Psychological effects of dietary components of tea: caffeine and L-theanine

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This review summarizes the literature on the association between two dietary components of tea, caffeine and L-theanine, and the psychological outcomes of consumption; it also identifies areas for future research. The studies reviewed suggest that caffeinated tea, when ingested at regular intervals, may maintain alertness, focused attention, and accuracy and may modulate the more acute effects of higher doses of caffeine. These findings concur with the neurochemical effects of L-theanine on the brain. L-theanine may interact with caffeine to enhance performance in terms of attention switching and the ability to ignore distraction; this is likely to be reflective of higher-level cognitive activity and may be sensitive to the detrimental effects of overstimulation. Further research should investigate the interactive effects of caffeine, L-theanine, and task complexity, utilize a range of ecologically valid psychological outcomes, and assess the neuroprotective effects of L-theanine using epidemiological or longer-term intervention studies among individuals at risk of neurodegenerative disease.

INTRODUCTION

Historically and universally, the consumption of both black and green tea has been associated with relaxation and refreshment.[1,2] Tea is the most widely consumed beverage apart from water, with black tea being consumed mainly in Europe, North America, and North Africa and green tea consumed mainly in Asia;[2,3] however, the consumption of green tea is increasing in Western countries as well. Recently, there has been an emerging interest in the active dietary components of tea and the psychological effects of tea consumption. According to recent studies, some dietary components of tea, especially caffeine and the amino acid L-theanine, have an impact on brain activity and have positive effects on psychological outcomes, including enhanced cognitive performance and psychological well-being. This review summarizes findings from the existing literature on the psychological benefits of caffeine and L-theanine as dietary components of tea, identifies the limitations of the research to date, and proposes steps for future research.

EFFECTS OF CAFFEINE IN TEA ON ALERTNESS, PSYCHOLOGICAL WELL-BEING, AND COGNITIVE PERFORMANCE

An average cup of tea contains around 40 mg of caffeine, depending on the blend of tea and the brewing procedure,[4] and black tea and coffee are the main sources of caffeine in the Western diet. It takes around 30 minutes for the effects of caffeine to be detected, with peak plasma concentrations of caffeine being reached between 30 and 120 minutes after consumption.[5] Caffeine easily crosses the blood-brain barrier and its effects on the brain include a general increase in neurotransmitter activity by blocking the inhibitory action of adenosine, a neuromodulator.

There is a relatively large body of literature reporting the positive effects of caffeine *per se* and at doses equivalent to one to two cups of tea.[6–8] Caffeine is typically associated with improved performance of tasks that require sustained effort and attention.[9–14] Other studies have shown some specific effects of caffeine on speed of response,[15,16] and on feelings of well-being, energy,

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motivation, self-confidence, alertness, and concentration.[17] However, the direct effects of caffeinated tea are less well known.

There follows a summary of studies that have compared the effects of tea and coffee containing varying doses of caffeine (Table 1), many of which represented the typical intake levels for these beverages. Both immediate and day-long statistically significant effects have been reported. For the purpose of this review, the studies were divided into those that describe psychological well-being, mood, and alertness, and those that describe changes in cognitive performance.

Effects on well-being, mood, and alertness

There is little evidence from cross-sectional studies for an association between tea consumption and increased psychological well-being and mood. Although Hintikka et al.[18] reported daily tea drinkers had a 50% reduced risk of depression, even after controlling for risk factors for depression, these results have not been replicated. Shimbo et al.[2] found no link between green tea consumption and mental health, and Steptoe and Wardle[19] similarly found no relationship between tea and coffee intake and mood. There are considerable differences in the sample populations in these studies which may have influenced the outcome, but it is also possible that in the stratified sample of 2011 people in Finland,[18] tea drinking was associated with other behaviors that reduced the risk of depression.

Reports from experimental studies of mood have produced more consistency. Findings indicate that 37.5–150 mg caffeine, which are doses found in 1–4 cups of tea, produces acute effects, with participants reporting statistically significant increased wakefulness, vigor, energy, clarity of thought, efficiency, hedonic tone, and decreased perceptions of sedation. Caffeine is arguably most well known for this latter effect, and in this context caffeine in tea and coffee is thought to deliver positive dose-response relationships with regard to energetic arousal.[20,21] However, in one study, similar doses of caffeine in water did not produce the same results, indicating that at least some of these effects could be placebo or learned effects.

Caffeinated tea has also been found to have longer-term benefits when taken at regular intervals throughout the course of a day. Tea is significantly associated with lower perceived sedation or fatigue than coffee,[22,23] and it is less disruptive than coffee on sleep quality at night.[22]

Effects on cognitive performance

Studies of caffeinated tea have tended to focus on simple rather than complex cognitive outcomes, such as speed of perception, decision making, and response. The advantage of assessing cognition using these tasks is that they are able to be given quickly on repeated occasions throughout the day with minimal practice effects. One example is the critical flicker fusion test (CFF), which measures the threshold at which the speed of a flickering light appears to flicker compared with appearing to be constant. Those who perceive a light to be flickering at a faster rate are considered to have a higher speed of perception.

One of the most interesting and potentially important findings is that very low doses of caffeine (37.5 mg), such as would be found in a single cup of tea, taken at regular intervals throughout the day, have been found to significantly benefit speed of perception, as measured by the CFF.[22] Furthermore, when the level of caffeine in tea is increased such that it is equivalent to coffee (i.e. 75 mg and 100 mg per serving), caffeinated tea appears to provide an advantage over coffee in the rapid increase and maintenance of the CFF threshold.[20,22] This suggests that regular tea intake across the course of a day may result in more consistent levels of simple task performance.

The effects of caffeine in tea on reaction time are less clear. Hindmarch et al.[22] found no chronic effects of caffeine across the course of a day on reaction time, but found significant acute effects, with coffee drinking resulting in faster reaction times than tea drinking. Motor reaction time was benefited by lower doses of caffeine (75 mg, the equivalent of two cups of tea), whereas higher doses (150 mg) resulted in slower performance. Overall, participants consuming tea containing 75 mg caffeine were able to maintain their baseline levels of performance during the course of a day, while the performance of participants with no caffeine declined.

Whilst simple cognitive tasks appear to be affected by intakes of caffeine in tea, the performance of more complex tasks, such as the high-speed scanning and retrieval of information from short-term memory, was shown to be unaffected following intake of 100 mg of caffeine from either tea or coffee.[20] To date, the effect of intakes of caffeine in tea on a variety of more complex cognitive tasks has not been investigated.

EFFECTS OF L-THEANINE ON BRAIN FUNCTION, BRAIN ACTIVITY, ANXIETY, AND COGNITIVE PERFORMANCE

L-theanine is an amino acid found almost exclusively in tea. It constitutes between 1 and 2% of the dry weight of tea, which results in around 25–60 mg per 200 ml serving of liquid tea.[24–26] L-theanine was first identified in green tea[27] and in the mushroom *Xerocomus badius*.[28] Tea is therefore the major source of L-theanine in the diet. It readily crosses the blood-brain barrier in a dose-dependent manner within 30 minutes, reaching maximal levels 5 hours after ingestion in animals, and it is thought to influence the central nervous system (CNS) through a variety of mechanisms, including

Table 1 **Effects of caffeine in tea and tea consumption on alertness and sedation, psychological well-being, and mood and cognitive performance.**

Study	Participants	Study design	Outcomes
Quinlan et al. (2000)[21]		RCT: crossover design, manipulation of beverage type (study 1 only) and caffeine levels	
	Study 1: 8 male, 9 female (21–51 y)	Study 1: effects of no drink, hot water, tea (37.5 mg), tea (75 mg), coffee (75 mg), coffee (150 mg) on blood pressure, heart rate, skin conductance and temperature, saliva, current mood.	Study 1: both tea and coffee produced mood elevation ($p < 0.05$); beverage type or caffeine dose had no effect
	Study 2: 7 male, 8 female (22–52 y)	Study 2: effects of hot water, decaffeinated tea (5 mg), decaffeinated tea plus 25, 50, 100, and 200 mg caffeine on measures used in study 1	Study 2: caffeine affected energetic arousal ($p < 0.001$); no dose-response effects
Hindmarch et al. (1998)[20]	10 female, 9 male (mean age 29.2 y), healthy	Five-way crossover design. Effects of black tea (100 mg), black decaffeinated tea, coffee (100 mg), water (100 mg), non-caffeinated water on CFF performance, choice reaction time, short-term memory, ratings of tiredness, drowsiness, and alertness and state anxiety	Consumption of tea, compared with water, associated with transient improvements in CFF performance (all significant effects $p < 0.001$), prevented the steady decline in alertness and cognitive capacity. Effects of tea vs. coffee similar, but tea associated with less variation in CFF performance
Hindmarch et al. (2000)[22]	15 female, 15 male aged 19–36 years (mean age 27.3 y)	RCT: five-way crossover design. Effects of caffeinated black tea (37.5 mg) caffeinated black tea (75 mg), caffeinated black coffee (75 mg), caffeinated black coffee (150 mg) and boiled water on CFF performance, choice reaction time, subjective ratings of tiredness, drowsiness and alertness and sleep quality	Caffeinated beverages maintained cognitive and psychomotor performance across the day when administered repeatedly ($p < 0.05$). Day-long tea vs. coffee consumption had similar effects; tea was less likely to disrupt sleep
Scott et al. (2004)[23]	13 mountain climbers: 9 men, 4 women (age range 18–51 y; mean age 33.5 y)	Experimental, within-subjects design including 2 × 24-h treatment periods. Effects of tea versus no tea consumption, in the presence of no other caffeinated or alcoholic beverages, on dimensions of mood (Profile of Mood States)	Tea consumption associated with reduced fatigue ($p < 0.01$) compared with no tea
Steptoe & Wardle (1999)[19]	18 men (mean age 41.2 y) and 31 women (mean age 40.9 y) from two occupational groups (psychiatric nursing and school teaching).	Correlational, cross-sectional naturalistic diary study assessing day-by-day associations between tea, coffee, and alcohol consumption and dimensions of mood (Profile of Mood States)	Coffee and tea not related to mood. Alcohol consumption related to high positive and low anxious mood among those with low drinking-to-cope ratings ($p < 0.05$)
Hintikka et al. (2005)[18]	Age- and gender-stratified sample of 890 men (mean age 44.8 y) and 1121 women (mean age 44 y), age range 25–64 years, living in Finland	Correlational, cross-sectional study assessing associations between frequency of tea and coffee consumption and self-reported depression	Those reporting daily tea consumption reported lower levels and prevalence of depression than those who did not drink tea (OR 0.45, 95% CI 0.30–0.70)
Shimbo et al. (2005)[2]	380 Japanese men ($n = 180$) and women ($n = 200$) aged 20–60 years from urban and rural areas	Correlational, cross-sectional study assessing associations between green tea consumption and mental health (General Health Questionnaire)	No relationship between green tea consumption and decreased risk of mental ill-health. Daily caffeine intake was associated with a higher risk of ill-health among females (OR 1.26, 95% CI 1.01–1.56)

Abbreviations: CFF, critical flicker fusion; RCT, randomized control trial.

effects on neurotransmitters. L-theanine is structurally similar to glutamic acid, an excitatory neutrotransmitter.[29] Animal studies have found that L-theanine is associated with the following: an increased release and concentration of dopamine;[30,31] an inhibition of glutamate reuptake and blockade of glutamate receptors in the hippocampus;[32] increases in gamma-aminobutyric acid (GABA – a neurotransmitter associated with the regulation of responses) concentrations;[33] decreases in norepinephrine levels, possibly as a result of increased GABA);[34] and both increases in serotonin in the stratum, hippocampus, and hypothalamus and suppression of the generalized release of serotonin.[29] In addition, some findings suggest that L-theanine might interact with caffeine because L-theanine has been found to decrease serotonin levels that have been artificially elevated by caffeine.[34] Furthermore, L-theanine appears to antagonize the stimulatory effects of caffeine, which may contribute to its effects on lowering blood pressure.[35] Overall, these effects on neurotransmitters suggest that L-theanine may have a regulatory role in the CNS such that it may modulate and perhaps "tone down" CNS responses. These effects on the CNS would predict that L-theanine might have a role in the regulation of anxiety due to effects on serotonin and GABA; the enhancement of cognitive performance due to increases in monoamines, and the possibility of neuroprotective effects due to antagonistic effects on glutamate.

Neuroprotective effects of L-theanine

The similarity of L-theanine to glutamate has lead to the suggestion that it may have neuroprotective effects through the antagonism of this excitatory neurotransmitter.[32,36] Indeed, in animals, L-theanine has been found to reduce post-ischemic neural death in the hippocampus,[32] reduce the size of cerebral infarcts,[37] and inhibit neural death caused by brief exposure to glutamate.[38] These findings from animal studies suggest that L-theanine may have neuroprotective effects against brain injury, such as that resulting from stroke. There are no studies that have investigated the neuroprotective effects of L-theanine in humans and the little work that has been done has focused on the relationship between flavanoid consumption and neurodegenerative disease. There is mixed support for the validity of this relationship. One cohort study conducted in the Netherlands, in which black tea consumption provided 61% of flavanoid intake, found no relationship between flavanoid intake and cognitive decline.[39] In contrast, a cohort study conduced in France, in which black tea contributed only 16% of flavanoid inake, found that total flavanoid intake was negatively related to risk of dementia.[40]

Effects of L-theanine on α-brainwave activity

Consistent with its effects on the CNS, and unlike caffeine, there is evidence that L-theanine could be associated with relaxation. There have been a small number of studies using electroencephalography to investigate the ability of L-theanine to increase α-brainwave activity (Table 2), which is indicative of a state of wakeful relaxation. Alpha activity has also been associated with increased creativity, increased performance under stress, and improved learning and concentration, as well as decreased anxiety[35] so if L-theanine impacts alpha activity, then it may also be associated with these psychological outcomes. The effects of L-theanine on brain electrical activity, as evident from the EEG, are consistent with its association with increased relaxation. Ito et al.[41] examined the effects of 50–200 mg L-theanine on α-wave activity in eight participants, half of whom scored high and half low on a self-reported anxiety scale. In both groups, tested 30 minutes after administration, alpha activity increased significantly in the occipital and parietal areas, and blood pressure decreased, indicating relaxation. The results were interpreted as evidence that L-theanine could promote a state of relaxation without causing drowsiness. These findings were supported by Song et al.[42] who found that in individuals reporting high levels of anxiety, 200 mg L-theanine increased alpha activity in the frontal and occipital areas 40 minutes after intake compared with placebo. Evidence for an effect of L-theanine consumption on alpha activity at more realistic dietary levels comes from Owen et al.[43] who reported significantly greater and increasing alpha activity at 45, 60, 75, 90, and 105 minutes after ingestion of 50 mg L-theanine compared with placebo. While these studies suggest that doses of L-theanine at levels found in one to two cups of tea have an influence on alpha brain activity, one limitation they have is that the subjective states of relaxation and related constructs, such as anxiety, were not assessed; instead, they were inferred from effects on the EEG.

One recent study indicates that L-theanine's effects on alpha activity may indicate a role in learning and concentration. Gomez-Ramirez et al.[44] assessed whether 250 mg L-theanine, compared with placebo, could regulate the brain's activity as it prepares to focus attention on a task to be performed using one sensory modality while ignoring stimuli presented to another. They found significantly increased alpha activity in relation to the task being attended to and a decrease in background alpha activity, suggesting that L-theanine may have specific positive effects on focused attention.

Table 2 **Effects of L-theanine on brain activity, anxiety, psychological stress, and cognitive performance.**

Study	Participants	Study design	Outcome
Ito et al. (1998)[41]	8 female university students (age range 18–22 y): 4 with high reported anxiety and 4 with low reported anxiety	Three-way crossover assessing the effects of water, 50 mg L-theanine solution, and 200 mg L-theanine solution on brainwave activity	Reported dose-dependent increase in alpha activity in occipital and parietal brain areas 30 min after consumption of L-theanine compared with water.
Song et al. (2003)[42]	20 healthy males (age range 18–30 y)	Placebo-controlled experiment comparing 200 mg L-theanine with placebo on alpha brain activity	L-theanine increased alpha activity in the occipital area, compared with placebo, among those with higher reported anxiety ($p < 0.05$)
Owen et al. (2006)[43]	35 healthy young participants	Randomized, placebo-controlled experiment comparing 50 mg L-theanine with placebo on EEG at 45, 60, 75, 90, and 105 min after ingestion	L-theanine produced greater and increasing alpha activity compared with placebo ($p < 0.05$)
Gomez-Ramirez et al. (2007)[44]	15 participants (mean age 27.8 y)	EEG data gathered from 168 scalp sites while participants engaged in an intersenory attention-cuing task after ingesting either 250 mg L-theanine or placebo (water)	Attention-related alpha activity was greater and background alpha reduced for the L-theanine condition compared with placebo (significant attention modulation index, $p < 0.05$)
Lu et al. (2004)[45]	12 male (age range 18–34 y, mean 24.8 y) and 4 female (range 28–31 y, mean 29.0 y) university students	Double-blind, placebo-controlled, repeated measures design assessing effects of three treatments, placebo, L-theanine (200 mg), and alprazolam (1 mg), on self-reported depression, trait and state anxiety, and relaxation under conditions of anticipatory anxiety or relaxation	L-theanine had a positive effect on relaxation under relaxed conditions only ($p < 0.05$); no other effects were found
Kimura et al. (2006)[46]	12 healthy male university students (age range 20–25 y, mean 21.5 y)	Double-blind, placebo-controlled within-subjects repeated measures design assessing the effects of one or two doses of 200 mg L-theanine compared with placebo or no treatment on self-reported stress and anxiety and physiological indices of stress (heart rate and s-IgA concentration) under high-stress and low-stress conditions	No statistically significant levels reported; L-theanine reported to reduce self-reported anxiety and physiological indices of stress under high-stress conditions compared with placebo
Haskell et al. (2005)[49]	17 female and 9 male university students (age range 18–34 y, mean 21.61 y).	Double-blind, placebo-controlled crossover study assessing the effects of four drinks containing 0 mg caffeine plus 0 mg L-theanine, 150 mg caffeine, 250 mg L-theanine, and 150 mg caffeine plus 250 mg L-theanine on response and memory reaction time, sentence verification, working memory, self-reported mood and alertness	Caffeine improved mood, reaction time, and accuracy (various significance levels). L-theanine had mixed effects on reaction time but significantly potentiated the effects of caffeine on simple reaction time, the accuracy of rapid information processing, mental fatigue and tiredness (various significance levels). The combination of L-theanine and caffeine enhanced speed of rapid information processing ($p < 0.001$), sentence verification ($p < 0.05$), word recognition reaction time ($p < 0.001$), and alertness ($p < 0.001$)
Parnell et al. (2006)[50]	13 female and 14 male healthy volunteers (mean age 28.3 y)	RCT: double-blind, crossover design assessing the effects of 50 mg caffeine with or without 100 mg L-theanine or placebo on memory performance, rapid visual information processing, attention switching, and mood	Caffeine improved alertness after 60 min ($p < 0.01$) and response speed and accuracy after 60 ($p < 0.001$) and 90 min ($p < 0.01$). L-theanine and caffeine improved speed and accuracy on an attention-switching task and reduced interference from distracting information at 60 ($p < 0.001$) and 90 min ($p < 0.05$)

Abbreviations: EEG, electroencephalograph; RCT, randomized control trial.

Effects on anxiety and psychological stress

Studies of the effects of L-theanine on brain activity suggest it may be associated with relaxation and the alleviation of anxiety. However, only two studies to date have investigated the effect of L-theanine on subjective ratings of anxiety and other measures of psychological stress (Table 2). Lu et al.[45] assessed the effects of 200 mg L-theanine, in comparison with the benzodiazepine alprazolam, on self-reported measures of anxiety in 16 healthy volunteers. This study tested the relaxing and anxiolytic effects of L-theanine under conditions of anticipatory anxiety (anticipation of an electric shock). They found that while L-theanine significantly reduced anxiety on one sub-scale (tranquil-troubled) of anxiety under resting conditions, both L-theanine and alprazolam did not reduce anxiety under conditions of anticipatory anxiety, even after controlling for trait anxiety. The authors suggest that the lack of effect of both treatments under anticipatory anxiety may have been due to the intensity of the stressor being too strong, leading to ineffective anxiolytic effects.

Kimura et al.[46] reported that 200 mg L-theanine reduced heart-rate and salivary immunoglobin A, indices of psychological stress, during engagement in a stressful mental arithmetic task. The graphs provided in the paper suggest an interaction between treatment condition and stress level such that the effect was evident in the L-theanine group but not in the control groups (placebo and no treatment). However, as details of statistical tests were not provided, it is not clear whether this was an effect of stress condition regardless of treatment group. In addition, self-reported anxiety was also lower in the L-theanine condition compared to control conditions. Although not statistically significant due to the small sample size ($n = 12$), there were moderate correlations between self-reported and physiological measures.

Effects on cognitive performance

The findings to date suggest complex associations between L-theanine intake and cognitive performance. Animal studies have shown that chronic administration of L-theanine (180 mg per day for 3–4 months) is able to decrease the latency and increase the accuracy of rats performing operant, passive, and active avoidance tasks, as well as increase learning and behavior.[47,48] Findings in humans are more complex (Table 2). Haskell et al.[49] assessed the effects of L-theanine (250 mg) and caffeine (150 mg), separately and in combination, as well as placebo, on a range of cognitive performance and mood measures assessed at baseline, 30 minutes, and 90 minutes after ingestion in 22 participants. They found that caffeine alone produced the well-replicated enhancement of cognitive performance and mood. Whilst L-theanine alone resulted in significantly faster choice reaction time, it produced slower numerical working memory and delayed word recall reaction times and had a detrimental effect on serial seven subtractions. Therefore, there were virtually no positive effects of L-theanine alone on cognitive performance. However, this study produced some evidence that L-theanine significantly interacted with caffeine in that it enhanced the effects of caffeine on simple reaction time, the accuracy of rapid information processing, mental fatigue, and tiredness when given in combination. Also, the combination of L-theanine and caffeine significantly enhanced the speed of rapid information processing, sentence verification, word recognition reaction time, and alertness when caffeine alone did not. However, L-theanine also reduced the positive effects of caffeine on spatial memory and choice reaction time.

The synergistic effects of L-theanine and caffeine have also been found at lower doses of each.[50] In this study, the effects of 100 mg L-theanine plus 50 mg caffeine (such as would be found in two cups of tea) were compared with the effects of 50 mg caffeine alone and placebo on tests of cognition and mood at pre-treatment as well as 60 and 90 minutes post-treatment. Both treatments demonstrated a positive effect at 60 and 90 minutes; however, the significant effects of the combination of L-theanine and caffeine on the speed and accuracy of attention switching and the ability to ignore distracting information during a cognitively demanding attention-switching task support the suggested synergistic effects of these key components of tea. The authors suggest that the combination of both caffeine and L-theanine at low doses interact to produce a better ability to focus attention, with improvement of both speed and accuracy.

General summary

The major findings from studies investigating the effects of caffeine in tea on psychological outcomes is that caffeine at lower doses, such as would be found in one to two cups of tea, is associated with reports of increased alertness and decreased sedation. In addition, lower doses of caffeine appear to have a positive effect on maintaining alertness and reducing fatigue across the course of the day. These acute and chronic effects are also reflected in the effects of lower doses of caffeine on the performance of simple cognitive performance tasks. Indeed, caffeine in tea appears to have an advantage over similar doses in coffee in maintaining the speed of perception and reaction times across the course of a day. Interestingly, lower doses of caffeine (75 mg) appear to benefit motor reaction time whereas higher doses (150 mg) hinder it. It could be the case that lower doses of caffeine, such as those found in tea, are more beneficial to cognitive performance, serving to maintain cognitive performance over time rather than providing an acute burst of stimulation, which may be found with higher doses.

This potential chronic regulation of levels of alertness and performance of simple tasks afforded by tea consumption is consistent with the neurochemical effects of L-theanine and the interaction between L-theanine and caffeine. The effects of L-theanine on neurotransmitters suggest it has a regulatory role in brain function, modulating excitatory brain responses. Furthermore, L-theanine appears to antagonize the stimulatory effects of caffeine on the brain. This is supported by the few studies that have investigated the effects of L-theanine, in conjunction and in comparison with caffeine, on cognitive performance. These studies suggest an interactive effect of these two dietary components of tea. L-theanine appears to enhance the effects of caffeine on speed and accuracy of information processing, mental fatigue and tiredness, and, importantly, on more complex tasks such as sentence verification, word recognition, the speed and accuracy of sustained attention, and the ability to ignore distraction. These tasks may be more reflective of the cognitive performance required in stressful, everyday occupations than the simple speed of perception and speed of reaction tasks used in the caffeine-only research.

There is less support for positive effects of tea and coffee consumption on psychological well-being and mood. Only correlational, cross-sectional studies have been conducted to date. Although one study found an association between black tea consumption and a reduced risk of depression among a large population-based sample, these findings were not supported by a naturalistic diary study of tea and coffee consumption, nor were those of a study conducted in Japan on the association between green tea consumption and mental health.

There is indirect support for the effects of L-theanine on relaxation, anxiety, stress, and concentration. L-theanine levels of 50–200 mg have been shown to increase alpha brainwave activity in occipital, parietal, and frontal brain areas 30–40 minutes after consumption. Alpha brainwave activity is, however, an indirect measure of relaxation only. Studies that have investigated the effects of L-theanine on self-reported anxiety and stress have found some support for the relationship, as well as under conditions of performance stress. Importantly, L-theanine seems to have a role in focusing attention, with dual effects on alpha activity serving to both increase attention on task-specific information and reduce activity associated with distracting attention.

Finally, animal studies have shown that L-theanine may have a neuroprotective role, which is consistent with its apparent antagonistic effects on the excitatory neurotransmitter, glutamate. Although no studies have been conducted in humans, there is mixed support from cohort studies in humans for an inverse relationship between flavanoid intake and cognitive decline.

Taken together, the findings of studies examining the effects of caffeine in tea and L-theanine on psychological outcomes suggest that lower doses of caffeine, when ingested at regular intervals, may maintain alertness, focused attention, and accuracy and may modulate the more acute effects of higher doses of caffeine, such as those found in coffee. The findings may suggest that L-theanine exerts slow and constant effects and modulates the spikes in performance that caffeine brings about. Importantly, L-theanine may also work in combination with caffeine to enhance performance of more complex tasks, such as attention switching and the ability to ignore distraction, which may be reflective of higher-level cognitive activity, such as the executive functions, and which may be sensitive to the detrimental effects of overstimulation on cognitive performance.

DIRECTIONS FOR FUTURE RESEARCH

The cognitive outcomes employed in the research to date have, in general, been limited to laboratory-based simple tasks that have low ecological validity, such as reaction time and speed of perception. Everyday cognitive tasks, such as determining the most efficient route around a supermarket, remembering a shopping list, following a knitting pattern, planning and synchronizing a meal, writing a report, and chairing a meeting, are more complex. These tasks require the integration of a host of cognitive abilities including memory performance, working memory, executive functions, as well as speed of information processing, all of which can be tested in laboratory settings. Furthermore, complex tasks reflecting real-life work performance have their laboratory-based analogues that can be used as outcomes in intervention studies. The use of these more ecologically valid tasks along with other outcome measures, reflecting such things as work engagement and "flow"[51] would greatly enhance the external validity of findings. In addition, the interactive effects of caffeine, L-theanine, and task complexity should be investigated to test the hypothesis that L-theanine modulates the potential negative effects of caffeine on performance under high levels of stress or high-performance conditions.

There are very few experimental studies on the effects of tea or L-theanine consumption on mood and psychological well-being. Effects on relaxation and anxiety are largely inferred from studies that assess the effects of L-theanine on electrical brainwave activity. Psychological well-being and mood are multidimensional constructs and typically include components such as depressive symptoms or negative affect, positive affect, anxiety, and perceived stress. Many studies assessing the effects of tea and L-theanine on mood have used measures that require self-report using visual analogue scales in response to descriptors of mood. There are many standardized assessment instruments that may more validly and reliably assess psychological well-being.

Finally, the potential neuroprotective effects of L-theanine could be investigated using epidemiological and longer-term intervention trials. Epidemiological studies are expensive to conduct, but pre-existing data on nutritional intake and cognitive outcomes could be investigated in order to test this hypothesis. Longer-term intervention studies, over the course of 12–24 months among people with mild cognitive impairment or risk of cerebrovascular disease could provide further evidence for or against the neuroprotective role of L-theanine.

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