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Caffeine and theanine exert opposite effects on attention under emotional arousal

Grace E. Giles, Caroline R. Mahoney, Tad T. Brunyé, Holly A. Taylor, and Robin B. Kanarek

Abstract: Tea is perceived as more relaxing than coffee, even though both contain caffeine. L-theanine in tea may account for the difference. Consumed together, caffeine and theanine exert similar cognitive effects to that of caffeine alone, but exert opposite effects on arousal, in that caffeine accentuates and theanine mitigates physiological and felt stress responses. We evaluated whether caffeine and theanine influenced cognition under emotional arousal. Using a double-blind, repeated-measures design, 36 participants received 4 treatments (200 mg caffeine + 0 mg theanine, 0 mg caffeine + 200 mg theanine, 200 mg caffeine + 200 mg theanine, 0 mg caffeine + 0 mg theanine) on separate days. Emotional arousal was induced by highly arousing negative film clips and pictures. Mood, salivary cortisol, and visual attention were evaluated. Caffeine accentuated global processing of visual attention on the hierarchical shape task ($p < 0.05$), theanine accentuated local processing ($p < 0.05$), and the combination did not differ from placebo. Caffeine reduced flanker conflict difference scores on the Attention Network Test ($p < 0.05$), theanine increased difference scores ($p < 0.05$), and the combination did not differ from placebo. Thus, under emotional arousal, caffeine and theanine exert opposite effects on certain attentional processes, but when consumed together, they counteract the effects of each other.

Key words: caffeine, theanine, arousal, attention, cortisol, emotion, cognition.

Résumé : Le thé est perçu comme étant plus relaxant que le café, même si tous deux contiennent de la caféine. La L-théanine du thé pourrait être à l'origine de la différence entre les deux. Consommées ensemble, la caféine et la théanine exercent des effets similaires sur les facultés cognitives que la caféine seule, mais elles exercent des effets contraires sur l'éveil : effets d'accentuation de la caféine et effets mitigés de la théanine sur le plan des réactions au stress de natures physiologique et des sensations. Nous avons tenté de vérifier l'hypothèse selon laquelle la caféine et la théanine pourraient influencer les facultés cognitives en situation d'excitation émotionnelle. À l'aide d'un modèle à double insu avec mesures répétées sur des jours distincts, nous avons administré les traitements suivants chez 36 participants : caféine à 200 mg + théanine à 0 mg, caféine à 0 mg + théanine à 200 mg, caféine à 200 mg + théanine à 200 mg et caféine à 0 mg + théanine à 0 mg. Nous avons provoqué une excitation émotionnelle à l'aide d'images et de séquences filmées négatives. Nous avons évalué l'humeur, les taux de cortisol dans la salive et l'attention visuelle. La caféine entraînait une accentuation du traitement global par l'attention visuelle aux tâches de catégorisation de formes (« hierarchical shape task »; $p < 0{,}05$), la théanine entraînait une accentuation du traitement local ($p < 0{,}05$), et l'association des deux donnait les mêmes résultats que le placebo. La caféine entraînait une réduction des scores de différence des conflits en présence d'un coacteur au test des réseaux attentionnels (« Attention Network Test »; $p < 0{,}05$), la théanine entraînait une augmentation des scores de différence ($p < 0{,}05$), et l'association des deux donnait les mêmes résultats que le placebo. Par conséquent, sous excitation émotionnelle, la caféine et la théanine exercent des effets contraires sur certains processus attentionnels, mais leurs effets se neutralisent quand elles sont consommées ensemble. [Traduit par la Rédaction]

Mots-clés : caféine, théanine, éveil, attention, cortisol, émotion, fonctions cognitives.

Introduction

Traditionally, tea is perceived as more relaxing than coffee, even though both contain behaviorally significant amounts of caffeine (Barone and Roberts 1996). For instance, black tea has been shown to mitigate felt and physiological responses to stress (Steptoe et al. 2007), whereas coffee exacerbates the stress response (Lovallo et al. 2006). L-theanine, which is present in black, green, and white tea but not coffee (Keenan et al. 2011), may account for such reported differences. Theanine diminishes the stress response, reducing heart rate, blood pressure, cortisol, and perceived stress and anxiety (Kimura et al. 2007; Steptoe et al. 2007; Unno et al. 2013; Yoto et al. 2012). Theanine also alters neural indices of relaxation, such as augmenting α brain waves (Juneja et al. 1999).

Caffeine is a central nervous system stimulant that increases alertness, wakefulness, motivation, and motor activity (Nehlig et al. 1992). Caffeine enhances physiological arousal, by activating both the sympathetic nervous system by increasing heart rate and blood pressure (Davidson and Smith 1991; Green and Suls 1996; James and Gregg 2004) and the hypothalamic pituitary adrenal axis by increasing cortisol (Lovallo et al. 1996, 2005). Caffeine exerts physiological effects similar to those of acute stress (Gerra et al. 2001; Kudielka et al. 2004) and may augment the physiological stress response (Lovallo et al. 2006).

Caffeine and theanine, both alone and together, enhance cognition. The effects of caffeine on cognitive function have been studied extensively. This research has demonstrated that caffeine reliably enhances vigilance and psychomotor performance (Smith 2011) and may enhance processes that require executive control,

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including response inhibition (Barry et al. 2007), selective visual attention (Brunyé et al. 2010*a*, 2010*b*), and working memory (Addicott and Laurienti 2009). Caffeine and theanine, consumed together, exert similar effects to that of caffeine alone, in that 35–50 mg caffeine and 90–100 mg theanine enhanced mental alertness, task-switching attention, and recognition memory relative to placebo (Einöther et al. 2010; Giesbrecht et al. 2010; Kelly et al. 2008; Owen et al. 2008). Opposite doses, i.e., 90–100 mg caffeine and 36–46 mg theanine exerted similar effects (De Bruin et al. 2011). Other work has evaluated the independent and combined effects of caffeine and theanine. Caffeine (50–75 mg) and theanine (50–100 mg), alone and together, reduced errors on sustained and selective attention tasks, but only caffeine reduced response times (Dodd et al. 2015; Foxe et al. 2012). Caffeine (150 mg) and theanine (250 mg) together reduced response time on tasks of sustained attention, working memory, and simple response time, but only caffeine enhanced accuracy on a task of sustained attention (Haskell et al. 2008). Most recently, caffeine (160 mg) and theanine (200 mg) enhanced recognition visual response time and certain event-related potential (ERP) components, specifically N2-P300 amplitudes indicating enhanced attentional processing. Notably, such effects appeared to be additive in that visual response time and N2-P300 amplitudes were similar between caffeine with theanine together and the sum of caffeine and theanine alone (Kahathuduwa et al. 2016). Thus, some work suggests that the cognitive benefits of caffeine are similar with and without theanine (Kelly et al. 2008; Owen et al. 2008), indicating that the cognitive effects of tea may be driven by caffeine, whereas other work suggests that theanine has independent or additive effects when consumed with caffeine (Haskell et al. 2008; Kahathuduwa et al. 2016).

Research into the cognitive benefits of caffeine and theanine has been completed under conditions of normal arousal; thus, it is unclear how caffeine and theanine might influence cognitive function under conditions of heightened emotional arousal. To our knowledge, the present study was the first to evaluate the influence of caffeine and theanine on mood and cognition under heightened emotional arousal. Given that theanine has been shown to reduce both physiological and felt stress responses (Kimura and Murata 1986; Steptoe et al. 2007), it could also benefit performance of cognitive control domains thought to be affected by stress (Liston et al. 2009; Plessow et al. 2011, 2012*a*, 2012*b*) and emotional arousal (Brunyé et al. 2009). Thus, the objective of the current study was to examine the effects of caffeine and theanine, administered alone and together, on measures of visual attention during a heightened state of emotional arousal. The 2 measures chosen to assess visual attention have been shown to be sensitive to caffeine-induced physiological arousal (Brunyé et al. 2010*a*, 2010*b*; Mahoney et al. 2011). These measures include global versus local processing (Kimchi and Palmer 1982) and higher- versus lower-order visual attention (Fan et al. 2002). Based on the limited work to date showing that caffeine accentuates the stress response (Lovallo et al. 2006) while theanine mitigates it (Kimura and Murata 1986; Steptoe et al. 2007), and work showing that stress impairs certain aspects of cognitive control (Plessow et al. 2011, 2012*a*), we hypothesized that the physiological arousal associated with caffeine consumption would increase the effects of emotional arousal on visual attention and that the consumption of theanine, because of its suggested calming properties (Juneja et al. 1999), would decrease the effects of emotional arousal on visual attention. When theanine is administered in combination with caffeine, we expected theanine to mitigate any effects of arousal associated with caffeine consumption.

Materials and methods

Participants

Thirty-six Tufts University students (12 male, 24 female; mean ± SD age: 19.3 ± 1.7 years; mean ± SD BMI: 23.2 ± 4.2) participated. Typical caffeine consumption ranged from 0 mg/day to 820 mg/day (mean ± SD = 129.4 ± 143.9 mg/day). Typical tea consumption ranged from 0 ounces/day to 42.3 ounces/day (mean ± SD = 7.2 ± 3.0 ounces/day). All participants reported being non-smokers, in good health, not using prescription medication other than oral contraceptives, and not using nicotine in any form. Written informed consent was obtained, and all procedures were approved by the Tufts University Institutional Review Board.

Design

A double-blind, repeated-measures design was used with caffeine and theanine treatment as the independent variables (0 mg caffeine + 0 mg theanine, 0 mg caffeine + 200 mg theanine, 200 mg caffeine + 0 mg theanine, and 200 mg caffeine + 200 mg theanine). The dose of caffeine chosen was roughly equivalent to an 8-ounce coffee purchased at a local coffee chain (Starbucks short coffee; 180 mg) and the dose of theanine was approximately that which could be consumed with five 8-ounce cups of tea (Cooper et al. 2005). Similar doses of theanine have been shown to reduce perceived stress (Kimura et al. 2007) and influence attention-related electroencephalographic activity (Gomez-Ramirez et al. 2007, 2009; Kahathuduwa et al. 2016). Treatment order was counterbalanced across participants using a complete Latin square. Participants were tested during morning sessions following a 12 h fast, which is thought to be a sufficient wash-out period to attenuate the effects of earlier caffeine and theanine consumption, particularly given that the mean plasma elimination half-life ranges from 3 to 10 h in caffeine (Blanchard and Sawers 1983; Nehlig et al. 1992; Scott et al. 1989) and from 65 to 75 min in theanine (Scheid et al. 2012; van der Pijl et al. 2010). Participants were further instructed not to use any over-the-counter medications or herbal supplements for 24 h prior to testing.

Caffeine or placebo administration

To control for taste, treatments were administered in capsule form. Each treatment dose was administered in a capsule of identical color, size, mass, and shape. Capsules contained 0 mg caffeine + 200 mg theanine, 200 mg caffeine + 0 mg theanine, 200 mg caffeine + 200 mg theanine, or 0 mg caffeine + 0 mg theanine. Placebo capsules were filled with physiologically inert microcrystalline cellulose powder. The caffeine was 99.8% pure anhydrous United States Pharmacopoeia (USP)-grade powder. Theanine capsules contained theanine (L) powder (99.1% pure) and physiologically inert microcrystalline cellulose powder. Capsules were provided by a registered pharmacist at Compounded Solutions (Monroe, Connecticut, USA).

Salivary cortisol

Saliva was collected for analyses of salivary cortisol, a biomarker of physiological arousal (Kirschbaum and Hellhammer 1989). Samples were immediately aliquoted and stored at –20 °C or colder until they were assayed. Samples were analyzed in duplicate using the ELISA procedure by an independent laboratory (Salimetrics LLC, State College, Pennsylvania, USA) with estimated sensitivity of <0.007 μg/dL.

Questionnaires

Typical Consumption Questionnaire

The Typical Consumption Questionnaire asked participants to report their consumption of caffeinated beverages, including frequency and type of beverage (Lieberman et al. 2012). Total caffeine consumption per day (mg/day) was calculated for each participant.

Profile of Mood States (POMS) questionnaire

The POMS is an inventory of subjective mood and arousal states (McNair et al. 1971). Participants were asked to rate a series of 65 mood-related adjectives on a five-point scale, using the response set of "how are you feeling right now?" The adjectives factor into 6 mood subscales (tension, depression, anger, vigor, fatigue, and confusion), as well as composite score for total mood disturbance (Lieberman et al. 1996). The POMS is sensitive to a wide range of environmental factors: sleep loss, nutritional manipulations, and subclinical doses of various drugs (Banderet and Lieberman 1989; Fine et al. 1994; Lieberman et al. 2002).

Cognitive tasks

Hierarchical shape task

The hierarchical shape task tests attentional biases for global versus local perceptual analyses of objects. Participants viewed a target array located on the upper portion of a computer screen and 2 comparison arrays located below the target. One of the comparisons matched the global configuration of the target and the other matched the target's local information. The task was to indicate which of the 2 comparison arrays was more similar to the target by pressing a corresponding key (Kimchi and Palmer 1982). For example, a target figure could consist of either a square or a triangle (global form) made up of smaller squares or triangles (local form). Thus, it is possible to perceive a single figure from either a global or a local perspective. The dependent measure is the proportion of local versus global matches selected.

Attention Network Test (ANT)

The ANT simultaneously tests the individual performance of the 3 networks in Posner's (1990) attention model by combining a cued reaction time (RT) (Posner 1980) and flanker test (Eriksen and Eriksen 1974). The ANT involves viewing a sequence of visual cues and arrows and responding to the direction of a central arrow (Fan et al. 2002). A cue can alert an individual that a trial is about to be presented only, or it can also orient the individual to a particular region of space (above or below fixation). A central target arrow is then presented within an array of congruent (same facing direction), incongruent (opposite facing direction), or neutral (no facing direction) flankers. Response time and accuracy are measured when the participant responds to the direction (left or right) of the central arrow. Three primary indicators of attentional function are calculated from the ANT data: (1) the extent to which cues are alerting the participant of an upcoming trial, relative to when no cue is provided (i.e., alerting network function); (2) the extent to which spatially determinate cues are orienting the participant towards a particular region of the screen, relative to spatially indeterminate cues (i.e., orienting network function); and (3) the extent to which incongruent relative to congruent or neutral flankers interfere with the determination of and response to a central arrow's facing direction (i.e., executive control network function).

The ANT involves 3 blocks of 96 trials (total of 288 trials) presented in random order. Each block presents 2 trials for each of the 4 cue conditions (none, center, double, spatial), 2 target locations (top, bottom), 2 target directions (left, right), and 3 flanker conditions (neutral, congruent, incongruent). In each trial, the participants identify and respond to the center arrow's facing direction (left or right).

Procedure

Participants completed 6 sessions: one screening session, one practice session to become familiarized with the experimental procedure and tasks, and 4 test sessions corresponding to each treatment. During the screening session, participants were screened for exclusion criteria and completed the informed consent and Typical Consumption Questionnaire. During the practice session, participants first completed baseline measures of the POMS and salivary cortisol. They then watched a 1 h video of the popular television series Band of Brothers. The video was of neutral content and intended to give the participants the context of the characters and plot of the videos they would be viewing during the test sessions (from the same television series). Following the video, the participants completed a second POMS and saliva sample. They then viewed the first series of pictures from the International Affective Picture System (IAPS; Lang et al. 2005), which were neutral with regard to arousal and valence, followed by the Hierarchical Shape Task. After the Hierarchical Shape Task, the participants viewed a second series of neutral pictures, followed by the ANT. One practice session was sufficient to avoid learning effects during the test sessions, given that the ANT shows little evidence of practice effects (Fan et al. 2002) and practice effects on the Hierarchical Shape Task occur relatively quickly, stabilizing within half an hour (Weissman et al. 2002). The participants then provided a third POMS and saliva sample.

Test sessions were similar to the practice session. Following baseline POMS and saliva sample, participants consumed their assigned treatment capsule. Following a 25-minute break, participants watched a 30-minute video clip from Band of Brothers, which was characterized through pilot testing as high arousal, negative valence[1]. Following the video, the procedure for the remainder of each test session was identical to that of the practice session, with the exception of the pictures' content, which was characterized as negative valence and high arousal, such as a crying boy, patient illness and disease, and injury. Viewing such pictures was intended to induce and maintain a psychologically aroused state with a negative valence and was completed prior to each of the cognitive tasks (see Fig. 1 for schematic of study design).

Statistical analyses

Analysis consisted of repeated-measures analysis of variance (ANOVA) with treatment (Caffeine, Theanine, Caffeine+Theanine, Placebo) and time (Before intake, 60 min after intake, 120 min after intake) as the within-participant variables. An effect was deemed statistically significant if the likelihood of its occurrence by chance was $p < 0.05$. In the case of a significant interaction, post hoc analyses using the Bonferroni correction were used. All statistical analyses were performed using SPSS 12.0.

Results

Salivary cortisol

Analyses of salivary cortisol were limited to 32 participants, as 4 participants did not provide sufficient saliva to detect cortisol. Analyses revealed main effects for treatment ($F_{[3,99]} = 2.973$, $p < 0.05$) and time ($F_{[2,66]} = 7.96$, $p < 0.01$). Cortisol was significantly higher following caffeine than theanine intake (Table 1) and showed the typical decline throughout the morning (Kirschbaum and Hellhammer 1989).

POMS

Analyses of the POMS revealed main effects of treatment for "tension" ($F_{[3,105]} = 3.444$, $p < 0.05$), "anger" ($F_{[3,105]} = 5.342$, $p < 0.01$),

[1]Pilot testing on Band of Brothers video clips was performed with 25 participants in a repeated measures design, in which participants watched the neutral video clip (i.e., the pilot episode) and negative video clips on separate days. They rated their mood according to the Profile of Mood States immediately before and after viewing the video clips. Participants felt greater anger, vigor, fatigue, confusion, and total mood disturbance after viewing the negative clips relative to the neutral clips (ps < 0.01), but not before viewing the clips.

Fig. 1. Schematic representation of the study schedule. During the study sessions, participants first completed baseline measures of the Profile of Mood States (POMS) and provided 6 mL saliva samples to test for salivary cortisol. They consumed their assigned treatment capsule. They then took a 30-minute break. They then watched a highly arousing and negatively valenced film. Participants then completed a second POMS and saliva sample. They then watched a series of highly arousing and negatively valenced pictures from the International Affective Picture System (IAPS), completed the hierarchical shape task watched a second series of IAPS, and completed the Attention Network Test (ANT). Finally, they completed a third POMS and saliva sample.

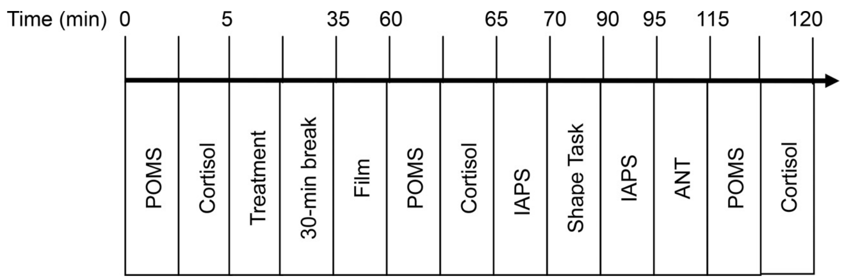


Table 1. Effects of caffeine and theanine, alone and in combination, on salivary cortisol (μg/dL).

	Before intake	60 min after intake	120 min after intake
Theanine	0.20 (0.03)	0.18 (0.03)	0.10 (0.01)
Caffeine	0.23 (0.04)	0.23 (0.04)	0.19 (0.03)
Caffeine+Theanine	0.21 (0.03)	0.21 (0.03)	0.17 (0.03)
Placebo	0.21 (0.03)	0.20 (0.03)	0.13 (0.02)

Note: Means (SD) are shown for each time point. Cortisol was higher under caffeine than theanine intake ($p < 0.05$) and decreased throughout the morning ($p < 0.01$).

"confusion" ($F_{[3,105]} = 3.896$, $p < 0.05$), and "total mood disturbance" ($F_{[3,105]} = 5.154$, $p < 0.01$) (Table 2). Participants felt less tense and angry following Caffeine and Caffeine+Theanine intake relative to Placebo, but not after Theanine intake. Relative to Placebo, total mood disturbance was higher following Caffeine and Caffeine+Theanine intake, but not following Theanine intake.

Main effects of time were found for "anger" ($F_{[2,70]} = 7.897$, $p < 0.01$), "confusion" ($F_{2,70]} = 3.533$, $p < 0.05$), "vigor" ($F_{[2,70]} = 6.54$, $p < 0.01$), and "total mood disturbance" ($F_{[2,70]} = 4.125$, $p < 0.05$). Across all treatments, participants felt more anger, confusion, vigor, and total mood disturbance 60 and 120 min after intake relative to before intake.

Treatment by time interactions were found for "depression" ($F_{[6,210]} = 2.879$, $p < 0.05$), "confusion" ($F_{[6,210]} = 2.815$, $p < 0.05$), "vigor" ($F_{[6,210]} = 2.16$, $p < 0.05$), and "total mood disturbance" ($F_{[6,210]} = 2.285$, $p < 0.05$), which were characterized by increased depression and vigor 60 and 120 min after Caffeine intake relative to before intake ($ps < 0.01$) and increased confusion and total mood disturbance 60 and 120 min after Caffeine and Caffeine+Theanine intake relative to before intake ($ps < 0.05$). Rated depression, confusion, vigor, and total mood disturbance did not change following Theanine or Placebo intake ($ps > 0.05$).

No main effects or interactions were found for "fatigue" ($ps > 0.19$).

Hierarchical shape task

Analyses from the hierarchical shape task revealed a main effect of treatment, $F_{[3,105]} = 6.11$ $p < 0.01$ (Fig. 2). Planned comparisons revealed a significantly greater global processing bias with Caffeine relative to Placebo, $t(35) = 2.28$, $p < 0.05$, a significantly greater local processing bias with Theanine relative to Placebo, $t(35) = -2.15$, $p < 0.05$, and no significant differences in global versus local processing between Caffeine+Theanine and Placebo.

Attention network task

Each of the 3 attention networks: alerting, orienting, and executive control were assessed independently by calculating difference scores for each network (Fan et al. 2002, 2005; Redick and Engle 2006). The alerting difference score was calculated by subtracting mean double-cue RTs from the no-cue RTs. The orienting difference score was calculated by subtracting mean spatial cue RTs from center-cue RTs. Finally, an executive control score was calculated by subtracting mean congruent flanker RTs (across all cue types) from incongruent flanker RTs. Note that for the alerting and orienting systems, higher difference scores indicate more

Table 2. Effects of caffeine and theanine, alone and in combination, on the Profile of Moods States.

	Before intake	60 min after intake	120 min after intake
Tension			
Theanine	5.94 (0.52)	6.31 (0.62)	6.00 (0.57)
Caffeine	6.03 (0.63)	7.42 (0.74)	7.56 (0.71)
Caffeine+Theanine	6.25 (0.57)	7.47 (0.73)	7.31 (0.66)
Placebo	5.86 (0.56)	5.72 (0.55)	6.25 (0.50)
Depression			
Theanine	10.58 (0.77)	10.33 (1.04)	11.78 (0.87)
Caffeine	10.53 (0.92)	12.58 (0.86)**	12.72 (0.94)**
Caffeine+Theanine	11.33 (0.91)	12.17 (0.85)	11.64 (0.86)
Placebo	11.28 (0.87)	10.25 (0.81)	11.64 (0.99)
Anger			
Theanine	4.67 (0.81)	6.81 (1.16)	6.83 (1.25)
Caffeine	6.19 (1.07)	9.83 (1.44)	9.67 (1.65)
Caffeine+Theanine	6.36 (0.93)	9.58 (1.28)	8.06 (1.10)
Placebo	5.64 (0.76)	7.03 (0.79)	7.39 (1.17)
Vigor			
Theanine	7.94 (0.64)	8.94 (0.70)	8.92 (0.77)
Caffeine	7.39 (0.58)	10.31 (0.72)**	9.28 (0.65)**
Caffeine+Theanine	8.50 (0.66)	9.31 (0.69)	9.06 (0.73)
Placebo	8.64 (0.65)	9.06 (0.65)	9.47 (0.74)
Fatigue			
Theanine	3.94 (0.55)	5.00 (0.62)	5.06 (0.77)
Caffeine	4.81 (0.78)	5.81 (0.88)	5.06 (0.95)
Caffeine+Theanine	4.83 (0.71)	5.92 (0.78)	4.89 (0.69)
Placebo	4.61 (0.63)	4.47 (0.60)	5.17 (0.75)
Confusion			
Theanine	3.78 (0.47)	4.67 (0.67)	4.78 (0.63)
Caffeine	4.39 (0.59)	6.25 (0.72)*	6.00 (0.75)*
Caffeine+Theanine	4.89 (0.53)	6.11 (0.66)*	5.03 (0.57)*
Placebo	4.81 (0.54)	4.61 (0.62)	4.44 (0.53)
Total mood disturbance			
Theanine	20.97 (2.21)	24.17 (3.17)	25.53 (3.03)
Caffeine	24.56 (2.99)	31.58 (3.56)*	31.72 (3.97)*
Caffeine+Theanine	25.17 (2.58)	31.94 (3.17)*	27.86 (2.74)*
Placebo	23.56 (2.16)	23.03 (2.20)	25.42 (2.74)

Note: Means (SD) are shown for each mood subscale and time point. Caffeine, with and without theanine, increased ratings of tension, depression, anger, confusion, and total mood disturbance ($ps < 0.05$) and caffeine alone increased ratings of vigor ($p < 0.01$).

*$p < 0.05$ and **$p < 0.01$ relative to before intake.

Fig. 2. Mean proportion global responses and standard errors for each of the 4 treatment conditions. *, $p < 0.05$ relative to placebo.

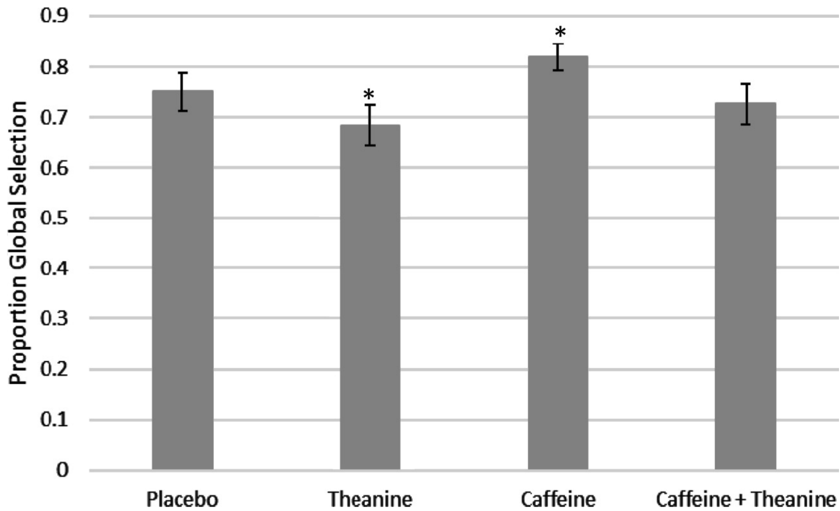
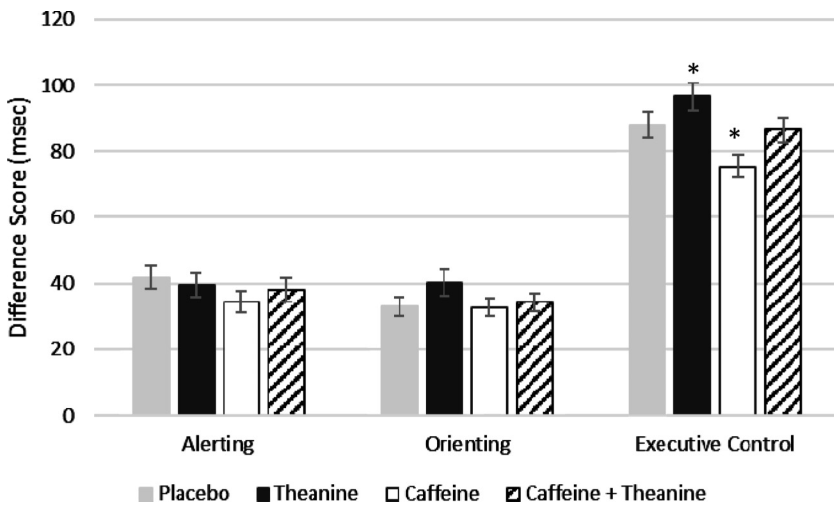


Fig. 3. Mean difference scores and standard errors for each of the 3 attention networks and 4 treatment conditions. Note that higher difference scores in the alerting and orienting networks indicate greater performance, and lower difference scores in the executive control network indicate greater performance. *, $p < 0.05$ relative to placebo.



efficient functioning, whereas for executive control, higher difference scores indicate poorer functioning.

Analyses of the executive function score revealed a main effect of treatment ($F_{[3,105]} = 8.175$, $p < 0.01$) (Fig. 3). Planned comparisons confirmed higher conflict difference scores in the Placebo condition relative to the Caffeine condition, $t(35) = -2.64$, $p < 0.05$, higher conflict difference scores in the Theanine condition relative to the Placebo condition, $t(35) = 2.62$, $p < 0.05$, and no significant differences in conflict scores between the Placebo condition and the Caffeine+Theanine condition. No significant differences were found for the alerting and orienting systems.

Discussion

The present study examined the effects of theanine and caffeine, administered alone and together, on measures of physiological arousal, mood, and visual attention during a heightened state of emotional arousal. Results showed that, when consumed prior to exposure to highly arousing and emotional material, caffeine and theanine differentially modulated the physiological stress response, mood, and visual attention.

Subjective and physiological mood and arousal

Caffeine consumption, both with and without theanine, elevated feelings of tension, depression, anger, confusion, and total mood disturbance. In the absence of theanine, caffeine also enhanced feelings of vigor and depression. Such findings are consistent with previous studies showing that caffeine reliably increases self-reported arousal measures across a range of doses (e.g., 100–400 mg caffeine) (Addicott and Laurienti 2009; Mahoney et al. 2011; Smith et al. 2006). Thus, under heightened emotional arousal, the mood effects of caffeine and theanine appear to be driven by caffeine. Such results are in line with previous research showing that tea containing caffeine (40–90 mg) and theanine (36–97 mg) enhanced alertness and reduced calmness relative to a placebo tea (De Bruin et al. 2011; Giesbrecht et al. 2010). Similarly, studies that differentiated between the influence of caffeine (50–150 mg) and theanine (100–250 mg) found that, when consumed together, caffeine and theanine enhanced alertness and reduced fatigue (Haskell et al. 2008; Owen et al. 2008). However, we found no evidence that theanine ameliorated the effects of caffeine on other mood dimensions, including tension, anger, and confusion. Although some research suggests that 200 mg theanine enhanced self-reported relaxation following a stressful situation (Kimura et al. 2007), there is other research to suggest that the same dose of theanine reduces anxiety during a relatively relaxed state, but not an anxious state (Lu et al. 2004).

Cortisol levels were higher following caffeine than theanine intake. Theanine has been shown to reduce stress-induced cortisol increases (Steptoe et al. 2007) and attenuate stress-induced increases in the level of perceived stress, anxiety, and sympathetic nervous system activation, as assessed by heart rate and salivary immunoglobulin A (Kimura et al. 2007). Thus, converging evidence suggests that, when consumed alone, theanine diminishes physiological indices of emotional arousal.

Global versus local processing

The way we perceive our environment has implications for our ability to attend to environmental cues. The present results suggest that ingesting coffee, for example, could enhance attention to the general location of key landmarks or regions (e.g., theater district, Empire State Building), while ingesting tea could enhance attention to particular landmarks (e.g., particular theaters, buildings adjacent to the Empire State Building). Caffeine accentuated global processing on the hierarchical shape task, whereas theanine accentuated local processing. The combination of caffeine and theanine did not differ from placebo, suggesting that the 2 compounds negated each other's effects. The results are consistent with recent research suggesting that caffeine accentuates global processing biases in visual perception including the same hierarchical shape task employed in the present experiment (Mahoney et al. 2011), language-based tasks (Brunyé et al. 2012), and spatial memory tasks (Giles et al. 2013). Additionally, emotional arousal, regardless of positive or negative valence, has been shown to augment global spatial processing (Brunyé et al. 2009), suggesting that increasing arousal via either caffeine intake or emotion induction magnifies the global processing bias, whereas reducing arousal via theanine intake results in enhanced attention to details. Subsequent studies should address whether caffeine- and emotion-induced arousal act independently or synergistically to modulate global visual processing. Results support the hypothesis that caffeine, consumed prior to an emotionally arousing experience, accentuates a selective processing bias towards global features. However, when theanine is consumed with caffeine, theanine reduces this effect. Caffeine and theanine's influence on global and local spatial processing may stem, in part, from their influence on resting state arousal. Though tentative, arousal such as via aerobic exercise (Woo et al. 2009) and caffeine intake (Koppelstaetter et al. 2008; Lorist and Snel 1997) may be associated with greater right than left hemisphere activity, and there is evidence for a right-hemisphere advantage for global processing (Heinze and Münte 1993; Proverbio et al. 1998; Yamaguchi et al. 2000).

Attention

Results from the ANT show that, across a range of habitual caffeine consumption profiles, a dose of 200 mg caffeine or theanine did not affect lower order visual attention (i.e., alerting or orienting) following an emotionally arousing experience. However, these doses were sufficient to affect executive function. Caffeine consumption resulted in the expected improvement in executive function (Brunyé et al. 2010*a*, 2010*b*). In contrast, theanine prior to an emotionally arousing experience resulted in decrements in executive function, potentially related to its anxiolytic properties. Under non-stressful conditions, increasing relaxation through meditation and mindfulness training has been shown to enhance ANT performance (Jha et al. 2007; Tang et al. 2007). However, under stressful conditions, research has indicated that decreasing arousal leads to less efficiency in controlling behavior and reduced ability to produce an appropriate response (Eysenck and Calvo 1992; Eysenck et al. 2007).

Previous studies specifically addressing the influence of caffeine and theanine on attention and other cognitive processes have elicited inconsistent results. For instance, tea containing 100 mg caffeine and 46 mg theanine improved intersensory attention and task switching in habitual caffeine consumers relative to placebo (De Bruin et al. 2011). Opposite doses, i.e., 40–50 mg caffeine with 90–100 mg theanine, improved attention switching in habitual caffeine consumers relative to placebo (Giesbrecht et al. 2010) and sustained attention across a range of habitual consumption profiles (Foxe et al. 2012), but not without exception (Einöther et al. 2010). Other studies suggest that caffeine is primarily responsible for any beneficial influence on attention, as 50 mg caffeine, with and without 100 mg theanine, improved sensitivity on an attention task, whereas theanine alone had no effects (Kelly et al. 2008). Similarly, 50 mg caffeine and 100 mg theanine together improved attention switching 60 min after intake, but only caffeine showed the effect 90 min after intake (Owen et al. 2008). It is possible that while theanine may provide some benefit to regulating emotion, decreasing arousal in a stressful situation actually leads to less efficiency in controlling behavior and a reduced ability to produce an appropriate response.

Limitations

Several limitations are worth noting. First, typical caffeine consumption averaged 129 mg per day, whereas typical tea consumption averaged just under 1 cup of tea per day. Thus, the caffeine dose was within the range of daily consumption for many participants, but the theanine dose likely exceeded typical daily consumption. Although it is unknown whether theanine consumption leads to habituation, habitual caffeine consumption results in increased tolerance for its stimulating properties and withdrawal effects upon cessation of intake (James and Rogers 2005). Relevant to the present study, in previous work, caffeine enhanced executive function on the ANT and detection for global errors on a language-based task beginning at 200 mg caffeine in low habitual caffeine consumers and 400 mg caffeine in high habitual caffeine consumers (Brunyé et al. 2010*a*, 2010*b*, 2012). Additionally, a global processing bias was evident on the hierarchical shape task after 100 mg caffeine in low habitual caffeine consumers (Mahoney et al. 2011). Thus, sufficient evidence suggests that caffeine influences visual attention across a wide range of habitual caffeine consumption profiles and caffeine doses.

Second, the study design did not include a neutral condition, in which participants were not exposed to the emotionally arousing stimuli. Without this condition, it is impossible to determine whether caffeine and theanine influence arousal-induced changes in mood and cognition, or whether the effects seen here would be similar regardless of emotional arousal state. Previous results that theanine enhances self-reported feelings of relaxation following a stressful situation and diminishes stress-induced increases in perceived stress, anxiety, and sympathetic nervous system activation (Kimura et al. 2007; Steptoe et al. 2007) are hampered by the same design weakness. Future research should compare the influence of caffeine and theanine, alone and in combination, under stressful or emotionally arousing conditions versus a neutral condition to further examine the interaction between caffeine, theanine, and arousal.

Third, the doses of caffeine and theanine were not representative of a typical cup of tea. A standard cup of black or green tea contains 20–60 mg caffeine and 20–40 mg theanine (Cooper et al. 2005). Thus, the present doses equates to 3–10 cups of prepared tea. Approximately 15%–55% of individuals in the United States drink tea (Duffey and Popkin 2007; Ozen et al. 2012) with a mean intake of 23–30 mg caffeine per day from tea (Frary et al. 2005; Fulgoni et al. 2015). However, in other countries, such as the United Kingdom, anecdotal evidence suggests that tea intake may reach 6–9 cups per day (Khokhar and Magnusdottir 2002). Further, the caffeine dose in the current study is representative of that of the United States population, whose per capita caffeine consumption averaged 211 mg caffeine per day among habitual caffeine consumers (Fulgoni et al. 2015). Thus, although the doses chosen in the current study are higher than those in tea in the United States, they are relevant to tea intake in other countries and caffeine intake in the United States.

Conclusions

Given the prevalence of coffee and tea consumption, it is critical to understand the effects of caffeine and theanine on the brain and associated cognitive processes. Our results add to a growing body of evidence showing that caffeine can have beneficial effects on executive control of visual attention (Brunyé et al. 2010*a*, 2010*b*; Giles et al. 2013; Mahoney et al. 2011), as well as add to a relatively new area suggesting that theanine may have calming properties following arousing conditions (Kimura et al. 2007; Steptoe et al. 2007). The present study is the first, to our knowledge, to show that when exposed to heighted emotional stimuli, theanine and caffeine alone exert differential effects on physiological response and attentional processes, but when consumed together, they counteract the effects of each other.

The present results provide evidence that physiological arousal associated with caffeine consumption produces reliable and pronounced increases in global biases in human perception and that theanine, when consumed with caffeine, decreases this effect, potentially related to its calming effects. Our findings also suggest that a dose of 200 mg caffeine or theanine does not affect relatively lower order visual attention, but does influence executive control. Given the popularity of tea worldwide (Grigg 2002), these results carry significant implications for the way in which people attend to and process information.

Conflict of interest

The authors declare that there is no conflict of interest associated with this work.

References

Addicott, M.A., and Laurienti, P.J. 2009. A comparison of the effects of caffeine following abstinence and normal caffeine use. Psychopharmacology, **207**(3): 423–431. doi:10.1007/s00213-009-1668-3.

Banderet, L.E., and Lieberman, H.R. 1989. Treatment with tyrosine, a neurotransmitter precursor, reduces environmental stress in humans. Brain Res. Bull. **22**: 851–856. doi:10.1016/0361-9230(89)90096-8.

Barone, J.J., and Roberts, H.R. 1996. Caffeine consumption. Food Chem. Toxicol. **34**(1): 119–129. doi:10.1016/0278-6915(95)00093-3. PMID:8603790.

Barry, R.J., Johnstone, S.J., Clarke, A.R., Rushby, J.A., Brown, C.R., and McKenzie, D.N. 2007. Caffeine effects on ERPs and performance in an auditory go/NoGo task. Clin. Neurophysiol. **118**(12): 2692–2699. doi:10.1016/j.clinph.2007.08.023. PMID:17905651.

Blanchard, J., and Sawers, S.J.A. 1983. The absolute bioavailability of caffeine in man. Eur. J. Clin. Pharmacol. **24**: 93–98. doi:10.1007/BF00613933. PMID:6832208.

Brunyé, T.T., Mahoney, C.R., Augustyn, J.S., and Taylor, H.A. 2009. Emotional state and local versus global spatial memory. Acta Psychol. **130**(2): 138–146. doi:10.1016/j.actpsy.2008.11.002.

Brunyé, T.T., Mahoney, C.R., Lieberman, H.R., and Taylor, H.A. 2010*a*. Caffeine modulates attention network function. Brain Cogn. **72**(2): 181–188. doi:10.1016/j. bandc. 2009.07.013. PMID:19733954.

Brunyé, T.T., Mahoney, C.R., Lieberman, H.R., Giles, G.E., and Taylor, H.A. 2010*b*. Acute caffeine consumption enhances the executive control of visual attention in habitual consumers. Brain Cogn. **74**: 186–192. doi:10.1016/j.bandc.2010.07.006. PMID:20832925.

Brunyé, T.T., Mahoney, C.R., Rapp, D.N., Ditman, T., and Taylor, H.A. 2012. Caffeine enhances real-world language processing: Evidence from a proofreading task. J. Exp. Psychol. Appl. **18**(1): 95–108. doi:10.1037/a0025851. PMID:21988325.

Cooper, R., Morré, D.J., and Morré, D.M. 2005. Medicinal benefits of green tea: Part I. review of noncancer health benefits. J. Altern. Complement. Med. **11**(3): 521–528. doi:10.1089/acm.2005.11.521. PMID:15992239.

Davidson, R.A., and Smith, B.D. 1991. Caffeine and novelty: Effects on electrodermal activity and performance. Physiol. Behav. **49**(6): 1169–1175. doi:10.1016/0031-9384(91)90346-P. PMID:1896498.

De Bruin, E.A., Rowson, M.J., Van Buren, L., Rycroft, J.A., and Owen, G.N. 2011. Black tea improves attention and self-reported alertness. Appetite, **56**(2): 235–240. doi:10.1016/j.appet.2010.12.011. PMID:21172396.

Dodd, F.L., Kennedy, D.O., Riby, L.M., and Haskell-Ramsay, C.F. 2015. A double-blind, placebo-controlled study evaluating the effects of caffeine and L-theanine both alone and in combination on cerebral blood flow, cognition and mood. Psychopharmacology, **232**(14): 2563–2576. doi:10.1007/s00213-015-3895-0.

Duffey, K.J., and Popkin, B.M. 2007. Shifts in patterns and consumption of beverages between 1965 and 2002. Obesity, **15**(11): 2739–2747. doi:10.1038/oby.2007.326.

Einöther, S.J., Martens, V.E., Rycroft, J.A., and De Bruin, E.A. 2010. L-theanine and caffeine improve task switching but not intersensory attention or subjective alertness. Appetite, **54**(2): 406–409. doi:10.1016/j.appet.2010.01.003. PMID:20079786.

Eriksen, B.A., and Eriksen, C.W. 1974. Effects of noise letters upon the identification of a target letter in a nonsearch task. Percept. Psychophys. **16**: 143–149. doi:10.3758/BF03203267.

Eysenck, M.W., and Calvo, M.G. 1992. Anxiety and performance: The processing efficiency theory. Cogn. Emot. **6**(6): 409–434. doi:10.1080/02699939208409696.

Eysenck, M.W., Derakshan, N., Santos, R., and Calvo, M.G. 2007. Anxiety and cognitive performance: Attentional control theory. Emotion, **7**(2): 336–353. doi:10.1037/1528-3542.7.2.336. PMID:17516812.

Fan, J., McCandliss, B.D., Sommer, T., Raz, A., and Posner, M.I. 2002. Testing the efficiency and independence of attentional networks. J. Cogn. Neurosci. **14**: 340–347. doi:10.1162/089892902317361886. PMID:11970796.

Fan, J., McCandliss, B.D., Fossella, J., Flombaum, J.I., and Posner, M.I. 2005. The activation of attentional networks. Neuroimage, **26**(2): 471–479. doi:10.1016/j.neuroimage.2005.02.004. PMID:15907304.

Fine, B.J., Kobrick, J.L., Lieberman, H.R., Marlowe, B., Riley, R.H., and Tharion, W.J. 1994. Effects of caffeine or diphenhydramine on visual vigilance. Psychopharmacology, **114**: 233–238. doi:10.1007/BF02244842.

Foxe, J.J., Morie, K.P., Laud, P.J., Rowson, M.J., de Bruin, E.A., and Kelly, S.P. 2012. Assessing the effects of caffeine and theanine on the maintenance of vigilance during a sustained attention task. Neuropharmacology, **62**(7): 2320–2327. doi:10.1016/j.neuropharm.2012.01.020. PMID:22326943.

Frary, C.D., Johnson, R.K., and Wang, M.Q. 2005. Food sources and intakes of caffeine in the diets of persons in the united states. J. Am. Diet. Assoc. **105**(1): 110–113. doi:10.1016/j.jada.2004.10.027. PMID:15635355.

Fulgoni, V.L., 3rd, Keast, D.R., and Lieberman, H.R. 2015. Trends in intake and sources of caffeine in the diets of US adults: 2001-2010. Am. J. Clin. Nutr. **101**(5): 1081–1087. doi:10.3945/ajcn.113.080077. PMID:25832334.

Gerra, G., Zaimovic, A., Mascetti, G.G., Gardini, S., Zambelli, U., Timpano, M., et al. 2001. Neuroendocrine responses to experimentally-induced psychological stress in healthy humans. Psychoneuroendocrinology, **26**(1): 91–107. doi:10.1016/S0306-4530(00)00046-9. PMID:11070337.

Giesbrecht, T., Rycroft, J.A., Rowson, M.J., and De Bruin, E.A. 2010. The combination of L-theanine and caffeine improves cognitive performance and increases subjective alertness. Nutr. Neurosci. **13**(6): 283–290. doi:10.1179/147683010X12611460764840. PMID:21040626.

Giles, G.E., Mahoney, C.R., Brunyé, T.T., Taylor, H.A., and Kanarek, R.B. 2013. Caffeine promotes global spatial processing in habitual and non-habitual caffeine consumers. Front. Psychiatry, **7**. doi:10.3389/fnhum.2013.00694.

Gomez-Ramirez, M., Higgins, B.A., Rycroft, J.A., Owen, G.N., Mahoney, J., Shpaner, M., and Foxe, J.J. 2007. The deployment of intersensory selective attention: A high-density electrical mapping study of the effects of theanine. Clin. Neuropharmacol. **30**(1): 25–38. doi:10.1097/01.WNF.0000240940.13876.17. PMID:17272967.

Gomez-Ramirez, M., Kelly, S.P., Montesi, J.L., and Foxe, J.J. 2009. The effects of L-theanine on alpha-band oscillatory brain activity during a visuo-spatial attention task. Brain Topogr. **22**(1): 44–51. doi:10.1007/s10548-008-0068-z. PMID:18841456.

Green, P.J., and Suls, J. 1996. The effects of caffeine on ambulatory blood pressure, heart rate, and mood in coffee drinkers. J. Behav. Med. **19**(2): 111–128. doi:10.1007/BF01857602. PMID:9132505.

Grigg, D. 2002. The worlds of tea and coffee: Patterns of consumption. GeoJournal, **57**: 283–294. doi:10.1023/B:GEJO.0000007249.91153.c3.

Haskell, C.F., Kennedy, D.O., Milne, A.L., Wesnes, K.A., and Scholey, A.B. 2008. The effects of L-theanine, caffeine and their combination on cognition and mood. Biol. Psychol. **77**(2): 113–122. doi:10.1016/j.biopsycho.2007.09.008. PMID:18006208.

Heinze, H.J., and Münte, T.F. 1993. Electrophysiological correlates of hierarchical stimulus processing: Dissociation between onset and later stages of global and local target processing. Neuropsychologia, **31**(8): 841–852. doi:10.1016/0028-3932(93)90132-J. PMID:8413904.

James, J.E., and Gregg, M.E. 2004. Effects of dietary caffeine on mood when rested and sleep restricted. Hum. Psychopharmacol. Clin. Exp. **19**(5): 333–341. doi:10.1002/hup.589. PMID:15252825.

James, J.E., and Rogers, P.J. 2005. Effects of caffeine on performance and mood: Withdrawal reversal is the most plausible explanation. Psychopharmacology, **182**: 1–8. doi:10.1007/s00213-005-0084-6.

Jha, A.P., Krompinger, J., and Baime, M.J. 2007. Mindfulness training modifies subsystems of attention. Cogn. Affect. Behav. Neurosci. **7**(2): 109–119. doi:10.3758/CABN.7.2.109. PMID:17672382.

Juneja, L.R., Chu, D.C., Okubo, T., Nagato, Y., and Yokogoshi, H. 1999. L-theanine-a unique amino acid of green tea and its relaxation effect in humans. Trends Food Sci. Tech. **10**: 199–204. doi:10.1016/S0924-2244(99)00044-8.

Kahathuduwa, C.N., Dassanayake, T.L., Amarakoon, A.M., and Weerasinghe, V.S. 2016. Acute effects of theanine, caffeine and theanine-caffeine combination on attention. Nutr. Neurosci. doi:10.1080/1028415X. 2016.1144845.

Keenan, E.K., Finnie, M.D.A., Jones, P.S., Rogers, P.K., and Priestley, C.M. 2011. How much theanine in a cup of tea? effects of tea type and method of preparation. Food Chem. **125**(2): 588–594. doi:10.1016/j.foodchem.2010.08.071.

Kelly, S.P., Gomez-Ramirez, M., Montesi, J.L., and Foxe, J.J. 2008. L-theanine and caffeine in combination affect human cognition as evidenced by oscillatory alpha-band activity and attention task performance. J. Nutr. **138**(8): 1572S–1577S. PMID:18641209.

Khokhar, S., and Magnusdottir, S.G. 2002. Total phenol, catechin, and caffeine contents of teas commonly consumed in the United Kingdom. J. Agric. Food Chem. **50**(3): 565–570. doi:10.1021/jf010153l. PMID:11804530.

Kimchi, R., and Palmer, S.E. 1982. Form and texture in hierarchically constructed patterns. J. Exp. Psychol. Hum. Percept. Perform. **8**(4): 521–535. doi:10.1037/0096-1523.8.4.521. PMID:6214605.

Kimura, K., Ozeki, M., Juneja, L.R., and Ohira, H. 2007. L-theanine reduces psychological and physiological stress responses. Biol. Psychol. **74**(1): 39–45. doi:10.1016/j. biopsycho.2006.06.006. PMID:16930802.

Kimura, R., and Murata, T. 1986. Effect of theanine on norepinephrine and serotonin levels in rat brain. Chem. Pharm. Bull., **34**(7): 3053–3057. doi:10.1248/cpb.34.3053.

Kirschbaum, C., and Hellhammer, D.H. 1989. Salivary cortisol in psychobiological research: An overview. Neuropsychobiology, **22**(3): 150–169. doi:10.1159/000118611. PMID:2485862.

Koppelstaetter, F., Poeppel, T.D., Siedentopf, C.M., Ischebeck, A., Verius, M., Haala, I., et al. 2008. Does caffeine modulate verbal working memory processes? an fMRI study. NeuroImage, **39**: 492–499. doi:10.1016/j.neuroimage.2007.08.037. PMID:17936643.

Kudielka, B.M., Schommer, N.C., Hellhammer, D.H., and Kirschbaum, C. 2004. Acute HPA axis responses, heart rate, and mood changes to psychosocial stress (TSST) in humans at different times of day. Psychoneuroendocrinology, **29**(8): 983–992. doi:10.1016/j.psyneuen.2003.08.009. PMID:15219648.

Lang, P.J., Bradley, M.M., and Cuthbert, B.N. 2005. International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical report A-6. University of Florida, Gainesville, FL.

Lieberman, H.R., Mays, M.Z., Shukitt-Hale, B., Chinn, K.S.K., and Tharion, W.J. 1996. Effects of sleeping in a chemical protective mask on sleep quality and performance. Aviat. Space Environ. Med. **67**(9): 841–848. PMID:9025799.

Lieberman, H.R., Tharion, W.J., Shukitt-Hale, B., Speckman, K.L., and Tulley, R. 2002. Effects of caffeine, sleep loss, and stress on cognitive performance and mood during U.S. navy SEAL training. Psychopharmacology, **164**(3): 250–261. doi:10.1007/s00213-002-1217-9.

Lieberman, H.R., Stavinoha, T., McGraw, S., White, A., Hadden, L., and Marriott, B.P. 2012. Caffeine use among active duty US army soldiers. J. Acad. Nutr. Diet. **112**(6): 902–912.e4. doi:10.1016/j.jand.2012.02.001. PMID:22709816.

Liston, C., McEwen, B.S., and Casey, B.J. 2009. Psychosocial stress reversibly disrupts prefrontal processing and attentional control. Proc. Natl. Acad. Sci. U. S. A. **106**(3): 912–917. doi:10.1073/pnas.0807041106. PMID:19139412.

Lorist, M.M., and Snel, J. 1997. Caffeine effects on perceptual and motor processes. Electroencephalogr. Clin. Neurophysiol. **102**(5): 401–413. doi:10.1016/S0921-884X(97)95729-5. PMID:9191584.

Lovallo, W.R., Al'Absi, M., Blick, K., Whitsett, T.L., and Wilson, M.F. 1996. Stress-like adrenocorticotropin responses to caffeine in young healthy men. Pharmacol. Biochem. Behav. **55**(3): 365–369. doi:10.1016/S0091-3057(96)00105-0. PMID:8951977.

Lovallo, W.R., Whitsett, T.L., al'Absi, M., Sung, B.H., Vincent, A.S., and Wilson, M.F. 2005. Caffeine stimulation of cortisol secretion across the waking hours in relation to caffeine intake levels. Psychosom. Med. **67**(5): 734–739. doi:10.1097/01.psy.0000181270.20036.06. PMID:16204431.

Lovallo, W.R., Farag, N.H., Vincent, A.S., Thomas, T.L., and Wilson, M.F. 2006. Cortisol responses to mental stress, exercise, and meals following caffeine intake in men and women. Pharmacol. Biochem. Behav. **83**(3): 441–447. doi:10.1016/j.pbb.2006.03.005. PMID:16631247.

Lu, K., Gray, M.A., Oliver, C., Liley, D.T., Harrison, B.J., Bartholomeusz, C.F., et al. 2004. The acute effects of L-theanine in comparison with alprazolam on anticipatory anxiety in humans. Hum. Psychopharmacol. **19**(7): 457–465. doi:10.1002/hup.611. PMID:15378679.

Mahoney, C.R., Brunyé, T.T., Giles, G., Lieberman, H.R., and Taylor, H.A. 2011. Caffeine-induced physiological arousal accentuates global processing biases. Pharmacol. Biochem. Behav. **99**(1): 59–65. doi:10.1016/j.pbb.2011.03.024. PMID:21463650.

McNair, D.M., Lorr, M., and Droppleman, L.F. 1971. Profile of mood states. Educational and Industrial Testing Service, San Diego, CA.

Nehlig, A., Daval, J.L., and Debry, G. 1992. Caffeine and the central nervous system: Mechanisms of action, biochemical, metabolic and psychostimulant effects. Brain Res. Rev. **17**(2): 139–170. doi:10.1016/0165-0173(92)90012-B. PMID:1356551.

Owen, G.N., Parnell, H., De Bruin, E.A., and Rycroft, J.A. 2008. The combined effects of L-theanine and caffeine on cognitive performance and mood. Nutr. Neurosci. **11**(4): 193–198. doi:10.1179/147683008X301513. PMID:18681988.

Ozen, A.E., Pons, A., and Tur, J.A. 2012. Worldwide consumption of functional foods: A systematic review. Nutr. Rev. **70**(8): 472–481. doi:10.1111/j.1753-4887.2012.00492.x. PMID:22835140.

Plessow, F., Fischer, R., Kirschbaum, C., and Goschke, T. 2011. Inflexibly focused under stress: Acute psychosocial stress increases shielding of action goals at the expense of reduced cognitive flexibility with increasing time lag to the stressor. J. Cogn. Neurosci. **23**(11): 3218–3227. doi:10.1162/jocn_a_00024. PMID:21452940.

Plessow, F., Kiesel, A., and Kirschbaum, C. 2012*a*. The stressed prefrontal cortex and goal-directed behaviour: Acute psychosocial stress impairs the flexible implementation of task goals. Exp. Brain Res. **216**(3): 397–408. doi:10.1007/s00221-011-2943-1. PMID:22101494.

Plessow, F., Schade, S., Kirschbaum, C., and Fischer, R. 2012*b*. Better not to deal with two tasks at the same time when stressed? acute psychosocial stress reduces task shielding in dual-task performance. Cogn. Affect. Behav. Neurosci. **12**(3): 557–570. doi:10.3758/s13415-012-0098-6. PMID:22684896.

Posner, M.I. 1980. Orienting of attention. Q. J. Exp. Psychol. **32**: 3–25. doi:10.1080/00335558008248231. PMID:7367577.

Posner, M.I. 1990. Hierarchical distributed networks in the neuropsychology of selective attention. *In* Cognitive neuropsychology and neurolinguistics. *Edited by* A. Caramazza. Lawrence Erlbaum, Hillsdale, New Jersey. pp. 187–210.

Proverbio, A.M., Minniti, A., and Zani, A. 1998. Electrophysiological evidence of a perceptual precedence of global vs. local visual information. Cogn. Brain Res. **6**(4): 321–334. doi:10.1016/S0926-6410(97)00039-6.

Redick, T.S., and Engle, R.W. 2006. Working memory capacity and attention network test performance. Appl. Cogn. Psych. **20**(5): 713–721. doi:10.1002/acp.1224.

Scheid, L., Ellinger, S., Alteheld, B., Herholz, H., Ellinger, J., Henn, T., et al. 2012. Kinetics of L-theanine uptake and metabolism in healthy participants are comparable after ingestion of L-theanine via capsules and green tea. J. Nutr. **142**(12): 2091–2096. doi:10.3945/jn.112.166371. PMID:23096008.

Scott, N.R., Stambuk, D., Chakraborty, J., Marks, V., and Morgan, M.Y. 1989. The pharmacokinetics of caffeine and its dimethylxanthine metabolites in patients with chronic liver disease. Br. J. Clin. Pharmacol. **27**: 205–213. doi:10.1111/j.1365-2125.1989.tb05352.x. PMID:2713214.

Smith, A.P. 2011. Caffeine: Practical implications. *In* Diet, brain, behavior: Practical implications. *Edited by* R.B. Kanarek and H.R. Lieberman. CRC Press, Boca Raton, FL. pp. 271–292.

Smith, A.P., Christopher, G., and Sutherland, D. 2006. Effects of caffeine in overnight withdrawn consumers and non-consumers. Nutr. Neurosci. **9**(1–2): 63–71. doi:10.1080/10284150600582927. PMID:16910172.

Steptoe, A., Gibson, E.L., Vounonvirta, R., Williams, E.D., Hamer, M., Rycroft, J.A., et al. 2007. The effects of tea on psychophysiological stress responsivity and post-stress recovery: A randomised double-blind trial. Psychopharmacology, **190**(1): 81–89. doi:10.1007/s00213-006-0573-2.

Tang, Y.Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., et al. 2007. Short-term meditation training improves attention and self-regulation. Proc. Natl. Acad. Sci. U. S. A. **104**(43): 17152–17156. doi:10.1073/pnas.0707678104. PMID:17940025.

Unno, K., Tanida, N., Ishii, N., Yamamoto, H., Iguchi, K., Hoshino, M., et al. 2013. Anti-stress effect of theanine on students during pharmacy practice: Positive correlation among salivary alpha-amylase activity, trait anxiety and subjective stress. Pharmacol. Biochem. Behav. **111**: 128–135. doi:10.1016/j.pbb.2013.09.004. PMID:24051231.

van der Pijl, P.C., Chen, L., and Mulder, T.P.J. 2010. Human disposition of L-theanine in tea or aqueous solution. J. Funct. Foods, **2**(4): 239–244. doi:10.1016/j.jff.2010.08.001.

Weissman, D.H., Woldorff, M.G., Hazlett, C.J., and Mangun, G.R. 2002. Effects of practice on executive control investigated with fMRI. Cogn. Brain Res. **15**(1): 47–60. doi:S092664100200215X.

Woo, M., Kim, S., Kim, J., Petruzzello, S.J., and Hatfield, B.D. 2009. Examining the exercise-affect dose-response relationship: Does duration influence frontal EEG asymmetry? Int. J. Psychophysiol. **72**(2): 166–172. doi:10.1016/j.ijpsycho.2008.12.003. PMID:19110012.

Yamaguchi, S., Yamagata, S., and Kobayashi, S. 2000. Cerebral asymmetry of the "top-down" allocation of attention to global and local features. J. Neurosci. **20**(9): RC72. PMID:10777814.

Yoto, A., Motoki, M., Murao, S., and Yokogoshi, H. 2012. Effects of L-theanine or caffeine intake on changes in blood pressure under physical and psychological stresses. J. Physiol. Anthropol. **31**. doi:10.1186/1880-6805-31-28. PMID:23107346.