Original Paper

Cocoa polyphenols enhance positive mood states but not cognitive performance: a randomized, placebo-controlled trial

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Abstract

This study aimed to examine the acute and sub-chronic effects of cocoa polyphenols on cognition and mood. In a randomized, double-blind study, healthy middle-aged participants received a dark chocolate drink mix standardized to contain 500 mg, 250 mg or 0 mg of polyphenols (placebo) in a parallel-groups design. Participants consumed their assigned treatment once daily for 30 days. Cognition was measured with the Cognitive Drug Research system and self-rated mood with the Bond–Lader Visual Analogue Scale. Participants were tested at baseline, at 1, 2.5 and 4 h after a single acute dose and again after receiving 30 days of treatment. In total, 72 participants completed the trial. After 30 days, the high dose of treatment significantly increased self-rated calmness and contentedness relative to placebo. Mood was unchanged by treatment acutely while cognition was unaffected by treatment at all time points. This randomized controlled trial is perhaps the first to demonstrate the positive effects of cocoa polyphenols on mood in healthy participants. This provides a rationale for exploring whether cocoa polyphenols can ameliorate the symptoms associated with clinical anxiety or depression.

Keywords

cocoa, polyphenol, flavonol, cognition, mood, anxiety

Introduction

Polyphenols, a group of compounds found naturally in plants, are a basic component of the human diet (Bravo, 1998). Flavanoids are a commonly ingested class of polyphenols, which include related compounds known as flavones, flavonols and isoflavonoids. These and other like compounds have been shown to reduce oxidative stress (Sánchez-Moreno et al., 1999; Visioli et al., 1998), with increased consumption linked to advantageous health outcomes such as a reduction in cardiovascular risk (Covas et al., 2006; Vita, 2005).

Many fruits, berries, legumes and teas are high in polyphenols (Bravo, 1998). Cocoa, the main constituent of dark chocolate, is also high in polyphonic compounds and contains a unique mixture of epicatechin, catechin as well as oligomeric procyanidins (Lazarus et al., 1999). Several lines of evidence suggest that chocolate, and its isolated constituents, may have beneficial psychological effects.

Anecdotally, chocolate is often associated with pleasure and positive wellbeing although empirical support for this is limited (Parker et al., 2006). Polyphonic compounds have an affinity for adenosine and benzodiazepine (GABAa) receptors, meaning that their ingestion may initiate a calming effect (Medina et al., 1997). Some preclinical studies have supported this idea by showing that certain polyphenolic compounds harvest anxiolytic properties (Ratnasooriya et al., 2007; Vignes et al., 2006). A recent small randomized, controlled pilot study reported that polyphenol-rich versus polyphenol-poor chocolate reduced symptoms of anxiety in humans with chronic fatigue (Sathyapalan et al., 2010).

The psychopharmacological effects of cocoa may not be limited to benzodiazepine receptor binding and resultant changes in anxiety. Cocoa polyphenols have previously been shown to reduce blood pressure (Desch et al., 2010), improve endothelial function (Faridi et al., 2008) and increase cerebral blood flow (Francis et al., 2006). Given the well-documented links between cardiovascular health and cognitive performance (Decarli, 2012), cocoa polyphenols may also have indirect effects on neuropsychological function. In a randomized controlled trial, the short-term administration of a cocoa beverage high in polyphenols (172 mg/day) augmented the Blood Oxygenation Level Dependent (BOLD) signal intensity response without altering the behavioural results during a cognitive switching task (Francis et al., 2006). The same authors also showed that a single acute dose of cocoa (450 mg polyphenols) increased cerebral blood flow. More recently, a randomized, controlled, double-blind, cross-over study (n=30) investigated the acute cognitive-enhancing effects of cocoa during

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sustained mental effort (Scholey et al., 2010). Both a high (994 mg) and low (520 mg) dose of cocoa flavonols improved aspects of cognition including mental arithmetic. The low dose also attenuated feelings of mental fatigue (Scholey et al., 2010). In contrast to this finding, a randomized, controlled study reported that the combined consumption of a cocoa bar and beverage (11 g of natural cocoa each, equal to 357–397 mg/g proanthocyanidins) had no effects on neuropsychological performance following 6 weeks of supplementation (Crews Jr et al., 2008).

Given the known actions of polyphenols on GABAa receptors (Medina et al., 1997), further human clinical trials are needed to substantiate the effects of cocoa polyphenols on anxiety and calmness. Moreover, emerging evidence suggests that cocoa polyphenols may improve cardiovascular health and augment brain blood flow (Francis et al., 2006), providing a rationale for investigating the neuropsychological effects of cocoa supplementation. The aim of the present study was to explore both the acute (1, 2.5 and 4 h post dose) and sub-chronic (30 day) effects of cocoa polyphenols on cognition and mood. Participants were randomized to receive a dark chocolate drink mix containing 500 mg (high dose), 250 mg (low dose) or 0 mg (placebo) of cocoa polyphenols. It was hypothesized that, relative to placebo, both doses of polyphenols would improve cognition and mood at all time points.

Methods

The current trial investigated the effects of cocoa polyphenols on cognitive, neurocognitive (Camfield et al., 2012) and cardiovascular performance as well as mood. The current paper reports on the results pertaining to cognition and mood.

Participants

Healthy middle-aged participants were recruited via newspaper advertisements, posters and emails. The age range of participants was restricted to 40–65 years in order to limit the variability in cognitive test performance associated with ageing. A middle-aged rather than older sample was also chosen to facilitate the recruitment of a healthy sample free from age-related disease such as dementia and cardiovascular disease. Interested participants were screened for the following exclusion criteria: previously diagnosed heart disease or hypertension; anxiety, depression, psychiatric disorders or epilepsy; any other health disorders effecting food metabolism such as kidney, liver or gastrointestinal disease; not pregnant or breastfeeding; not currently taking vitamin supplements, herbal extracts or elicit drugs; a non-smoker.

Of the 87 participants randomized to treatment, 78 participants completed baseline and acute assessment (Figure 1). In total, 72 participants consumed their assigned treatment for 30 days before returning for their second testing session. One further participant (from the placebo group) was eliminated from statistical analysis for having a low compliance to treatment (<80%).

Measures

Cognitive performance. Cognitive performance was measured using the Cognitive Drug Research (CDR) computerized assessment system. CDR has been used extensively worldwide, is highly validated, and is sensitive to cognitive changes following supplementation (Kennedy et al., 2002; Scholey and Kennedy, 2004). The battery comprised 10 individual tasks taking approximately 30 min to complete in total. The order of the cognitive tasks was as follows: Immediate Word Recall, Simple Reaction Time, Digit Vigilance, Choice Reaction Time, Tracking, Spatial Working Memory, Numeric Working Memory, Delayed Word Recall, Delayed Word Recognition and Delayed Picture Recognition. These tasks have previous been described in detail (Kennedy et al., 2002).

To minimize the chance of a type-one error and as recommended, task outcome scores were summed to create factors representing Quality of Working Memory, Quality of Episodic Secondary Memory, Power of Attention, Speed of Memory and Continuity of Attention (Wesnes et al., 2000). Factors are described below.

Quality of Working Memory combines the percentage accuracy outcome measures from the Spatial Working Memory and Numeric Working Memory tasks. This factor reflects working memory performance with higher scores indicating better accuracy.

Quality of Episodic Secondary Memory combines the percentage accuracy scores from the Delayed Word Recognition, Delayed Picture Recognition, Immediate Word Recall and Delayed Word Recall tasks. This factor reflects long-term memory performance, with higher scores reflecting superior accuracy.

Continuity of Attention combines the percentage accuracy outcome measures from both the Choice Reaction Time and Digit Vigilance tasks. Continuity of Attention therefore reflects a participant's vigilance and ability to respond accurately to target stimuli in the face of irrelevant distracters. Higher scores reflect more accurate attention.

Speed of Memory combines a participant's speed of response, in milliseconds, across all timed memory tasks (Spatial Working Memory, Numeric Working Memory, Delayed Word Recognition and Delayed Picture Recognition). With smaller values reflecting faster memory retrieval, this factor reflects the speed at which participants can draw information from memory.

Power of Attention is the sum of the speed of response outcome measures, in milliseconds, across all timed tasks that assess attention (Simple Reaction Time, Choice Reaction Time and Digit Vigilance). Lower values therefore reflect faster processing across attention-related tasks.

Mood. Self-reported mood was assessed using the Bond and Lader Visual Analogue Scales (Bond and Lader, 1974). These scales were presented electronically directly following cognitive assessment. Using the mouse, participants were asked to click, on a 100 mm line, to what extent the described states were appropriate to them at that moment in time. There were a total of 16 scales each anchored with the following end-points; alert–drowsy, calm–excited, strong–feeble, muzzy–clearheaded, well-coordinated–clumsy, lethargic–energetic, contented–discontented, troubled–tranquil, mentally slow–quick witted, tense–relaxed, attentive–dreamy, incompetent–proficient, happy–sad, antagonistic–friendly, interested–bored, withdrawn–sociable. As recommended (Bond and Lader, 1974), scale scores were summed to provide outcome scores across affective dimensions of alertness, contentedness, and calmness.

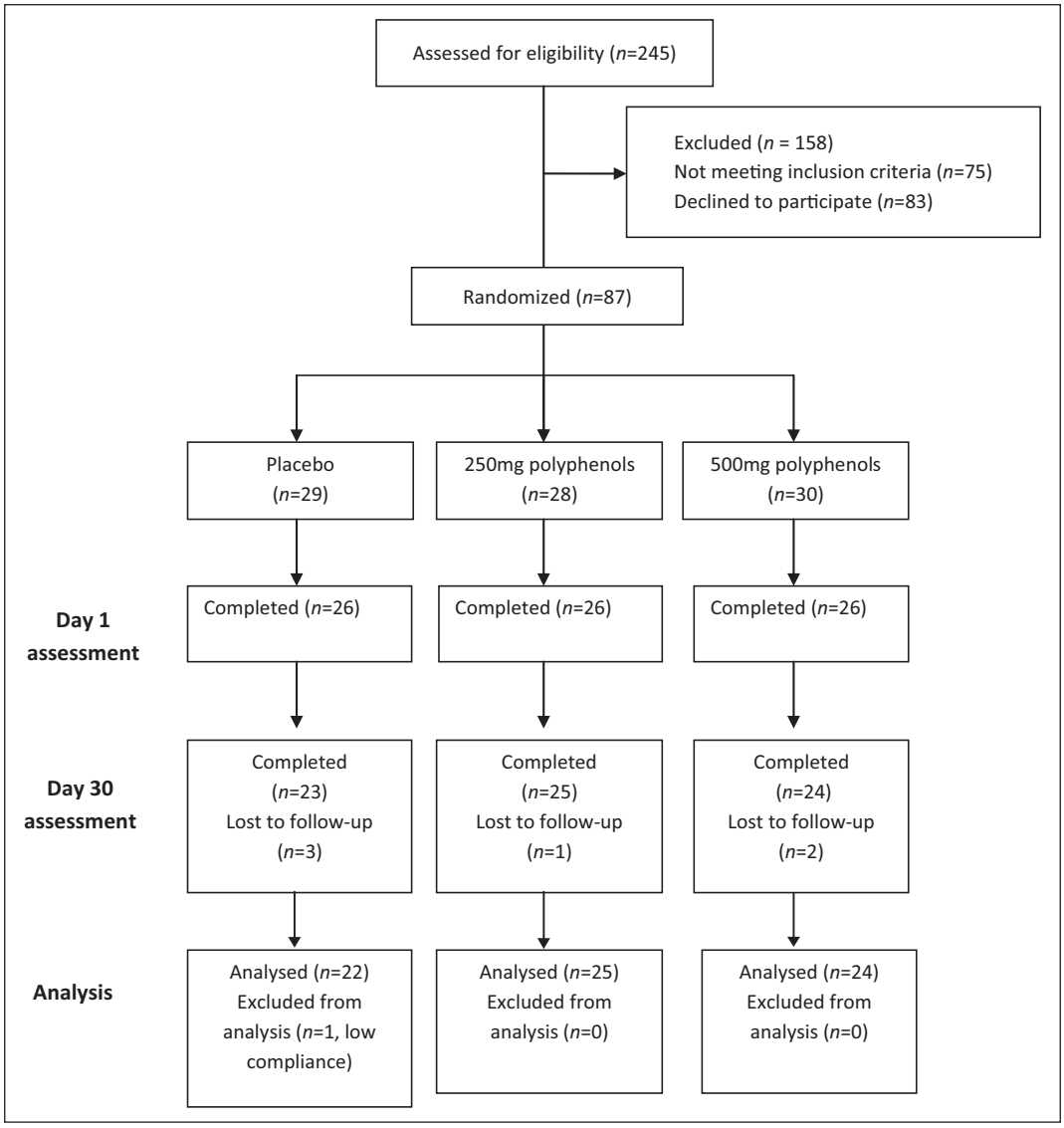

Figure 1. Study flow diagram.

Treatment

The current study implemented a randomized, placebo-controlled, double-blind, parallel-groups design. Using a computer-based random number generator, participants were randomized to receive either a 20 g dark chocolate drink mix standardized to contain either 500 mg of cocoa polyphenols (high dose), 250 mg of cocoa polyphenols (low dose) or 0 mg of cocoa polyphenols (placebo). Randomization was completed by an independent third party. All drink mixes were administered dissolved in 200 mL of water. Furthermore, drink mixes were matched for taste, energy and calories, differing only in their polyphenol content (Table 1). The high-dose treatment is called Acticoa cocoa powder, developed by Barry Callebaut, and is commercially available. All treatments were supplied in identically appearing gold sachets that were differentiated only by a code letter corresponding to treatment allocation. Both the researchers and participants alike were blind to the meaning of the code. The code breaker was provided to the researchers only after preliminary analysis of all study outcomes, meaning that both the study testing and the statistical analysis were performed under a double-blind protocol.

Procedure. Participants completed a total of three testing sessions. The first was a training day where participants completed the cognitive test battery four times to reduce the effects of practice on the following testing sessions. Data from the training day was not statistically analysed. The second day involved baseline and acute testing of cognition and mood. Participants then returned for testing after 30 days of daily supplementation.

On the morning of baseline assessment, participants were instructed to eat only a light breakfast while avoiding alcohol and caffeinated beverages (such as tea and coffee) as well as foods high in polyphenols (such as berries, apples and chocolates). Baseline assessment began in the morning with participants

Table 1. Nutritional composition of the study treatments.

Nutrients per 20 g (1 serve)	Treatment		
	Control	Low polyphenol	High polyphenol
Crude protein, g	2.1	2.1	2.1
Crude fat, g	1	1	1
Sugar, g	10	10	10
Energy, kcal	132	132	132
Cocoa flavonols, mg	0	250	500
Theobromine, mg	240	240	240
Caffeine, mg	40	40	40

completing both the cognitive test battery and Bond–Lader Visual Analogue Scales. Following baseline assessment, participants were provided with a single dose of their assigned treatment before being reassessed on all cognitive and mood measures at 1, 2.5 and 4 h intervals following the administration of treatment. Participants were provided with a standardized lunch, consisting of either a salad or chicken roll, following the first acute testing session (1.5 h following treatment). Following this testing day, participants were instructed to consume their assigned treatment once daily for a total period of 30 days. Following 30 days, participants returned to have their cognitive performance and mood reassessed. The same aforementioned testing day restrictions were enforced with sub-chronic assessments performed at the same time of day as baseline assessment. Treatment was not consumed on the day of follow-up testing.

During the study, participants were required to avoid foods high in polyphenols while avoiding additional chocolate. Participants were given a food diary which listed many commonly consumed foods and beverages that contain polyphenols including tea, coffee and wine as well as specific fruits and berries. During a 1 month period, participants recorded how many serves they consumed of each listed food and beverage. The listed foods and beverages were then categorized into three groups according to their respective polyphenol content per serve (low <100 mg/serve, medium 100–350 mg/serve or high >350 mg/serve). Polyphenol content per serve was based on the values proved by Manach et al (2004). Total polyphenol intake was then calculated for each participant according to the following formula: number of serves in low polyphenol group + 2 times the number of serves in medium polyphenol group + 3 times the number of serves in high polyphenol group. This score was designed to give a relative estimate of total polyphenol intake and to ensure that the groups were well matched for habitual polyphenol consumption during the study.

All procedures were conducted in accordance with the Good Clinical Practice Guidelines and the declaration of Helsinki (2008). The study was approved by the Swinburne University Human Research Ethics Committee. The study, including recruitment and participant testing, took place solely at Swinburne University of Technology, Melbourne, Australia. The Australian Clinical Trials Registration Number (ACTRN) for this trial is 12609000879268.

Statistical analysis. Analysis was performed using the Statistical Package for Social Sciences (SPSS) Version 19. We aimed to have 20–25 participants in each of the three treatment groups. We thus recruited a sample of approximately 90 participants in order to account for a 20% dropout rate. To ensure that the treatment groups were well matched at baseline, between groups Analysis of Variance (ANOVA) were used to compare the treatment groups across measures of interest at baseline. To investigate the acute effects of treatment on cognition and mood, separate 3 (placebo, 250 mg and 500 mg) × 3 (1, 2.5 and 4 h post dose) mixed-design Analyses of Co-variance (ANCOVAs) were used, controlling for baseline performance. For the sub-chronic analyses, univariate ANCOVAs were used to examine whether performance at day 30 differed according to treatment group (placebo, 250 mg and 500 mg), controlling for baseline performance.

Prior to performing ANCOVAs, the distribution of each variable was checked graphically using histograms. Those variables that were not normally distributed were transformed using recommended statistical techniques (Tabachnick and Fidell, 2001). Time by treatment interactions, means and standard deviations are reported for all ANCOVAs. Statistical significance was determined at $p < .05$.

Results

Participants were tested between January and August, 2009. The trial was stopped due to the acquisition of our desired sample size. During the trial, there was one adverse event where a participant, assigned to the placebo condition, developed mouth ulcers. This participant was withdrawn from the study and the blinding code was not broken.

Preliminary results

Table 2 displays the means and standard deviations for the three treatment groups across all variables of interest at baseline. Univariate ANOVA indicated that Quality of Working Memory scores varied significantly between the treatment groups (F (2, 71) = 4.09, $p < .05$), with the placebo group having the highest score. Inspection of the variables' distribution indicated that Quality of Working Memory scores were severely negatively skewed, as were Continuity of Attention scores. Power of Attention scores were also significantly different between groups at baseline (F (2, 75) = 3.03, $p = .05$), with the high-dose polyphenol group having the lowest score. No other significant group differences were observed and all other variables were normally distributed.

A square root inflection transformation was successfully applied to the Continuity of Attention variables (Tabachnick and Fidell, 2001) at all time points in order to satisfy the assumption of normality for ANCOVA. For the Quality of Working Memory factor scores, initial transformations were unsuccessful at correcting the negative skew. Extreme outliers were then Winsorized, to the mean ± 2 SDs (Tabachnick and Fidell, 2001), before applying inflection transformations at all time points. This improved the normality distribution of the Working Memory factor scores.

Treatment results

Means and SDs for each cognitive and mood variable at baseline, 1, 2.5 and 4 h post dose are presented in Table 3. There were no significant time by treatment interactions. Thus, following a

Table 2. Baseline means and standard deviations for each study variable across each treatment condition.

Variables	Condition					
	Placebo		250 mg		500 mg	
	M	(SD)	M	(SD)	M	(SD)
Demographics						
Males, %	39		36		26	
Age, years	51.15	(7.88)	53.35	(7.47)	52.62	(7.83)
BMI	24.98	(3.91)	24.56	(5.15)	25.643	(4.33)
Education, years	14.80	(2.16)	16.36	(3.76)	16.24	(3.47)
CDR Measures						
Secondary memory	206.45	(59.67)	214.40	(57.85)	199.87	(48.39)
Working memory	1.85	(0.14)	1.78	(0.20)	1.64	(0.39)
Continuity of attention	67.68	(7.57)	50.97	(37.53)	54.28	(35.10)
Power of attention	1216.82	(119.44)	1203.24	(100.42)	1141.10	(127.40)
Speed of memory	3397.85	(590.83)	3578.78	(630.68)	3356.06	(621.60)
Bond–Lader VAS						
Alert	59.20	(10.30)	56.88	(13.97)	56.30	(15.27)
Calm	57.30	(12.66)	63.77	(16.72)	58.98	(14.47)
Content	66.00	(12.46)	67.33	(13.77)	65.33	(14.06)
Polyphenol intake	156.80	(87.66)	161.50	(83.10)	153.68	(62.88)

BMI: body mass index; CDR: Cognitive Drug Research; VAS: Visual Analogue Scales; Polyphenol intake reflects habitual consumption during the trial based on food diary responses.

single acute administration, neither the high nor low dose of cocoa polyphenols significantly altered cognition or mood.

Table 4 displays means and SDs for each cognitive and mood variable at baseline and day 30. Following 30 days of treatment, there were no significant effects of cocoa polyphenols on any of the cognitive factor scores. However, a significant effect of treatment was found for the Calm (F (2, 68) = 3.62, $p < .05$) and Content (F (2, 68) = 3.66, $p < .05$) Visual Analogue Scale scores. Follow-up paired t-tests revealed a significant increase in Calmness for the high polyphenol group (t = -2.36, $p < .05$) but not for the low polyphenol (t = 1.89, p = .07) or placebo (t = -1.05, p = 0.31) groups. Similarly, follow-up paired t-tests revealed a significant increase in Contentedness for the high polyphenol group (t = -2.54, $p < .05$) but not for the low polyphenol (t = 1.02, p = .32) or placebo (t = 0.03, p = 0.76) groups.

Discussion

The current randomized, placebo-controlled, double-blind trial investigated both the acute and sub-chronic effects of polyphenol supplementation on mood and cognitive performance. The administration of cocoa polyphenols improved self-rated calmness and contentedness. This effect was seen only for the high dose of polyphenols following 30 days of treatment. Neither the high nor low dose significantly improved cognitive performance at any time point.

Chocolate is often anecdotally claimed to enhance positive mood states. Certain polyphonic compounds act on GABAa receptors and have consequently been hypothesized to harvest anxiolytic properties (Medina et al., 1997). Preclinical research suggests that polyphenols found within green tea (epigallocatechin gallate; EGCG) exert anxiolytic effects through the modulation of GABA receptors (Vignes et al., 2006). Experimental animal studies suggest that suggest that black and green tea infusions possess anxiolytic properties (Ratnasooriya et al., 2007). One previous study conducted in humans showed that overweight males receiving EGCG for 8 weeks scored higher on the 'hedonic tone' subscale of a mood questionnaire relative to placebo (Brown et al., 2009). Although these studies point towards an anxiolytic effect of tea, the mixture of polyphenols found within cocoa is unique (Lazarus et al., 1999).

Only limited research has investigated the psychopharmacological effects of cocoa. Using a highly demanding cognitive test battery, Scholey and colleagues (2010) reported that the acute administration of cocoa flavonols significantly attenuated mental fatigue, although state anxiety was unchanged. Reductions in mental fatigue were also accompanied by improvements in serial subtraction accuracy (Scholey et al., 2010). In a small pilot study, polyphenol-rich, relative to polyphenol-poor, chocolate reduced symptoms of anxiety and depression in 10 subjects with chronic fatigue (Sathyapalan et al., 2010). However, to our knowledge, the current randomized controlled trial is the first to report enhancement in positive mood states following cocoa polyphenol supplementation in a healthy non-clinical sample. These results provide a rationale for investigating whether cocoa polyphenol supplementation can ameliorate the symptoms associated with clinical anxiety.

Consistent with Crews Jr and colleagues (2008), we found that cognition was unchanged following cocoa polyphenol supplementation. Although Scholey et al. (2010) previously reported cognitive changes following cocoa supplementation, this was in

Table 3. Analysis of co-variance results comparing each treatment condition across 1, 2.5 and 4 h post dose, controlling for baseline.

Measure	Treatment	Baseline		1 h		2.5 h		4 h		ANOVA		
		M	(SD)	M	(SD)	M	(SD)	M	(SD)	*n*	*F*	*p*
Secondary	Placebo	210.08	(58.42)	181.67	(52.44)	190.98	(38.09)	196.74	(46.26)	22	1.41	0.23
Memory	250 mg	214.40	(57.85)	172.40	(55.31)	172.60	(52.33)	160.07	(50.49)	25		
	500 mg	199.87	(48.39)	160.40	(54.41)	164.33	(55.31)	162.07	(53.53)	25		
Speed of	Placebo	3345.45	(540.94)	3302.58	(455.94)	3413.08	(529.84)	3183.26	(425.29)	24	0.81	0.52
Memory	250 mg	3526.12	(582.42)	3491.24	(519.97)	3568.84	(571.37)	3314.52	(442.52)	25		
	500 mg	3271.85	(575.75)	3329.47	(525.16)	3315.58	(458.28)	3099.07	(392.91)	22		
Quality of	Placebo	0.88	(0.90)	0.85	(0.11)	0.83	(0.13)	0.88	(0.12)	25	0.27	0.90
	250 mg	0.84	(0.12)	0.83	(0.14)	0.80	(0.14)	0.85	(0.12)	26		
	500 mg	0.79	(0.18)	0.82	(0.14)	0.75	(0.19)	0.84	(0.15)	23		
Power of	Placebo	1210.57	(117.77)	1193.03	(129.92)	1204.06	(139.85)	1183.54	(104.23)	24	2.34	0.07
Attention‡	250 mg	1203.24	(100.42)	1214.20	(105.57)	1213.80	(96.92)	1236.89	(119.95)	26		
	500 mg	1141.10	(127.40)	1135.88	(118.52)	1143.57	(120.03)	1143.56	(128.06)	25		
Continuity of	Placebo	1.01	(0.28)	0.90	(0.25)	1.06	(0.15)	0.89	(0.31)	25	0.51	0.73
Attention*	250 mg	1.25	(0.40)	0.99	(0.35)	1.17	(0.20)	1.07	(0.30)	26		
	500 mg	1.11	(0.52)	0.96	(0.39)	1.18	(0.42)	1.03	(0.47)	25		
Calm	Placebo	57.30	(12.66)	56.60	(11.81)	58.86	(13.97)	59.14	(14.25)	25	0.75	0.54
	250 mg	63.77	(16.72)	64.17	(17.96)	62.12	(16.54)	58.90	(19.06)	26		
	500 mg	58.98	(14.47)	63.06	(12.44)	62.44	(14.60)	61.88	(15.93)	25		
Content	Placebo	66.00	(12.45)	62.53	(14.19)	62.18	(16.92)	60.76	(18.59)	25	1.32	0.27
	250 mg	67.33	(13.77)	68.55	(14.35)	63.35	(15.71)	61.69	(19.89)	26		
	500mg	65.33	(14.06)	67.85	(14.48)	63.38	(12.83)	62.20	(15.73)	25		
Alert	Placebo	59.20	(10.30)	55.76	(14.75)	54.06	(16.28)	51.32	(18.83)	25	1.04	0.38
	250 mg	56.88	(13.97)	56.32	(18.24)	47.26	(16.57)	47.23	(17.60)	26		
	500 mg	56.30	(15.27)	59.28	(14.69)	50.67	(16.87)	50.54	(18.67)	25		

*Square root inflection transformation of variable.
†Inflection transformation of variable.
‡analysed as change from baseline co-varying for baseline performance.

response to a highly effortful cognitive testing protocol involving six consecutive repetitions (10 min each) of a highly demanding cognitive test battery. Given the current findings, whereby cocoa polyphenols increased feelings of calmness and contentedness, cognitive enhancement following cocoa may only emerge in situations where a calm or content demeanour is advantageous, such as under conditions of high stress.

As previously reported elsewhere (Camfield et al., 2012), participants in this study also had Steady State Visually Evoked Potentials (SSVEP) measured in response to a spatial working memory task. The task was performed at baseline and then again after 30 days of treatment. Although cocoa polyphenols supplementation did not affect accuracy or response time, some phase differences at posterior-parietal and frontal sites were significantly different between the treatment groups. These results suggest that sub-chronic cocoa polyphenol supplementation may improve neural efficiency, even in the absence of behavioural changes (Camfield et al., 2012).

Our study failed to substantiate any acute effects of treatment. With little information available on the acute effects of cocoa, we can only speculate as to why chronic but not acute effects were observed. At the current dosage, a single acute dose may be too small to perturb GABAergic systems enough to create measureable difference in psychological states. With repeated administration, polyphenol levels may accumulate slowly leading to the observed chronic effects. Alternatively, the timing of the acute testing time points may have also contributed to the lack of acute effects. Two of the three acute testing time points were conducted after a standardized lunch break and it is possible that post-prandial factors masked any acute effects of treatment.

The optimal dosage of cocoa polyphenols required for improving cognition and positive mood remains unclear. The low dose of cocoa polyphenols used in the current study was less than half the size (250 mg vs. 520 mg) of the low dose used by Scholey et al (2010), while the high dose used by Scholey et al. was considerable higher than that of the current study (994 mg vs. 500 mg). However, Scholey et al. found that the 520 mg dose of cocoa polyphenols attenuated mental fatigue and improve aspects of cognitive functioning, suggesting that the high dosage used in the current study was also sufficient to elucidate any nootropic effects. Dosages (172 mg/day) lower than that used by the current study have been shown to alter the brains haemodynamic response, albeit in the absence of significant behavioural differences (Francis et al., 2006). To better ascertain the behavioural effects of cocoa polyphenols, future research is still required to investigate the effects of varied dosages and supplementation durations.

Strengths of the current study include the use of a highly validated and sensitive computerized cognitive test battery, the double-blind and placebo-controlled nature of our study design, as well as the exploration of both a high and low polyphenol

Table 4. Analysis of co-variance results comparing each treatment condition after 30 days of supplementation, controlling for baseline.

Measure	Treatment	Baseline		Day 30		ANOVA		
		M	(SD)	M	(SD)	*n*	*F*	*p*
Secondary	Placebo	199.68	(57.17)	232.70	(58.07)	21	1.46	0.24
Memory	250 mg	216.87	(57.73)	223.05	(67.44)	24		
	500 mg	201.53	(48.70)	213.17	(58.28)	24		
Speed of	Placebo	3437.52	(585.50)	3344.95	(536.00)	22	0.11	0.90
Memory	250 mg	3547.06	(622.16)	3429.55	(569.94)	25		
	500 mg	3208.30	(538.73)	3191.75	(569.94)	20		
Quality of	Placebo	0.88	(0.10)	0.90	(0.10)	22	0.20	0.82
WM†	250 mg	0.84	(0.12)	0.85	(0.12)	25		
	500 mg	0.80	(0.18)	0.84	(0.16)	22		
Power of	Placebo	1209.62	(113.96)	1198.57	(121.40)	22	0.18	0.84
Attention	250 mg	1203.03	(102.48)	1203.50	(119.78)	25		
	500 mg	1140.33	(130.08)	1140.33	(130.08)	24		
Continuity of	Placebo	1.03	(0.28)	1.00	(0.23)	22	0.29	0.75
Attention*	250 mg	1.26	(0.41)	1.09	(0.27)	25		
	500 mg	1.11	(0.53)	0.98	(0.41)	24		
Calm	Placebo	58.14	(13.14)	61.11	(14.08)	22	3.62	0.03
	250 mg	62.38	(15.45)	58.86	(14.89)	25		
	500 mg	59.00	(14.78)	64.73	(15.53)	24		
Content	Placebo	67.61	(12.91)	66.86	(14.11)	22	3.66	0.03
	250 mg	66.73	(12.21)	63.72	(13.64)	25		
	500 mg	65.75	(14.20)	71.78	(13.99)	24		
Alert	Placebo	61.06	(8.30)	64.45	(13.08)	22	1.43	0.25
	250 mg	56.23	(13.84)	57.13	(14.06)	25		
	500 mg	56.01	(15.53)	62.90	(15.64)	24		

†inflection transformation of variable.
*Square root inflection transformation of variable.

condition across both acute and sub-chronic time points. The following limitations warrant discussion. Firstly, the duration of our treatment administration was limited to 30 days given that longer durations of treatment were considered impractical. We cannot exclude the possibility that longer supplementation durations may produce significantly different results. Secondly, participants in our sample were middle-aged and highly educated (average education level was 16 years), meaning that participants were likely to be high functioning. It is possible that there is little scope for cognitive enhancement in participants who are high functioning as compared with participants who have sub-optimal cognitive performance. As we did not implement measures of general intelligence or cognitive screening tools we were unable to determine our samples general level of cognitive functioning. A further limitation is that, given our small sample and limited statistical power, post-hoc tests following significant ANCOVAs were not corrected for multiple comparisons. Larger studies are required to confirm the current findings.

In conclusion, a high dose of cocoa polyphenols, relative to placebo, was found to improve self-rated calmness and contentedness following 30 days of treatment. Neither a high nor low dose of cocoa polyphenols significantly altered cognitive performance acutely or after 30 days of treatment. To our knowledge, this is the first randomized, controlled trial to substantiate the effects of cocoa polyphenols on positive mood states in a non-clinical sample. Future research is needed to investigate whether cocoa polyphenols can ameliorate the symptoms associated with clinical anxiety or depression.

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Conflict of interest

The authors declare that there is no conflict of interest.

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