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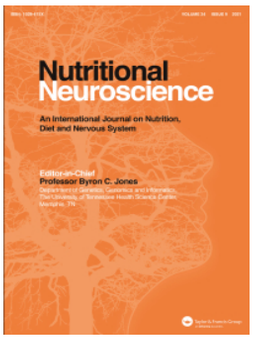

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Acute effects of *Hibiscus sabdariffa* on blood pressure and cognitive function

Lucy Ellis [a,b], Stephania Aragón-Rojas [b], Louise Dye [b,c] and Christine Boesch [b]

[a]School of Psychology, University of Leeds, Leeds, UK; [b]School of Food Science and Nutrition, University of Leeds, Leeds, UK; [c]Institute of Sustainable Food, University of Sheffield, Sheffield, UK

ABSTRACT

Introduction: *Hibiscus sabdariffa* is well known for its blood pressure lowering properties, particularly in hypertensive individuals. To date, effects of hibiscus on cognitive performance have not been assessed, hence the current pilot study explored the acute effects of hibiscus consumption on cognitive performance and metabolic outcomes in overweight individuals.

Methods: Twenty participants aged 35 ± 2.8 years with a BMI of 30 ± 1.2 (kg/m^2) were recruited to a randomised, placebo-controlled crossover study. Participants received either a hibiscus-containing beverage or an inert placebo alongside a high carbohydrate breakfast. Metabolic and cognitive measures were assessed across a 2-hour postprandial period.

Results: Consumption of the hibiscus drink significantly reduced postprandial glucose response compared to placebo after 30 and 45 min, with no change in blood pressure. Hibiscus consumption significantly attenuated the decline in delayed word recall on the visual verbal learning test. Additionally, there was a decrease in retroactive interference after hibiscus, suggesting that newly learned information interfered less with recall of previously learned information in comparison to placebo. Furthermore, non-significant improvements ($p = 0.063$) in executive function and pattern separation were observed following hibiscus consumption.

Conclusion: To summarise, this pilot study demonstrates that acute hibiscus consumption moderately affects aspects of memory and executive function, coupled with beneficial effects on postprandial glucose response. Further research is warranted to confirm these findings in larger sample sizes and to determine the effect of longer-term consumption of hibiscus on these outcomes.

KEYWORDS

Hibiscus sabdariffa; blood pressure; cognitive function; memory; postprandial glucose response; pattern separation; verbal memory; placebo

Introduction

High blood pressure (HBP) is estimated to cause around 7.5 million deaths per year and is a significant contributor towards cardiovascular disease (CVD) [1]. Apart from effects on peripheral vascular functionality, blood pressure is also an important predictor of cognitive health. Cerebral blood flow (CBF) is critical for normal cognitive function and relies on adequate blood flow to the brain, transporting vital nutrients and oxygen to brain regions involved in cognitive processes. There is a strong relationship between high blood pressure and cognitive dysfunction, particularly for tasks of executive function [2], supported by MRI studies which reveal smaller prefrontal cortex volume in hypertensive individuals [3]. Existing approaches to manage high blood pressure include pharmaceuticals, lifestyle modifications and dietary interventions.

Hibiscus sabdariffa (hibiscus) is an anthocyanin-containing plant from the Malvaceae family. Regular consumption of hibiscus has been shown to significantly lower high blood pressure compared to placebo and other tea beverages such as green or black tea [4]. Apart from the blood pressure lowering properties, hibiscus intake at the equivalent of 130 and 220 mg anthocyanins has demonstrated acute benefits to reduce blood glucose peak and AUC after a high carbohydrate meal [5]. The effects of anthocyanins on cognitive function are well researched, with evidence demonstrating that consumption of anthocyanin-containing foods, in particular blueberries, can elicit a positive effect on cognition, particularly on tasks assessing memory [6,7]. Whilst there is evidence of cognitive benefits from anthocyanins, there are no human studies assessing the effects of hibiscus on cognition.

CONTACT Christine Boesch c.bosch@leeds.ac.uk School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, UK

Evidence from animal models has shown that hibiscus ethyl acetate fraction improved spatial memory (Y-maze test) in a streptozotocin-induced diabetic mouse model [8]. In addition, gossypetin, a flavonoid found in hibiscus, was found to improve spatial learning and memory, and concurrently decreased Aβ deposition in the hippocampus and cortex of a mouse model of Alzheimer's disease [9].

In addition to the established reduction of high blood pressure, hibiscus may have potential to influence cognitive function in humans. Therefore, the purpose of this pilot study was to explore the impact of hibiscus consumption on cognitive performance, blood pressure and glucose in overweight individuals.

Materials and methods

Intervention samples

Hibiscus concentrate was kindly provided by IBIS Organics, Carlisle, UK. White bread (Warburtons®), Clover (spread), household sugar and low nitrate Buxton® water were all purchased from a local Sainsburys store (Leeds, UK).

Characterisation of hibiscus samples and anthocyanin analysis

Total phenolic and total monomeric anthocyanin contents were determined in the hibiscus sample using Folin–Ciocalteu assay and the pH differential method, respectively, as previously reported [5]. Samples were diluted accordingly, and in the case of Folin assay, measured at 765 nm against a standard curve with gallic acid (GA) with the results expressed as GA equivalents. Anthocyanins were determined using the molecular weight (597.5) and molar absorptivity (26,600) of delphinidin-3-sambubioside as reference. The total amounts of phenolics and anthocyanins in the intervention drink were calculated as 420 and 264 mg per drinkable portion, respectively. The total phenolics and anthocyanins in the control drink were calculated as < 0.01 and < 0.001 mg per drinkable portion.

Human pilot study

Participant recruitment

The study was approved by the University of Leeds, Psychology, Ethics Committee (PSYCETHS-808), and work conducted in accordance with the Declaration of Helsinki. The study was retrospectively registered: ISRCTN14881129, Date of registration: 20/06/2024. G* power was used to calculate the sample size based on a medium effect size, statistical power of 80% and an alpha level of 0.05 based on data from a published meta-analysis [4]. Based on this estimate, a sample size of 18 participants was calculated as sufficient. To allow for potential drop-outs, 20 participants were recruited using posters, emails and personal communications according to the inclusion criteria: age 18–55 years, BMI >27 kg/m^2, and presence of elevated blood pressure. Participants were excluded if they were taking medication for blood pressure, diabetes, or cholesterol in addition to excluding peri-menopausal/menopausal women. All potential volunteers were invited to a screening visit to determine eligibility for the study and to practice the cognitive tests to minimise potential learning effects [10]. The included participants were asked to avoid consumption of polyphenol-rich foods (fruits, vegetables, tea, coffee, red wine, and cocoa) the day prior to each visit. Participants were provided with a standardised evening meal (840 kcal, 90 g carbohydrates, 40 g protein, 34 g fat) and were instructed to refrain from food and beverages (except water) for 12 h prior to each visit. An evening meal was provided to ensure maintenance of glycogen stores as there is evidence that an evening meal can influence cognitive performance [11].

Participants were asked to attend the Human Appetite Research Unit (HARU) 1–2 days before their first visit to collect their study food. At this visit, a continuous glucose monitor (CGM, FreeStyle Libre Pro iQ, Abbott GmbH, Germany) was attached to the triceps, and anthropometric measures (height and weight) were obtained for all participants. All participants completed a health questionnaire and a food frequency questionnaire prior to study commencement.

Study design and procedure

The study conformed to a randomised, single-blind, crossover design. Participants were invited to attend the HARU on two occasions separated by a minimum of 5 days. Participants were assigned to drink order according to a counterbalanced randomisation design. On arrival at the lab, participants were requested to relax for 15 min before baseline blood pressure (Omron M3 automatic blood pressure cuff) was measured. Following this, baseline cognitive tests were completed and the participants were then asked to consume the test drink containing hibiscus or a control drink (both provided with low nitrate water to a 300 ml volume), alongside a carbohydrate-rich breakfast. The control drink was made with artificial cranberry flavour drops (4 drops) in an attempt to

match the flavour of the hibiscus drink as closely as possible although the strong flavour profile of hibiscus made it difficult to achieve a control drink identical in taste. Drinks were provided in an opaque cup with a straw for participant blinding and were administered one week apart. Each drink contained 25 g sugar (sucrose added), and together with the bread provided 53 g available carbohydrates.

Blood pressure was measured at regular intervals following the drink and meal consumption (20, 40, 60, 80, 110, 130 min) at each visit. Interstitial glucose values were recorded every 15 min by the CGM device which remained in place for both study visits. Data from the CGMs were downloaded to a laptop using Freestyle Libreview (version 3.15). Incremental area under the curve (AUCi) was calculated using the trapezoidal method [12]. The cognitive test battery was repeated 90 min after consumption of the drink and test meal.

At the end of the study, participants were provided with a full study debrief disclosing the study protocol which also asked participants which study beverage they thought they had received on each study visit.

Assessment of cognitive performance

The cognitive domains selected for this study have previously been identified to be sensitive to polyphenol intervention studies [13–15]. The tests were programmed and run through E-Prime version 3.0 or through JATOS depending on the test.

Visual verbal learning test. The Visual Verbal Learning Test (VVLT) measures both immediate and long-term verbal learning and memory. Three trials of list A (16 words) were presented randomly in the middle of a computer screen at a rate of 1 word every 2 s. Participants were then given 1 min to recall as many words as possible (immediate recall). An interference list (16 words) was then presented, which was followed by subsequent free recall of these words (proactive interference, PI). A free recall of List A immediately preceded this (retroactive interference, RI), and after 25 min, participants were asked to recall as many words from list A as they could (delayed recall). All free recall trials lasted for 1 min.

Tower of Hanoi. The Tower of Hanoi (ToH) is a measure of planning ability and considered a strong measure of executive function. Participants completed the computerised version of this task that consists of a visual representation of 3 rods on which 4 discs of different sizes are placed. The aim of the task was to rearrange the discs on the starting formation rods to match the target formation with a specific number of moves. There was only one correct sequence of moves for each trial ($n = 10$ trials with increasing difficulty). If a participant deviates from the correct sequence, this was considered an error and the screen resets. Outcome variables for this task were time to start which was classified as the time it took participants to make the first move, total completion time, and the number of errors.

Pattern separation task. The pattern separation task can be used to detect hippocampal-based memory alterations and impairments associated with clinical pathology from a variety of disorders such as hypertension [16]. During the encoding phase of the task, participants were shown 64 images of everyday objects on a white background, and they were asked to indicate whether they associate the image with 'indoors' or 'outdoors' (64 images, 2 s each, 0.5 s between images). Immediately afterwards during the testing phase, the subjects were shown another set of images and asked to identify them as 'old', 'similar' or 'new' (194 items, 2 s each, 0.5 s between images). The images were divided into three categories: exact repetitions of images previously presented (targets), new images not previously seen (foils) and images similar but not identical to images presented in the encoding phase (lures).

Recognition memory was assessed using a recognition score as the difference between the rate of 'old' responses given to repeat, minus 'old' responses given to foils. The lure discrimination index (LDI) is the ability to correctly detect the differences between similar images.

Mental workload. The NASA TLX is a measure of subjective mental workload [17]. Studies have used the NASA TLX and shown that increased workload is associated with inferior task performance and a higher likelihood of errors. Ratings of mental workload in relation to the cognitive tests were measured after each cognitive test battery using a Visual Analogue Scale (VAS) of 1-100.

Statistical analysis

Data were extracted into Excel (365). All statistical analyses were conducted in SPSS (SPSS v29, Chicago, IL, USA). Linear Mixed Models (LMM) analysis was performed with drink (hibiscus or placebo) as a fixed factor, participants as a random factor, and baseline performance as a fixed factor. An unstructured covariance matrix was used as covariances were deemed unpredictable. Blood pressure and blood

glucose at the time of each cognitive test were included as covariates alongside age, gender, and BMI.

The procedure for model selection for analysis of each outcome variable was as follows. All main effects and interactions were requested in the first model and all covariates were included. The model fit, F values and significance of main effects, interactions and covariates were examined, and non-significant covariates were removed. The model was rerun and further, non-significant interactions were removed, starting with highest order interactions. Each resulting model was compared to the previous model using Akaike's Information Criterion (AIC) which gives an indication on the amount of remaining unexplained variance after the model has been fitted, with a smaller AIC value indicating a better fitting model [18]. If an improvement in model fit was found, other non-significant effects were removed and again the AIC criterion used to evaluate the model fit. Models were chosen on the basis of 'best fit', and interaction terms and covariates that improved the fit were retained. F values and corresponding significance values for the main effects and interactions in the final model for each cognitive outcome variable are reported. Where outliers, based on standardised residuals were indicated, the analysis was re-run with the outlying data points excluded. Only where the exclusion led to a difference in inference were the data permanently removed and the corresponding final models reported. Bonferroni adjusted pairwise comparisons explored any significant effects ($p < 0.05$) or trends (the latter defined as $p < 0.07$).

Results

Participant demographics

Of the 28 participants who were assessed for eligibility at a screening visit, one person presented with potential intolerance to the study food and hence was not eligible and a further seven declined to participate (Figure 1). Hence 20 participants were enrolled in the study (Female/Male ($n = 13$, $n = 7$), mean age 35 ± 2.8 years, mean BMI of 30 ± 1.2 (kg/m^2), mean weight 84 ± 5.2 kg and mean blood pressure 130/87 mmHg).

Blood pressure

The effects of hibiscus or placebo drink on SBP, DBP and HR are shown in Figure 2. There were no significant main effects of condition, time, visit, or condition * time interactions for SBP, DBP or HR. For SBP, an increase in BMI ($R^2 = 0.036$) was associated with higher SBP [$F(1, 173) = 3.625$, $p = 0.059$]. No other covariates influenced blood pressure or HR.

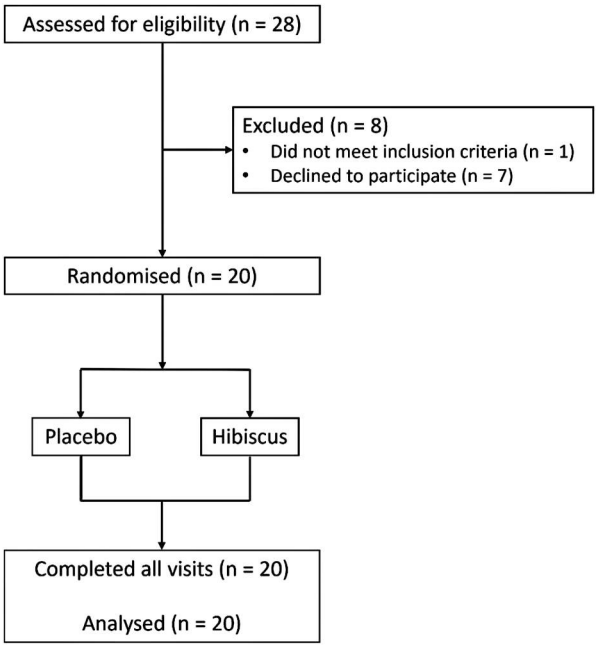

Figure 1. CONSORT flow diagram demonstrating participant enrolment in the study.

Interstitial glucose

A significant condition * time interaction was observed for glucose [$F(11, 331) = 0.590$, $p = 0.037$]. Pairwise comparisons revealed that peak glucose was significantly lower 30 min after hibiscus consumption compared to the placebo drink (Figure 3). A significant main effect of condition was also observed [$F(1, 346) = 6.634$, $p = 0.010$] with hibiscus being significantly lower than placebo overall (mean: -0.172 ± 0.066 mmol/L, $p = 0.005$). There were no significant main effects of time or visit for glucose.

Analysis of incremental $AUC_{0\text{-}150}$ revealed no significant effects of condition [$F(1, 19) = 1.760$, $p = 0.200$]. No covariates influenced the glucose or AUC analysis.

Cognition

VVLT

There was no effect of condition, session or visit, or interaction of condition * session for total words recalled or proactive interference. For total words recalled, a significant condition * session * visit interaction was observed. Less words were recalled when placebo was consumed on session 2 of visit 1 compared to hibiscus at the same session and visit [$F(1, 65) =$

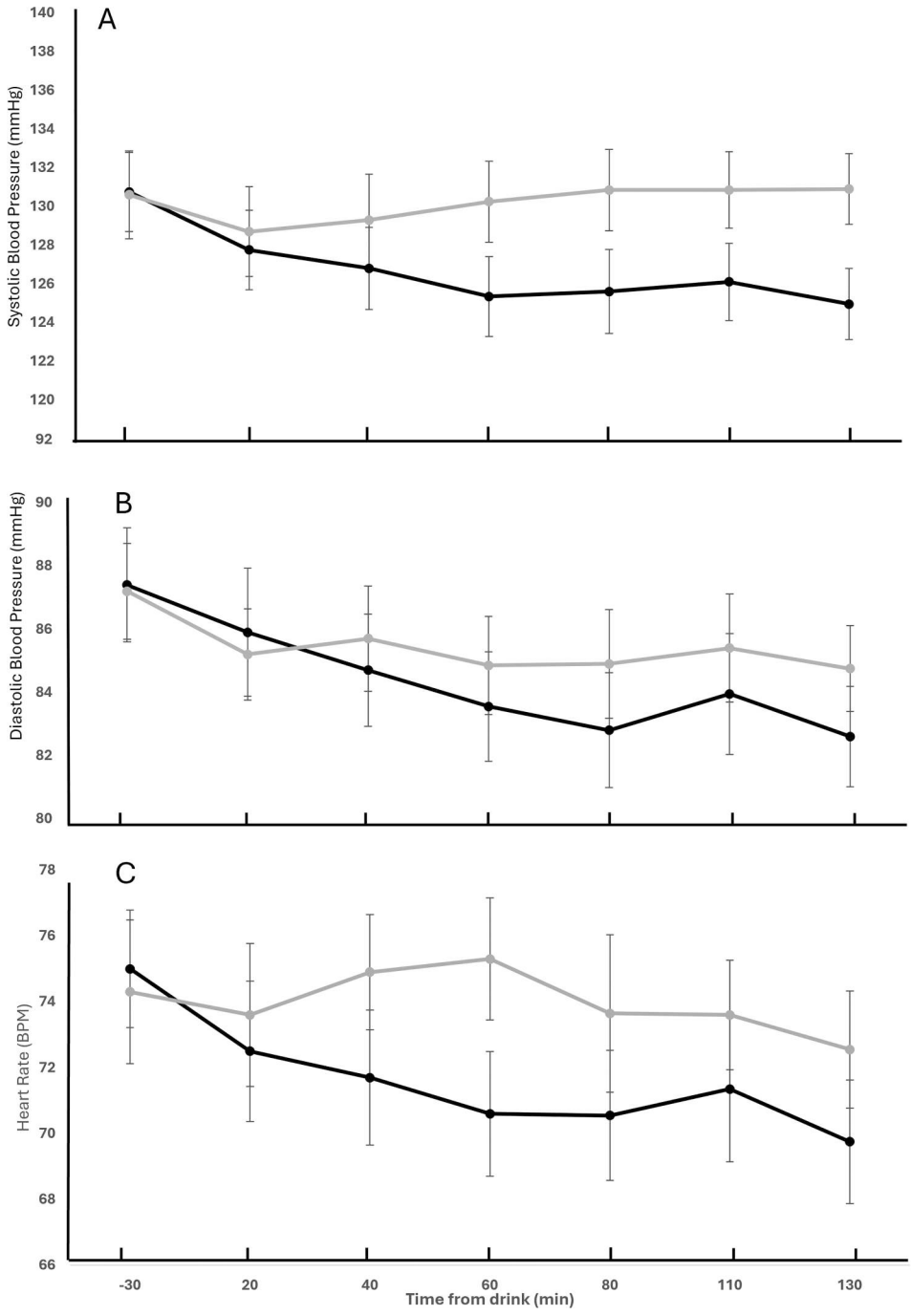

Figure 2. Systolic blood pressure (A) (mmHg), diastolic blood pressure (B) (mmHg) or heart rate (C) (BPM) following hibiscus (black line) or placebo (grey line) drink consumption (mean ± SE).

5.706, $p = 0.020$]. Glucose was a significant covariate [$F(1, 53) = 7.875$, $p = 0.007$] whereby lower glucose was associated with more words recalled ($R^2 = 0.043$).

For delayed recall, there was a significant condition * session interaction [$F(1, 49) = 8.711$, $p = 0.005$] (Figure 4(A)). Pairwise comparisons showed that significantly less words were recalled post-drink following placebo whereas performance was maintained following the hibiscus intervention. The effect of condition was also significant [$F(1, 51) = 8.814$, $p = 0.005$] such that overall, more words were recalled on the hibiscus intervention than on placebo. Age [$F(1,42) = 7.399$, $p = 0.009$], and glucose [$F(1, 67) = 6.549$, $p = 0.013$] were significant covariates in the model. Lower age ($R^2 = 0.074$) and lower glucose ($R2 = 0.089$) were associated with better recall.

For RI, a significant main effect of session was observed [$F(1, 60) = 4.507$, $p = 0.038$]. Pairwise

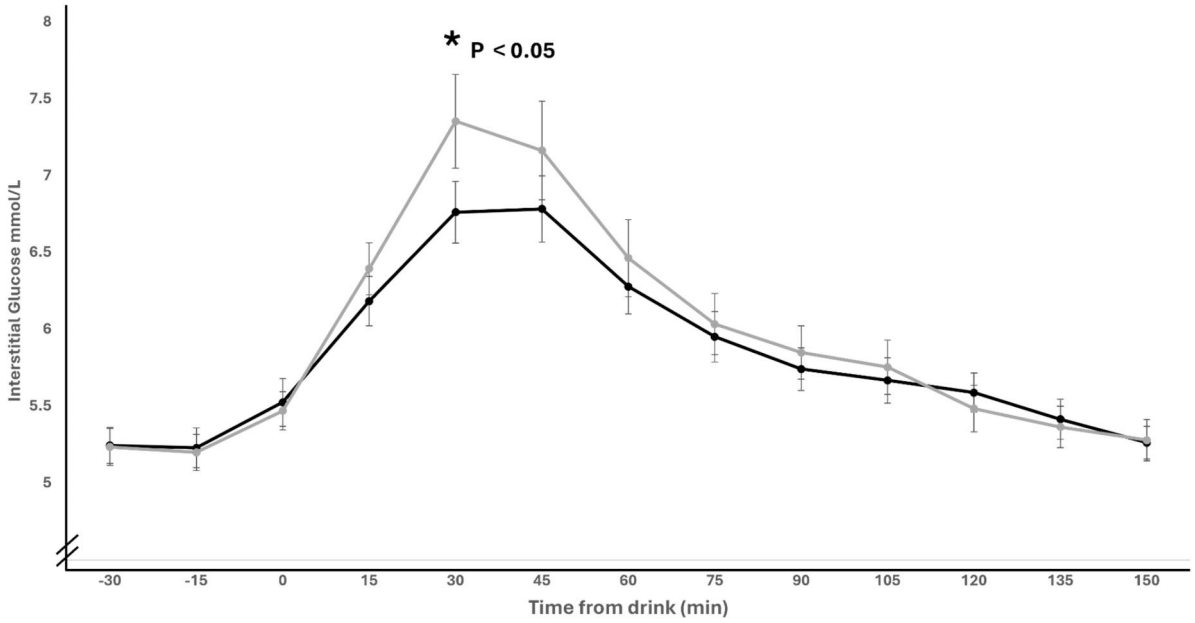

Figure 3. Interstitial glucose concentration (mmol/L) after consumption of the hibiscus (black line) or placebo drink (grey line) alongside a carbohydrate breakfast (time point 0). A significant difference between the drinks was observed at 30 min postprandial with hibiscus being lower than placebo (means ± SE).

comparisons revealed a nonsignificant increase in RI post drink (mean: 0.745 ± 0.378, $p = 0.053$). The condition * session interaction just failed to reach significance [$F(1, 60) = 5.487$, $p = 0.066$], as did the effect of condition [$F(1, 60) = 5.487$, $p = 0.068$]. This trend was due to a decrease in RI after consumption of hibiscus whereas RI increased after consumption of the placebo.

Tower of Hanoi. There was no effect of condition, session or visit, or interaction of condition*session for the number of errors on TOH. For the time taken to start, there were no main effects of condition, session or visit, however a significant interaction of session * visit was observed [$F(1, 48) = 10.375$, $p = 0.002$], whereby time taken to start the ToH task was significantly slower pre-drink at visit 2 (mean: 8587 ± 3790 ms) compared to pre-drink at visit 1 (mean: 7624 ± 4110 ms) irrespective of condition.

For the total completion time the condition * session interaction failed to reach significance [$F(1, 45) = 3.326$, $p = 0.063$]. Hibiscus reduced the time to complete the ToH task (mean: -6526 ± 3731 ms) compared to the placebo (mean: -701 ± 2989 ms) (Figure 4(B)). Visit also influenced completion time ($F(1, 45) = 4.542$, $p = 0.039$), such that time to complete was faster on visit 2 (mean: -3703 ± 1810 ms) than visit 1, possibly indicative of a learning or practice effect. A significant interaction of session * HR was observed [$F(1, 45) = 7.625$, $p = 0.008$], with a higher HR associated with slower completion time pre-drink ($R^2 = 0.032$). There were no main effects of condition or session on time to complete TOH.

Pattern separation task. For recognition memory, the statistical analysis demonstrated significant main effects of condition [$F(1,37) = 15.974$, $p < 0.001$] and visit [$F(1, 37) = 7.633$, $p = 0.009$]. Pairwise comparisons revealed that recognition memory was higher albeit not significant (0 = 0.089) after placebo compared to hibiscus (mean: 0.80 ± 0.046). Recognition memory was significantly lower at visit 2 compared to visit 1 (mean: -0.124, SE 0.046, $p = 0.011$). There was no main effect of session [$F(1, 37) = 0.331$, $p = 0.568$] or condition * session interaction [$F(1, 37) = 0.028$, $p = 0.868$]. Heart rate was a significant covariate in the model [$F(1, 37) = 4.323$, $p = 0.045$], with a lower heart rate associated with higher recognition scores ($R^2 = 0.156$).

For LDI, the condition * session interaction failed to reach significance [$F(1, 44) = 3.613$, $p = 0.063$]. Pairwise comparisons indicated LDI was lower post drink for placebo compared to hibiscus (Figure 4(C)). There were no significant effects of condition, session or visit or other interactions.

Mental workload. There were no significant effects of condition, session or visit and no significant interactions for ratings of mental demand, time pressure, effort, success rate, frustration or tiredness.

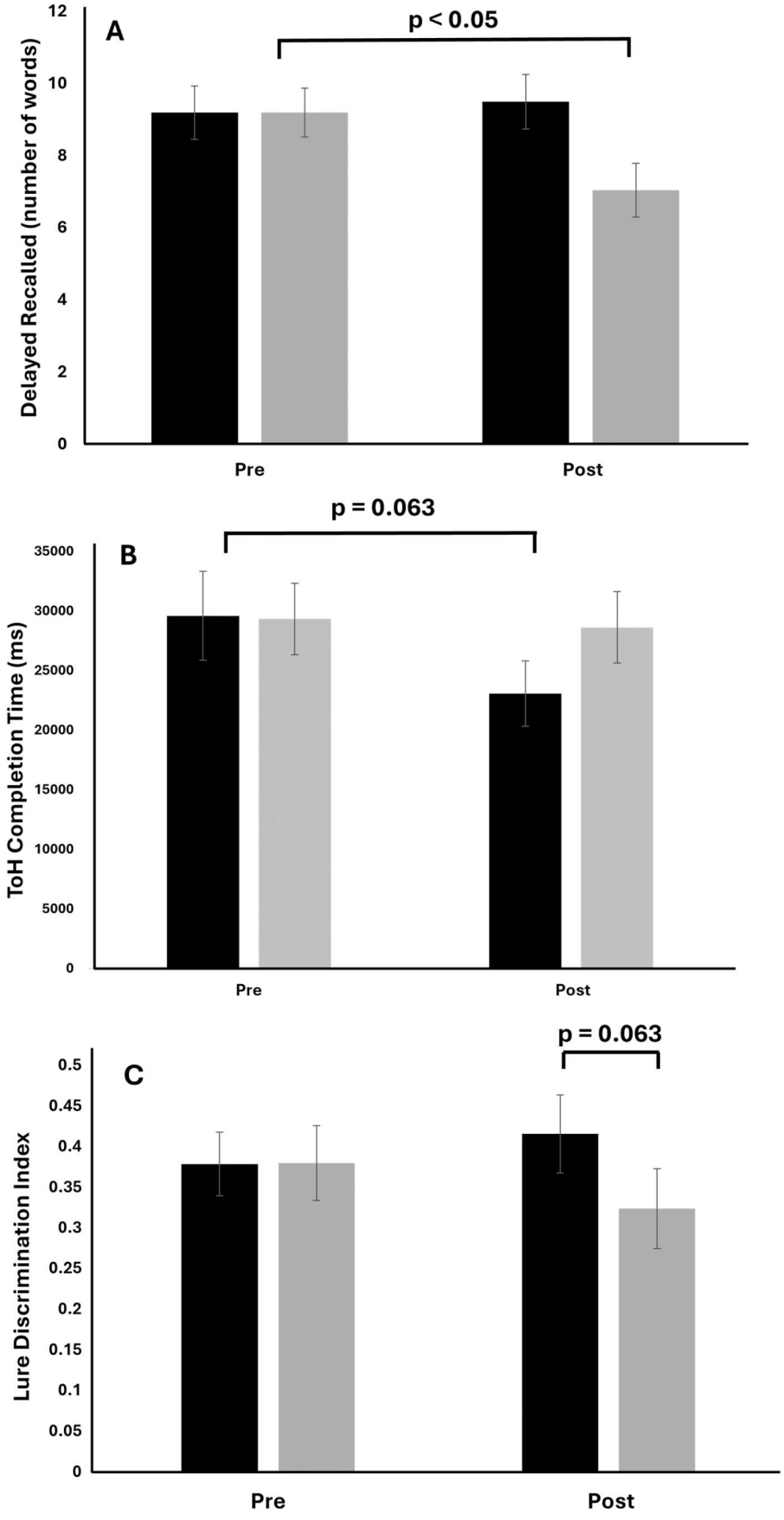

Figure 4. Outcomes from the cognitive tests comparing hibiscus (black bars) and placebo (grey bars). All data is means ± SE. (A) Delayed recall on the VVLT. (B) Tower of Hanoi completion time (ms). (C) Lure Discrimination Index from the Pattern Separation Task.

Discussion

Results from this pilot study, which is the first study of hibiscus on cognitive performance in humans, contribute to the growing body of evidence suggesting that anthocyanin-containing foods have a positive influence on cognitive performance. After hibiscus consumption, improvements in cognitive performance across various domains were observed. Notably, significant improvements were seen in delayed recall on the VVLT, with greater word retention after a ~25-minute delay following hibiscus compared to the placebo. These findings align with other research, e.g. anthocyanin-rich blueberries have previously been shown to improve both immediate and delayed word recognition alongside improvements in metabolic parameters in an acute study in healthy middle-aged adults [15].

The dentate gyrus (DG) of the hippocampus is recruited in pattern separation tasks and is highly sensitive to blood pressure changes [19]. In one study on hypertensive adults, an increase in 24-hour mean SBP was significantly associated with lower volume of the left DG. Cognitive performance, measured using the Trail Making Test, and a test of verbal fluency were worse in hypertensive compared to normotensive individuals [19]. Previously, improvements in pattern separation and concurrent increased blood flow to the DG were reported in older adults after consumption of cocoa flavanols [14]. The current study observed a slight improvement in lure discrimination on the pattern separation task, however, recognition memory declined post drink irrespective of condition. A decrease in recognition memory concurrent with improvement in lure discrimination was reported by Kim et al [20] following calorie restriction for four weeks. This suggests a dissociation between recognition and lure discrimination aspects of the pattern separation task.

Pattern of learning was not consistent across the cognitive tests in this study. Recognition memory on the pattern separation task was significantly lower at visit 2 compared to visit 1 irrespective of condition which is not indicative of a practice effect. However, participants completed the ToH task faster on their second visit irrespective of treatment which could suggest a practice effect. Other indices on the ToH e.g. error rate and time taken to start the task did not demonstrate practice effects. The hibiscus drink reduced completion time on the ToH task although this effect was not significant. These results are consistent with previous literature [21] and suggest that some outcomes of the ToH are robust with good test-retest reliability. No other practice effects were observed on any of the other cognitive tests administered in this study.

Elevated glucose levels and high BMI, which are both indicators of poor metabolic health, interacted significantly with several outcomes. A relationship was observed such that increased BMI correlated with higher SBP, and similarly higher baseline glucose correlated with poorer performance on verbal memory. These findings indicate that metabolic challenges, in particular high glucose, have a critical role in cognitive function, corroborating previous findings [15].

There are only a few human intervention studies reporting beneficial effects of acute hibiscus consumption on postprandial glycaemia. Consumption of hibiscus extract (220 mg anthocyanins) alongside a 50 g carbohydrate meal significantly reduced postprandial glucose concentration at 30 and 60 min [5]. Similarly, postprandial glucose response was lower at 30 min after 150 mg anthocyanins from hibiscus (with 70 g carbohydrate), although this did not reach statistical significance [22]. Other polyphenolic beverages such as pomegranate also demonstrate potential to reduce the early glucose response after carbohydrate consumption [23]. Consistent with the previous research, a significant reduction in postprandial glucose was observed in the present study. Synergistic mechanisms involving inhibition of glucose uptake in the gut and stimulating glucose uptake in different tissues by glucose transporters and PI3K-dependent mechanisms are likely responsible for these benefits [24]. However, there is limited evidence that hibiscus can reduce fasting plasma glucose with repeated intake [4].

The effects of hibiscus on acute blood pressure response remain to be discerned. A reasonable amount of evidence suggests that repeated intake of hibiscus can lower blood pressure however, the small reduction of SBP and DBP in our study did not reach statistical significance compared to placebo, despite the presence of elevated blood pressure (130/87 mmHg) and overweight (BMI > 27 kg/m^2) being the primary inclusion for participation in this study. In addition, no association was observed between higher baseline blood pressure and the magnitude of blood pressure reduction by hibiscus. This finding aligns with a recent clinical trial which examined individuals with mildly elevated blood pressure, where acute intake of hibiscus also failed to statistically reduce blood pressure compared to a placebo but did demonstrate a favourable effect of hibiscus on

vascular function by improving flow-mediated dilation (FMD) [22]. However, within the same study, hibiscus exerted a favourable effect on vascular function by improving FMD [22]. Repeated ingestion of hibiscus may be necessary to lower blood pressure and such effects may be more readily detectable in individuals with elevated blood pressure or hypertension [4].

Potential mechanisms of hibiscus

The recognised effects of anthocyanins on cognitive function have been attributed to mechanisms on the brain or by improvement of vascular function. There are few mechanistic studies which investigate the neuroprotective potential of hibiscus. For example, pretreatment of neuronal cells (Neuro2A) with hibiscus prior to exposure to high glucose concentrations inhibited acetylcholinesterase activity (preserving concentrations of acetylcholine) and reduced reactive oxygen species formation, thereby extending the lifespan of the cells [25]. Moreover, pretreatment with hibiscetin, a component of hibiscus, induced the synthesis of endogenous antioxidant glutathione and enzymes catalase and superoxide dismutase, as well as neurotransmitters dopamine, norepinephrine, and serotonin in rat brain tissues in a Parkinson's disease model [26]. These findings from *in vitro* and *in vivo* mechanistic research strengthen the possibility that hibiscus could exert direct effects on the brain.

It is also plausible that hibiscus can exert indirect effects on the brain through modulation of blood pressure or glucose levels. The vasodilatory effects of hibiscus have been largely attributed to cyanidin-3-sambubioside and delphinidin-3-sambubioside which demonstrated IC50 values of 84.5 and 68.4 μg/ml to inhibit ACE enzyme [27], although it is not likely that ACE inhibition could be replicated *in vivo* at sufficiently high doses. In contrast, chronic hyperglycaemia, linked to impaired brain insulin signalling, is associated with poor cognitive function [28]. Cognitive performance has been shown to be better after consumption of a low glycaemic index (GI) food versus high GI food, an effect suggested to be due to the slow released of glucose postprandially which also creates less metabolic load [29].

Our study demonstrated the capacity of hibiscus to significantly reduce postprandial glucose response, compared to a sugar matched placebo drink at both 30 min (33% difference) and 45 min (21% difference). These results align with previous literature demonstrating the *in vivo* hypoglycaemic effects of hibiscus, which has been linked to inhibition of α-glucosidase *in vitro*, lowering starch digestion and therefore glucose availability for absorption [5]. Similar reductions in postprandial blood glucose have also been observed in studies utilising other anthocyanin-containing foods such as blueberries [30] and blackcurrants [31]. However, it is difficult to compare the magnitude of glucose reduction between these studies due to differences in methodology such as carbohydrate load, anthocyanin dose and participant characteristics.

Improving glucoregulation in synergy with benefits on vascular function may underlie improvements in cognitive function. Further studies are required to investigate the individual and combined contribution of different mechanisms to the potential benefits of hibiscus consumption.

Study limitations

The results reported in this pilot study are subject to limitations. Whilst a double-blind protocol was developed, due to the nature of preparation of the study drink and the strong intrinsic flavour profile of hibiscus the study was performed as single blinded. Participants were not aware of which drink they received at each study visit. The study debrief form revealed that participants preferred the taste of the control drink, but most were unable to determine which drink was the hibiscus beverage.

Despite achieving the power calculation recommended, a larger sample size would be advantageous to accommodate high interindividual variability. Finally, due to study constraints it was not possible to include analysis of blood samples to investigate bioavailability. Timings of outcome measures within the study were selected around the expected peak of anthocyanin appearance. Previous literature showed that hibiscus metabolites (gallic acid, hippuric acid, 3-*O*-methyl gallic acid and 4-*O*-methyl gallic acid) peaked at 1 hr post drink consumption although improvements in FMD were observed significantly at 2 hr [22]. Furthermore, blueberry metabolites were shown to peak at 2 hr post consumption and this aligned with significant improvements in FMD [32]. Future research should focus on determining the bioavailability of hibiscus anthocyanins and their metabolites across different time points.

Conclusion

The results of this first trial of hibiscus on cognitive performance in humans demonstrate modest beneficial effects on verbal memory, executive function

and pattern separation after acute consumption of hibiscus. Corroborating previous findings, the intake of hibiscus can facilitate better postprandial glucose response. However, effects on blood pressure in acute settings were not detectable. Further large-scale studies are required to validate the clinical efficacy of hibiscus on cognitive performance in humans.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Notes on contributors

Lucy Ellis is a researcher within the School of Psychology, University of Leeds. Her current research is focussed on the effects of bioactive compounds on cardiovascular disease risk factors and cognitive function.

Stephania Aragón Rojas is an academic working in Microbiology and Food Conservation at the University of La Sabana. Her research focuses on developing functional foods using probiotics, prebiotics, postbiotics, and bioactive plant compounds.

Louise Dye is a Chartered Health Psychologist and Professor of Nutrition and Behaviour in the School of Psychology and the School of Food Science at the University of Leeds. She is also Co-Director of the Institute for Sustainable Food at the University of Sheffield. For 3 decades her research has focused on the effects of nutrition on cognitive function, health and wellbeing and the potential for bioactives such as anthocyanins to support cognitive performance and prevent cognitive decline across the life course.

Christine Boesch is an Associate Professor of Nutrition in the School of Food Science and Nutrition at the University of Leeds. Her focus is on health benefits of phytochemicals and other functional ingredients in food, structure–function relationships, as well as safety and efficacy of dietary bioactive supplementation strategies.

Author contributions

LE, CB and LD conceived and designed the experiment; LE performed the experiment, analysed the data and wrote the paper; SAR performed the analysis of the Hibiscus and placebo samples. All authors critically reviewed the manuscript and approved its final version.

Data availability

The data from this study is available from the authors on request subject to approval. The data for this manuscript is available from the corresponding author at request.

ORCID

Lucy Ellis http://orcid.org/0000-0002-0750-7248
Stephania Aragón-Rojas http://orcid.org/0000-0002-3743-5417
Louise Dye http://orcid.org/0000-0002-2331-4227
Christine Boesch http://orcid.org/0000-0001-6705-5709

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