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Tea Drinking: A Systematic Review of Randomized Controlled Trials Focusing on Human Cognition, Mental Wellbeing and Brain Function

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Abstract

Tea has been gaining in popularity due to its potential health benefits and the three predominant forms of tea are black, oolong and green tea. Whilst previous reviews have tended to focus on green tea or generic health benefits, the present paper concentrates on the effects of habitual black, oolong and green tea drinking in relation to markers of human cognition, mental wellbeing, and brain function. Emphasis has been placed on these due to growing awareness in this field and the realisation that their deterioration contributes heavily to the global burden of non-communicable diseases. We conducted a systematic search using the PubMed database and selected studies using specific eligibility criteria. Seventy-eight publications were first identified and after exclusions 11 RCTs reviewed comprising of 557 participants. The approach was structured according to the PRISMA statement and the quality of trials graded using the Jadad criterion. The studies reviewed indicated that tea drinking - particularly black tea may benefit aspects of cognition function (attention, mind-wandering and focus), mental wellbeing (stress, mood) and markers of brain function (sensorimotor gating, cerebral blood flow). Some benefits could be seen at relatively low intakes equivalent to just one to two cups daily although benefits cannot be pinpointed to specific tea components - they are most likely to be cumulative. Given the growing body of evidence it seems reasonable to suggest that tea drinking could be disseminated as a way to improve cognitive wellbeing, mood and focus, alongside other health recommendations.

Keywords

Tea, Black, Oolong, Green, Cognition, Mental wellbeing, Brain function, Concentration, Attention and mood

Introduction

After water, tea is the second most commonly consumed beverage globally and more than two-thirds of the world population are tea drinkers [1,2]. Historically tea has been used to 'lift mood', aid concentration and relaxation [3,4]. The three major tea forms include: Black (aerated), oolong (semi-aerated) and green (non-aerated) [2]. It is well established that tea contains thousands of different biological compounds including alkaloids, flavonoids (catechins, thearubigins and theaflavins), amino acids (including L. theanine), vitamins A, C and K, phenolic acids (caffeic, chlorogenic, hydroxycinnamic and gallic acids) along with lipids, proteins, carbohydrates, volatile compounds and fluoride [5]. Green tea, in particular, provides epigallocatechin-3-gallate (EGCG) which has been demonstrated to have anti-inflammatory actions [6]. Oolong tea also provides EGCG which has been linked to reduced diabetes and obesity risk in pharmacological studies [7]. Black tea has been well studied and reported to provide thousands of bioactive components including alkaloids, polyphenols, amino acids, and volatile compounds [8].

A recent umbrella review [9] of 96 meta-analysis publications concluded that drinking just two to three cups of tea daily was associated with a reduced risk of total mortality, cardiac death, coronary artery disease, stroke and type 2 diabetes mellitus. Other beneficial effects were also observed in relation to several cancers, maternal outcomes, skeletal and cognitive outcomes [9]. A growing body of evidence has also been accruing in relation to tea consumption, its constituents and their potential effects on human cognition, mood, including depressive symptoms and brain function [10-15]. For ex-

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ample, a recent review of 21 studies focusing on green tea observed that this influenced memory and attention (cognition), psychopathological symptoms (anxiety) and activation of working memory (brain function)- although the effects could not be attributed to a single tea constituent [10].

Presently mental and neurological diseases represent one of the greatest global burdens of disease [16]. A true estimate of global mental illness is difficult to determine due to under-reporting - possibly by more than a third [17]. However, some data indicates that the global burden of mental illness accounts for 32.4% of years lived with disability (YLDs) and 13.0% of disability-adjusted life-years (DALYs) [17]. In the UK alone 45 million cases of brain disorders have been reported annually, with a corresponding cost of approximately €134 billion euros [18]. Across Europe it has been estimated that over a third of the population (around 38.2% annually) experiences a mental disorder [19]. These figures are, however, likely to be a gross under-estimation of the problem as the "true size" of brain disorders is thought to be substantially larger [19].

As shown in Table 1 and Table 2 an assembly of tea components can influence cognitive/mental wellbeing and brain function via an array of underpinning mechanisms. It is recognised that certain dietary factors - including what we drink can influence multiple brain processes by, for example, regulating neurotransmitter pathways, membrane fluidity and signal-transduction pathways [20]. For example, γ-amino butyric acid (GABA) - an amino acid present in green tea leaves has

Table 1: Tea components and potential mechanisms in relation to cognition, mental wellbeing and brain function.

Tea/Tea component	Potential Mechanisms of action	Source
γ-Aminobutyric acid	GABA may alleviate stress induced by mental tasks -EEG activities including alpha band and beta band brain waves decreased.	Yoto, et al. [21]
Black tea aroma	Inhalation of black tea aroma (Darjeeling and Assam) reduced salivary chromogranin-A levels - a marker of stress.	Yoto, et al. [46]
Epigallocatechingallate/Green TeaExtracts/Catechins	EGCG appears to induce a relaxed and more attentive state after consumption.	Scholey, et al. [26]
	EGCG undergoes microbial degradation in the small and large intestine resulting in the formation of microbial ring-fission metabolites which could reach the brain parenchyma through the blood-brain barrier and induce neuritogenesis.	Pervin, et al. [25]
	Green tea extract activated brain activity in the DLPFC - a key area that mediates working memory processing in the human brain.	Borgwardt, et al. [27]
	Green tea improves psychopathological symptoms (e.g. reduced anxiety), cognition (e.g. benefits in attention/memory) and brain function (e.g. activation of working memory).	Mancini, et al. [10]
	These may prevent age-related neurodegeneration through improved antioxidant defence mechanisms, modulation of neural growth factors, attenuation of neuroinflammatory pathway, and regulation of apoptosis.	Farzaei, et al. [23]; Pervin, et al. [22]
L-theanine& Caffeine	L-theanine significantly increased activity in the alpha frequency band indicating that it relaxes the mind without inducing drowsiness.	Nobre, et al. [31]
	L-theanine at particular dosages (200-400 mg/d) has been found to increase sensorimotor gating in humans and assist in the reduction of anxiety and stress amongst those exposed to stressful conditions.	Ota, et al. [38]; Williams, et al. [30]
	Caffeine may improve performance on demanding long-duration cognitive tasks and self-reported alertness, arousal, and vigor at low doses of 40 mg. L-theanine alone improved self-reported relaxation, tension, and calmness starting at 200 mg.	Dietz & Dekker [29]
	L-theanine and caffeine may be reduce deviation of attention to distractors (i.e. mind wandering) subsequently enhancing attention.	Kahathuduwa, et al. [28]
Polyphenols	Polyphenols including EGCG can inhibit the activation of caspase-3 and modulate mitogen-activated protein kinases known to play an important role in neuronal apoptosis.	Bastianetto, et al. [24]
Other constituents	Bioactives in tea have been found to have anti-amyloid effects in epidemiological research.	Polito, et al. [52]
	Teasaponin along with L-theanine, EGCG, catechins and their metabolites appear to up-regulate the ERK/CREB/BDNF signalling pathway which could collectively reduce depression risk.	Rothenberg, et al. [44]

Key: DLPFC: Dorsolateral prefrontal cortex; EEG: Electroencephalogram; EGCG: Epigallocatechin gallate; GABA: γ-Aminobutyric acid.

Table 2: Further comparisons for black, oolong and green tea.

Black tea	Oolong tea	Green tea
Theaflavins - reduced neural inflammation	Oolong tea ethanol extract - reduced nitric oxide activity	Restored hypothalamic-pituitary-adrenal activity
Theaflavins - suppressed cytokine production	Reduced interleukin activity	Normalization of 5-HT serotonin tone
Caffeine - reduced mind wandering		Reduced glucocorticoids and adrenocorticotrophin hormone
Caffeine - improved attention		γ-aminobutyric acid associated with attenuation of stress.
L-theanine - reduced stress and anxiety		Epigallocatechin-3-gallate - increased alpha and beta brain waves.
Black tea aroma - reduced Chromogranin-A levels after stress tasks		Green tea extract - increased dorsolateral pre-frontal cortex activity
		Green tea aroma - reduced chromogranin-A levels after stress tasks

References from Table 1 and Rothenberg, et al. [44].

been found to attenuate stress induced by mental tasks [21].

Other reviews [22-24] conclude that green tea polyphenols avert age-related neurodegeneration, possibly by modulating inflammatory pathways, levels of oxidative damage and cellular transcription/transduction/apoptotic pathways. Allegedly EGCG undergoes microbial degradation in the small and large intestine forming microbial ring-fission metabolites which pass through the blood-brain barrier inducing neuritogenesis (formation of new neurites) and could have a beneficial role in reducing neurodegenerative diseases [25]. Other work demonstrates that EGCG increases alpha and beta brain waves, and that the brain activity and subsequent feelings of self-rated calmness - indicating that it could induce a more attentive, relaxed state [26]. Borgwardt, et al. (2012) found that green tea extract increased dorsolateral pre-frontal cortex activity which mediates working memory [27].

The amino acid L-theanine and caffeine are also thought to have potential synergistic actions - they are anticipated to reduce mind-wandering and improve attention to targeted stimuli [28,29]. In one systematic review [30] 200-400 mg/day of L-theanine was thought to be a potential means of reducing stress and anxiety in people exposed to stressful conditions. However, it should be considered that the dosages used in these studies are high given that a typical cup of black tea normally provides around 20 mg L-theanine [31]. In a more realistic study - 50 mg L-theanine (equivalent to 2-3 cups of tea) increased alpha brain wave activity, indicating that it improved attention and mental arousal [31]. In other work L-theanine reinforced relaxation by attenuating caffeine-induced stimulation [29].

Taken together, given the growing body of evidence in this field, the present study aimed to conduct a systematic review of randomized controlled trials analysing the effects of tea drinking (black, oolong and green) on broad aspects of cognitive/mental wellbeing and brain function in adults only.

Methods

Search Strategy

The search for relevant studies was conducted using the National Centre for Biotechnology Information (NCBI) search engine (PubMed) to extract relevant publications. For the identification of relevant publications, the search was first limited to: 1) Human Studies; 2) Studies published in English-Language; 3) Randomized Controlled Trials (RCTs); 4) Studies conducted on adults aged 19 + years; 5) Studies published over the last 10 years (January 2010 to April 27th 2020).

The search terms "Tea "combined with "cogn*" and then "mental" and "brain" were used in the PubMed search algorithm. Manual searches of reference lists of previous reviews were also performed, to identify additional relevant articles. The following outcomes were included in the systematic review: Cognitive function/wellbeing, mental health/wellbeing, which included mood, anxiety and depression and brain function.

Study design

The search for human trials used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach [32]. The quality of human trials was deciphered using the validated Jadad criterion [33].

Inclusion/Exclusion criteria

The present systematic review analysed findings from Randomized Controlled Trials studying effects of tea drinking on markers of cognitive and mental wellbeing or brain function. Human trials used black, oolong or green tea within the intervention Studies were restricted to RCTs as these are considered to be the 'gold-standard' for identifying causal relationships as they eradicate bias that tends to be associated with other study designs [34].

Studies that used high-dose capsules, extracts or inhaled infusions that were not representative of daily habitual tea drinking patterns were excluded. For example, it has been previously reported that one cup of black tea provides ap-

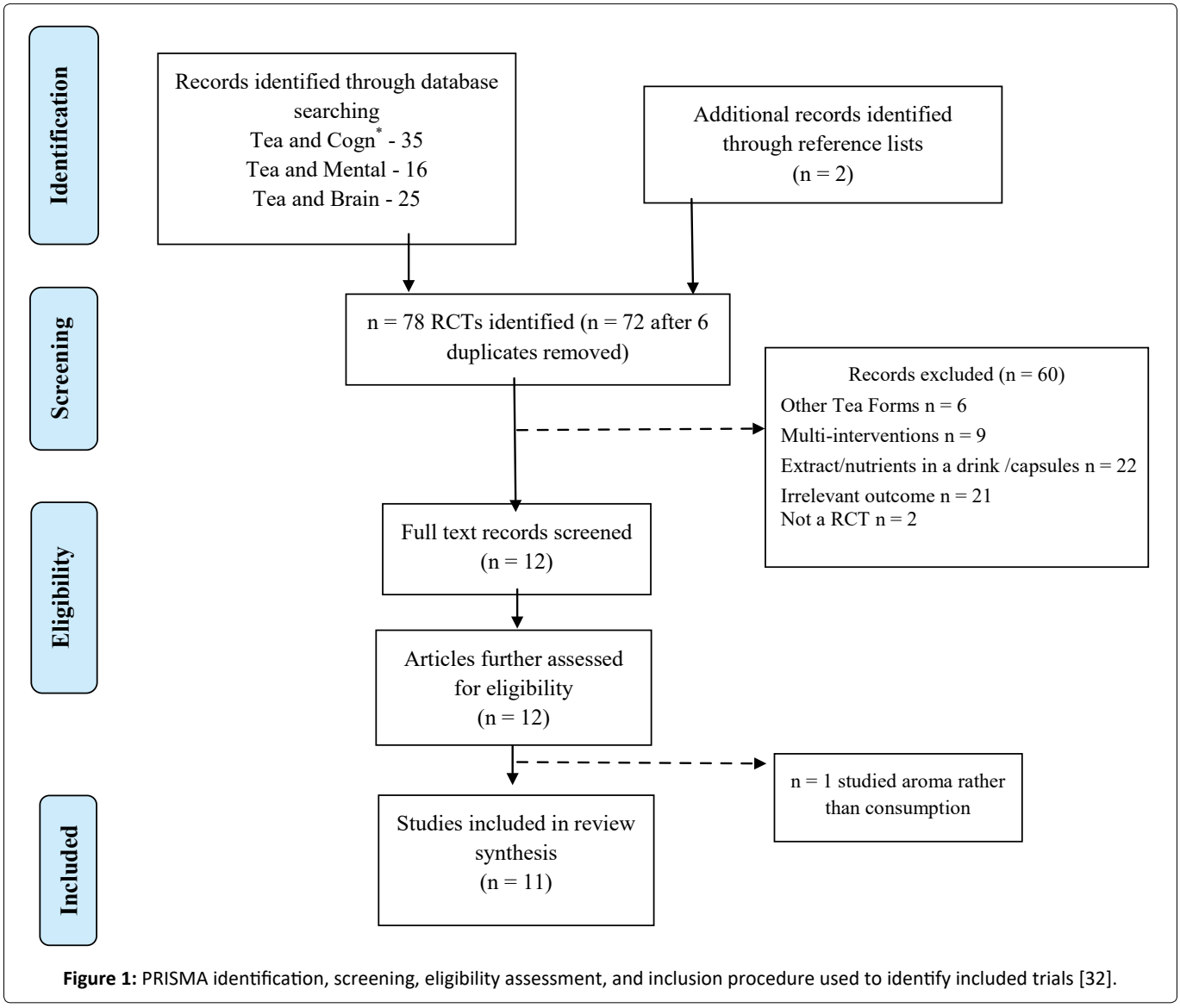

Figure 1: PRISMA identification, screening, eligibility assessment, and inclusion procedure used to identify included trials [32].

proximately 20 mg L-theanine [31]. Subsequently, this could translate into approximately five cups if 100 mg was administered as an intervention. Such studies were included, but those using significantly higher dosages e.g. 400 mg (equivalent to 20 cups of black tea daily) were excluded on the basis that this was not representative of normal habitual tea drinking habits.

Multi-interventions using combinations of various tea infusions or tea in conjunction with medication use, or another intervention e.g. cognitive behavioural therapy were excluded. Studies, however, where tea interventions in beverage form were randomly allocated to separate arm of participants were included. Equally studies, where interventions could be translated into practical tea drinking patterns were included.

Data charting

Data charted from the trials included the following: General details of the study (author, year, and location), participants (age, gender, and health status), sample size (number), study design, time period, tea Intervention (type), Dosage (cup/s or ml ingested per day), health outcome(s) studied and main findings with any reported significant p-values.

Studies were identified by authors and screened based on the specified inclusion and exclusion criteria. Studies were initially checked using their title, they were then further verified and screened based on their abstract. The procedure of identification, screening, evaluation of eligibility and inclusion is illustrated in Figure 1.

Results

The NCBI PubMed search engine ascertained 76 trials using the specified search terms. A further two trials were identified from publication reference lists. Of these, six duplicate publications were removed yielding 72 trials for further screening. After reading the abstracts and full texts of publications, where available, an additional 60 papers were excluded. The reasons for these exclusions included: 21 were irrelevant (outcomes did not relate to cognition, mental health or mood), 22 used concentrated extracts or supplements, nine used multi-interventions, six used other tea forms e.g. Greek mountain tea and two publications were reviews rather than RCTs. A further study was excluded as it focused on aroma

Table 3: Tea & cognition, mental wellbeing and brain function: Identified trials.

Study (author, year, location)	Participants (gender, health, age)	Sample size (n)	Study design	Time period	Tea intervention	Dosage	Health outcome(s)	Main findings
Kahathuduwa, et al. [28] USA	Healthy males	n = 9	4-way crossover design	60 minutes post intervention	L-theanine, 160 mg of caffeine, their combination, or the vehicle (distilled water; placebo)	Solutions of 200 mg of L-theanine, 160 mg of caffeine, their combination, or the vehicle (distilled water; placebo)	Mind wandering	L-theanine and caffeine appear to have a synergistic action in decreasing mind wandering.
Kahathuduwa, et al. [35] USA	Healthy male volunteers, mean 21.9 yrs.	n = 20	Placebo-controlled, five-way crossover trial	4-hours	Black tea. L-theanine, caffeine, their combination, and a placebo (distilled water)	Black tea (150 ml) providing L-theanine (200 mg), caffeine (160 mg).	Cognitive and recognition visual reaction time and neurophysiological measures of attention	A dose of theanine equivalent to around eight cups of back tea improves cognitive and neurophysiological measures of selective attention, to a degree that is comparable with that of caffeine. Theanine and caffeine seem to have additive effects on attention.
Einöther, et al. [3] Netherlands	Dutch regular tea drinkers, mean 33.5 yrs.	n = 153 (n = 30 M)	Parallel study, 3 groups	75 minutes post intervention	Tea, placebo tea, or a glass of water	200 ml black tea, placebo or water	Mood	The effects of a single cup of tea may be limited to an immediate increase in pleasure and decrease in arousal, which can increase interest in activities.
Ide, et al. [36] Japan	Nursing home residents with cognitive dysfunction, mean 84.8 yrs.	n = 33 (n = 4 M, n = 29 F)	Double-blind, randomized controlled study	12 months	Green tea or placebo	2 g/day of green tea powder (containing 220.2 mg of catechins) or placebo powder (containing 0.0 mg of catechins).	Cognitive function	12 months green tea consumption may not significantly affect cognitive function but did prevent an increase of oxidative stress.
Dodd, et al. [37] UK	Twelve habitual consumers and 12 non-habitual caffeine consumers, mean 21.8 yrs	n = 24	Placebo-controlled, double-blind, counterbalanced, crossover study	30 minutes post intervention	L-theanine, L-theanine + caffeine or a placebo	50 mg L-theanine, 75 mg caffeine plus 50 mg L-theanine, and placebo (equivalent to 1-2 cups of tea)	Cerebral blood flow, cognition, mood	Combining L-theanine with caffeine, at levels and ratios equivalent to 1-2 cups of tea, eliminated vasoconstrictive effects and behavioural effects of caffeine.
Ota, et al. [38] Japan	Healthy adults, mean 31 yrs	n = 14 (n = 7 M, n = 7 F)	Randomized controlled trial	120 minutes post intervention	L-theanine or placebo	L-theanine given at 0, 200, 400, and 600 mg	Sensorimotor gating	The observed effect with 200-400 mg of L-theanine on PPI suggested that L-theanine at a particular dose range increases sensorimotor gating in humans.

Yoto, et al. [39] Japan	Healthy volunteers, mean 23.4 yrs.	n =18 (n = 9 M, n = 9 F)	Single-blind randomized crossover (3 separate trials)	60 minutes post intervention	Green tea, white tea and warm water	250 ml tea sample	Mental stress, mood disturbance/states	Green tea had anti-stress effects - lowering levels of salivary CgA.
Shiah & Radin [40] Taiwan	Taiwanese adults	n = 189	Randomized trial	1-week	Oolong tea	600 mL in the morning and again in the afternoon	Mood	Tea blessed by a monk improved mood more than ordinary tea derived from the same source. Belief that one was drinking treated tea produced a large improvement in mood, but only if one was actually drinking the treated tea, indicating that belief and intentional enhancement interact.
Foxe, et al. [41] USA	Medically healthy participants, mean 26 yrs	n = 27	Double-blind, randomized, cross-over study	4-days	Theanine, caffeine, a combination, or placebo	Theanine (100 mg), Caffeine (50 mg),	Vigilance and sustained attention tasks	When treated with placebo, participants showed a rise in error rates, a pattern that is commonly observed with increasing time-on-task, whereas after caffeine and theanine ingestion, error rates were significantly reduced.
De Bruin, et al. [42] Netherlands	Healthy participants	n = 26	Two double-blind, randomized, placebo-controlled, crossover studies.	Short-term approx. 30 minutes post intervention	Black tea or placebo (two 200 ml servings)	About 23 mg theanine and 50 mg caffeine per cup	Attention, self-reported alertness	Auditory ($p < 0.001$) and visual ($p = 0.030$) intersensory attention were enhanced after black tea compared to placebo ingestion.
Giesbrecht, et al. [43] Netherlands	Young adults, mean 21.2 yrs	n = 44	Randomized, placebo-controlled, double-blind, within-subjects design	Approx. 70 minutes post intervention (self-paced)	Combination of L-theanine and caffeine vs placebo treatment	97 mg L-theanine and 40 mg caffeine	Cognitive performance, self-reported mood	During a challenging cognitive task 97 mg of L-theanine in combination with 40 mg of caffeine helped to focus attention.

Key: CgA: Chromogranin A; PPI: Prepulse Inhibition.

rather than tea consumption leaving eleven RCTs.

As shown in Table 3 eleven RCTs studied inter-relationships between tea consumption and aspects of cognition, mental wellbeing or brain function [3,28,35-43]. Of these, a range of relevant outcomes were investigated which included measures of cognitive function [35-37,43], mood and mind-wandering [3,28,40,43], mental stress [39], sensorimotor gating [38], vigilance, alertness and attention [41,42] and cerebral blood flow [37].

Of the studies identified four were conducted in Asia (Japan and Taiwan), three studies in the United States, three in the Netherlands and one in the United Kingdom. Regarding quality, nine trials scored three or higher using the Jadad criterion [3,28,36,37,39-43]. The remaining two studies lacked finer details regarding randomisation methods, blinding techniques and subject compliance and withdrawal pathways (Table 4).

Overall, a total of 557 participants were studied across all the eleven identified trials. Of these most recruited medically healthy participants at baseline. Only one studied enlisted participants from nursing homes who had cognitive dysfunction at baseline [36]. Within the studies the gender ratio of participants had a tendency to be skewed towards a higher ratio of females [3,36,38]. In terms of study duration the majority of trials investigated the effects of tea consumption ”post ingestion” with this ranging from 30 minutes to 4 hours [3,28,35,37-39,42,43]. The longest RCT was conducted over 12-months [36] with others lasting for 4-days [41] or over the course of 1-week [40].

Regarding tea forms, eight studies used black tea or L-theanine and caffeine components typically found within black tea [3,28,35,37,38,41-43]. The remaining three studies used green or oolong tea forms within their interventions [36,39,40]. Kahathuduwa, et al. [28] observed that a solution providing 200 mg of L-theanine and 160 mg of caffeine reduced attention towards distracters such a mind-wandering and improved attention towards target stimuli. Earlier work conducted by the same team found that a dose of L-theanine (200 mg) equivalent to about eight cups of back tea significantly improved recognition visual reaction time ($p = 0.019$) - a cognitive and neurophysiological marker of selective attention, indicating that theanine and caffeine had potential additive effects on human attention [35].

Dodd, et al. [37] observed that lower doses of L-theanine and caffeine (50 and 75 mg, respectively) equivalent to 1-2 cups of black tea are also capable of modulating autonomic indicators, cerebral haemodynamics, cognitive performance and mood. In addition to these effects Ota, et al. [38] found that 200-400 mg of L-theanine increased sensorimotor gating in humans. Foxe, et al. [41] studied the effects of 100 mg L-theanine and 50 mg caffeine finding that error rates when undertaking performance tasks were higher in the placebo compared with the theanine and caffeine intervention. Upon further investigation it was caffeine that mostly appeared to affect brain alpha-band activity.

De Bruin and colleagues [42] studied the effect of drinking 200 ml black tea (approximately 23 mg L-theanine and 50 mg caffeine) detecting significant improvements in attention and self-reported alertness indicating that tea is an important contributor to daily cognitive functioning. Einöther, et al. [3]

Table 4: Jadad criteria used to assess quality of RCTs.

Publication	Randomization	Method of randomization described & appropriate	Blinding mentioned	Method of blinding described and appropriate	Withdrawal and dropout of subjects provided	Total score
Kahathuduwa, et al. [28] USA	1	1	1	0	1	4
Kahathuduwa, et al. [35] USA	1	0	1	0	0	2
Einöther, et al. [3] Netherlands	1	0	1	1	0	3
Ide, et al. [36] Japan	1	1	1	0	1	4
Dodd, et al. [37] UK	1	1	1	1	0	4
Ota, et al. [38] Japan	1	0	1	0	0	2
Yoto, et al. [39] Japan	1	1	1	0	0	3
Shiah & Radin [40] Taiwan	1	1	1	0	1	4
Foxe, et al. [41] USA	1	0	1	0	1	3
De Bruin, et al. [42] Netherlands	1	1	1	1	1	5
Giesbrecht, et al. [43] Netherlands	1	0	1	1	0	3

Total quality assessment score for which scores range between 1 and 5: with 1 being the lowest quality and 5 being the highest quality. 3 = Above average quality; *Described elsewhere.

found that ingestion of 200 ml black tea improved interest in activities compared with the placebo. Using slightly higher dosages (97 mg L-theanine and 40 mg caffeine) Giesbrecht, et al. [43] observed significant improvements in attention during cognitively challenging tasks.

Of the three studies using green and oolong tea [36,39,40] findings were mixed. Yoto, et al. [39] found that 250ml green tea inhibited increases in salivary chromogranin A indicating that it helped to attenuate levels stress induced by mental tasks. Shiah and Radin [40] studied the effects of oolong tea observing improvements in mood although this could have been attributed to psychological effects. One of the longest studies to be undertaken was conducted by Ida and colleagues [36] who investigated the effects of green tea consumption over 12 months amongst 33 residential participants with cognitive dysfunction. Whilst its consumption prevented oxidative stress no cognitive benefits were observed. It is, however, possible that the sample size was too small to detect an effect, or the intervention dosage too low.

Discussion

The present systematic review evaluated associations between tea consumption (black, oolong and green) in relation to cognition, mental wellbeing and brain function in adults revealing potential beneficial effects - particularly for black tea and its constituent components. It has previously been reported that tea consumption (2 to 3 cups daily) could positively impact on other aspects of health, including reduced risk of total mortality, cardiac death, coronary artery disease, stroke, and type 2 diabetes mellitus [9]. The present systematic review found that tea consumption could influence other aspects of wellbeing including cognition (attention, mind-wandering and focus) [28,35,41-43], mental wellbeing (stress, mood) [3,39,40] and aspects of brain function (sensorimotor gating, cerebral blood flow) [37,38]. The overarching body of evidence was larger for black tea and its relevant constituents [3,28,35,37,38,41-43].

Regarding tea consumption amounts, most benefits could be seen at relatively low habitual intakes - amounts equivalent to just one to two cups daily [3,28,37,39,42]. It should, however, be considered that dosages of L-theanine and caffeine varied between studies, depending on tea forms and strengths used. De Bruin, et al. [42] observed that drinking two cups of black tea each providing just 23 mg L-theanine and 50 mg caffeine (intakes at the lower end compared with other studies) significantly improved auditory and visual attention. Similarly, Einöther, et al. [3] observed that a single cup of black tea could increase interest in activities.

Regarding potential mechanisms the effects of tea consumption on aspects of cognitive, mental and/or brain function cannot be restricted to a single constituent. As reported elsewhere, [10] it is most likely that any beneficial effects are cumulative, particularly in relation to L-theanine and caffeine. It is also highly likely, as shown in Table 1 and Table 2 that other active constituents present in tea could affect the brain and mind, so the short- and long-term effects are these require further investigation.

For example, it has recently been proposed that certain tea constituents including L-theanine, polyphenols and polyphenol metabolites could curtail depression by influencing multiple pathways, including the up regulation of the ERK/CREB/BDNF signalling pathway [44]. Investigative work looking at brain connectivity has found that tea drinking also appears to have a protective effect on age-related decline in brain organisation [45]. The stress-reductive properties of tea drinking have even been attributed to its smell [46]. In one study the inhalation of black tea aroma (Darjeeling and Assam) reduced salivary chromogranin-A levels (a stress marker) when participants were subjects to 30 minutes of mental arithmetic stress [46]. Certain neurodegenerative conditions have also been linked to copper homeostasis and, interesting, a novel tea bag has been developed to remove excess copper ions from drinking water [47,48].

In terms of study limitations and future research directions, ongoing work is warranted in some areas. For example, most of the studies identified used healthy populations at baseline. Clearly further work is needed using samples of patients with defined medical conditions e.g. who are clinically depressed or anxious at baseline before firm conclusions can be made. Dosages of L-theanine and caffeine were also variable between studies so ongoing work is needed to study the effects of these. It should also be considered that the composition of tea can be highly variable and differs with the climate, species, season, leaves and horticultural practices [49]. Subsequently, the use of biomarkers such as 4'-O-methylepigallocatechin and epigallocatechin - some of the most sensitive markers of black and green tea ingestion should be embedded within future studies investigating tea intakes and cognitive outcomes [50].

Overall, looking at the totality of evidence to date and the potential benefits of tea drinking on aspects of cognitive, mental wellbeing and brain function there appears to be little reason not to encourage healthy people to drink tea as a means of improving their brain health - cognitive wellbeing, mood and focus [51,52].

Conclusions

Previously the health benefits of drinking tea have largely been confined to cardiovascular health and wellbeing. The present review collated evidence from human RCTs focusing on black, oolong and green tea in relation to markers of cognition, mental wellbeing, and brain function. Of these tea forms black tea and its relevant tea constituents (L-theanine and caffeine) appeared to exhibit some of the most consistent effects, improving attention, mind-wandering, focus, stress, mood, sensorimotor gating and cerebral blood flow. This implies that tea drinking could help to improve aspects of cognition, mental wellbeing, and brain function. Ongoing research is now needed.

Author Contributions

Dr. Emma Derbyshire researched, wrote and edited the publication together with Dr. Gill Jenkins and Dr. Chris Etheridge.

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Conflict of Interest

All authors declare there is no conflict of interest.

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