64	0.45
10-m dribbling sprint (s)	2.07 ± 0.11	2.05 ± 0.12	0.02	-0.97	0.55
20-m dribbling sprint (s)	3.65 ± 0.15	3.56 ± 0.25	0.04	-2.47	0.15
Repeated-sprint performance					
Suicide Run (s)	32.20 ± 1.74	31.80 ± 1.62	0.34	-1.24	0.28

Note: CMJ – countermovement jump; SWC – smallest worthwhile change; Δ (%) – percent change between placebo vs. caffeine conditions [(placebo – caffeine) / placebo]; *significantly different from placebo ($p < 0.05$)

Table 2. Individual responses in jump height, change-of-direction speed, linear sprint speed, and repeated-sprint performance following the ingestion of placebo and caffeine (3 mg/kg body mass) capsules in professional, female basketball players (n = 10).

Outcome measure	Participant										Responders	Non-responders	Negative-responders
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*			
Jump height													
CMJ without arm swing	↔	↑	↑	↔	↑	↑	↔	↑	↑	↓	6	3	1
CMJ with arm swing	↑	↑	↑	↑	↓	↓	↔	↑	↑	↔	6	2	2
Squat jump	↔	↑	↑	↔	↔	↓	↑	↑	↑	↔	5	4	1
Change-of-direction speed													
Lane Agility Drill	↔	↑	↓	↑	↑	↑	↔	↑	↑	↓	6	2	2
Linear sprint speed													
5-m sprint	↑	↑	↑	↔	↓	↔	↑	↓	↔	↑	5	3	2
10-m sprint	↑	↑	↑	↓	↓	↑	↔	↔	↔	↑	5	3	2
20-m sprint	↑	↑	↑	↔	↔	↑	↔	↔	↔	↑	5	5	0
5-m dribbling sprint	↑	↑	↑	↑	↓	↑	↑	↓	↓	↑	7	0	3
10-m dribbling sprint	↑	↑	↑	↔	↓	↑	↑	↓	↓	↑	6	1	3
20-m dribbling sprint	↑	↑	↑	↓	↓	↓	↑	↔	↔	↔	4	3	3
Repeated-sprint performance													
Suicide Run	↓	↑	↓	↑	↑	↑	↓	↑	↑	↔	6	1	3

Note: CMJ – counter movement jump; ↑ – positive responder; ↔ – non-responder; ↓ – negative responder

Table 3. Prevalence of side-effects (%), rating of perceived exertion (RPE), and perceived performance with caffeine ingestion (3 mg/kg body mass) in professional, female basketball players (n = 10).

Outcome measure	**Condition**	
	Placebo	*Caffeine*
Side-effect		
Headache	20	10
Abdominal discomfort	10	20
Muscle soreness	0	10
Increased vigor/activeness	0	30
Tachycardia	10	30
Insomnia	20	10
Increased urine output	10	10
Increased anxiety	10	0
Perceptual responses		
RPE (AU)	7.8 ± 1.2	5.6 ± 2.5*
Performance (AU)	3.6 ± 2.8	4.2 ± 2.7

Note: AU – arbitrary units; *significantly different from placebo ($p < 0.05$).

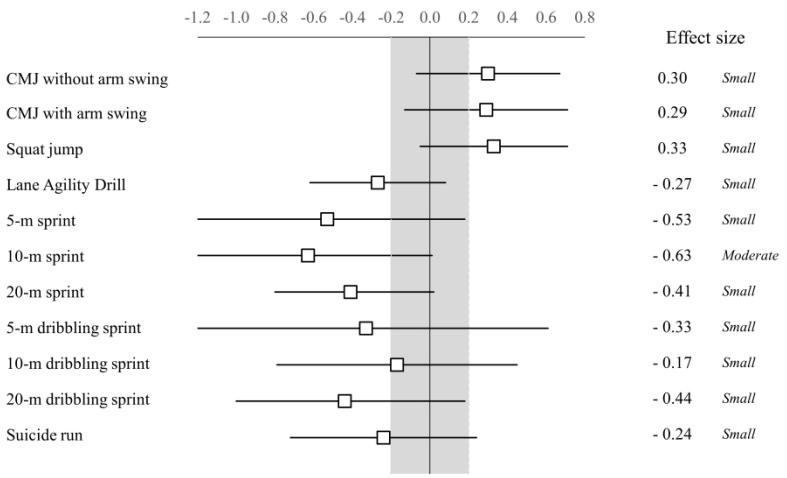

Figure 1. Forest plot of the effect sizes (boxes) and 95% confidence intervals (horizontal lines) in each outcome measure following caffeine ingestion. Note: comparisons presented as caffeine vs placebo; shaded area represents borders for trivial changes; CMJ – countermovement jump.

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