

Caffeine Supplementation for Powerlifting Competitions: an Evidence-Based Approach

by

Jozo Grgic¹, Filip Sabol^{2,3}, Sandro Venier³, Jason Tallis⁴, Brad J. Schoenfeld⁵,
Juan Del Coso⁶, Paole Mikulic³

In this paper, we review the effects of caffeine on muscle strength and provide suggestions for caffeine supplementation in powerlifting competitions. The currently available studies indicate that caffeine ingestion may enhance strength in two powerlifting competition events, the squat and the bench press. For the deadlift, the same might be expected even though studies directly using this event are lacking. Optimal doses of caffeine are likely in the range from 2 to 6 mg·kg⁻¹, and are highly individual. When using caffeine-containing capsules, 60 minutes pre-exercise seems to be a good timing of caffeine consumption. For other sources such as caffeinated chewing gum, a shorter period (5 to 10 min) from consumption to the start of the exercise seems to be effective. For shorter duration powerlifting competitions (e.g., 2 hours), one pre-competition dose of caffeine could be sufficient for acute performance-enhancing effects that might be maintained across all three events. For longer duration competitions (with longer rest periods between one repetition maximum attempts), there might be a benefit to repeated dosing with caffeine; for example, ingesting smaller doses of caffeine before each attempt or event. During training, powerlifters may consider ingesting caffeine only before the training sessions with the highest intensity. This approach might eliminate the attenuation of caffeine's effects associated with chronic caffeine ingestion and would help in maximizing performance benefits from acute caffeine ingestion at the competition. Nonetheless, withdrawal from caffeine (e.g., no caffeine intake seven days before competition) does not seem necessary and may have some indirect negative effects.

Key words: ergogenic, performance-enhancing, supplements, strength sports, 1RM.

Introduction

Powerlifting is a sport of relative and absolute strength (Grgic and Mikulic, 2017a). Powerlifting competitions were instituted in the 1960s, and since then, the sport has gained in popularity (Ferland and Comtois, 2019). Powerlifting competitions are weight category specific and include three events: squat, bench press, and deadlift, held in that order. For each event, powerlifters are allowed up to three attempts whereby the goal is to lift the highest

amount of weight possible in a one repetition maximum (1RM). In each event, the athlete must adhere to a set of rules regarding the range of motion of the lift as well as to the specific commands from the main referee. The sport of powerlifting is divided into 'classic' and 'equipped' powerlifting. Powerlifting with equipment is characterized by greater intensity (i.e. higher external loads), and a longer duration warm-up. One aspect that is characteristic of powerlifting competitions is their unpredictable

¹ - Institute for Health and Sport (IHES), Victoria University, Melbourne, Australia.

² - Fitness Academy, Zagreb, Croatia.

³ - Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia.

⁴ - Centre for Sport, Exercise and Life Sciences, Coventry University, Coventry, UK.

⁵ - Health Sciences Department, CUNY Lehman College, Bronx, USA.

⁶ - Exercise Physiology Laboratory, Universidad Camilo Jose Cela, Villanueva de la Cañada, Spain.

duration. Depending on the number of athletes, the competition may last anywhere from one to two hours or, when there are many competitors, it may last even longer.

As with many sports, both chronic and acute nutritional strategies are important in maximizing performance gains during training and in competition. Given the growing body of evidence outlining the ergogenic effect of caffeine for improving athletic performance (Grgic et al., 2019a), and more specifically muscle strength, caffeine supplementation is likely an effective acute nutritional strategy to improve powerlifting performance. Among athletes, caffeine supplementation is highly prevalent especially since it was removed from the World Anti-Doping Agency list of within-competition banned substances (Aguilar-Navarro et al., 2019). When analyzing urine samples of 4633 athletes tested for doping control in 2004, caffeine concentrations in samples from powerlifters were significantly higher in comparison to athletes from other sports (Van Thuyne and Delbeke, 2006). From 2004 to 2015, urinary caffeine concentration significantly increased among weightlifters (Aguilar-Navarro et al., 2019), and a similar pattern is also likely in powerlifting, even though recent data for powerlifters are not available.

For those interested in supplementing with caffeine for acute performance-enhancing effects, current guidelines suggest using a dose of caffeine in the range from 3 to 6 mg·kg⁻¹ 60 minutes before exercise (Goldstein et al., 2010). However, if we factor in the unpredictable duration of competitions in powerlifting and the fact the athletes perform up to nine 1RM attempts in one competition, it becomes evident that adhering to these guidelines may yield results in the practical context that are less than ideal. Specifically, in longer duration competitions it is unlikely that one dose of caffeine 60 minutes before exercise will maintain peak plasma concentration over the entire duration of the event. This may be an issue as the time course over which caffeine has performance enhancing effects will inevitably decrease over time. In this paper, we review the effects of caffeine on strength (with a focus on powerlifting events) and provide suggestions for caffeine supplementation in powerlifting competitions. Based on these suggestions, we hope to give a better context on this topic for

powerlifters interested in harnessing the ergogenic effects of caffeine while minimizing side-effects.

Effects of caffeine on maximal strength

There is compelling evidence that caffeine enhances muscle strength, as shown in several meta-analyses (Grgic et al., 2018, 2019a; Grgic and Pickering, 2019; Warren et al., 2010; Table 1). Warren et al. (2010) analyzed the results from 27 studies that explored the effects of caffeine on strength. The authors considered all tests of maximal force production, including 1RM, isokinetic, and isometric tests. In this analysis, the pooled ergogenic effect of caffeine on maximal strength amounted to an effect size of 0.19 (+4%). The effects of caffeine were most pronounced in the lower-body, specifically in the knee extensors (+7%). A caveat that powerlifters need to keep in mind when interpreting these findings is that only two out of the 27 included studies explored the effects of caffeine on 1RM strength and these two studies did not report significant ergogenic effects of caffeine on 1RM strength. This limitation is relevant to highlight given that data obtained using isometric and isokinetic tests of strength cannot necessarily be generalized to 1RM tests (Gentil et al., 2017).

A follow-up meta-analysis explored the effects of caffeine only on 1RM strength (Grgic et al., 2018). A total of 10 studies were included in the analysis, and the magnitude of the pooled ergogenic effect of caffeine on 1RM strength was 0.20 (~3%). Subgroup analyses revealed that caffeine's effects were statistically significant for upper-body strength (effect size of 0.21; ~4%), but not lower-body strength, although the effect size favored the caffeine condition (effect size: 0.15; 95% confidence interval: -0.05, 0.34). The majority of studies that tested upper-body strength used the bench press exercise, making these results are directly relevant to powerlifting (Table 2). Even though many of these studies did not report statistically significant ergogenic effects of caffeine, in all of them, performance data favored the caffeine condition as compared to the placebo. Therefore, these studies might have been statistically underpowered to observe small, yet possibly practically relevant performance-enhancing effects. Essentially, this idea was confirmed in the meta-analytical findings by Grgic et al. (2018).

For the lower-body, studies generally used machine-based exercises (such as the leg press) and these data, therefore, may be less applicable to powerlifters. The only published study included in the meta-analysis that used free weight barbell back squat exercise for assessing lower-body strength was the work by Grgic and Mikulic (2017b). In this study, 17 resistance-trained men were assessed for their 1RM in the squat once following the ingestion of 6 mg·kg⁻¹ caffeine, and once following the ingestion of placebo. On average, caffeine ingestion enhanced 1RM strength by ~3% as compared to the placebo. Others report that the ingestion of caffeine in a very low dose (75 mg) also increases 1RM squat (Martin, 2015). These two studies, coupled with the meta-analytic findings for the bench press, highlight that caffeine ingestion may be ergogenic for strength in at least two powerlifting events. We are not aware of any studies examining the effects of caffeine on strength while using the deadlift. While a degree of prudence must be exercised when extrapolating the effects of caffeine on the bench press and squat 1RM strength to the deadlift exercise, we see no scientific rationale why caffeine would not exhibit the same or similar ergogenic effects in the deadlift. In summary, the evidence to support the ergogenic effect of caffeine in two out of three powerlifting events suggests that caffeine supplementation may enhance performance in this sport.

One limitation of the current body of evidence is that the majority of studies were conducted among individuals with low habitual caffeine intake (Table 2). Additionally, even though some studies included resistance-trained individuals, their levels of strength do not mirror those of elite powerlifters. Therefore, it remains unclear to what extent can the results of these studies be generalized to competitive powerlifters with high habitual caffeine intake. In this context, it might be that the effects of caffeine are even higher in trained than untrained individuals as trained individuals have a greater density of adenosine receptors (see Characteristics and mechanisms of caffeine section) as well as greater mental discipline to exercise hard enough to benefit more from the caffeine stimulus (Graham, 2001; Mizuno et al., 2005). However, studies directly including powerlifters as participants are needed to explore this topic fully. It is well-established that exercise performance varies

according to the time of day (Grgic et al., 2019b). A recent analysis on the time of day-specific resistance training effects on strength indicated that greater strength is observed in the evening hours as compared to early morning (Grgic et al., 2019b). Therefore, powerlifters that train in the evening and compete in the morning hours might experience a performance decrement at the competition. Caffeine ingestion could avert this decrease in performance in the morning hours (Pickering and Grgic, 2019; Figure 1) and therefore, may present a valuable ergogenic aid in these instances (Mora-Rodríguez et al., 2015). Besides its positive effects on increasing strength, caffeine may also be useful for attenuating the fatigue-induced decline in muscle strength (Pethick et al., 2018) that might be associated with multiple 1RM attempts, as performed in powerlifting competitions. This conceivably could allow for better maintenance of strength over the course of a powerlifting meet and thus impact a competitor's final result.

In summary, the current literature indicates that caffeine ingestion enhances maximal strength by ~3-4% and thus, might be considered as a beneficial ergogenic aid for competitive powerlifting. While such increases in strength might be considered as small in statistical terms, this small difference might be important in elite-level powerlifters because the difference in the 'total' (sum of highest weight lifted across all three lifts) between the first- and the second-classified powerlifter in the 2018 World Open Powerlifting Championships was 2.8% in men and 4.7% in women. These results add veracity to the notion that caffeine may provide ergogenic effects on strength that are valuable in powerlifting competitions.

Characteristics and mechanisms of caffeine

Caffeine is rapidly absorbed by the gastrointestinal tract and it is sufficiently hydrophobic to pass through many biological membranes to be readily distributed throughout all tissues of the body (Magkos and Kavouras, 2005). Peak concentrations of caffeine in plasma are usually obtained between 15 and 120 min after oral ingestion, although peak values and the time for peak concentration might be affected by the dose (Kamimori et al., 2002). After ingestion,

caffeine is catabolized by the cytochrome P450 system in the liver (Graham, 2001). Caffeine's half-life (the time required for the quantity to reduce to half of its initial value) is generally around four to six hours (Graham, 2001). Caffeine's ergogenic actions are primarily explained by its effect on adenosine receptors (McLellan et al., 2016). After ingestion, caffeine binds to adenosine receptors and alters the sensations of fatigue and exertion. Caffeine ingestion may reduce the rating of perceived exertion (Grgic and Mikulic, 2017b; Grgic et al., 2019c) which is relevant for powerlifters, as a reduced rating of perceived exertion during the warm-up may increase the lifter's confidence and affect the final decision regarding the load in the first attempt. There is also solid evidence that caffeine may elicit its ergogenic effect on muscle strength by increasing motor unit recruitment and muscle fiber conduction velocity (Bazzucchi et al., 2011; Kalmar and Cafarelli, 1999). Studies using isolated animal muscle fiber models show caffeine-induced increases in force production, with the effects being more pronounced in type I than type II muscle fibers (Tallis et al., 2012). The mechanisms of caffeine are reviewed in greater detail elsewhere (McLellan et al., 2016).

Caffeine supplementation in powerlifting competitions

Dose of caffeine

Current guidelines suggest that doses in the range of 3 to 6 mg·kg⁻¹ produce optimal performance-enhancing effects (Goldstein et al., 2010). However, in general, there is only a small number of studies that explored the dose-response effects of caffeine on exercise performance. Such studies generally do not support a linear dose-response relationship between the dose of caffeine and the magnitude of the ergogenic effect (Pickering and Grgic, 2019). With that being said, when examining barbell velocity in resistance exercise, one study reported that a caffeine dose of 9 mg·kg⁻¹ (but not 3 or 6 mg·kg⁻¹) was needed to increase barbell velocity with loads of 90% 1RM in a Smith machine squat and bench press exercises (Pallarés et al., 2013). For lower loads, the two lower caffeine doses were sufficient. However, these findings have not yet been replicated in the literature with other studies suggesting that lower doses of caffeine enhance barbell velocity across

both moderate (i.e., 50% and 75% 1RM) and high loads (i.e., 90% 1RM) (Venier et al., 2019a).

Minimal effective doses for strength improvements remain unclear, but they might be lower than the initially suggested 3 mg·kg⁻¹ (Goldstein et al., 2010; Sabol et al., 2019). In the previously mentioned study by Martin (2015), 75 mg of caffeine (0.9 mg·kg⁻¹ according to the average body mass of participants) also provided ergogenic effects on strength, even though contrasting findings on the topic of low doses of caffeine have been reported by others (Del Coso et al., 2012). While acknowledging that higher doses of caffeine may offer possible benefits (Pallarés et al., 2013), such doses may also result in strong side-effects (e.g., tachycardia, anxiety or nervousness, headache, gastrointestinal problems, insomnia, etc.). Other side-effects from caffeine ingestion reported in the literature include tremor, muscle soreness, and inability to verbally communicate and stay focused (Grgic et al., 2018). These side-effects seem to be more pronounced in individuals with low habitual caffeine intake (Astorino et al., 2008; Goldstein et al., 2010). Therefore, athletes need to be mindful of these drawbacks that ultimately might outweigh the benefits of caffeine supplementation. In summary, caffeine seems to be ergogenic for strength across a wide range of doses. However, optimal doses are highly individual which ultimately indicates that individual experimentation with caffeine dosage is needed (Grgic, 2018; Pickering and Kiely, 2018).

Timing of caffeine ingestion

In most research studies that use caffeine-containing capsules, caffeine is ingested one hour before the start of the exercise session (Grgic et al., 2019a). This timing is employed given that one-hour post ingestion, plasma levels of caffeine are believed to be the highest (Graham, 2001). However, the timing of caffeine ingestion may be influenced by the form of caffeine. For example, caffeine from cola and coffee sources reaches peak levels at ~40 minutes following consumption (Liguori et al., 1997). When administered via caffeinated chewing gums, caffeine's absorption is even faster in comparison to other caffeine forms (Kamimori et al., 2002). We have recently reported that consuming caffeine using chewing gum 10 minutes before exercise may acutely enhance jumping performance, isokinetic strength, and barbell velocity in the bench press exercise (Venier

et al., 2019a). Similar results were observed in a subsequent study that used caffeine gels (Venier et al., 2019b), even though there is a lack of studies that explored the absorption of caffeine with this source. In summary, powerlifters interested in supplementing with caffeine should consider the time course of caffeine's effects; if consumed in a capsule, 60 minutes of waiting time post-ingestion should generally be used. However, consuming caffeine in cola or coffee reduces the time to peak concentrations to ~40 minutes and, if consumed in caffeinated chewing gums (and possibly caffeinated gels), waiting for as little as 10 minutes before exercise seems to be sufficient. When determining optimal timing of caffeine ingestion, it is also important to note that the rate of caffeine metabolism may be influenced by factors such as age, sex and hormones, obesity, smoking, and diet (for a review on this topic see Nehlig, 2018).

The role of genes in caffeine metabolism also warrants a brief discussion when it comes to the timing of caffeine ingestion. There remains a possibility that the timing of caffeine ingestion is dependent on the *CYP1A2* genotype that impacts caffeine metabolism (Pickering, 2019). Individuals with the AA variation in this gene are classified as 'fast caffeine metabolizers', while C allele carriers (AC/CC) are considered 'slow caffeine metabolizers'. When ingesting caffeine 60 minutes before exercise, studies indicate that caffeine may

enhance performance for the AA genotype, but not for AC/CC genotypes (Pickering and Kiely, 2018). Individuals with the AC/CC genotype, therefore, may need to utilize caffeine 90 or 120 minutes (or maybe even longer) before exercise (Pickering, 2019). While this idea is speculative, it might present a possible solution for those that do not respond to the generally used timing of 60 minutes.

Repeated dosing

As noted in the introduction, competitions in powerlifting are characterized by their unpredictable duration. This aspect may impact the optimal protocol for the ingestion of caffeine. When the duration of the event is shorter (e.g., one to two hours), ingesting one dose of caffeine 60 minutes before the start of the competition would likely be sufficient for increases in performance, possibly even in all three events. However, what approach should an athlete take when there are long breaks between individual attempts and events? Evidently, ingesting one dose of caffeine 60 minutes before the start of the competition, and performing the final event several hours later is not a recipe for success as the time course over which caffeine has performance enhancing effects will inevitably decrease over time. In longer duration competitions, repeated dosing with caffeine may be required.

Table 1

Summary of meta-analyses that explored the effects of caffeine on strength

Reference	Strength test(s) and number of included studies	Main findings
Grgic et al. (2018)	1RM (10 studies)	1RM upper and lower-body values combined: ↑ by an effect of 0.20 (+3.2%) Only upper-body 1RM: ↑ by an effect of 0.21 (+3.4%) Only lower-body 1RM: ↔ even though the effect favored caffeine (effect size: 0.15; +2.9%)
Grgic and Pickering (2019)	Isokinetic tests (10 studies)	Upper and lower-body values combined: ↑ by an effect of 0.16 (+5.3%)
Warren et al. (2010)	Isometric, isokinetic, and 1RM tests (27 studies)	Upper and lower-body values combined: ↑ by an effect of 0.19 (+4%) Only lower-body tests: ↑ by an effect of 0.37 (+7%)

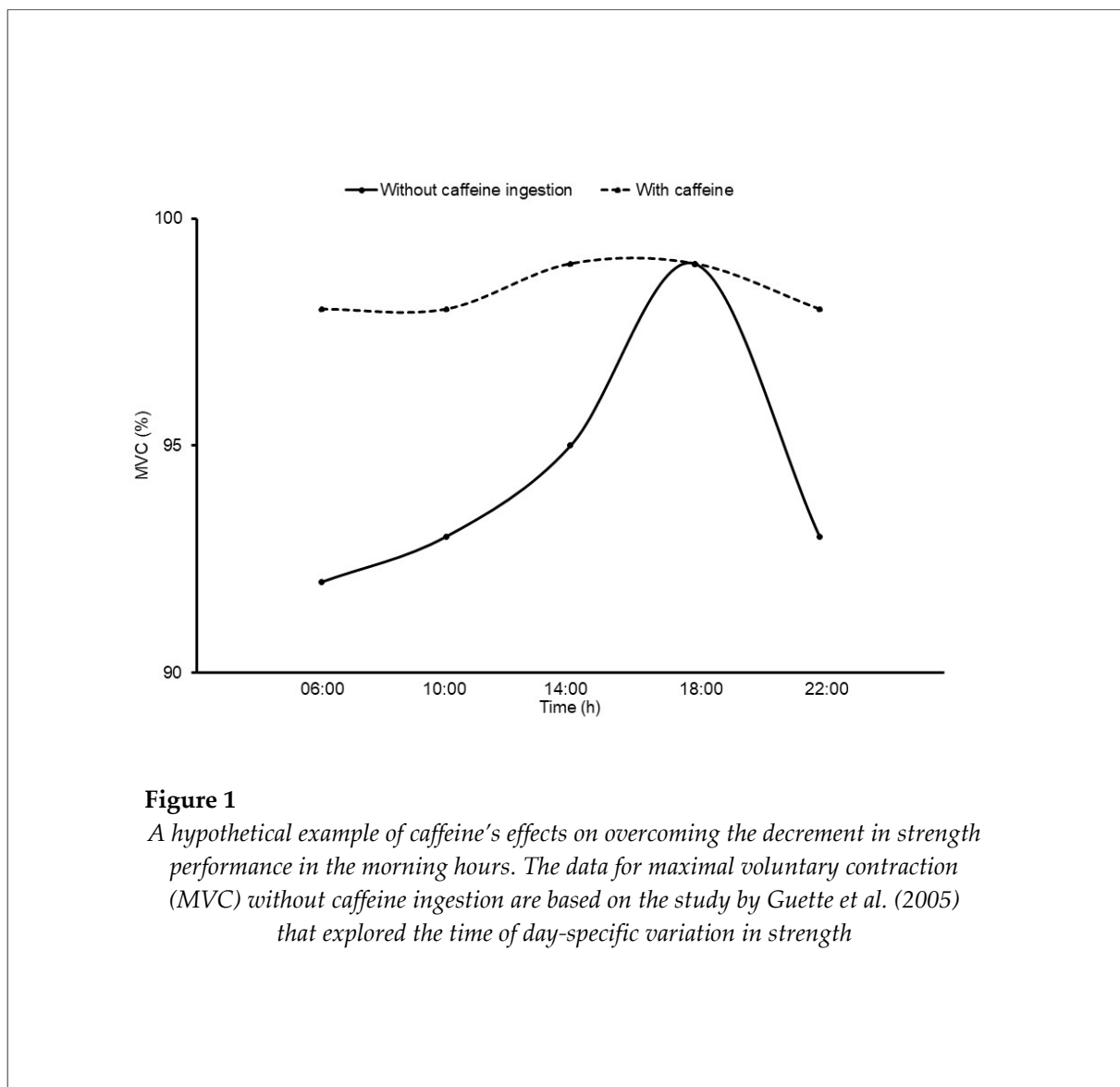
1RM: one repetition maximum; ↑ significant increases as compared to the placebo; ↔ no significant differences

Table 2

Summary of studies that explored the effects of caffeine on one repetition maximum strength using the free-weight bench press or squat exercises

Reference	Sample; habitual caffeine intake	Caffeine dose, form, and timing	1RM strength test	Strength performance data (kg)*
Arazi et al. (2016)	15 young resistance-trained men; not reported	6 mg·kg ⁻¹ in capsule form 60 minutes pre-exercise	Bench press	Placebo: 56.3 ± 6.5 Caffeine: 59.7 ± 7.3
Astorino et al. (2008)	22 young resistance-trained men; 110 ± 152 mg per day	6 mg·kg ⁻¹ in capsule form 60 minutes pre-exercise	Bench press	Placebo: 114.9 ± 22.8 Caffeine: 116.4 ± 23.6
Diaz-Lara et al. (2016)	14 young male Jiu-jitsu athletes; <60 mg per day	3 mg·kg ⁻¹ in capsule form 60 minutes pre-exercise	Bench press	Placebo: 90.5 ± 7.7 Caffeine: 93.3 ± 7.5
Eckerson et al. (2013)	17 young resistance-trained men; <50 mg per day	160 mg of caffeine anhydrous mixed with liquid 60 minutes pre-exercise	Bench press	Placebo: 114.1 ± 16.1 Caffeine: 114.8 ± 16.2
Fett et al. (2018)	8 young resistance-trained females; not reported	6 mg·kg ⁻¹ in capsule form on two different occasions 30 minutes pre-exercise	Bench press	Placebo: 25 ± 2 Caffeine (first): 26 ± 2 Caffeine (second): 27 ± 2
Goldstein et al. (2010)	15 young resistance-trained females; < 250 mg per day (<i>n</i> = 8) > 250 mg per day (<i>n</i> = 7)	6 mg·kg ⁻¹ of caffeine anhydrous mixed with liquid 60 minutes pre-exercise	Bench press	Placebo: 52.1 ± 11.7 Caffeine: 52.9 ± 11.1
Grgic and Mikulic (2017)	17 young resistance-trained men; 58 ± 92 mg per day	6 mg·kg ⁻¹ of caffeine anhydrous mixed with liquid 60 minutes pre-exercise	Bench press and squat	<i>Bench press</i> Placebo: 106.9 ± 11.9 Caffeine: 107.9 ± 11.9 <i>Squat</i> Placebo: 131.6 ± 19.2 Caffeine: 135.3 ± 18.7
Martin (2015)	12 young resistance-trained men; not reported	75 mg in caffeine gel 60 minutes pre-exercise	Squat	Placebo: 138.3 ± 22.1 Caffeine: 143.1 ± 23.1
Sabblah et al. (2015)	10 young resistance-trained men and 7 young resistance-trained women; not reported	5 mg·kg ⁻¹ of caffeine anhydrous mixed with liquid 60 minutes pre-exercise	Bench press	<i>Males</i> Placebo: 101.5 ± 28.9 Caffeine: 107.5 ± 30.5 <i>Females</i> Placebo: 32.2 ± 9.0 Caffeine: 35.3 ± 7.3
Williams et al. (2008)	9 young resistance-trained men; 'low' (no exact values)	300 mg in capsule form 45 minutes pre-exercise	Bench press	Placebo: 108.9 ± 19.5 Caffeine: 109.5 ± 14.7

* Data presented as mean ± standard deviation; 1RM: one repetition maximum



Even though there are no studies exploring repeated dosing directly in the context of strength performance, we may be able to draw some conclusions from studies using other exercise tests. Negaresh et al. (2019) investigated the effects of caffeine on combat performance in five matches consisting of 2×3 -minutes of wrestling with 45 to 185 minutes of between-match rest intervals. Performance was examined under five different conditions: (a) placebo; (b) high-dose of caffeine ($10 \text{ mg}\cdot\text{kg}^{-1}$) administered in one dose before the first match; (c) moderate dose of caffeine ($4 \text{ mg}\cdot\text{kg}^{-1}$) delivered in the same fashion as $10 \text{ mg}\cdot\text{kg}^{-1}$; (d) repeated-dosing with caffeine ($2 \text{ mg}\cdot\text{kg}^{-1}$ before each match equating to a total of $10 \text{ mg}\cdot\text{kg}^{-1}$); and,

(e) repeated-dosing before each match with caffeine doses that were individualized for each participant. The $10 \text{ mg}\cdot\text{kg}^{-1}$ caffeine dose enhanced performance only in the first match while the moderate dose of caffeine was not at all ergogenic. The two protocols that used repeated dosing with caffeine before each match yielded the highest improvements in performance. Repeated dosing with $2 \text{ mg}\cdot\text{kg}^{-1}$ enhanced performance in the first four matches and repeated dosing with an individualized dose was ergogenic in all five matches. How do we explain these findings? A caffeine dose of around $5 \text{ mg}\cdot\text{kg}^{-1}$ saturates the P450 system and therefore higher doses of caffeine may result in disproportionate increases in

plasma caffeine concentration (Graham, 2001). Ingesting smaller, repeated doses may be superior to one large dose, given that smaller doses would not saturate the P450 system (Graham, 2001). Smaller, repeated doses might help maintain a moderate, but stable concentration of caffeine in plasma through several hours (Conway et al., 2003).

A parallel here can be drawn to powerlifting competitions; instead of ingesting one large dose of caffeine before the start of the competition, athletes may consider splitting up the total dose of caffeine into several smaller doses. A dose of $6 \text{ mg}\cdot\text{kg}^{-1}$ administered in capsules could be divided into $3 \times 2 \text{ mg}\cdot\text{kg}^{-1}$ doses that are ingested 30-60 minutes before each event. This approach would ensure the maintenance of high circulating levels of caffeine throughout the competition. Some form of individual experimentation would be required for such an approach, but it may be a viable option for competitions that are of longer duration. Using caffeinated chewing gums instead of caffeine in capsules is also an option given the faster absorption of caffeine when chewing gums are used as a source. Repeated dosing with caffeine may also have important implications for other sports or events where qualifications, quarter-finals, semi-finals, and finals are held on the same day.

Caffeine habituation and withdrawal

Given the widespread use of caffeine among powerlifting competitors (Van Thuyne and Delbeke, 2006) and the ubiquitous nature of caffeine in food and drinks as well as pre-workout supplements, it is likely that many powerlifters are moderate to high habitual users of caffeine. For those interested, the caffeine content in foods and drinks is summarized in a review by Burke (2008). In animal models, habitual use of caffeine upregulates adenosine receptor concentration which subsequently attenuates caffeine's effects (Svenningsson et al., 1999). Given that the ergogenic effects of caffeine are strongly linked to its effects on adenosine receptors, it has been posited that habitual caffeine users may experience smaller improvements in performance (if any) following acute caffeine ingestion as compared to those who are caffeine naïve (Bell and McLellan, 2002). Studies that have explored

this topic in the context of exercise performance show mixed results. Some found that caffeine's effects are dependent on habitual caffeine intake, while others indicate that caffeine elicits similar acute performance-enhancing effects regardless of habituation (Bell and McLellan, 2002; Gonçalves et al., 2017). More importantly, there are no studies that explored the topic in the context of strength-based performance. Despite the paucity of data, a possible pre-competition approach may be to ingest a larger dose of caffeine than the dose of caffeine ingested habitually (Pickering and Kiely, 2019). As an illustration, an athlete with a body mass of 100 kg who has a daily caffeine intake of 200 mg might consider ingesting a dose of $3 \text{ mg}\cdot\text{kg}^{-1}$ or higher prior to competition. This approach may help ensure that any habitual intake-related reduction in caffeine's effects is modified by increasing the dose for acute supplementation above the amount of caffeine habitually ingested (Pickering and Kiely, 2019). Also, it is worth noting that the ergogenic effects of caffeine seem to attenuate after 20 days of consecutive caffeine supplementation (Lara et al., 2019). This suggests that powerlifters may consider ingesting caffeine only before the highest intensity training sessions as this would likely eliminate the attenuation of effects and therefore, maximize performance benefits from acute caffeine ingestion at the competition. A highly pervasive idea in the literature is the one that athletes should stop caffeine consumption approximately one week prior to competition and restart caffeine consumption on the day of the competition (Sökmen et al., 2008). This approach is purported to elicit acute ergogenic effects for a habitual caffeine user, as it would, hypothetically, for a nonuser. This idea, however, has received little support in the literature. In one study, habitual caffeine users (average daily caffeine intake of 761 mg) performed a cycling to exhaustion test under three conditions: (a) no withdrawal, (b) two days of withdrawal, and (c) four days of withdrawal from dietary caffeine (Van Soeren and Graham, 2002). Similar improvements in performance following caffeine ingestion were attained in all three cases, which suggests that withdrawal is not necessary, at least in endurance-based sports. Moreover, withdrawal from caffeine may provoke side-effects among habitual users such as headache, fatigue, decreased energy/activeness,

decreased alertness, drowsiness, depressed mood, difficulty concentrating, and irritability (Juliano and Griffiths, 2004). These symptoms peak 24 to 48 hours after caffeine restriction and last about one week. Powerlifters generally perform their tapering and peaking practices one week out of the competition. National level New Zealand and Croatian powerlifters (Grgic and Mikulic, 2017a; Pritchard et al., 2016) indicate that they still train at a high intensity in the final week before the competition. Experiencing side-effects due to caffeine withdrawal one week out of the competition may hinder the quality of training during the final week, which may have negative effects on mental factors such as confidence as well as performance at the competition. Taken together, withdrawal from caffeine should likely be avoided. However, athletes who are high habitual caffeine users may consider limiting their intake of dietary caffeine at the day of the competition to avoid 'over-dosing' with caffeine through the use of targeted supplementation.

Conclusion

The currently available studies indicate that caffeine ingestion may enhance strength in two powerlifting competition events, the squat and the bench press. For the deadlift, the same might be expected even though studies directly examining the effects of caffeine ingestion on strength performance in this event are lacking.

References

- Aguilar-Navarro M, Muñoz G, Salinero JJ, Muñoz-Guerra J, Fernández-Álvarez M, Plata MDM, Del Coso J. Urine caffeine concentration in doping control samples from 2004 to 2015. *Nutrients*, 2019; 11(2). pii: E286
- Arazi H, Dehlabinejad N, Gholizadeh R. The acute effect of caffeine supplementation on strength, repetition sustainability and work volume of novice bodybuilders. *Turk J Kin*, 2016; 2(3): 43–8
- Astorino TA, Firth K, Rohmann RL. Effect of caffeine ingestion on one-repetition maximum muscular strength. *Eur J Appl Physiol*, 2008; 102(2): 127–32
- Bazzucchi I, Felici F, Montini M, Figura F, Sacchetti M. Caffeine improves neuromuscular function during maximal dynamic exercise. *Muscle Nerve*, 2011; 43(6): 839–44
- Bell DG, McLellan TM. Exercise endurance 1, 3, and 6 h after caffeine ingestion in caffeine users and nonusers. *J Appl Physiol*, 2002; 93(4): 1227–34
- Burke LM. Caffeine and sports performance. *Appl Physiol Nutr Metab*, 2008; 33(6): 1319–34
- Conway KJ, Orr R, Stannard SR. Effect of a divided caffeine dose on endurance cycling performance, postexercise urinary caffeine concentration, and plasma paraxanthine. *J Appl Physiol*, 2003; 94(4): 1557–62
- Del Coso J, Salinero JJ, González-Millán C, Abián-Vicén J, Pérez-González B. Dose response effects of a

- caffeine-containing energy drink on muscle performance: a repeated measures design. *J Int Soc Sports Nutr*, 2012; 9(1): 21
- Diaz-Lara FJ, Del Coso J, García JM, Portillo LJ, Areces F, Abián-Vicén J. Caffeine improves muscular performance in elite Brazilian Jiu-jitsu athletes. *Eur J Sport Sci*, 2016; 16(8): 1079–86
- Eckerson JM, Bull AJ, Baechle TR, Fischer CA, O'Brien DC, Moore GA, Yee JC, Pulverenti TS. Acute ingestion of sugar-free red bull energy drink has no effect on upper body strength and muscular endurance in resistance trained men. *J Strength Cond Res*, 2013; 27(8): 2248–54
- Ferland PM, Comtois AS. Classic powerlifting performance: a systematic review. *J Strength Cond Res*, 2019. doi: 10.1519/JSC.0000000000003099
- Fett CA, Aquino NM, Schantz Junior J, Brandão CF, de Araújo Cavalcanti JD, Fett WC. Performance of muscle strength and fatigue tolerance in young trained women supplemented with caffeine. *J Sports Med Phys Fitness*, 2018; 58(3): 249–55
- Gentil P, Del Vecchio FB, Paoli A, Schoenfeld BJ, Bottaro M. Isokinetic dynamometry and 1RM tests produce conflicting results for assessing alterations in muscle strength. *J Hum Kinet*, 2017; 56: 19–27
- Goldstein E, Jacobs PL, Whitehurst, Penhollow T, Antonio J. Caffeine enhances upper body strength in resistance-trained women. *J Int Soc Sports Nutr*, 2010; 7: 18
- Goldstein ER, Ziegenfuss T, Kalman D, Kreider R, Campbell B, Wilborn C, Taylor L, Willoughby D, Stout J, Graves BS, Wildman R, Ivy JL, Spano M, Smith AE, Antonio J. International society of sports nutrition position stand: caffeine and performance. *J Int Soc Sports Nutr*, 2010; 7(1): 5
- Gonçalves LS, Painelli VS, Yamaguchi G, Oliveira LF, Saunders B, da Silva RP, Maciel E, Artioli GG, Roschel H, Gualano B. Dispelling the myth that habitual caffeine consumption influences the performance response to acute caffeine supplementation. *J Appl Physiol*, 2017; 123(1): 213–20
- Graham TE. Caffeine and exercise: metabolism, endurance and performance. *Sports Med*, 2001; 31(11): 785–807
- Grgic J, Grgic I, Pickering C, Schoenfeld BJ, Bishop DJ, Pedisic Z. Wake up and smell the coffee: caffeine supplementation and exercise performance—an umbrella review of 21 published meta-analyses. *Br J Sports Med*, 2019. doi: 10.1136/bjsports-2018-100278
- Grgic J, Lazinica B, Garofolini A, Schoenfeld BJ, Saner NJ, Mikulic P. The effects of time of day-specific resistance training on adaptations in skeletal muscle hypertrophy and muscle strength: A systematic review and meta-analysis. *Chronobiol Int*, 2019; 36(4): 449–60
- Grgic J, Mikulic P, Schoenfeld BJ, Bishop DJ, Pedisic Z. The influence of caffeine supplementation on resistance exercise: a review. *Sports Med*, 2019; 49(1): 17–30
- Grgic J, Mikulic P. Caffeine ingestion acutely enhances muscular strength and power but not muscular endurance in resistance-trained men. *Eur J Sport Sci*, 2017; 17(8): 1029–36
- Grgic J, Mikulic P. Tapering practices of Croatian open-class powerlifting champions. *J Strength Cond Res*, 2017; 31(9): 2371–8
- Grgic J, Pickering C. The effects of caffeine ingestion on isokinetic muscular strength: A meta-analysis. *J Sci Med Sport*, 2019; 22(3): 353–60
- 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*, 2018; 15: 11
- Grgic J. Are there non-responders to the ergogenic effects of caffeine ingestion on exercise performance? *Nutrients*, 2018; 10(11). pii: E1736
- Guette M, Gondin J, Martin A. Time-of-day effect on the torque and neuromuscular properties of dominant and non-dominant quadriceps femoris. *Chronobiol Int*, 2005; 22(3): 541–58
- Juliano LM, Griffiths RR. A critical review of caffeine withdrawal: empirical validation of symptoms and signs, incidence, severity, and associated features. *Psychopharmacology*, 2004; 176(1): 1–29
- Kalmar JM, Cafarelli E. Effects of caffeine on neuromuscular function. *J Appl Physiol*, 1999; 87(2): 801–8
- Kamimori GH, Karyekar CS, Otterstetter R, Cox DS, Balkin TJ, Belenky GL, Eddington ND. The rate of absorption and relative bioavailability of caffeine administered in chewing gum versus capsules to normal healthy volunteers. *Int J Pharm*, 2002; 234(1-2): 159–67
- Lara B, Ruiz-Moreno C, Salinero JJ, Del Coso J. Time course of tolerance to the performance benefits of caffeine. *PLoS One*, 2019; 14(1): e0210275

- Liguori A, Hughes JR, Grass JA. Absorption and subjective effects of caffeine from coffee, cola and capsules. *Pharmacol Biochem Behav*, 1997; 58(3): 721–6
- Martin J. Does caffeine ingestion prior to high intensity exercise act as an ergogenic aid in sporting performance in male athletes? 2015. Available at: <https://repository.cardiffmet.ac.uk/handle/10369/6982>; accessed on 26.04.2019
- McLellan TM, Caldwell JA, Lieberman HR. A review of caffeine's effects on cognitive, physical and occupational performance. *Neurosci Biobehav Rev*, 2016; 71: 294–312
- Mizuno M, Kimura Y, Tokizawa K, Ishii K, Oda K, Sasaki T, Nakamura Y, Muraoka I, Ishiwata K. Greater adenosine A(2A) receptor densities in cardiac and skeletal muscle in endurance-trained men: a [¹¹C]TMSX PET study. *Nucl Med Biol*, 2005; 32(8): 831–6
- Mora-Rodríguez R, Pallarés JG, López-Gullón JM, López-Samanes Á, Fernández-Elías VE, Ortega JF. Improvements on neuromuscular performance with caffeine ingestion depend on the time-of-day. *J Sci Med Sport*, 2015; 18(3): 338–42
- Negaresh R, Del Coso J, Mokhtarzade M1, Lima-Silva AE, Baker JS, Willems MET, Talebvand S, Khodadoost M, Farhani F. Effects of different dosages of caffeine administration on wrestling performance during a simulated tournament. *Eur J Sport Sci*, 2019; 19(4): 499–507
- Nehlig A. Interindividual differences in caffeine metabolism and factors driving caffeine consumption. *Pharmacol Rev*, 2018; 70(2): 384–411
- Pallarés JG, Fernández-Elías VE, Ortega JF, Muñoz G, Muñoz-Guerra J, Mora-Rodríguez R. Neuromuscular responses to incremental caffeine doses: performance and side effects. *Med Sci Sports Exerc*, 2013; 45(11): 2184–92
- Pethick J, Winter SL, Burnley M. Caffeine ingestion attenuates fatigue-induced loss of muscle torque complexity. *Med Sci Sports Exerc*, 2018; 50(2): 236–45
- Pickering C, Grgic J. Caffeine and exercise: what next? *Sports Med*, 2019. doi: 10.1007/s40279-019-01101-0.
- Pickering C, Kiely J. 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*, 2018; 48(1): 7–16
- Pickering C, Kiely J. What should we do about habitual caffeine use in athletes? *Sports Med*, 2019; 49(6): 833–42
- Pickering C. Caffeine, CYP1A2 genotype, and sports performance: is timing important? *Ir J Med Sci*, 2019; 188(1): 349–50
- Pritchard HJ, Tod DA, Barnes MJ, Keogh JW, McGuigan MR. Tapering practices of New Zealand's elite raw powerlifters. *J Strength Cond Res*, 2016; 30(7): 1796–804
- Sabblah S, Dixon D, Bottoms L. Sex differences on the acute effects of caffeine on maximal strength and muscular endurance. *Comp Exerc Physiol*, 2015; 11: 89–94
- Sabol F, Grgic J, Mikulic P. The Effects of three different doses of caffeine on jumping and throwing performance: a randomized, double-blind, crossover study. *Int J Sports Physiol Perform*, 2019. doi: 10.1123/ijsp.2018-0884
- Sökmen B, Armstrong LE, Kraemer WJ, Casa DJ, Dias JC, Judelson DA, Maresh CM. Caffeine use in sports: considerations for the athlete. *J Strength Cond Res*, 2008; 22(3): 978–86
- Svenningsson P, Nomikos GG, Fredholm BB. The stimulatory action and the development of tolerance to caffeine is associated with alterations in gene expression in specific brain regions. *J Neurosci*, 1999; 19(10): 4011–22
- Tallis J, James RS, Cox VM, Duncan MJ. The effect of physiological concentrations of caffeine on the power output of maximally and submaximally stimulated mouse EDL (fast) and soleus (slow) muscle. *J Appl Physiol*, 2012; 112(1): 64–71
- Van Soeren MH, Graham TE. Effect of caffeine on metabolism, exercise endurance, and catecholamine responses after withdrawal. *J Appl Physiol*, 1998; 85(4): 1493–501
- Van Thuyne W, Delbeke FT. Distribution of caffeine levels in urine in different sports in relation to doping control before and after the removal of caffeine from the WADA doping list. *Int J Sports Med*, 2006; 27(9): 745–50

- Venier S, Grgic J, Mikulic P. Acute enhancement of jump performance, muscle strength, and power in resistance-trained men after consumption of caffeinated chewing gum. *Int J Sports Physiol Perform*, 2019. doi: 10.1123/ijsp.2019-0098
- Venier S, Grgic J, Mikulic P. Caffeinated gel ingestion enhances jump performance, muscle strength, and power in trained men. *Nutrients*, 2019; 11(4): 937
- Warren GL, Park ND, Maresca RD, McKibans KI, Millard-Stafford ML. Effect of caffeine ingestion on muscular strength and endurance: a meta-analysis. *Med Sci Sports Exerc*, 2010; 42(7): 1375–87
- Williams A, Cribb P, Cooke M, Hayes A. The effect of ephedra and caffeine on maximal strength and power in resistance-trained athletes. *J Strength Cond Res*, 2008; 22(2): 464–70

Corresponding author:**Jozo Grgic**

Institute for Health and Sport (IHES),
Victoria University, Melbourne, Australia.
E-mail: jozo.grgic@live.vu.edu.au