American Journal of Biomedical Science & Research

www.biomedgrid.com

ISSN: 2642-1747

Research Article

The Effect of Meal Timing and Caffeine Intake on Energy Expenditure, Substrate Use and Exercise Efficiency in Healthy Male Individuals

Dima Al Wattar, Cecile Borgi, Omar Obeid and Elie-Jacques Fares*

Department of Nutrition and Food Sciences, Faculty of Agricultural and Food Sciences, American University of Beirut, Lebanon

***Corresponding author:** Elie Jacques Fares, Department of Nutrition and Food Sciences, Faculty of Agricultural and Food Sciences, American University of Beirut, Lebanon.

To Cite This Article: *Dima Al Wattar, Cecile Borgi, Omar Obeid, Elie-Jacques Fares. The Effect of Meal Timing and Caffeine Intake on Energy Expenditure, Substrate Use and Exercise Efficiency in Healthy Male Individuals. Am J Biomed Sci & Res. 2022 - 15(3). AJBSR.MS.ID.00212*
DOI: 10.34297/AJBSR.2022.15.002112

Received: November 11, 2021; **Published:** January 28, 2022

Abstract

Caffeine supplementation by athletes in small to moderate doses has been shown to be an effective ergogenic aid. Studies have recognized that caffeine supplementation decreases perceived exertion, delays fatigue, and improves time trial performance. This study aims to investigate the effect of timing of caffeine and meal intake on metabolic parameters in healthy individuals. Eight active males were randomly given 3 mg/kg caffeine, followed by a standardized meal 2 hours later (C2M) and vice versa (M2C) before being required to cycle for 5 minutes at 20W, 35W, 50W, 65W, and 80W. Caffeine (C), meal + caffeine (M+C), and meal (M) only were tested separately. Mean changes in energy expenditure differed significantly for C vs M+C and M+C vs M: 3.971±0.653 vs 4.205±0.637 kcal/min; $p < 0.05$ and 4.205±0.637 vs 3.938±0.617; $p < 0.05$). Delta efficiency was significantly greater in C2M than in M2C (25.5±1.2 vs 23.6±0.8 %; $p < 0.05$). Mean changes in respiratory quotient were significant (C2M vs M2C, 0.012±0.004; $p < 0.05$, and M vs C, M+C vs C, and M+C vs M, 0.062±0.008 ($p < 0.001$), -0.024±0.009 ($p < 0.01$), -0.038±0.015 ($p < 0.01$). The timing of meals and caffeine intake resulted in metabolic alterations in a non-dependent manner. This makes it difficult to explain the relationship between muscular efficiency and substrate use; however, it does require more research to target exercise performance, as well as body composition regulation.

Keywords: Caffeine, Energy Expenditure, Substrate Use, Glycogenesis, Delta Efficiency

Introduction

Caffeine is a naturally occurring stimulant typically found in coffee, tea, and chocolate (cacao) [1]. It has been proven to be protective against non-communicable diseases such as type II diabetes [2]. However, caffeine's impact on the individual's metabolic rate and substrate use remains controversial. A study conducted by Jarrar and Obeid [3] found that rats that ingested caffeine alongside or after a meal had higher insulin levels than control rats. However, no alterations in postprandial plasma glucose were witnessed, suggesting that caffeine may decrease insulin sensitivity. Interestingly, caffeine decreased postprandial triglycerides, which may be due to a decrease in fat absorption. However, pre-meal caffeine ingestion decreased hepatic glycogen synthesis in comparison to co-meal and post-meal ingestion, which lacked this inhibitory effect. The authors suggest that gluconeogenesis might have been triggered in the pre-meal caffeine intake protocol. Another study done by Acheson et al. [1] has demonstrated that ingesting caffeine without a meal increased metabolic rate and fat oxidation in comparison to the control groups. Furthermore, when ingested with a meal, caffeine was found to decrease carbohydrate utilization more rapidly than the control group and to increase fat oxidation as well. After caffeine ingestion, a rise in metabolic rate was observed in both obese and lean groups. However, fat oxidation only increased in the lean group.

In sport-related activities, it is established that caffeine intake exerts an ergogenic effect [4]. Ingesting caffeine in doses of 6 mg per kg of body mass [5-7] and even in lower doses (1-3 mg/kg) [8,9] one hour before exercise provides a significant enhancement of endurance performance. High caffeine doses (>6mg/kg) offer no additional benefit and increase the risk and magnitude of side effects [10]. They are linked to performance impairment, jitters, and increased heart rate. On the other hand, some subjects are simply non-responders to caffeine [10, 11]. Inter-individual variations in ergogenicity do exist [12], due to different genes that dictate the body's response to caffeine [13]. The two major genes responsible for this response are CYP1A2 and ADORA2A [14]. The former determines how fast caffeine is metabolized, while the latter is more related to its sensitivity [13-15]. In the recovery period, especially after a glycogen-depleting exercise, issues regarding caffeine and glucose disposal have been covered extensively. Glycogen synthesis during the 5 hours following exercise was not affected by doses of 6mg/kg of caffeine before and during exercise when carbohydrates were ingested [11].

Other studies have suggested that there is an enhancement in glycogen re-synthesis in trained participants [12]. Although, both caffeine and non-caffeine users benefit from caffeine intake prior to exercise, it is not advised for caffeine users to withdraw. Withdrawal (24-48h) might lead to negative outcomes (headaches, irritability, fatigue…) [13]. People who exercise few hours after caffeine intake still receive some benefits. These benefits can apply to athletes who train or compete twice per day [16]. The effect of caffeine on sleep should be examined individually, especially because sleep deprivation might impair exercise performance [17,18]. Caffeine intake among athletes became a popular trend. Its inclusion in combination with other ingredients claimed to improve exercise performance and made it a staple ingredient in the sport industry. The timing of caffeine intake- whether before, during, or at the end of the event- does not alter its beneficial effects on exercise performance [9,19]. This study aims to investigate the effect of caffeine intake during normal life situations (pre-, post, or during a meal) on energy expenditure, substrate use, and muscle efficiency in healthy male individuals.

Materials and Methods

Research Design and Methods

Nine healthy physically active males were initially recruited for the study. One participant dropped out because of the long test period duration. The remaining eight (n = 8) took part in a single-blinded randomized crossover study. The participants were between 20 and 31 years old (mean 23.3±4.3). They had a mean height of 181.3± 5.0 cm, mean weight of 76.1±9.3 kg, and mean body mass index (BMI) of 23.1±2.3 kg/m2. Participants were included if they were healthy males, covered by health insurance, and not taking supplements or medicine that might affect their metabolic rate. During the preliminary visit, participants were informed about the experiment protocol, signed a written consent form, and filled out a lifestyle questionnaire. Their anthropometric and body composition measurements were taken. The study protocol was approved by the Institutional Review Board (IRB) at the American University of Beirut. This trial was registered at clinicaltrials.gov under the number of NCT04106752.

Experimental Trials

On the day of testing, participants came to the laboratory at 08:00 following a 12-hour overnight fast. All participants were requested to avoid physical activity, caffeine, and dietary supplements for the 24 hours before testing. Energy expenditure was measured by indirect calorimetry (Cosmed Quark CPET, Cosmed srl, Rome, Italy). Participants briefly sat in a comfortable seat for calorimetric monitoring using a high-end Hans Rudolph facemask (FM) that was conducted until stabilization of the energy expenditure (EE) for at least 15 minutes after half an hour of rest [20]. During this period, participants were instructed to relax and avoid movements. Heart rate (HR) was monitored using a Cosmed heart rate belt. Participants then completed the following protocols on five separate days, separated by at least 48 hours, in a randomized order. The protocol numbers were placed inside a bowl on small papers and chosen randomly.

The five protocols are displayed in Figure 1. In Protocol 1 (M2C), participants were fed a standardized meal of two slices of toast bread, organic peanut butter, and jam (providing 440 kcal, 51% carbohydrates, 13% protein, and 36% fat). A small meal was chosen because it reflects what older adults often eat on a regular basis [21,22]. Two hours later, the participant ingested a caffeinated drink [3 mg per kg of body weight of caffeine powder (AnalaR, BDH laboratories, Poole, UK) dissolved in water]. After 1 hour, resting EE was measured using FM for 15 minutes while the participant was seated on a comfortable seat, and then for 5 minutes while the participant was seated on a cycle ergometer (Cosmed E100 P). Ninety minutes after ingestion, a cycling exercise was performed. Participants were asked to pedal at 60 revolutions per minute (rpm) for 5 minutes per load at 20W, 35W, 50W, 65W, 80 W respectively. During cycling, EE was measured using the FM, HR was monitored, and the rating of perceived exertion (RPE) was recorded (Borg- RPE 6 -20 scale) [23] in the last minute of every load cycle (Figure 1A). In Protocol 2 (C2M), Caffeine was given to the participant. Two hours later, the standardized meal was given, followed by the same exercise protocol mentioned above at ninety minutes after ingestion (Figure 1A & 1B displays Protocols 3, 4 and 5, where the participant was given Caffeine (C), a standardized meal (M) and a combination of both (M+C), respectively. Ninety minutes later, the same exercise protocol mentioned above was applied.

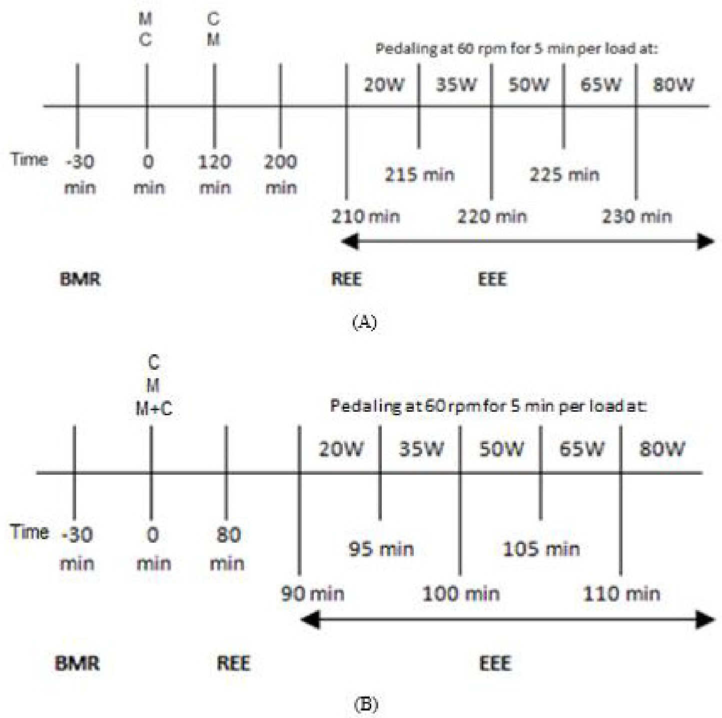

Figure 1: *The Five Protocols (M2C, C2M, C, M, M+C) Adopted in the Study. Measurements: Basal Metabolic Rate (BMR); Resting Energy Expenditure (REE); Exercise Energy Expenditure (EEE).*

Statistical Analysis

All values are reported as means±SE, except for participant's characteristics (age, height, weight, BMI). Statistical analysis was performed by Paired t tests (M2C vs C2M) and repeated measures ANOVA with time and treatment (caffeine and/or meal treatment - C vs M vs M+C) followed by Tukey's post-hoc tests. Analysis of participant factors were conducted using statistical software (GraphPad Prism). The level of statistical significance is set as $P < 0.05$. Sample size calculations were done using the online sample size calculator (http://hedwig.mgh.harvard.edu/sample_size/js/js_parallel_quant.html). A total number of 8 is required to obtain a power of approximately 80% ($\alpha = 0.05$) for a 2.4 difference in means and a 0.8 difference in SD of muscular efficiency [24].

Results

Effect of Meal Timing and Caffeine Intake on Energy Expenditure and Delta efficiency

The results of varying meal and caffeine timing according to protocol 1-5 on EE are presented in Figure 2A and B. Mean changes in EE across workloads reached significance for sub-group 2 (C vs M+C and M+C vs M, 3.971 ± 0.653 vs 4.205 ± 0.637; $p < 0.01$ and 4.205 ± 0.637 vs 3.938 ± 0.617; $p < 0.01$) but not for sub-group 1 (M2C vs C2M, 4.187 ± 0.637 vs 4.201 ± 0.589 kcal/min, $p > 0.05$). Delta efficiency (DE) values (Figure 3A and 3B) were significantly different in sub-group 1 (C2M vs M2C, 25.5±1.2 vs 23.6±0.8; $p < 0.05$) but not in sub-group 2 (M+C vs C vs M, 24.9±1.7 vs 23.2±0.8 vs 23.2±0.6; $p > 0.05$).

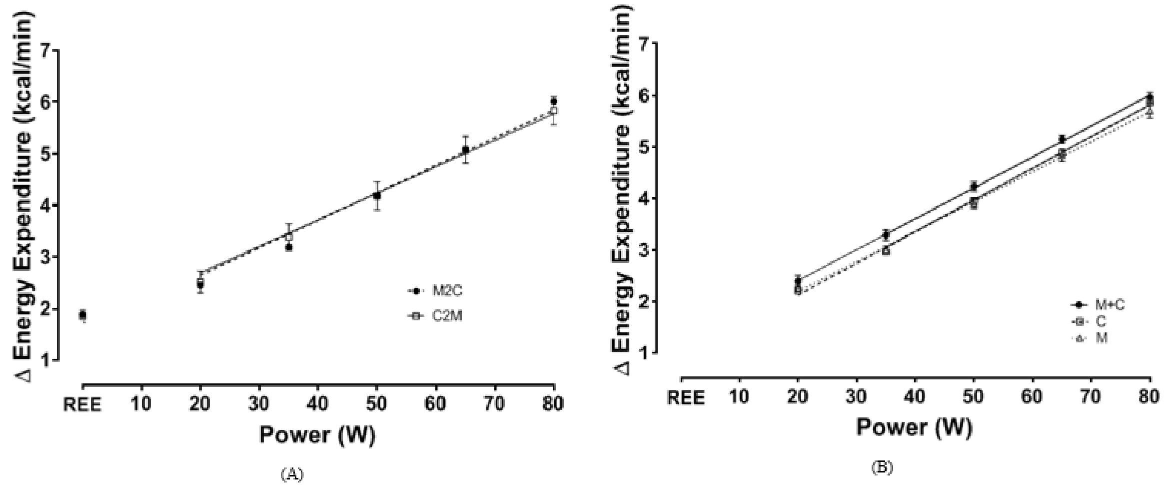

Figure 2: The Effect of Various Protocols on Energy Expenditure.

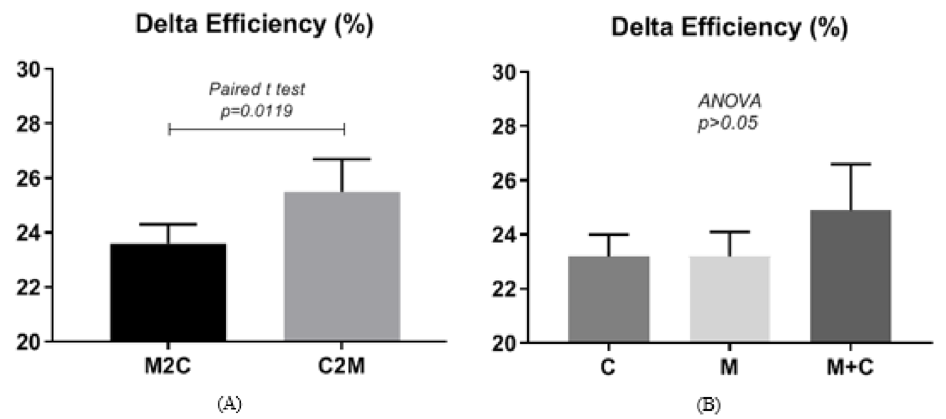

Figure 3: The Effect of Various Protocols on Delta Efficiency.

Effect of Meal Timing and Caffeine Intake on Respiratory Quotient

Changes in RQ (ΔRQ) values for the two sub-groups are compared in Figure 4A and $B. ΔRQ significantly increased across the different loads during C2M vs M2C with a mean difference of 0.012 ± 0.004 ($p < 0.01$), and 0.062 ± 0.008 ($p < 0.001$), -0.024 ± 0.009 ($p < 0.01$), -0.038 ± 0.015 ($p < 0.05$) during M vs C, M+C vs C, and M+C vs M respectively.

Effect of Meal Timing and Caffeine Intake on Perception of Effort

Within the range of cycling (20-80 W), the perceived exertion evaluated on the Borg scale ranged from "extremely light" to "somewhat hard," as depicted in Figure 5 (panel A and B). Perceived exertion ratings did not reach statistical significance between M2C and C2M ($p > 0.05$). However, values were higher in M vs C ($p = 0.0717$) and in M+C vs C ($p = 0.0529$) when tested separately.

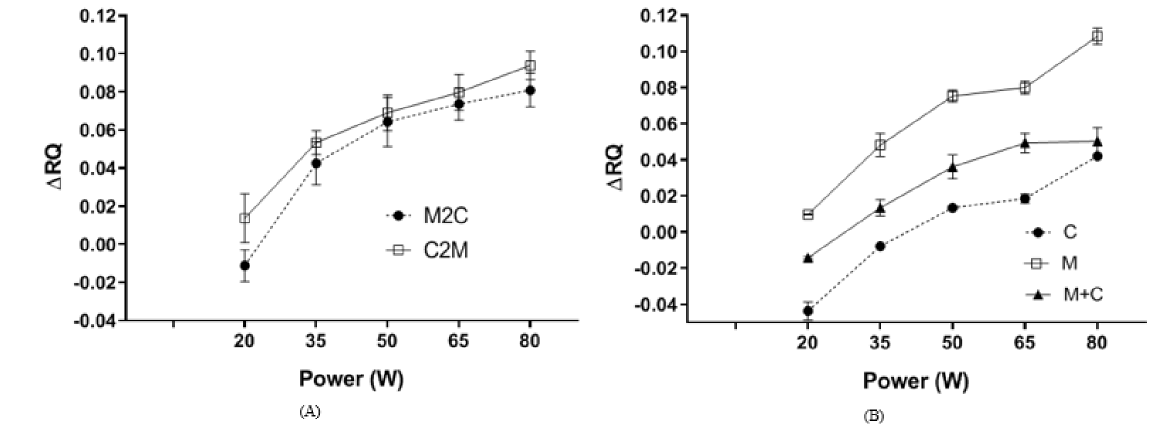

Figure 4: The Effect of Various Protocols on Respiratory Quotient

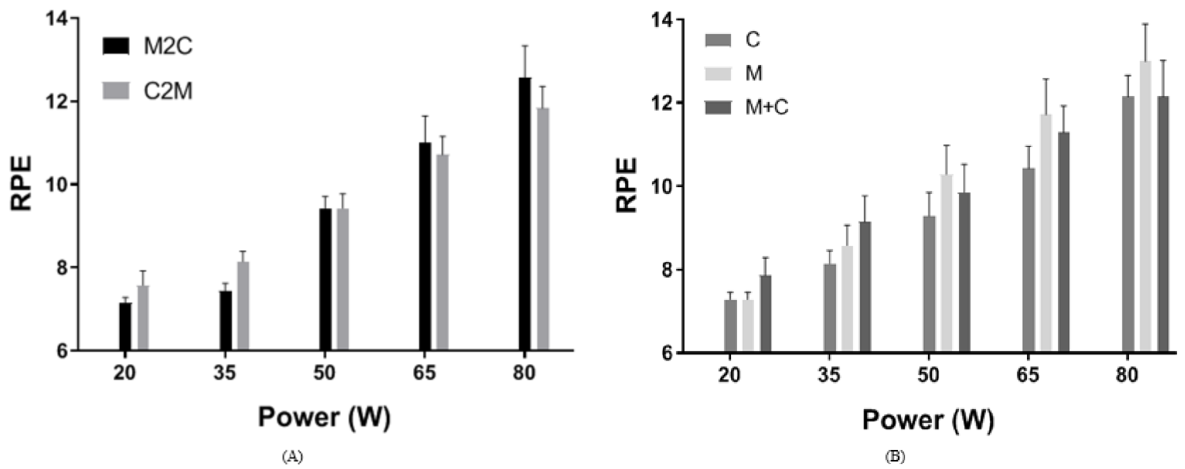

Figure 5: The Effect of Various Protocols on Perception of Effort.

Discussion

Most research studies have underestimated light to moderate intensity exercise in comparison to vigorous physical activities. Light intensity exercise does not go beyond three times the resting metabolic rate, 3 METs, and moderate intensity exercise ranged between 3.0-5.9 METs [25]. Our participants reached 5.2 METs at 80W, which is still considered in the range of moderate intensity activity. Few studies have utilized protocols that involve cycling at light intensities, and fewer still have calculated DE. It is not yet well known whether the timing of caffeine consumption influences EE, exercise efficiency, and substrate oxidation at these intensities energetically comparable with those of daily life [26].

Controversies do exist regarding caffeine and glycogen sparing [27]. Caffeine stimulates the sympathetic nervous system and causes the release of catecholamines, which in turn activates the breakdown of glycogen [28,29]. However, other studies have reported opposite results; caffeine apparently inhibits skeletal muscle glycogen phosphorylase and thus glycogenolysis [30]. It has been demonstrated that a dose-response between caffeine intake and exercise performance exists but plateaus at 3 mg per kg of body weight. A switch in substrate oxidation favoring fat usage might be the reason for increased performance, according to several studies [31-33]. However, more recent studies demonstrated no effect at all [34,35]. Jarrar and Obeid [3] investigated the timing of caffeine ingestion on postprandial metabolism in rats. Insulin sensitivity decreased following caffeine ingestion, and a retarded postprandial triglyceride absorption arose. Furthermore, they found a biphasic role of caffeine on glycogen synthesis, which was accelerated in the first 60 minutes and inhibited later. Acute caffeine supplementation in the range of 2-6 mg per kilogram of body weight enhanced exercise performance by 2-16% in different types of sports (team, racquet, endurance, and high intensity sports) [4,18]. Greater motor recruitment patterns in addition to altering neurotransmitter functions explain this performance enhancement [9].

In this study, caffeine increased the change of mean energy expenditure by 6.8% and 5.9% in M+C vs M and C. These findings are compatible with those of Acheson et al. who demonstrated an increase in the metabolic rate after consuming a meal with caffeine. On the other hand, differences in DE (3.5%) were only seen in M2C vs C2M, which favors C2M [1]. The addition of caffeine with a meal regardless of timing induced a lower perception of effort (- 7%) in comparison to having a meal only during the exercise test. This effect has been demonstrated elsewhere [9, 17, 36] and was a result of caffeine binding to adenosine receptors and overriding fatigue signals during the test [4, 9]. In fact, trained individuals respond better than untrained ones due to an increased adenosine A2a receptor density. However, this speculation remains to be verified since it was not in agreement with other studies [4,37]. According to our results, substrate oxidation differed between the different protocols, and higher values of RQ were found when a meal was consumed. Caffeine attenuated this increase but failed to explain the increase in exercise efficiency. Different studies have yielded contradictory findings. Some could not explain the increase in exercise performance by a shift in substrate oxidation favoring fat usage [38]. Other studies found positive results [1] or individual variability, especially during the first 15 minutes of exercise [39]. Limitations related to this study include the small sample size (n=8). In the future, research protocols should be tailored to be less time consuming to accommodate the busy participants' schedule. In addition, this study was conducted exclusively on males; it would be interesting to see if females respond differently.

Conclusion

In conclusion, meal timing and caffeine intake modestly manipulate changes in energy expenditure and have a greater effect on muscular efficiency. The effect of caffeine timing on other metabolic and cardiovascular parameters requires further exploration. Research is needed to clarify the underlying genetic and inter-individual variations and draw comparisons between different populations and genders. A greater understanding of these factors will assist in the provision of personalized sports nutrition recommendations in the future.

Author Contributions

E-J.F. and O.O, conceptualization, and study design; D.W., acquisition of data; E-J.F. and O.O., analysis and interpretation of data. E-J.F., D.W., and C.B., drafting of manuscript; E-J.F., critical revision.

Acknowledgements

We thank all the participants for their valuable time and the University Research Board (URB) for funding this study (Award# 103366; Project# 23878). In addition, we would like to thank Dr. Samer Kharroubi for his advice on data analysis.

Disclosure statement

No conflict of interest was reported by the authors.

Orcid

Elie Jacques Fares https://orcid.org/0000-0001-6506-9867

Omar Obeid https://orcid.org/0000-0002-7554-1296

References

1. Acheson KJ, B Zahorska M, P Pittet, K Anantharaman, E Jéquier, et al. (1980) affeine and coffee: their influence on metabolic rate and substrate utilization in normal weight and obese individuals. The American journal of clinical nutrition 33(5): 989-997.
2. Grosso G, Justyna G, Fabio G, Edward LG (2017) Coffee, Caffeine, and Health Outcomes: An Umbrella Review. Annual Review of Nutrition 37(1): 131-156.
3. Jarrar SF, OA Obeid (2014) Timing of caffeine ingestion alters postprandial metabolism in rats. Nutrition 30(1): 107-111.
4. Grgic J, Ivana Grgic, Craig P, Brad JS, David JB, et al. (2020) Wake up and smell the coffee: caffeine supplementation and exercise performance-an umbrella review of 21 published meta-analyses. British journal of sports medicine 54(11): 681-688.
5. Jones G (2008) Caffeine and other sympathomimetic stimulants: modes of action and effects on sports performance. Essays in biochemistry 44: 109-124.
6. Graham TE (2001) Caffeine, coffee, and ephedrine: impact on exercise performance and metabolism. Canadian Journal of Applied Physiology 26(S1): S103-S119.
7. Graham TE, JW Rush, MH v Soeren, (1994) Caffeine and exercise: metabolism and performance. Canadian Journal of Applied Physiology 19(2): 111-138.
8. Bridge CA, MA Jones (2006) The effect of caffeine ingestion on 8 km run performance in a field setting. J Sports Sci 24(4): 433-439.
9. Cox GR, B Desbrow, Paul GM, Megan EA, Clinton RB, et al. (2002) Effect of different protocols of caffeine intake on metabolism and endurance performance. Journal of Applied Physiology 93(3): 990-999.
10. Baltazar Martins JG, Diego Brito S, Millán A, Jozo G, Juan DC, et al. (2020) Infographic. The road to the ergogenic effect of caffeine on exercise performance. British journal of sports medicine 54(10): 618-619.
11. Graham T, L Spriet (1995) Metabolic, catecholamine, and exercise performance responses to various doses of caffeine. Journal of applied physiology 78(3): 867-874.
12. Pickering C, John Kiely (2018) Are the Current Guidelines on Caffeine Use in Sport Optimal for Everyone? Inter-individual Variation in Caffeine Ergogenicity, and a Move Towards Personalised Sports Nutrition. Sports medicine (Auckland) 48(1): 7-16.
13. Pickering C, J Kiely (2019) What Should We Do About Habitual Caffeine Use in Athletes? Sports medicine (Auckland) 49(6): 833-842.
14. Southward K, Kay Rutherfurd M, Claire B, Ajmol Ali (2018) The Role of Genetics in Moderating the Inter-Individual Differences in the Ergogenicity of Caffeine. Nutrients 10(10): 1352.

15. Guest N, Paul Corey, Jason Vescovi, Ahmed El S (2018) Caffeine, CYP1A2 Genotype, and Endurance Performance in Athletes. Medicine and science in sports and exercise 50(8): 1570-1578.
16. Bell DG, TM Mc Lellan (2002) Exercise endurance 1, 3, and 6 h after caffeine ingestion in caffeine users and nonusers. Journal of Applied Physiology 93(4): 1227-1234.
17. Pickering C, J Grgic (2019) Caffeine and Exercise: What Next? Sports Med 49(7): 1007-1030.
18. Burke LM (2008) Caffeine and sports performance. Applied Physiology, Nutrition, and Metabolism 33(6): 1319-1334.
19. Kovacs EM, JH Stegen, F Brouns (1998) Effect of caffeinated drinks on substrate metabolism, caffeine excretion, and performance. Journal of Applied physiology 85(2): 709-715.
20. JLM Chan, D Sarafian, JP Montani, Y Schutz, AG Dulloo, et al. (2014) Sitting comfortably versus lying down: Is there really a difference in energy expenditure? Clinical Nutrition 33(1): 175-178.
21. Julie LLocher, Caroline OR, David LR, Christine SR, Kathryn LB, et al. (2005) The effect of the presence of others on caloric intake in homebound older adults. J Gerontol a Biol Sci Med Sci 60(11): 1475-1478.
22. Bastien G, Erik KG, Gayathri Y, Abdul GD, Jean PM, et al. (2015) Postprandial hypotension in older adults: Can it be prevented by drinking water before the meal? Clin Nutr 34(5): 885-891.
23. Borg GA (1982) Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14(5): 377-381.
24. Chavarren J, JA Calbet (1999) Cycling efficiency and pedalling frequency in road cyclists. Eur J Appl Physiol Occup Physiol 80(6): 555-563.
25. Nelson ME, WJ Rejeski, SN Blair, PW Duncan, JO Judge, et al. (2007) Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. Med Sci Sports Exerc 39(8): 1435-1445.
26. Fares EJ, Laurie I, Cathriona R M, Jennifer LMC, JP Montani, et al. (2017) Reliability of low-power cycling efficiency in energy expenditure phenotyping of inactive men and women. Physiological reports5(9): e13233.
27. Loureiro LMR, CEG Reis, THM da Costa (2018) Effects of Coffee Components on Muscle Glycogen Recovery: A Systematic Review. Int J Sport Nutr Exerc Metab 28(3): 284-293.
28. Belza A, E Frandsen, J Kondrup (2007) Body fat loss achieved by stimulation of thermogenesis by a combination of bioactive food ingredients: a placebo-controlled, double-blind 8-week intervention in obese subjects. Int J Obes (Lond) 31(1): 121-130.
29. Konig M, S Bulik, HG Holzhutter (2012) Quantifying the contribution of the liver to glucose homeostasis: a detailed kinetic model of human hepatic glucose metabolism. PLoS Comput Biol 8(6): e1002577.
30. Leão MHMR (2003) Glycogen. Encyclopedia of Food Sciences and Nutrition (Second Edition): 8.
31. EDD Costill, and PV Handel (1980) Effects of caffeine ingestion on utilization of muscle glycogen and lipid during leg ergometer cycling. International Journal of Sports Medicine 1(02): 86-90.
32. Erickson MA, RJ Schwarzkopf, RD McKenzie (1987) Effects of caffeine, fructose, and glucose ingestion on muscle glycogen utilization during exercise. Med Sci Sports Exerc 19(6): 579-583.
33. LL Spriet, DA MacLean, DJ Dyck, E Hultman, G Cederblad, et al. (1992) Caffeine ingestion and muscle metabolism during prolonged exercise in humans. Am J Physiol, 262(6 Pt 1): 891-898.
34. TE Graham, JW Helge, DA Mac Lean, BKiens, E A Richter, et al. (2000) Caffeine ingestion does not alter carbohydrate or fat metabolism in human skeletal muscle during exercise. The Journal of Physiology 529(3): 837-847.
35. Roy B, M Bosman, M Tarnopolsky (2001) an acute oral dose of caffeine does not alter glucose kinetics during prolonged dynamic exercise in trained endurance athletes. European journal of applied physiology 85(3-4): 280-286.
36. Mc Lellan TM, JA Caldwell, HR Lieberman (2016) A review of caffeine's effects on cognitive, physical, and occupational performance. Neurosci Biobehav Rev 71: 294-312.
37. Brooks JH, K Wyld, BC Chrismas (2015) Acute effects of caffeine on strength performance in trained and untrained individuals.
38. JL Ivy, DL Costill, WJ Fink, RW Lower (1979) Influence of caffeine and carbohydrate feedings on endurance performance. Med Sci Sports 11(1): 6-11.
39. A Chesley, RA Howlett, GJ Heigenhauser, E Hultman, LL Spriet (1998) Regulation of muscle glycogenolytic flux during intense aerobic exercise after caffeine ingestion. Am J Physiol 275(2): 596-603.