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Effect of caffeine ingestion on free-throw performance in college basketball players

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ABSTRACT

Background: It is currently unclear whether pre-exercise caffeine ingestion can improve free-throw shooting performance, a vital skill in basketball. The purpose of this study was to investigate the effects of caffeine on free-throw shooting performance in college-aged basketball players.

Methods: Twelve males (23.1 ± 1.9 years; 180.1 ± 8.8 cm; 77.1 ± 12.4 kg) and six females (22.0 ± 1.3 years; 169.4 ± 8.9 cm; 67.0 ± 11.1 kg) who competed at the college level ingested 6 mg per kg of body mass of (a) caffeine or (b) maltodextrin (placebo) on two separate occasions in a random order. After 60 min, they performed five sets of a match-simulated basketball protocol comprising six sideline-to-sideline sprints on a standard basketball court followed by two free-throws after each set. The number of successful shots was counted. Heart rate and rating of perceived exertion (RPE) after each sprint set were also recorded.

Results: Caffeine ingestion did not improve overall free-throw success (caffeine = 6.1 ± 1.7 vs. placebo = 5.5 ± 2.0 ; $p = 0.34$) compared with placebo across all five sets. There was no change in shooting accuracy across sprint sets in either trial despite significant increases in both heart rate and RPE. Caffeine increased heart rate ($p = 0.02$) but had no effect on RPE ($p = 0.57$) across five sets compared with placebo.

Conclusions: Ingestion of 6 mg of caffeine per kg of body mass did not improve basketball free-throw performance. Free-throw performance did not deteriorate with increasing number of sprint sets.

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Introduction

Consumption of caffeine as an ergogenic aid can be effective in improving athletic performance.^{1–3} The widespread use of caffeine can be attributed to its physiological effects on the body, for example, elevating heart rates and increasing catecholamine production, blood lactate and free fatty acid levels.⁴ The main mechanism via which caffeine exerts its effects on the body to improve sporting performance is to block the central and peripheral adenosine receptors, inhibiting the effects of adenosine on neurotransmission, and improving arousal and sports performance.⁵ While many previous studies have found caffeine useful in improving

various areas of sporting performance,^{1–3} the effects of caffeine use on accuracy-based sports are less clear. On one hand, caffeine ingestion can improve sporting performance by increasing attention as well as improving cognitive function and motor skill performance.^{6,7} Conversely, caffeine use may also result in side effects such as increased nervousness and tremors⁸ which potentially negate accuracy-based performances.

Free-throw is a vital skill in basketball which requires high accuracy. A free-throw is an attempt to shoot the ball into the hoop with no interference, awarded after the opposing player commits a foul or other violation of the rules. It was found that teams would often emerge victorious when they had higher free-throw shooting percentages at the end of the game.⁹ Hence, interventions which improve the accuracy of free-throw in basketball are potentially valuable. Using basketball-specific testing and a simulated game, Puente et al.¹⁰ investigated the effects of 3 mg per kg of body mass of caffeine administered through an opaque and unidentifiable capsule. For the basketball-specific testing, they found that pre-

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exercise caffeine ingestion did not improve free-throw performance (15.4 ± 1.6 vs. 15.6 ± 2.3 ; $p = 0.39$) when compared with a placebo. During the simulated game, the number of free-throws awarded increased (0.9 ± 1.1 vs. 1.5 ± 1.5 ; $p = 0.42$) and free-throw performance improved (0.6 ± 0.8 vs. 1.1 ± 1.1 ; $p = 0.03$) when compared with a placebo for both female and male professional players. However, their study design using a simulated game did not allow for a fair comparison between caffeine and placebo as the number of free-throws taken and shot by each player depended on the progression of the game and differed between games. Moreover, the average number of free-throws recorded during the simulated games were too few (0.9 ± 1.1 vs. 1.5 ± 1.5) to make a strong comparison or conclusion on the effects of caffeine on free-throw performance. Another study using basketball-specific testing showed no improvements in the number of free-throws scored following caffeine consumption.¹¹ Abian-Vicen et al.¹¹ reported that a caffeinated energy drink providing 3 mg per kg of body mass had no influence on the accuracy of free-throws in adolescent male basketball players. In their study, the total number of free-throws scored as well as the accuracy of the first and second set of free-throws were unaffected by caffeine ingestion. However, the participants were not exposed to any exercise protocol and were able to shoot free-throws without fatigue and thus the test condition lacked ecological validity from a real game situation. Moreover, the energy drink contained other active ingredients in significant proportion, including taurine, sodium bicarbonate, carnitine and maltodextrin, which could have influenced performance even though they were provided in equal proportion on the caffeine and placebo trials. Given the limited studies^{10,11} and inconsistent findings, further investigation is required to clarify the effects of caffeine on free-throw performance in basketball. However, since the benefits of increasing attention and improving cognitive function^{6,7} may be negated by undesirable effects such as increased nervousness and tremors,⁸ it does not automatically follow that caffeine ingestion will enhance free-throw performance.

In the physically and psychologically demanding team-sport of basketball, players are required to perform repeated bouts of sprinting and jumping over a prolonged duration.¹¹ Besides the biomechanical aspect of shooting playing a key role to scoring free-throws,¹² the ability to focus on spectatorship as well as controlling against the effects from fatigue are also vital to scoring a free-throw. Several studies in ball-based sports, including soccer, rugby, hockey and tennis, have shown that caffeine use can increase the total distance covered in a match, the number of sprint bouts, peak and maximum sprint velocities and sprint times,⁸ although there are exceptions.^{10,13} This capacity to offset fatigue may be important for basketball as increased physical exertion results in poorer biomechanics of shooting 3-point shots in elite basketball players¹⁴ and decreased shooting performance and altered techniques during speed spot shooting in youth basketball players.¹⁵ Collectively, these studies suggest that the effects of caffeine on basketball free-throw performance may be more obvious when fatigue exists but only the study by Puente and colleagues¹⁰ has attempted to simulate activity before free-throw shooting. The protocol, however, was not physically demanding and may not adequately resemble a basketball game. Their protocol involved only a single jump and an approximate 6-s sprint followed by a 15-s rest before two free throws, with the entire sequence repeated 10 times. A more realistic protocol that better simulates a basketball game is needed to study the effects of pre-exercise caffeine ingestion on free-throw performance. Another factor at play with the existing studies^{10,11} is that both used a low-dose (≤ 3 mg per kg of body mass) of caffeine. Whilst this dose of caffeine can benefit sports performance in many instances,⁸ the ergogenic effect in comparison with higher doses of caffeine has recently been

challenged.¹⁶

The aim of the present study was to investigate the effects of caffeine ingestion on free-throw shooting performance after sprinting in collegiate basketball players. It was hypothesised that a) the ingestion of 6 mg per kg of body mass of caffeine would improve performance of free-throw shooting and b) free-throw shooting performance would be negatively affected with increasing number of sprint sets.

Methods

Participants

This study was in compliance with the ethical standards for use of human subjects and was approved by Nanyang Technological University Institutional Review Board (IRB-2018-08-012).

Eighteen well trained, experienced basketball players who competed at the college level were recruited in this study. Informed written consent and parental consent (<21 years), where applicable, were obtained from the participants. All participants were varsity basketball team representatives. Out of the 18 participants, 12 were male (age 23.1 ± 1.9 years; height 180.1 ± 8.8 cm; weight 77.1 ± 12.4 kg) and six were female (age 22.0 ± 1.3 years; height 169.4 ± 8.9 cm; body mass 67.0 ± 11.1 kg). To be eligible for the study, all participants had to: 1) be between 18 and 30 years old, 2) have no caffeine allergy/intolerance, 3) have at least 3 years of prior basketball experience in both training and competing, 4) have competed in at least one post-secondary level basketball tournament, 5) have no health conditions prescribed by a doctor preventing exercise participation, 6) not be taking medications for any chronic medical conditions, 7) have no self-reported medical conditions (hypertension, cardiovascular disease, insomnia and frequent migraines), 8) consume < 200 mg caffeine per day,¹⁷ and 9) not ingest any supplements that may have a physiological effect on the body.

Study design and procedures

A single-blind, placebo-controlled, randomized design was used in this study. Each participant performed two trials separated by at least three days to ensure complete washout of the caffeine solution.¹⁸ Prior to each trial, participants were asked to abstain from consumption of any caffeinated food or beverage as well as alcoholic beverages for at least 24 h. Height and body mass of the participants were recorded using electronic column scales (seca 769, seca GmbH & Co. KG., Hamburg, Germany) before testing.

For each trial, participants consumed a solution containing caffeine or placebo (maltodextrin) 60 min before the testing protocol. For the caffeine trial, participants consumed a solution containing 6 mg of caffeine per kg of body mass (BulkPowders, Colchester, UK). This dosage of caffeine has been shown to improve performance without any negative side effects in many previous studies on sports.^{8,19} The caffeine powders were dissolved in 300 mL of tap water mixed with 2 sachets of non-caloric sweetener (Equal, Merisant Company, Chicago, USA) to mask any taste. The solution was ingested 60 min before the start of the experimental trial as caffeine absorption by the gastrointestinal tract into the blood stream is rapid and reaches peak plasma concentration approximately 1 h after ingestion.⁸ The absorption is independent of the dosage consumed, up to 10 mg per kg of body mass.²⁰ For the placebo trial, participants consumed a solution containing 6 mg of maltodextrin (placebo) per kg of body mass (BulkPowders, Colchester, UK) dissolved in the same manner as the caffeine solution.

On each trial, after arriving at the designated venue, participants were required to put on a heart rate sensor (Polar® H7, Kempele,

Finland) strapped firmly onto the chest and their resting heart rate was recorded. Participants then ingested the solution containing either caffeine or placebo 60 min before the protocol began (Fig. 1). During the waiting period of 60 min, heart rate was recorded every 15 min. After that, participants were instructed to conduct their own warm-up for roughly 15 min, typically involving a series of running, stretching and shooting drills with a basketball.

Once participants were ready, they performed five sets of 6×15 m repeated sprints on a standard basketball court (28 m \times 15 m). This protocol aimed to simulate fatigue levels similar to a real game situation as players who are awarded with free-throws following fouls are often slightly fatigued due to repeated sprinting in a basketball game (Fig. 1). It was found that the distance per sprint in repeated sprint protocols ranged from 15 to 35 m and the number of sprints per set ranged from three to twelve.²¹ Hence, each set included six sideline-to-sideline sprints before shooting free-throws. After each set of sprints, the heart rate was recorded and the rating of perceived exertion (RPE) was assessed using a 6 to 20 scale.²² Participants were then tasked to stand behind the free-throw line (4.6 m from the basket) and shoot two free-throws using their personal free-throw routine. The number of successful shots was counted. Five sets of the match-simulating protocol including 10 free-throws in total were administered for each participant. Between sets, a break of 2 min was given. The duration of the entire exercise protocol was approximately 15–20 min. During and after each set, participants were allowed to consume water ad libitum.

Statistical analysis

Data analysis was performed using SPSS 25.0 software (IBM Corp, Armonk, N.Y., USA). Normality of distribution was tested using the Shapiro-Wilk test. Data are presented as means \pm standard deviation. Paired *t*-test was used to assess the differences in total free-throw score (maximum 10 points) between caffeine and placebo trials. As each free-throw score for each set was 0, 1 or 2, the summation of scores for five sprint sets allow the score to be a continuous variable. Cohen's *d* effect size was calculated and interpreted as: trivial (0–0.19), small (0.20–0.49), medium

(0.50–0.79) and large (0.8 and larger).²³ The smallest worthwhile change (SWC) was calculated as $0.2 \times$ between-participant deviation for free-throw scores to identify participants as responders, non-responders or negative responders to caffeine. Responders were identified if an improvement in free-throw score greater than SWC was present. Non-responders were identified if the difference in free-throw score was found similar to the SWC. Negative responders were identified if the decrease in free-throw score greater than SWC was apparent.^{24,25} A two-way (2 intervention \times 5 sets) repeated measures analysis of variance (ANOVA) was used to determine any interaction and main effect between caffeine and placebo for free-throw scores, heart rate and RPE. Partial eta squared (η^2) was used as a measure of effect size for ANOVA. Greenhouse-Geisser correction was applied where assumption of sphericity was violated. When an interaction was found, *post-hoc* analysis was adjusted for multiple comparisons using the Bonferroni method. Statistical significance was set at $p < 0.05$. Mean differences between caffeine and placebo trials together with the 95% confidence interval (CI) were also calculated.

Results

During one of the trials, the heart rate sensor battery failed and hence, for that participant heart rate data were excluded from the analysis. In two other participants, several sets of heart rate data were excluded from the analysis as the data obtained were beyond the normal physiological range (three standard deviation less than the mean value of other participants). Overall, 15 participants were included in the analysis of heart rate data.

Free-throw score

Fig. 2a shows the total scores for five sets of free-throws between caffeine and placebo. In comparison to placebo, the ingestion of caffeine did not cause a significant increase in the overall free-throw scores (caffeine = 6.1 ± 1.7 vs. placebo = 5.5 ± 2.0 ; mean difference [95% CI] = $0.6 [-0.6 \text{ to } 1.7]$; $d = 0.27$, $p = 0.34$). Individual analysis using SWC of 0.47 showed that 10 out of 18 participants were responders, 3 were non-responders and 5 were negative

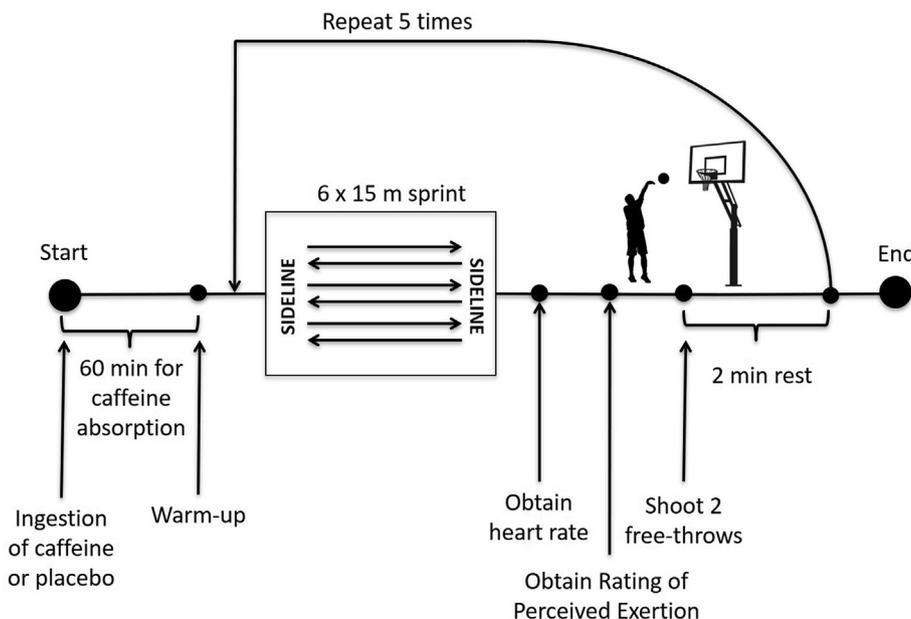


Fig. 1. Timeline of exercise protocol for one session.

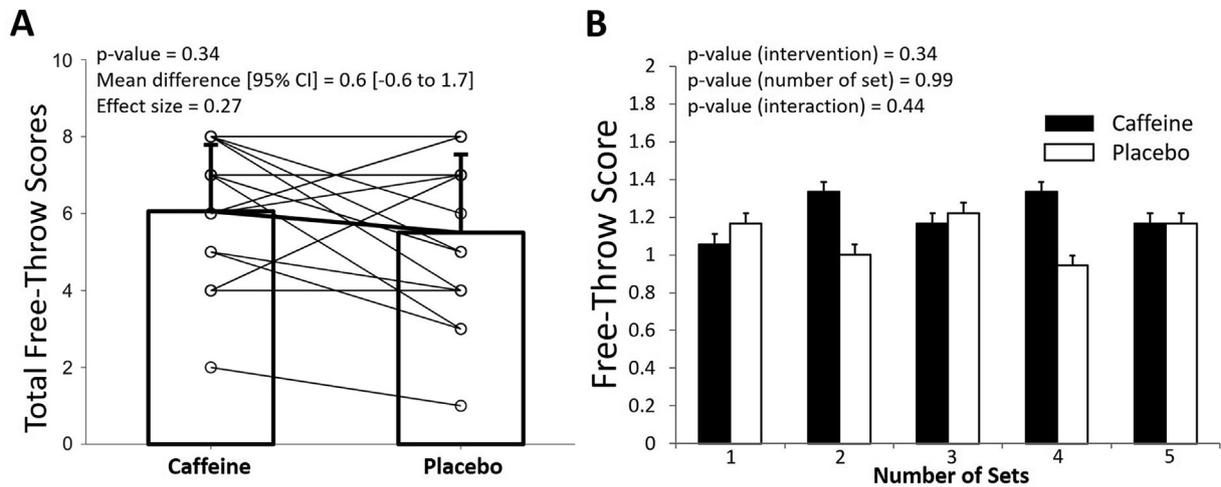


Fig. 2. A. Group mean and individual total free-throw scores of caffeine and placebo trials. B. Mean free-throw scores of all participants per set. Data are reported as mean \pm SD.

responders to pre-exercise caffeine ingestion (Table 1). ANOVA results showed no significant interaction between intervention and number of sets for free-throw scores ($p = 0.44$; partial $\eta^2 = 0.053$). There was no effect observed for both intervention ($p = 0.34$; partial $\eta^2 = 0.054$) and number of sets ($p = 0.99$; partial $\eta^2 = 0.004$) (Fig. 2b).

Heart rate

While there was no significant interaction between intervention and number of sets for heart rate ($p = 0.29$; partial $\eta^2 = 0.085$), an effect of intervention was observed with consistently higher heart rates in the caffeine than placebo trial across all five sprint sets ($p = 0.02$; partial $\eta^2 = 0.354$, Table 2). Furthermore, an effect for number of sets was also observed ($p < 0.001$; partial $\eta^2 = 0.434$), with increases in heart rate as the number of sets progressed from set 1 to set 5 (mean increase for CAF = 6.9 ± 4.9 bpm; PLA = 9.4 ± 6.6 bpm, Table 2).

Table 1

Individualized analyses showing the differences between caffeine (6 mg per kg of body mass) and placebo conditions relative to the smallest worthwhile change (SWC = 0.47) for free-throw score in college basketball players ($n = 18$).

Participant	Difference in Free-Throw Score	Response
1	1	↑
2	3	↑
3	-4	↓
4	2	↑
5	2	↑
6	2	↑
7	-2	↓
8	2	↑
9	4	↑
10	1	↑
11	-3	↓
12	0	↔
13	0	↔
14	-1	↓
15	4	↑
16	0	↔
17	-3	↓
18	2	↑

Difference = caffeine – placebo conditions. Individual response: ↑ responder, ↔ non-responder, ↓ negative responder.

Rating of perceived exertion

A significant interaction was found between intervention and number of sets ($p < 0.001$; partial $\eta^2 = 0.637$, Table 2) but *post-hoc* analyses could not identify where this occurred. There was no significant difference between the caffeine and placebo trials across the five sets ($p = 0.57$, partial $\eta^2 = 0.019$). However, a main effect of number of sets was observed ($p < 0.001$; partial $\eta^2 = 0.559$), with increases in RPE as the number of sets progressed from set 1 to set 5 (mean increase for CAF = 4.9 ± 3.5 ; PLA = 3.95 ± 2.8).

Discussion

The main aim of this study was to determine the effects of caffeine ingestion (6 mg per kg of body mass) on free-throw performance in basketball. In comparison to the placebo, the ingestion of caffeine did not improve the overall accuracy of free-throw in collegiate basketball players. There did exist some variations in inter-individual responses, however, with 10 out of 18 participants experiencing an increase in the overall number of successful free-throws after ingesting caffeine (mean increase = 2.3 ± 1.1). Free-throw shooting performance was unaffected by the number of sprint sets in either trial despite significant increases in heart rate or RPE with increasing sprints. The increases in heart rate observed were greater in the caffeine compared to the placebo trial but there was no clear effect of caffeine ingestion on RPE.

Contrary to the first hypothesis, caffeine consumption did not have any effects on the accuracy of free-throw performance. While studies have investigated the use of caffeine on physical abilities that impact team sports performance,^{13,18,26} we are aware of only two studies that have previously analysed the effects of caffeine on free-throw performance.^{10,11} Puente et al.¹⁰ found that ingestion of 3 mg per kg of body mass of caffeine improved free-throw performance and increased the number of free-throws awarded during a simulated basketball game. However, following basketball-specific testing, no positive effects on free-throw performance were noted. Similarly, Abian-Vicen et al.¹¹ reported no beneficial effects on free-throw performance using 3 mg of caffeine per kg of body mass. The present study used a higher dose of 6 mg of caffeine per kg of body mass which has been reported to produce positive results in team sporting performance.²⁷ However, despite this higher dosage, there was no improvement in free-throw shooting accuracy, as reflected by the similar scores obtained between caffeine and placebo trials. The lack of positive effect of caffeine use

Table 2Rating of perceived exertion (RPE) and heart rate (HR) per sprint set for all participants of caffeine and placebo trials. Data are reported as mean \pm SD.

Variables	Trials	Sets				p-values			
		1	2	3	4	5	Intervention	Sets	Interaction
HR	Caffeine	159 \pm 12.2	160 \pm 8.7	163 \pm 9.7	162 \pm 11.9	166 \pm 9.2	0.02	<0.001	0.29
	Placebo	154 \pm 15.6	154 \pm 10.7	158 \pm 11.7	161 \pm 9.4	163 \pm 12.1			
RPE	Caffeine	10.9 \pm 2.3	12.6 \pm 2.0	13.7 \pm 2.1	14.6 \pm 1.7	15.8 \pm 2.1	0.57	<0.001	<0.001
	Placebo	11.7 \pm 3.0	12.5 \pm 2.5	13.4 \pm 2.2	14.7 \pm 1.9	15.7 \pm 2.1			

could be due to several reasons. Free-throw is a skill that can be affected by multiple factors such as technique, the player's mental capacity to handle psychological stress and specificity of training. In the present study, participants were varsity basketball players, with several years of training and regular experience in competitions. For these skilled players, there was an absence of any effect of caffeine on free-throw accuracy. This contrasts with the findings by Puente and colleagues¹⁰ who found improvements in free throw scores with caffeine in professional female and semi-professional male basketball players during simulated game play. As noted previously, however, this difference could stem from the fact that, unlike in the present study, the simulated play did not match for the number of free throws between caffeine and placebo conditions. During the simulated play, the participants attempted considerably fewer free-throws (average less than 2 attempts) than the present study (10 attempts) and hence the results obtained may not be a good reflection of improved free-throw performance. Based on the findings from the present study, it can be concluded that 6 mg per kg of body mass of caffeine does not improve free-throw shooting performance and basketball players should consider other methods to improve free-throw accuracy rather than relying on the consumption of caffeine.

Whilst there was no overall difference in free-throw performance, 10 of 18 participants were responders who improved their performance with caffeine relative to the smallest worthwhile change. Genetic differences can determine the rate of caffeine metabolism.^{8,29} Whilst it can be hypothesised that a slower caffeine metabolism may be more beneficial for performance, rapid caffeine metabolism can lead to greater accumulation of metabolites (paraxanthine and theophylline) which have a higher binding affinity for the adenosine receptor than caffeine.²⁹ We did not have the capacity to measure genotype in the present study but it may be an explanatory variable between responders and non-responders and future studies should attempt to account for this where possible.

In a real basketball game, it was reported that during free-throws, heart rate responses would decrease from 85 to 95% to approximately 70–75% of maximum heart rate.^{30,31} In the present study the average heart rate for both trials was greater than 75% of the predicted maximum heart rate. This means that the physiological response in our experimental conditions may not truly reflect game play responses and is a potential limitation. Nevertheless, the average heart rate in the caffeine trials was significantly higher than placebo trials. Although this increase in heart rate observed could be undesirable for accuracy-based performances,⁴ no difference was seen in free-throw accuracy here. The increase in heart rate following caffeine ingestion, could be as a result of an increase in sympathetic nervous system activity.³¹ Altered sympathetic nervous system activity, one of the two components of the central nervous system, is one of the main pathways in which the human body responds to physical and psychological stress.³² It was also found that consumption of caffeine could possibly lead to increased anxiety, nervousness and stress.^{33,34} As shooting free-throws is considered to be a psychologically demanding task, the combined effect of caffeine consumption and shooting free-throws

could result in participants experiencing high stress levels and anxiety. The relationship between stress levels and sports performance is often denoted by a U-shaped theory, whereby low stress or high stress levels could result in poor sports performance.³⁰ Despite high levels of anxiety and stress induced by caffeine ingestion, the participants in the present study were experienced basketball players who may have had better coping strategies allowing them to deal with the increased stress levels. These coping strategies may have negated any negative outcomes from increased stress on free-throw shooting accuracy after ingesting caffeine. Hence, these results suggest that pre-exercise caffeine ingestion has no effects on shooting performance in experienced basketball players.

The second hypothesis of the present study was to examine free-throw performance with increasing number of sprints. Performance was not negatively affected with increasing number of sprints sets. From set 1 to set 5, the participants showed no decline in shooting accuracy (Fig. 2b) despite experiencing a substantial increase in heart rate and RPE in both the caffeine and placebo trials. Basketball is a sport that requires athletes to sprint frequently during games. While the exact duration and speed of the sprints would depend on the dynamics of each basketball game, it was reported that on average a sprint was performed every 39 s.²⁸ Hence, the ability to complete repeated sprints with only relatively short recovery periods is an important fitness component.³⁵ As such, when free-throws are awarded in a game, the player shooting the free-throw is often experiencing physiological effects associated with repeated sprinting up and down the basketball court. In the present study, the participants subjectively rated physical exertion following the repeated sprints using RPE. Although RPE increased as the number of sets progressed, no significant differences were found between caffeine and placebo trials. This indicates that the participants may have felt similarly tired under both conditions. Our finding is further supported by another study where it was found that the accuracy of jump shots was not affected by fatigue under a moderate to high intensity protocol.³⁶ As such, pre-exercise caffeine ingestion may not be effective in lowering perceived exertion. Collectively, the lack of negative effects from fatigue on shooting accuracy suggest that perhaps, regular exposure to these levels of exertion, such as experienced in game-play or training, means that players are able to maintain consistency in free-throw accuracy.

The main limitation of this study was the preparation of the caffeine and placebo drink. Despite the use of a sweetener to disguise the caffeine, all 18 participants were still able to tell the difference in taste between caffeine and placebo. However, they could not identify which was caffeine or placebo as they were unaware of the actual taste of caffeine. For better masking purposes in the future, the use of caffeine and placebo opaque pills is recommended so that participants are unable to identify any taste differences. The second limitation was replicating an environment to simulate a real basketball game. Despite using a sprint protocol to simulate physiological demands of a basketball game, it is extremely difficult to create an experimental environment

replicating the exact psychological demands of real game play, and free-throw itself is a complicated task affected by many factors. Lastly, to strengthen the present study design, future studies could use a double-blind, randomized and counterbalanced study design.

Future studies should move beyond free-throws and evaluate the effects of caffeine on other basketball-specific skills such as passing accuracy and 3-point shooting accuracy. This is because that the use of caffeine may still be effective in improving other aspects of physical performance in basketball game play. Many studies pertaining to the use of caffeine have shown positive effects on physical performances such as increased jumping performance as well as sprint times.^{1–3,26} Hence, it would seem that caffeine use might still improve overall performance for basketball athletes. Athletes should, however, be careful with the constant use of caffeine as a performance-enhancing supplement as they may develop a tolerance for its effects.³⁷

Conclusion

In summary, the ingestion of 6 mg per kg of body mass of caffeine did not affect the accuracy of free-throw performance in basketball. Also, free-throw accuracy was not negatively affected by the effects of increasing number of sprint sets. For practical recommendations, coaches and athletes should not rely on pre-exercise caffeine ingestion to improve basketball free-throw shooting accuracy regardless of whether the athletes are in fresh or fatigued conditions. Instead of caffeine ingestion, basketball players could consider developing other plans such as overcoming psychological stressors and improving the technique of free-throw.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jesf.2019.12.002>.

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