SZEREJ, Krzysztof, DOROBEK, Wioleta, STANKIEWICZ, Katarzyna and ŚWIECZKOWSKI-FEIZ, Janusz. The Role of Caffeine in Enhancing Physical Performance: From Metabolism to Muscle Function. Journal of Education, Health and Sport. 2024;59:158-165. eISSN 2391-8306. https://dx.doi.org/10.12775/JEHS.2024.59.010
https://apcz.umk.pl/JEHS/article/view/48125
https://zenodo.org/records/10656290

The journal has had 40 points in Minister of Science and Higher Education of Poland parametric evaluation. Annex to the announcement of the Minister of Education and Science of 05.01.2024 No. 32318. Has a Journal's Unique Identifier: 201159. Scientific disciplines assigned: Physical culture sciences (Field of medical and health sciences); Health Sciences (Field of medical and health sciences).
Punkty Ministerialne 40 punktów. Załącznik do komunikatu Ministra Nauki i Szkolnictwa Wyższego z dnia 05.01.2024 Lp. 32318. Posiada Unikatowy Identyfikator Czasopisma: 201159. Przypisane dyscypliny naukowe: Nauki o kulturze fizycznej (Dziedzina nauk medycznych i nauk o zdrowiu); Nauki o zdrowiu (Dziedzina nauk medycznych i nauk o zdrowiu).© The Authors 2024;
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The authors declare that there is no conflict of interests regarding the publication of this paper.
Received: 16.01.2023. Revised: 08.02.2024. Accepted: 14.02.2024. Published: 14.02.2024.

The Role of Caffeine in Enhancing Physical Performance: From Metabolism to Muscle Function

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Abstract

Introduction: Caffeine, a widely consumed stimulant, is recognized for its ability to block adenosine receptors, thereby enhancing alertness and possibly physical performance. Recent research examines caffeine's effectiveness in enhancing athletic performance, with numerous athletes supplementing with caffeine to gain a competitive edge.

The aim of this study: This article examines the complex relationship between caffeine and the physical performance of athletes, including its effects on the central nervous system, metabolism, muscle function, and its application in a variety of sports, as well as potential gender differences and individual response variations.

Materials and methods: This review was based on available data collected in the PubMed database and Google Scholar web search engine using the key words caffeine, athletic performance, physical performance

Conclusions: Caffeine boosts muscle, cognitive, and metabolic function in volleyball and cycling. Caffeine boosts muscle contractility, endurance, and focus, but details matter. Caffeine effects and sports outcomes vary by gender, emphasizing the need for individualized supplementation. Dosage, timing, and physiological conditions affect results, research shows. Caffeine boosts performance, but athletes, coaches, and practitioners should be careful. To maximize caffeine's benefits and minimize side effects, athletes must be treated individually and by sport.

Key words: caffeine, athletic performance, physical performance

Introduction

Caffeine, an inherent stimulant, is widely present in various plants such as beans, leaves, and fruits, and has become an integral part of global cultures due to its inclusion in beverages and medications. The principal method by which caffeine exerts its effects is through its function as an antagonist of adenosine receptors. The binding of adenosine to its receptors results in the manifestation of sedative effects, as adenosine functions as a neuromodulator. Caffeine exhibits competitive binding with these identical sites, resulting in increased vigilance and potentially improved physical performance [1].

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Throughout history, the stimulating effects of caffeine have been acknowledged and utilized for an extensive period of time. However, its intentional utilization as a drug to enhance performance in athletics is a more recent development. Given the abundance of research that has documented the ergogenic properties of caffeine on diverse facets of exercise performance, it is unsurprising that numerous athletes resort to caffeine supplements as a means to gain a competitive advantage [2]. Nevertheless, the impact of CBD on various sports and its potential disparities based on gender continue to be subjects of continuous investigation and scholarly discourse. The purpose of this review is to examine the complex connection between the use of caffeine supplements and its direct effects on the physical performance of professional athletes. This will be achieved by analyzing various empirical studies and presenting a fair and unbiased viewpoint based on scientific evidence.

Effects of caffeine supplementation on central nervous system

Caffeine, a frequently ingested stimulant, exerts significant effects on the central nervous system (CNS), making it particularly pertinent for professional athletes. The aforementioned chemical compound, which falls under the category of central nervous system stimulants, is a member of the methylxanthine group [3]. The global intake of this substance has had an upward trend, mostly influenced by factors such as increased focus, greater memory, and higher physical capabilities [4]. The significance of this is particularly relevant for athletes, as they frequently strive to enhance their physical and cognitive capabilities throughout both training and competitive events.

One of the principal mechanisms through which caffeine functions is by augmenting energy metabolism throughout the brain. Nevertheless, it concurrently results in a reduction in cerebral blood flow, so inducing a state of relative brain hypoperfusion (5). Notwithstanding the diminished blood circulation, the impact of caffeine on vigilance and focus is predominantly favorable. When consumed in moderate quantities, it has been observed to promote alertness and improve attention span, hence potentially providing benefits in sports that necessitate prolonged focus and quick decision-making [6].

The impact of caffeine on the cardiovascular system is clearly demonstrated, particularly in relation to athletes. The substance demonstrates favorable effects on cardiac contractility and heart rate. The aforementioned impacts have the potential to significantly influence the cardiac performance of athletes, particularly in sports that place a high emphasis on cardiovascular endurance [7]. Although the aforementioned advantages imply potential ergogenic effects, it is crucial to acknowledge that caffeine's effects extend to other systems, including the immune system. It is imperative to take into account the equilibrium between the positive and negative consequences [8].

In summary, the intricate manner in which caffeine interacts with the central nervous system (CNS) and other physiological systems renders it a stimulant that garners attention among elite athletes. The ability to improve cognitive and physical performance, along with its impact on cardiovascular function, implies a possible advantage in competitive environments. Nevertheless, it is crucial for athletes to exhibit awareness regarding the wider ramifications of caffeine, guaranteeing that its intake is well-informed and aligned with their specific requirements and reactions.

Effects of caffeine supplementation on metabolism

Caffeine, a psychoactive chemical that is extensively used, has garnered significant interest among the scientific community due to its potential effects on metabolism, particularly in relation to professional athletes. Metabolism, which encompasses the entirety of biochemical processes occurring in an organism to sustain vital functions, plays a pivotal role in the realm of athletic performance. Athletes consistently endeavor to enhance metabolic rates in order to enhance energy levels, enhance endurance, and facilitate efficient recovery following physical exercise.

A significant topic of debate pertaining to caffeine revolves around its capacity to enhance athletic performance. Numerous research have provided notable evidence about the beneficial impact of caffeine consumption on athletic performance. However, it is worth mentioning that a significant proportion of these studies have mostly focused on male participants [1]. The method through which caffeine affects metabolism mostly involves its capacity to facilitate the mobilization of fatty acids from adipose tissues, so rendering them accessible for energy generation. The presence of fatty acids promotes a shift in the body's energy utilization, favoring fat as the predominant source of energy over glycogen, which is the stored form of glucose. This transition possesses the

capacity to expand glycogen reserves, thereby delaying the onset of tiredness, a particularly crucial aspect for endurance activities [9].

Upon further examination of the existing literature, it becomes evident that although caffeine does offer certain advantages, the results of its addition are not consistently uniform throughout all research investigations. The International Society of Sports Nutrition recognises the immediate improvement in certain facets of exercise performance attributed to caffeine. However, it also acknowledges that there are dissenting findings in certain studies [10]. The observed variability may be ascribed to variations in doses, timings of administration, and the physiological condition of the athletes under investigation. It is important to acknowledge, however, that in the case of combat sports athletes, the immediate consumption of caffeine did not necessarily result in improved punch performance [3]. This implies that the potential metabolic and performance advantages of caffeine may vary depending on the specific sport, which warrants additional investigation.

In addition to its immediate impact on the use of energy substrates, there is currently no empirical evidence indicating that the consumption of caffeine before to exercise results in dehydration, ion imbalance, or any other detrimental effects [9]. This article aims to dispel certain misconceptions and apprehensions pertaining to the consumption of caffeine by athletes, with a particular emphasis on its safety when consumed in accordance with suggested guidelines.

Furthermore, the categorization of athletes based on their typology and training levels may influence the tactics employed for caffeine supplementation. Research has indicated that collegiate and professional athletes exhibit elevated levels of caffeine consumption, which reinforces the widely held belief in its performance-enhancing effects [11]. However, similar to other forms of supplementation, the presence of individual differences in metabolism, genetic composition, and caffeine tolerance suggests that a universal strategy may not be optimal.

In brief, the influence of caffeine on metabolism, namely its ability to potentially alter the usage of energy substrates in favor of fat, renders it a desirable ergogenic supplement for elite athletes. Although there is a substantial body of research supporting the advantages of this practice, particularly in the realm of endurance sports, the evidence does not exhibit uniform consistency across all athletic domains. Hence, it is advisable for athletes and their support personnel to exercise caution when considering the use of caffeine supplementation, taking into account the unique requirements of each individual and the special challenges posed by their respective sports.

Effects of caffeine supplementation on muscle function

In the domain of professional sports, the optimization of muscle function holds significant relevance. The ability of athletes to perform precise motions, exhibit explosive strength, and sustain endurance over protracted activity is facilitated by the complex interaction of muscles. In recent years, there has been significant interest in the supplementation of caffeine as a strategy to improve muscular performance. According to existing research, caffeine has been found to exert significant impacts on the functionality of human skeletal muscles, particularly when supplied at precise dosages [12]. A notable research study has provided evidence that the administration of caffeine at a dosage of 9 mg/kg to professional athletes who have habitual caffeine consumption has discernible impacts on muscle performance. These findings potentially indicate a potential role for caffeine in enhancing muscle contractility and diminishing the perception of exertion during high-intensity physical endeavors.

Furthermore, a significant proportion of research investigations that have illustrated the beneficial impacts of caffeine administration on athletic performance, encompassing muscle functionality, have predominantly focused on male participants [1]. This observation suggests a possible gender-related correlation between caffeine consumption and its impact on muscle mechanics. However, it is important to note that further extensive research is required to extrapolate these results to professional athletes as a whole. Caffeine supplementation has been the subject of substantial research in the context of soccer, a sport known for its emphasis on speed, agility, and endurance. These studies have shed light on the impact of caffeine on soccer-specific skills and its possible consequences for muscle damage[13]. The multifaceted nature of caffeine's effects becomes apparent when examining its purported involvement in mitigating delayed-onset muscular soreness (DOMS), a prevalent concern encountered by athletes following physical exertion. The consumption of caffeine may potentially mitigate the transient decline in muscular strength and alleviate the discomfort associated with delayed onset muscle soreness (DOMS), indicating its potential significance in both muscle function and recovery [14].

However, it is crucial to emphasize the stance of the International Society of Sports Nutrition, which recognizes the immediate positive impact of caffeine on all facets of physical performance during exercise. Nonetheless, it also emphasizes that the results of these studies are not uniformly consistent throughout all research endeavors

[10]. This implies that factors such as individual differences, dosage, timing, and maybe sport-specific requirements contribute to the influence of caffeine on muscle function.

In summary, caffeine, in addition to its widely recognized stimulating properties, seems to possess a diverse range of influences on muscle performance in elite athletes. Caffeine has been identified as a possible ergogenic aid due to its ability to enhance muscular contractility and performance, as well as facilitate post-exercise recovery. Nevertheless, it is improbable that a uniform strategy would yield favorable outcomes. Instead, it would be more judicious to implement personalized techniques that consider the athlete's characteristics, sport, and unique requirements.

Effects of Caffeine Supplementation by Sport

Volleyball

A double-blind study involving 13 elite female volleyball players examined the effects of caffeine consumption. [15] Participants ingested either an energy drink containing caffeine or a placebo. Caffeine improved ball velocity in particular spikes and boosted jump heights across all types of jumps, according to post-ingestion performance tests. After consuming caffeine, agility test durations were drastically reduced. Further analysis of a simulated volleyball match revealed that caffeine led to more successful actions and fewer imprecise ones, indicating that energy beverages containing caffeine can substantially improve female volleyball players' performance and precision.

Another study sought to determine the effect of a caffeinated energy drink on the performance of male volleyball players. [16] 15 college volleyball players were administered a caffeinated beverage or a placebo in discrete weeks, using a double-blind, placebo-controlled design. After imbibing the beverage, participants participated in a series of volleyball-related assessments. Compared to the placebo group, those who consumed the caffeinated beverage had faster ball velocities, greater leap heights, faster agility test times, and performed better in a simulated game. In conclusion, consuming an energy drink containing 3 mg of caffeine per kilogram of body weight may improve the physical performance and accuracy of male volleyball players.

Badminton

Additionally, another study examined whether a caffeinated energy drink could improve the performance of elite badminton players. [17] After consuming either a caffeinated beverage or a placebo, 16 athletes were tested. In squat and countermovement jumps, those who ingested the caffeinated beverage displayed greater strength and jumped higher. In addition, they were more active during a simulated match, resulting in a greater number of cumulative impacts. Elite badminton players' leaping ability and activity levels could be enhanced by consuming a caffeinated energy beverage.

Tennis

The purpose of a separate study was to determine whether a caffeinated energy drink could enhance the performance of elite juvenile tennis players. [18] 14 participants consumed the caffeinated beverage or the placebo in distinct sessions. After consuming the caffeinated beverage, participants demonstrated a 4.2% increase in handgrip strength, a quicker high-intensity running cadence, and an increase in sprints during a simulated game. In addition, there was a possible increase in maximal running speed and a greater proportion of service points gained. However, the beverage had no effect on the velocity of the projectile during serving. Caffeinated energy beverages can improve certain physical aspects of the performance of junior tennis players.

Cycling

There was an intriguing study conducted on cyclists. [19] A study examined the physical and cognitive effects of a performance bar containing caffeine on cyclists. Twenty-four cyclists ingested either the caffeinated bar, a non-caffeinated equivalent, or a placebo drink before a rigorous exercise session. Those who consumed the caffeinated bar demonstrated improved cognitive processing rates, particularly in the later phases and after exercise. Moreover, their endurance was substantially superior to that of those who consumed other products. In

conclusion, a caffeinated bar can significantly increase both endurance and concentration during strenuous activities, emphasizing its potential benefits in sports requiring intensive concentration.

Another experiment involving a distinct group of cyclists examined whether caffeine consumption, whether as a supplement or in coffee, improves endurance exercise performance. [20] In a test, eight trained male cyclists engaged in 30 minutes of continuous cycling followed by a 45-minute time trial. An hour prior to exercise, participants ingested caffeine, instant coffee (both containing equivalent quantities of caffeine), decaffeinated coffee, or a placebo. Caffeine and coffee significantly enhanced time trial performance by approximately 5% when compared to placebo and decaf. There was no difference between the caffeine and coffee groups in terms of performance. The conclusion of the study is that consuming caffeine or coffee an hour prior to exercise can improve endurance performance.

Soccer

In a study investigating the effects of caffeine on soccer performance, twelve male soccer players ingested caffeine or a placebo prior to two 90-minute simulated soccer activities that were separated by one week.[21] Caffeine consumption enhanced players' passing accuracy, resulting in fewer penalties and faster overall timings. Additionally, caffeine significantly enhanced the height of jumps. In conclusion, ingesting caffeine before soccer activities can improve certain performance factors, such as passing accuracy and leaping ability, without affecting other performance factors negatively.

Boxing

Before a match, caffeine or a placebo was administered to ten male boxers to determine the effect of caffeine on their performance. [22] While heart rate and perceived exertion were comparable in both conditions, caffeine consumption resulted in prolonged bouts of intensive activity during the match. Specifically, compared to the placebo group, the caffeine group had lengthier interaction periods and a lower effort] to pause ratio. Caffeine consumption prior to boxing matches enhances the duration of high-intensity actions without influencing the boxer's perception of exertion or heart rate.

Side Effects and Considerations

The use of caffeine supplementation has been widely acknowledged as an ergogenic aid that effectively boosts athletic performance across a range of sports disciplines. Numerous scholarly investigations have extensively examined the beneficial impacts of the subject matter at hand. However, it is important to additionally acknowledge the possible adverse consequences and dosage issues that accompany its ingestion, especially within the realm of athletic prowess.

A significant issue associated with the use of caffeine, particularly in excessive quantities, is to the frequency of adverse effects. According to de Souza's study, it has been noted that the incidence and severity of adverse effects tend to be more pronounced when greater amounts of caffeine are consumed, as compared to lesser levels [23].

1. Jitters, an often experienced phenomenon among athletes, is characterized by a sense of restlessness and is typically described as a feeling of being "shaky" or "wired". This issue might be especially worrisome in sports that need accuracy and stability.

2. Sleep disturbances may be caused by caffeine due to its classification as a central nervous system stimulant, which has the potential to disrupt normal sleep patterns. The recuperation of an athlete is greatly influenced by the quality of their sleep, therefore making it a crucial factor to consider while drinking caffeine, particularly in proximity to bedtime.

3. Gastrointestinal pain: Certain athletes have reported experiencing gastric pain or diarrhea after the use of caffeine, which might potentially have negative implications during competitive events or training sessions.

4. Elevated Heart Rate: Particularly at larger dosages, caffeine has the potential to elicit tachycardia, characterized by an abnormally rapid heart rate. This physiological response may provide challenges for athletes who have certain cardiovascular ailments.

5. Anxiety: The use of coffee has the potential to intensify sensations of uneasiness or anxiety, hence potentially compromising an athlete's cognitive concentration during competitive events.

The physiological impact of caffeine on a worldwide scale has resulted in several pragmatic suggestions. According to Sökmen [24], it has been emphasized that lesser dosages of caffeine may exhibit comparable efficacy to greater doses in the context of exercise, while perhaps presenting a decreased likelihood of the aforementioned adverse effects.

The likelihood of experiencing an overdose: It is crucial to comprehend that there exists a threshold for the ergogenic impacts of caffeine. The use of it in overly large quantities does not result in proportional improvements in performance. Conversely, it elevates the likelihood of encountering significant adverse effects, such as cardiac arrhythmias, vertigo, or even more severe manifestations in exceptional instances.

The phenomenon of diminishing returns arises from the body's adaptation processes, which imply that individuals who regularly drink caffeine may eventually encounter a reduction in the performance-enhancing benefits often associated with its consumption. The phenomenon of tolerance development requires an increased dosage in order to get the same ergogenic benefits. However, this also amplifies the potential for adverse consequences [25].

In summary, while the ergogenic effects of caffeine have been extensively studied and recorded, it is important to acknowledge some limitations and considerations associated with its use. It is important for athletes and their coaches to adopt a knowledgeable standpoint when evaluating the use of caffeine supplements, taking into account its benefits as well as any drawbacks. The crux of the matter is in the implementation of personalized tactics that maximize the advantages of performance while simultaneously ensuring the preservation of one's physical and mental well-being.

Conclusion

The extensive study of caffeine's multifaceted effects on athletic performance shows that caffeine has become a popular ergogenic aid in sports. From volleyball to cycling, caffeine can improve muscle function, cognitive alertness, and metabolic efficiency. Caffeine improves muscle contractility, endurance, and focus, but it's important to highlight the details. Notably, gender differences in caffeine's effects and sports outcomes emphasize the need for individualized caffeine supplementation. Research also shows that dosage, timing, and physiological conditions affect results. Caffeine improves performance, but athletes, coaches, and practitioners should be cautious. To maximize caffeine's benefits and minimize side effects, athletes must be treated individually and according to their sport.

Disclosures: No disclosures

Financial support: No financial support was received.

Conflict of interest: The authors declare no conflict of interest.

Bibliography:

1. Mielgo-Ayuso, J., Marqués-Jiménez, D., Refoyo, I., Del Coso, J., León-Guereño, P., & Calleja-González, J. (2019). Effect of caffeine supplementation on sports performance based on differences between sexes: a Systematic review. Nutrients, 11(10), 2313. https://doi.org/10.3390/nu11102313
2. Delleli, S., Ouergui, I., Messaoudi, H., Trabelsi, K., Ammar, A., Glenn, J. M., & Chtourou, H. (2022). Acute effects of caffeine supplementation on physical performance, physiological responses, perceived exertion, and Technical-Tactical Skills in Combat Sports: A Systematic Review and Meta-Analysis. Nutrients, 14(14), 2996. https://doi.org/10.3390/nu14142996
3. Fiani, B., Zhu, L., Musch, B., Briceno, S., Andel, R., Sadeq, N. A., & Ansari, A. Z. (2021). The neurophysiology of caffeine as a central nervous system stimulant and the resultant effects on cognitive function. Cureus. https://doi.org/10.7759/cureus.15032
4. Cappelletti, S., Piacentino, D., Sani, G., & Aromatario, M. (2015). Caffeine: cognitive and physical performance enhancer or psychoactive drug? Current Neuropharmacology, 13(1), 71–88. https://doi.org/10.2174/1570159x13666141210215655

5. Nehlig, A., Daval, J., & Debry, G. (1992). Caffeine and the central nervous system: mechanisms of action, biochemical, metabolic and psychostimulant effects. Brain Research Reviews, 17(2), 139–170. https://doi.org/10.1016/0165-0173(92)90012-b
6. National Academies Press (US). (2014, April 23). Caffeine Effects on the Central Nervous System and Behavioral Effects Associated with Caffeine Consumption. Caffeine in Food and Dietary Supplements: Examining Safety - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK202225/
7. Gutiérrez-Hellín, J., & Varillas-Delgado, D. (2021). Energy drinks and sports performance, cardiovascular risk, and genetic associations; future prospects. Nutrients, 13(3), 715. https://doi.org/10.3390/nu13030715
8. Rodak, K., Kokot, I., & Kratz, E. M. (2021). Caffeine as a factor influencing the functioning of the human Body—Friend or foe? Nutrients, 13(9), 3088. https://doi.org/10.3390/nu13093088
9. Graham, T. E. (2001). Caffeine and exercise. Sports Medicine, 31(11), 785–807. https://doi.org/10.2165/00007256-200131110-00002
10. Guest, N. S., VanDusseldorp, T. A., Nelson, M. T., Grgić, J., Schoenfeld, B. J., Jenkins, N. D., Arent, S. M., António, J., Stout, J. R., Trexler, E. T., Smith-Ryan, A. E., Goldstein, E. R., Kalman, D., & Campbell, B. (2021). International society of sports nutrition position stand: caffeine and exercise performance. Journal of the International Society of Sports Nutrition, 18(1). https://doi.org/10.1186/s12970-020-00383-4
11. Kreutzer, A., Graybeal, A. J., Moss, K., Braun-Trocchio, R., & Shah, M. (2022). Caffeine supplementation strategies among endurance athletes. Frontiers in Sports and Active Living, 4. https://doi.org/10.3389/fspor.2022.821750
12. Domaszewski, P., Pakosz, P., Konieczny, M., Bączkowicz, D., & Sadowska-Krępa, E. (2021). Caffeine-Induced effects on human skeletal muscle contraction time and maximal displacement measured by tensiomyography. Nutrients, 13(3), 815. https://doi.org/10.3390/nu13030815
13. Mielgo-Ayuso, J., Calleja-González, J., Del Coso, J., Urdampilleta, A., León-Guereño, P., & Fernández-Lázaro, D. (2019). Caffeine Supplementation and Physical Performance, Muscle damage and Perception of Fatigue in soccer players: A Systematic review. Nutrients, 11(2), 440. https://doi.org/10.3390/nu11020440
14. Tallis, J., Guimarães-Ferreira, L., & Clarke, N. D. (2022). Not another caffeine effect on sports performance Study—Nothing new or more to do? Nutrients, 14(21), 4696. https://doi.org/10.3390/nu14214696
15. Pérez-López, A., Salinero, J. J., Abián-Vicén, J., Valadés, D., Lara, B., Gómez-Hernández, C., Areces, F., González, C., & Del Coso, J. (2015). Caffeinated energy drinks improve volleyball performance in elite female players. Medicine and Science in Sports and Exercise, 47(4), 850–856. https://doi.org/10.1249/mss.0000000000000455
16. Del Coso, J., Pérez-López, A., Abián-Vicén, J., Salinero, J. J., Lara, B., & Valadés, D. (2014). Enhancing Physical Performance in Male Volleyball Players with a Caffeine-Containing Energy Drink. International Journal of Sports Physiology and Performance, 9(6), 1013–1018. https://doi.org/10.1123/ijspp.2013-0448
17. Abián, P., Del Coso, J., Gallo-Salazar, C., Areces, F., Ruiz-Vicente, D., Lara, B., Soriano, L., Muñoz, V. Z., & Abián-Vicén, J. (2014). The ingestion of a caffeinated energy drink improves jump performance and activity patterns in elite badminton players. Journal of Sports Sciences, 33(10), 1042–1050. https://doi.org/10.1080/02640414.2014.981849
18. Gallo-Salazar, C., Areces, F., Abián-Vicén, J., Lara, B., Salinero, J. J., González-Millán, C., Portillo, J., Muñoz, V. Z., Juárez, D., & Del Coso, J. (2015). Enhancing physical performance in elite junior tennis players with a caffeinated energy drink. International Journal of Sports Physiology and Performance, 10(3), 305–310. https://doi.org/10.1123/ijspp.2014-0103
19. Hogervorst, E., Bandelow, S., Schmitt, J., Jentjens, R. L. P. G., Oliveira, M., Allgrove, J., Carter, T., & Gleeson, M. (2008). Caffeine Improves Physical and Cognitive Performance during Exhaustive Exercise. Medicine and Science in Sports and Exercise, 40(10), 1841–1851. https://doi.org/10.1249/mss.0b013e31817bb8b7
20. Hodgson, A. B., Randell, R. K., & Jeukendrup, A. E. (2013). The Metabolic and Performance Effects of Caffeine Compared to Coffee during Endurance Exercise. PLOS ONE, 8(4), e59561. https://doi.org/10.1371/journal.pone.0059561
21. Foskett, A., Ali, A., & Gant, N. (2009). Caffeine Enhances Cognitive Function and Skill Performance during Simulated Soccer Activity. International Journal of Sport Nutrition and Exercise Metabolism, 19(4), 410–423. https://doi.org/10.1123/ijsnem.19.4.410
22. Coswig, V. S., Gentil, P., Irigon, F., & Del Vecchio, F. B. (2018). Caffeine ingestion changes time-motion and technical-tactical aspects in simulated boxing matches: A randomized double-blind PLA-

controlled crossover study. European Journal of Sport Science, 18(7), 975–983. https://doi.org/10.1080/17461391.2018.1465599
23. De Souza, J. G., Del Coso, J., De Souza Fonseca, F., Da Silva, B. V. C., De Souza, D. B., Da Silva Gianoni, R. L., Filip-Stachnik, A., Serrão, J. C., & Claudino, J. G. (2022). Risk or benefit? Side effects of caffeine supplementation in sport: a systematic review. European Journal of Nutrition, 61(8), 3823–3834. https://doi.org/10.1007/s00394-022-02874-3
24. Sökmen, B., Armstrong, L. E., Kraemer, W. J., Casa, D. J., Dias, J. C. T., Judelson, D. A., & Maresh, C. M. (2008). Caffeine use in sports: Considerations for the athlete. Journal of Strength and Conditioning Research, 22(3), 978–986. https://doi.org/10.1519/jsc.0b013e3181660cec
25. Pickering, C., & Kiely, J. (2017). 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 Medicine, 48(1), 7–16. https://doi.org/10.1007/s40279-017-0776-1