

**Review Article****The Effect of Caffeine on Health and Exercise Performance with a Cold Brew Coffee Approach: A Scoping Review**Hoseyn Fatolahi^{*1}, Alireza Farahmand², Shabnam Rezakhani³

1- Department of Physical Education, Pardis Branch, Islamic Azad University, Pardis, Iran

2- Department of Physical Education, Central Tehran Branch, Islamic Azad University, Tehran, Iran

3- Faculty of Nutrition and Food Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran

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ABSTRACT

Based on the effects of coffee and caffeine, in particular, a review study is needed to investigate associations between the caffeine consumption and its health-linked effects. Furthermore, effects of coffee on sport performance have not fully been elucidated. Based on the increased popularity of the cold-brew coffee, this study has provided a comprehensive overview of the effects of cold-brew coffee on health and exercise performance. Databases (PubMed, Science Direct and Google Scholar) were searched for articles on human models. Totally, 2805 articles were identified from 2000 to 2020. Keywords included coffee, caffeine, cold brew, exercise, training and sports performance. Studies involving caffeine-suppressing drugs and animal studies and cases with physical limitations were excluded and thus 84 articles were identified. Results showed that consumption of 3 to 4 cups of coffee (300–400 mg/day) was associated with decreased risk factors of cancers, cardiovascular diseases, diabetes and Alzheimer disease. It is noteworthy that caffeine intake in specific groups, particularly in women, needs special consideration. However, health benefits of the cold-brew coffee seem to be greater due to the drink low acidity and high antioxidant activity. In this study, the most important factor included decreases in chlorogenic acid. Moreover, consumption of cold-brew coffee in warm weather prevented hyperthermia. In fact, 3–9 mg/kg of caffeine improved physical performance in resistance and endurance exercises. Caffeine consumption could increase lipid oxidation in aerobic exercises as well as stimulate sympathetic nerves in anaerobic exercises. However, investigation of the acute and chronic effects of consuming coffee in various contexts to achieve integrated results needs further investigations.

Keywords: Coffee, Caffeine, Health, Cold brew, Sports performance**Introduction**

Coffee is the main source of caffeine and is widely consumed around the world. (1). By population, Brazilians rank the largest coffee consumers in world, with 1.32 cups of coffee daily (2). Consumption of coffee in Iran is nearly 1,000 tons/year, with each Iranian drinks 2–3 g/day (0.028 cups/day) of coffee on average (3, 4). By increasing interests in roles of coffee in public health, investigation of patterns of population consumption seems further important. Various studies have been carried out on effects of coffee on health (5). Roasted coffee contains numerous bioactive compounds with anti-inflammatory and anti-cancer properties (6). Researchers have reported that coffee consumption decreases mortality (17%), cardiovascular diseases (17%) (7) and risk of cancers (18%) (8). With the exception of pregnancy, where high consumption of

coffee is associated with low birth weight, preterm birth and decreased chance of pregnancy, consumption of three to four (or more) cups of coffee daily decreases risk of several specific cancers and improves neurological, metabolic and liver cell functions (9). Results of the studies have revealed that despite inverse non-linear relationships between the coffee consumption and the hypertension, normal coffee consumption is not directly linked to hypertension (10, 11). In addition, consumption of energy drinks, including coffee, in athletes and non-athletes is used as a supplement to improve performance (12). Recent studies have shown that coffee consumption includes verified effects on signal pathways of the sport performance (13, 14) and that caffeine is known as an ergogenic aid (15). However, debates on coffee consumption volume and its effects

***Address for correspondence:** Hoseyn Fatolahi, Department of Physical Education, Pardis Branch, Islamic Azad University, Pardis, Iran
E-mail address: hoseyn.fatolahi@pardisiau.ac.ir

on various exercise performances are still in progress (16, 17). Therefore, this review was carried out to better understand how to consume coffee or caffeine and how to prepare them to increase athletic performance and health. Studies have suggested various specific prescriptions based on the participant athletic or physical condition and the study method. For example, caffeine intake has been studied with other energy-producing factors; however, it has been reported that caffeine is the most important energy-enhancing factor (18).

It has been shown that quantitative and qualitative characteristics of the coffee are affected by several factors, including coffee variety, roasting method, processing method, temperature, packaging and preparation (19, 20). Due to the aroma, taste, complex characteristics and diverse needs of coffee consumers, various studies have been carried out on analysis of the processing devices (21) as well as coffee functional properties (22) and sensory aspects (23). Consumption of cold-brew coffees (or ready-to-drink, RTD) have become popular, especially in markets (24). A 460% increase in consumption of cold-brew coffee in the United States between 2015 and 2017 has been reported (25). Investments in rapidly growing markets such as cold-brew coffees have been reported for several reasons, including colder slower brewing processes alter flavor, aroma and bioactive compounds (3). However, health-linked benefits of the cold-brew coffee consumption are still controversial. Hot coffee consumption may include further exothermic effects in hot seasons and it is important to find an appropriate alternative for people, who are addicted to coffee. A systematic review on the relevant published articles can result in classification of the scientific recommendations in health and exercise physiology. It is noteworthy that studies on caffeine-based sports drinks have focused on competition times or exercise and only limited studies have assessed these effects on daily coffee consumption. Therefore, the aim of this study was to summarize current knowledge of caffeine effects on human health and exercise performance using cold-brew coffee approach. Results from this review study

hopefully provide directions for future studies and help athletes better use ergogenic effects of caffeine.

Methodology

In the present review study, three electronic databases of PubMed, Science Direct and Google Scholar were searched to find eligible studies published from January 2000 to January 2020. Keywords included coffee, caffeine, cold brew, exercise, training and sports performance, covering articles of human models. Totally, 2805 articles were identified. Inclusion criteria included empirical studies assessing effects of caffeine consumption as an independent variable and its effects on health and sport performance. Furthermore, meta-analyses were used to provide general findings. Studies involving caffeine-suppressing drugs, animal studies and cases with physical limitations or specific dietary plans were excluded. After a careful review and elimination of duplicates using Endnote Software v.9 (Microsoft, USA), 84 quality articles were identified and used in the present study. From each eligible study, abstracts, results, study designs, coffee types, studies numbers, statistical samples, consumed coffee volumes, dose responses or cup number and effect sizes were extracted (Figure 1).

Methods of making coffee drinks

Coffee preparation is the process of converting coffee beans into drinks, while specific stages of each method vary depending on the type of coffee and raw materials. The process involves four basic steps of roasting, milling, mixing with water (brewing) and separating coffee. All methods of coffee brewing can be divided into four major categories of boiling, pressing, filtering and wetting with differences in adding water (20). Most coffees used in different countries are prepared using different methods of boiling (26). Studies have shown that roasting temperature and size of the mill affect concentration of the soluble compounds. Increased temperature is associated with decreased chlorogenic acid and processable caffeine concentrations (27).

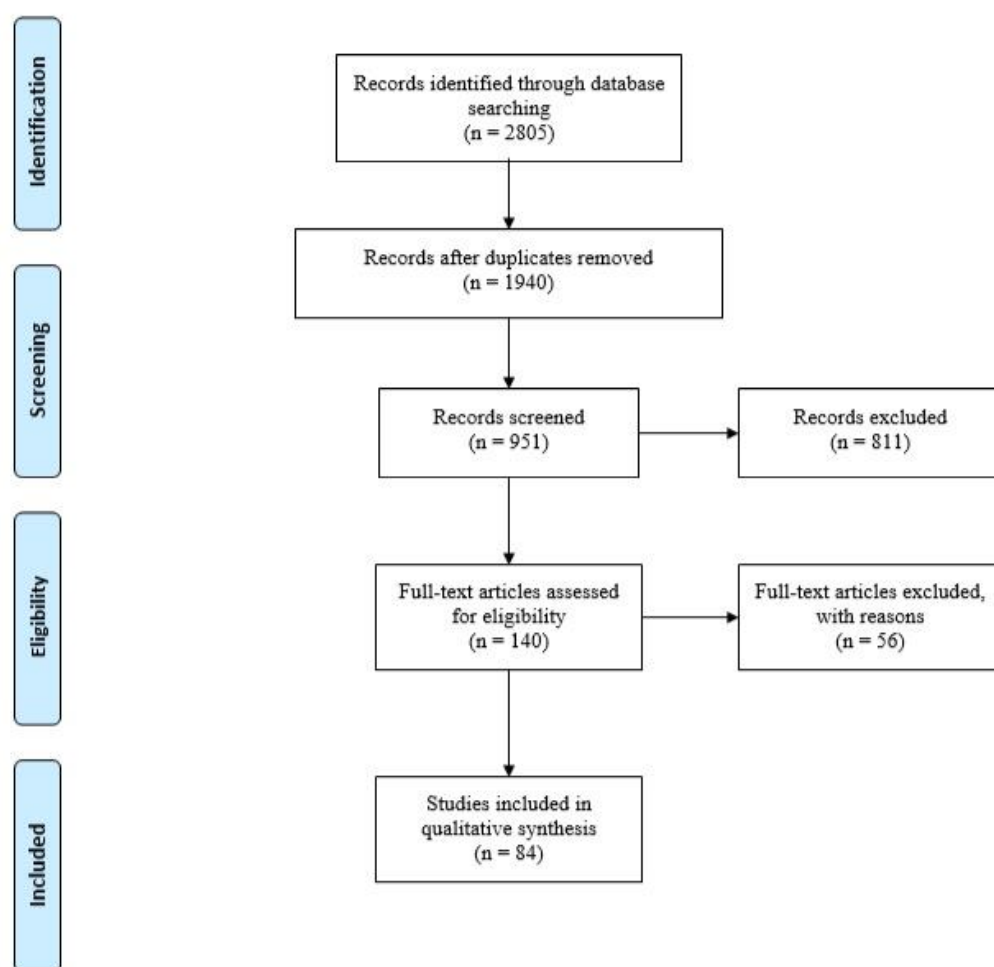


Figure 1. Results of database searching on the base of PRISMA Group

Chlorogenic acid compounds, as active antioxidants, transfer bitterness to coffee and cause health-linked benefits. These bioactive compounds have been used in numerous studies on extended health or risk effects of the coffee beverages (28–30). Researchers have found that caffeine is responsible for the symptoms of gastric irritation following decreases in gastric reflex after consumption of decaffeinated coffees (31). However, recent studies detected no significant relationships between the coffee consumption and four major gastrointestinal disorders of gastric ulcer, duodenal ulcer and esophageal reflux (8, 32). According to Bloomberg report,¹ “cold brew might save the coffee market”. Coffee-shop sales of hot coffee fell 3% in 2016, while

cold-brewed coffee sales grew up nearly 80%, compared to its last year record. Based on the reported controversies on health-linked effects of hot coffee, it is necessary to assess acidity, caffeine and antioxidant activity of other cauliflower coffees (30). Recent studies have highlighted therapeutic roles of the chlorogenic acids on health of the human brain (25). Understanding of the antioxidant effects of various coffee brewing methods is still uncompleted (33).

One of the various coffees based on the filtering methods is cold-brew or cold-press coffee. In this method, the coffee is prepared by long contact (8–24 h) with cold water using special condensation filter and then is added with warm water at 3:1 ratio. Coffee prepared with this method includes a low acidity and a sweeter taste and is often preferred by people with sensitive stomach (20). The cold-brew

¹ - Marvin G Perez. (2017). Cold Brew Might Save the Coffee Market. <https://www.bloomberg.com/news/articles/2017-07-19>

coffee has recently been released by the coffee industries, especially in warm weathers (34). However, a little research has been carried out on these coffee chemical properties, including pH and antioxidant activity as well as health-associated effects. In a late study, all samples of the cold-brew coffees were found to include low concentrations of acidic compounds, compared to that the samples of boiled coffee did. Cold-brew coffee includes several low molecular weight compounds, including carboxylic acids such as citric, malic, quinic, succinic and gluconic acids. However, a strong correlation is found in cold-brew coffee between the total caffeoylquinic acid (CQA) concentration and antioxidant activity (30). Results have shown that concentrations of chlorogenic acid and caffeine are higher in medium roasted coffee than high roasted coffee. Size of the milled coffee did not significantly affect concentrations of chlorogenic acid and caffeine in samples of cold-brew coffees. Concentrations of caffeine in coarse-grained samples of the cold-brew coffee were significantly higher than those other hot coffees. It also seems that concentrations of caffeine and chlorogenic acid in all samples of the cold-brew coffee are balanced within 6–7 h and need no further time (29). According to Angeloni et al. (2019), sensory properties of coffee vary with the processing methods and these sensory properties are affected by the process or temperature (24). In terms of the structural aspects, caffeine and volatile compounds of coffee include no significant relationships with human general tendencies, whereas chlorogenic acid and trigonellin are inversely linked to human sensory intentions (35). These results provide information on cold brew sensory profiles and can be used for coffee productions or marketing strategies. However, at the time of publication, a very little information was available on the chemistry of cold-brew coffee and very low published studies on the health-related effects of cold-brew coffee.

Biochemical, nutritional and health properties of the cold-brew coffee

Caffeine contains methylxanthines, the alkaloids with similar properties to theophylline and theobromine (36). As previously stated, roasted coffee contains several bioactive compounds such as caffeine, chlorogenic acid, diterpenes, cafestol, kahweol and trigonelline (6). Advances in detailed

analysis of the human genome, transcriptome, proteome and metabolome have provided researchers opportunities to achieve further detailed information on the health-linked effects of caffeine. Thus, several genetic variations have been identified associated with daily consumptions of coffee and caffeine (37). Barnung et al. (2018) linked effects of coffee consumption to metabolic, immune and inflammatory signaling pathways based on the results of gene expression analyses (38). Based on the study of biological systems of the body, positive relationships have been reported between daily caffeine intake and improvement of myocardial blood flow (39) as well as decreased symptoms of liver fibrosis (40), depression (41), hearing (42), cognitive parameters (43) and ileus obstruction (44). Researchers have detected that high caffeine intake (> 1000 mg/w) is a risk factor associated with anxiety and depression. However, these effects were sometimes detected at lower doses. The positive effects of caffeine intake are generally seen in consumers with low well-being, mental health problems such as depression and anxiety and self-medications such as energy drinks in short-terms (45). These positive effects are seen only in coffees with caffeine and caffeine-free coffees lack these properties (4). Quitting daily caffeine intake can cause headache, lack of energy and drowsiness (46). Researchers recommend that infants and children refrain consumption of caffeinated drinks to avoid anxiety or nervousness (47). Caffeine can also include major effects on sleep habits. High caffeine intake is associated with decreased eye movement speed in the REM sleep phase. Effects of caffeine on reproductive system need further investigations (48).

Coffee preparation techniques seem to involve antioxidant compounds associated with coffee flavor, taste, digestibility and health (20, 22, 23). Quantities of caffeine in cold-brew coffees increase calorie intakes at rest and thus decrease or maintain body weight. The 13% increase in basal metabolism caused by the consumption of cold-brew coffee doubles the circulation of lipids, with 24% being oxidized and 76% recycled, although no integrated reviews are available (49). Studies have shown that caffeine intake changes mood, especially in sleep-deprived people. Cold-brew coffees can improve mood and brain function while decreasing risk of depression (50). By every cup of coffee consumed per day, risk of depression is decreased by nearly 8%.

Furthermore, coffee boosts mood and brain function in elderly people by 17% (51). Phenolic compounds, magnesium, trigonelline and quinoids decrease risk of heart diseases by up to 15%. These elements increase insulin sensitivity, stabilize blood sugar and lower blood pressure (52). Moreover, caffeine acts as an antioxidant and anti-inflammatory agent with chlorogenic acid and diterpenes (53). Evidence suggests that people with uncontrolled hypertension should refrain from regular caffeine intake daily. However, effects of consumption of more than 600 mg (six cups) of caffeine per day have not been studied in healthy people (54). A review of studies shows that coffee consumption includes significant inverse relationships with type II diabetes. In middle-aged people, regular drinking of 4–6 cups of cold-brew coffee per day may decrease risk of type 2 diabetes by up to 30% due to the presence of chlorogenic acid (55, 56).

Consumption of coffee regulates intestinal peptides that slow digestion process and keep blood sugar constant (57). However, results of a study in Finland with 14 years of case follow-up showed that drinking six cups of boiled coffee daily was not associated with type II diabetes (55). In addition to increasing mental concentration and mood, drinking cold-brew coffee protects brain function from age-linked diseases (58). An observational study showed that people who daily consumed 3–5 cups of coffee during their middle age were 65% less likely to have dementia and Alzheimer's disease at older ages (59). Another study stated that coffee drinkers were five times less likely to develop Parkinson's disease (60). Several compounds in caffeinated coffee (phenolic, norharman and Harman) protect against Alzheimer's and Parkinson's diseases (61), while decaffeinated coffee does not seem to include similar protective benefits (62). Many people avoid coffees because of stimulating acid reflux and causing stomach upset and irritation. Generally, acidity of hot coffee and cobalt coffee are in ranges of 5–6; however, studies have shown that cobalt coffee is less acidic (29, 30). Another reason that the latter drink may be less irritating is linked to its crude polysaccharide contents. These carbohydrates, or chains of sugar molecules, enhance digestive immunity. Cold-brew coffees also contain compounds that protect the stomach from acidity (63). A longitudinal study of men and women aging 50 to 71 years demonstrated

that over-consumption of this coffee decreased risk of heart diseases, respiratory diseases, strokes, injuries, diabetes and infections (64). A possible reason for this association includes the presence of potent antioxidants such as polyphenols, hydroxycinnamates and chlorogenic acid (65). Although studies have shown that hot coffees contain more antioxidants than that cold-brew coffees do, strong antioxidants such as caffeoylquinic acid (CQA) in cold-brew coffees are not found in hot coffees (66).

Caffeine as an ergogenic aid in exercise performance

High caffeine use by athletes has urged researchers to focus on the optimal guidelines for caffeine effects on exercise and exercise performance (67). Caffeine is widely used during competitions and exercises because of its ergogenic properties, including central nervous system (CNS) stimulation and muscle strengthening (68, 69). Caffeine improves numerous cognitive and behavioral mechanisms, including sport performances, anaerobic and aerobic powers, cognitive functions, alertness, energy levels and fatigues (70). Ergogenic effects of caffeine are commonly seen at doses of 3–9 mg/kg (71). However, quality of exercise, fitness or athletic recovery may be diminished by the side effects of caffeine such as anxiety and sleep disorders (72). Caffeine intake can increase blood pressure, heart rate and catecholamine production and increase risk of the heart attack, especially during racing (73). Effects of caffeine are likely to be moderated by various interpersonal factors, including gender, age, drug use, circadian factors, time and volume of consumption, caffeine tolerance threshold, body mass, health status and genetic background (74, 75). These affect ergogenic responses of caffeine to a wide range of exercise tasks and cognitive skills such as endurance performances (lipid oxidation), weight liftings, reaction times, motivations, beliefs and habits of caffeine intake (76). Researchers from various sports have found that moderate doses of caffeine include a small but significant effect on endurance performance. These also improve overall average power output and timing of the trailer race by 30 min, compared to placebos (14, 77).

Table 1. Result of the included articles, which investigated cold-brew coffees

Authors	Article type/ Population	Methods	Conclusions
<u>Xu</u> et al, 2012 [65]	Research article	Investigate the profiles of antioxidant and DNA-protective activities of chlorogenic acid isomers	Hot coffee contains more antioxidants than cold brew coffee, there are some strong antioxidants in cold brew coffee, such as caffeoylquinic acid (CQA).
<u>Tallis</u> et al, 2013, [50]	Research Article- Older adults (9 females and 3 males)	Caffeine (3 mg/kg body mass) or a placebo. mood state by BRUMS and coincidence anticipation performance by Bassin	Every cup of coffee per day reduced risk of depression by about 8%, boosts mood and brain function by 17%.
<u>Liang</u> and <u>Kitts</u> , 2015 [52]	Review article	Chlorogenic acids in oxidative and inflammatory stress conditions	Mitigating oxidative stress. CGAs exhibit anti-inflammatory activities by modulating a number of important metabolic pathways.
<u>Fuller</u> and <u>Rao</u> , 2017 [33]	Research article/ Coffee samples	Cold and hot methods	3-CGA concentrations and pH were comparable between cold and hot brews. Caffeine concentrations in cold brew coarse grind samples were higher than their hot brew counterparts.
<u>Wierzejska</u> , 2017 [60]	Review article	Analysis of compounds in coffee (Phenolic, norharman and Harman)	Moderate consumption reduce the risk for common neurodegenerative conditions, i.e. Alzheimer's and Parkinson's diseases.
<u>Shin</u> , 2017 [62]	Research article	Chemical characteristics and immune-modulating activity of polysaccharides isolated (CCP-0) from Cold-Brew Coffee	CCP-0 potentially enhance macrophage functions and the intestinal immune system.
<u>Rao</u> and <u>Fuller</u> , 2018 [32]	Research article/ Brazil, Ethiopia, Columbia, Myanmar, Mexico.	Cold brew coffee chemistry was compared to that of hot brew coffee	PH values of the cold and hot brew samples were ranging from 4.85 to 5.13. Concentration of titratable acids and antioxidant activity correlated poorly with total CQA concentration in hot brew coffee.
<u>Artalejo</u> and <u>García</u> , 2018 [51]	Condensed review	Coffee Consumption	Phenolic compounds, magnesium, trigoneline, and quinoids reduce the risk of heart disease by up to 15%, increase insulin sensitivity, stabilize blood sugar, and lower blood pressure
<u>Ross</u> et al, 2018 [57]	Research article/ Three instant coffee extracts and six coffee components [caffeine, chlorogenic acid, quinic acid, caffeic acid, quercetin, and phenylindane]	Inhibition of A β and α -synuclein oligomerization was assessed using ELISA assays	Inhibit fibrillization of A β and tau, and promote α -synuclein oligomerization. Coffee component 6 , is a potent inhibitor of both A β and tau fibrillization, and also inhibits A β oligomerization.
<u>Heo</u> et al, 2019 [34]	Research article	Acceptability and perceived sensory attributes of cold brew coffee by check-all-that-apply (CATA) method	Consumers' liking were not influenced by caffeine contents and volatile compounds, but chlorogenic acid and trigonelline contents were negatively related with sensory data.

Table 2. Results of the included articles; in which, coffee or caffeine was used as an independent variable of health and exercise associated effects

Authors	Article type/ Population	Treatment	independent variable	Conclusions
<u>Kendler</u> et al, 2008 [73]	Research article/ 1796 male	Genes and environment factors from early adolescence through middle adulthood	Level of use of caffeine recorded for every year	Initiation and early patterns of use influenced by social and familial environmental factors while later levels influenced by genetic factors
<u>Foskett</u> et al, 2009 [69]	Research article/ 12 male soccer	6 mg/kg body mass of caffeine or a placebo in a double-blind fashion 60 min before exercise	Two 90-min soccer-specific intermittent running trials with tests of soccer skill (LSPT).	Improve players' passing accuracy and jump performance without any detrimental effects on other performance parameters.
<u>Richards and Smith</u> , 2016 [44]	Review article	Energy Drinks	Mental Health (Stress, Anxiety, and Depression)	Positive associations between energy drink consumption and symptoms of mental health problems.
<u>Poole</u> et al, 2017 [8]	Umbrella review	Coffee consumption	Multiple health outcomes	Generally safe within usual levels of intake, largest risk reduction for various health outcomes at three to four cups a day.
<u>Southward</u> et al, 2018 [14]	Systematic review	Acute caffeine ingestion	Endurance Performance	Small but evident effect in moderate doses (3–6 mg/kg) and improvement in mean power output
<u>Astley</u> et al, 2018 [81]	Research article/ 15 resistance-trained males	2.5 mg/kg body weight of caffeine or a placebo	80% 1RM in the bench press exercise and unilateral knee extension, maximal isometric hand-grip test, standing long jump and repeated sprint ability test	Increase performance only in specific strength tests in resistance trained men.
<u>D'Elia</u> et al, 2019 [9]	Editorial	Caffeine and coffee	Human functioning	The utility of coffee and caffeine to produce a change in human functioning.
<u>Del Coso</u> et al, 2019 [10]	Meta-analysis	Dose-response of coffee	Hypertension	Moderate coffee intake is not associated with risk of HPT, non-linear inverse dose-response relationship between coffee consumption and risk of HPT.
<u>Grgic</u> et al, 2019 [13]	Systematic review	Caffeine supplementation	Exercise performance	Ergogenic effects on muscle endurance, muscle strength, anaerobic power and aerobic endurance. The effect is greater for aerobic exercise.
<u>Grgic</u> et al, 2019 [16]	Review article	Caffeine supplementation	Resistance exercise	Coffee equally ergogenic as caffeine alone. Doses in the range of 3–9 mg/kg to be adequate when administered 60 min pre-exercise.
<u>Shen</u> et al, 2019 [76]	Systematic review and meta-analysis	Caffeine and placebo groups	Duration of endurance athletic time trial events	Effect size of caffeine increases along with the increasing duration of the time trial event.
<u>Salinero</u> et al, 2019 [79]	Systematic review and meta-analysis	Acute ingestion of caffeine	Team sports performance	Increase single and repeated jump height, sprint velocity and reduced the time to complete agility tests. During team sport matches increase running distance, distance covered at sprint velocity and number.
<u>Mielgo</u> et al, 2019 [83]	Systematic review/ men and women	Caffeine supplementation	Sports performance	Similar benefit for aerobic performance and the fatigue index in men and women athletes. Produce more power, total weight lifted and to improve sprint performance was higher in men than women athletes.
<u>Jodra</u> et al, 2020 [84]	Research article/ 8 elite athletes and 10 trained-recreational athletes	Caffeine supplementation (6 mg/kg) or placebo	Wingate test and questionnaires Profiles of Moods States (POMS)	Improve anaerobic performance in both the elite and recreational athletes. The ergogenic effect on several mood dimensions and subjective vitality was greater in the elite athletes.

Normally, caffeine improves endurance performance, adaptation to endurance training and improves health by accelerating the metabolic activities caused by muscle contractions (78, 79). In team exercises, moderate doses of caffeine include positive effects on several aspects of physical functions, including increased single and repeated jump heights, number of steps, running speeds, and decreased agility test times (80). Consumption of caffeinated beverages 60 min before the exercise improves physical performance in strength and exercise specific efforts (16, 81). Assessing effects of caffeine intake on various physical functions of men, only results of specific strength tests such as superior knee extension, bench press and isometric hand strength are affected (82). Analysis of existing studies shows that caffeine intake increases anaerobic power and aerobic endurance (83). However, effects of caffeine in aerobic exercises seem greater than those in anaerobic exercises (13). Furthermore, caffeine consumption includes similar ergogenic benefits in aerobic functions and fatigue indices in men and women. However, these effects are further significant in men in anaerobic functions (84). Recent studies on effects of caffeine on physical performances and mood dimensions of

expert and trained athletes show that caffeine improves anaerobic performances of athletes in both groups, while mood and vitality of expert athletes are more affected by the ergogenic effects of caffeine (17, 85).

Conclusion

In conclusion, results of this review study have shown that daily consumption of three to four cups of coffee with moderate doses of caffeine (300–400 mg) includes positive effects on human well-being and can partially prevent mental and physical disorders. However, benefits of cold-brew coffee seem greater because of its low acidity and high antioxidant activity with no digestive problems. Therefore, further studies are necessary to investigate and compare acute and chronic effects of consumption of various coffee beans. Results have shown that caffeine intake improves physical performance in trainings and exercises such as strength protocols, jumps, endurance tests and specific exercise movements. However, further studies are needed to group specific physical and sport performances to assess health effects of coffees, including cold-brew coffees.

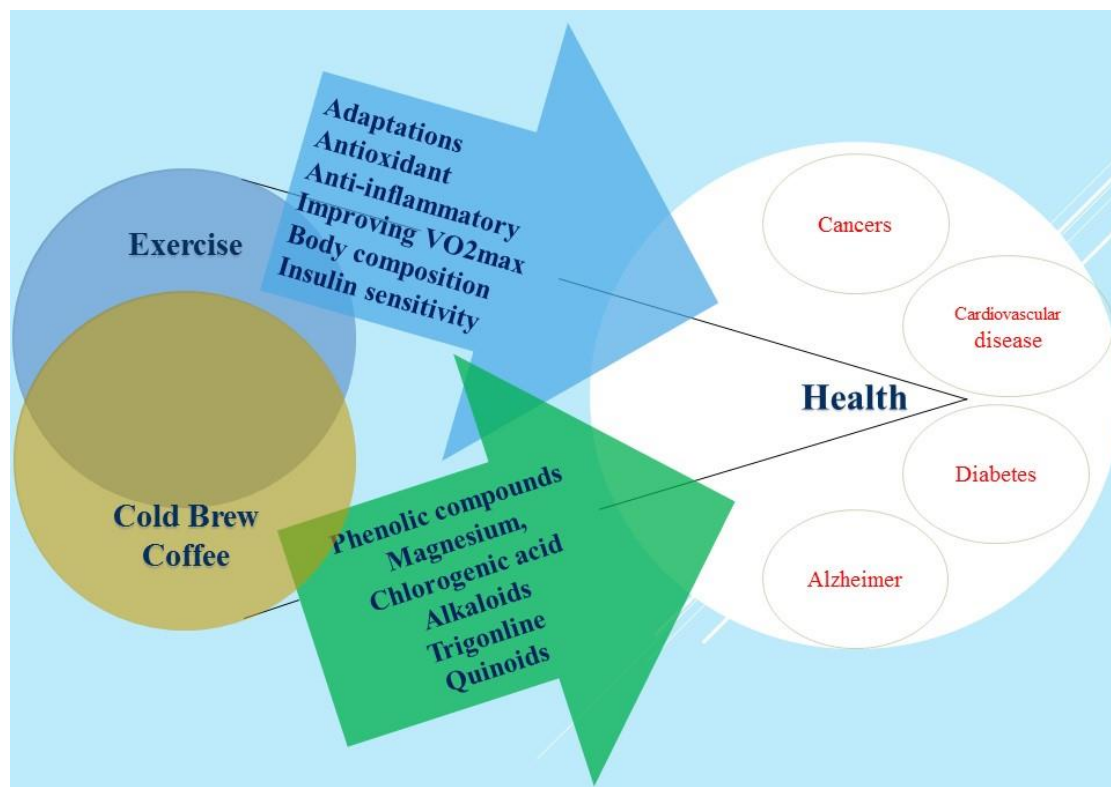


Figure 2. Useful effects of exercise and cold-brew coffee on health

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