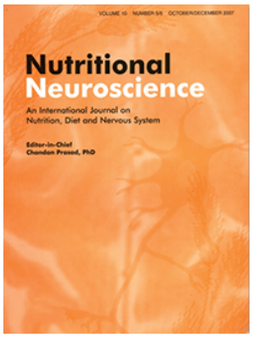

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Postprandial effects of breakfast glycaemic index on cognitive performance among young, healthy adults: A crossover clinical trial

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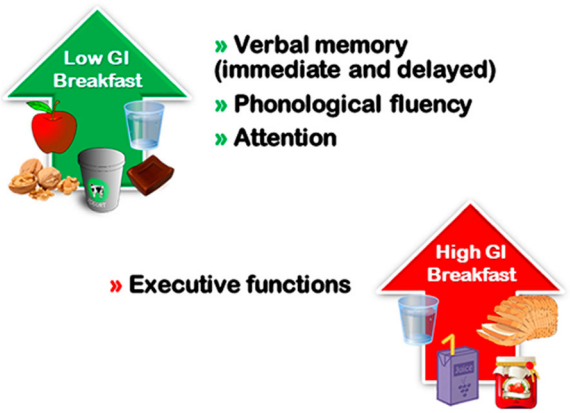
Objective: To evaluate the postprandial effects of high and low glycaemic index (GI) breakfasts on cognitive performance in young, healthy adults.
Methods: A crossover clinical trial including 40 young, healthy adults (aged 20–40 years, 50% females) recruited from primary healthcare centres in Salamanca, Spain. Verbal memory, phonological fluency, attention, and executive functions were examined 0, 60, and 120 minutes after consuming a low GI (LGI), high GI (HGI), or water breakfast. Every subject tried each breakfast variant, in a randomized order, separated by a washout period of 7 days, for a total of 3 weeks.
Results: A significant interaction between the type of breakfast consumed and immediate verbal memory was identified ($P<.05$). We observed a trend towards better performance in verbal memory (delayed and immediate), attention, and phonological fluency following an LGI breakfast.
Discussion: Cognitive performance during the postprandial phase in young, healthy adults was minimally affected by the GI of breakfast. The potential for breakfast's GI modulation to improve short- and long-term cognitive functioning requires further research.



Keywords: Breakfast, Glycaemic index, Postprandial period, Cognitive performance, Verbal memory, Phonological fluency, Attention, Executive functions

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Introduction

Cognitive function is influenced by countless factors, including but not limited to education, socioeconomic level, overall health, and nutritional state.[1] Diet is considered to be an important determinant of cognitive performance: both food-induced hyperglycaemia and variability in response to food ingestion have been implicated mechanistically in cognitive dysfunction.[2]

Breakfast is the most commonly studied meal when investigating the effects of diet on short-term cognitive functioning. Most of these studies compare performances between individuals who either had or had not consumed this meal[1,3] and overlook the more nuanced breakfast characteristics such as nutrient content or energy load, which can potentially modify cognitive domains through metabolic and hormonal alterations.[4] To date, a majority of the research on the link between breakfast composition and cognitive function has focused on carbohydrates (CHOs).[5] Nonetheless, the influence of CHO absorption rate, quantified using the glycaemic index (GI), on cognitive performance remains unclear.[6]

In children and adolescents, a growing body of data suggests that low GI (LGI) breakfasts enhance immediate verbal memory,[7–9] sustained attention,[7] and verbal fluency;[10] whereas high GI (HGI) breakfasts improve selective attention, processing speed, and working memory.[10] However, a limited number of studies targeting adults have been performed in this area. Lamport *et al*. found that acute glycaemic manipulations at breakfast do not confer benefits for cognitive function in adults with type 2 diabetes[11] or middle-aged obese females.[12] These findings are in contrast to other studies that have shown LGI breakfasts are beneficial for cognitive performance in young and middle-aged healthy adults[13–15] as well as in subjects with type 2 diabetes.[16]

Given this lack of consensus and the paucity of data from adult populations, the current study aimed to evaluate the postprandial effects of breakfast's GI on cognitive performance in young, healthy Spanish adults.

Methods

Study design and population

This crossover clinical trial was conducted at The Primary Care Research Unit of the Alamedilla Health Centre, a component of the Biomedical Research Institute of Salamanca (IBSAL) and the Spanish Network for Preventive Activities and Health Promotion (REDIAPP) in Salamanca, Spain. The protocol for the Breakfast Glycaemic Index (BGI) study (NCT02616276) has been previously published.[17] For this sample population, 42 subjects ranging from 20 to 40 years of age were enrolled through consecutive sampling at urban primary healthcare centres in Salamanca between 2015 and 2016. The exclusion criteria for this trial included the following conditions: (1) dyslipidaemia; (2) diabetes mellitus; (3) hypertension; (4) pharmacological treatment for any of these factors; (5) history of cardiovascular events; (6) consumption of toxic substances; (7) neurological and/or neuropsychological disorders; (8) pregnancy; (9) lactose intolerance; (10) Celiac's disease; (11) low-calorie and/or low-sodium diets; and (12) any other circumstance that researchers think could interfere with the study protocol (e.g. dietary aspects that could promote variability in measures). With a sample size of 40 subjects, calculated for the primary outcome variable,[17] the power needed to recognize a change of ≥1 unit in immediate verbal memory score was 80%, assuming an alpha risk of 0.05 and a standard deviation of 2.2.

Intervention

Participants consumed three experimental breakfasts in a randomized order, each one separated by a 1-week washout period. Test sessions lasted for 160 minutes and occurred between 8:15 AM and 10:55 AM.

The intervention arms were: (1) Control conditions: 350 mL of water served at room temperature; (2) HGI breakfast: 40 g of white bread, 29 g of strawberry jam, 200 mL of grape juice, and 350 mL of water served at room temperature; (3) LGI breakfast: 125 g of low-fat natural yogurt, one 150 g apple, three shelled walnuts, 17.5 g of 72% dark chocolate, and 350 mL of water served at room temperature. The HGI breakfast consisted of 72.0 g (91.4%) CHO, 3.9 g (5%) protein, 0.9 g (2.6%) fat, and 1.6 g (1%) fibre, and contained 315 kcal (1318 kJ). The LGI breakfast consisted of 31.5 g (35.4%) CHO, 9.7 g (10.9%) protein, 19.9 g (50.3%) fat, and 6.0 g (3.4%) fibre, and contained 356 kcal (1489 kJ). The calculated GIs for the HGI and LGI breakfasts were 64.0 and 29.4, respectively.

Study protocol

Subjects fasted for 12 hours overnight prior to the experimental breakfast, limited their physical activity, alcohol consumption, and smoking during the preceding 24–48 hours, and maintained stable dietary habits between test sessions. Upon arrival at the research unit each testing day, subjects were seated and remained in this position throughout the morning's visit. Baseline cognitive performance assessment was then obtained as described below towards controlling variability that state characteristics such as sleep deprivation, stress, anxiety, or menstrual cycle might introduce in cognitive abilities. Immediately after that, participants were provided with a randomly assigned breakfast to be consumed within 10 minutes. A timer was started at the beginning of the meal and two additional

cognitive performance evaluations were conducted at 60 and 120 minutes post-consumption.

Variables and measurement instruments

Cognitive performance evaluation variables

Verbal memory

For each of the three visits and for each evaluation within the same visit, a list of 15 different words from the Rey Auditory Verbal Learning Test[18] and its alternative versions[19,20] was used to evaluate the immediate verbal memory using immediate recall over three attempts. The outcome variable was the number of words recalled on the third attempt. Delayed verbal memory was assessed after 10 minutes by the free recall of the words learned during the first part of the evaluation.

Phonological fluency

Phonological fluency was evaluated by asking the subjects to enumerate as many words as possible starting with different letters for one minute.[21]

Attention and executive functions

The Trail Making Test A was used to measure attention and the Trail Making Test B was used to determine executive functions and processing speed.[22] A higher score on these tests indicates poorer performance.

Other variables

Procedures for collecting sociodemographic, anthropometric, and lifestyle-related data have been previously described.[17]

Ethics

This trial was approved by the Clinical Research Ethics Committee of the Health Area of Salamanca, Spain and all participants provided written informed consent for the study in accordance with the general recommendations of the Declaration of Helsinki.

Statistics

Quantitative variables are expressed as the mean ±standard deviation (SD) and qualitative variables are described as frequencies and percentages. To adequately evaluate the effect of the interventions, repeated measures analysis of variance (ANOVA) was performed, with results adjusted for age and educational level. If the assumption of sphericity was not tenable according to Mauchly's test,[23] the Greenhouse-Geisser correction was applied.[24] The Bonferroni test was used for *post hoc* analysis. An alpha risk of 0.05 was employed as the limit of statistical significance for contrasting hypotheses. Data were analysed using SPSS Statistics for Windows, Version 23.0 (IBM Corporation, Armonk, NY, USA).

Results

Of the 42 participants included in this study, two were lost after the first and second test days. As shown in Table 1, the average age of the sample group was 28.1±6.3 years (50% female) of whom 21 (52.5%) had received a higher education.

Changes in cognitive performance scores 60 minutes after breakfast consumption

Immediate verbal memory was higher than baseline following ingestion of water ($P<.05$). In contrast, attention was decreased postprandially by this breakfast condition ($P<.01$) relative to baseline. Finally, executive functions and processing speed were significantly elevated following intake of an HGI ($P<.01$) and LGI breakfast ($P<.001$) compared with baseline (Table 2).

Changes in cognitive performance scores 120 minutes after breakfast consumption

Significant reductions from baseline were detected in delayed verbal memory following consumption of all three experimental breakfasts (all differences $P<.05$). Similarly, phonological fluency decreased for water and LGI breakfasts (all differences $P<.05$). Finally, executive functions and processing speed were significantly increased over baseline after both HGI ($P<.01$) and LGI breakfasts ($P<.01$) (Table 2).

Effects of type of breakfast on postprandial responses

Postprandial cognitive responses following each experimental breakfast are presented in Figs. 1 and 2. Repeated measures ANOVA revealed a significant interaction between immediate verbal memory and the type of breakfast ($P<.05$) regardless of age and educational level. A trend towards better performance in executive functions and processing speed following both HGI and LGI breakfasts was observed, yet this interaction did not reach statistical significance.

Table 1 Baseline characteristics of the study population

	Mean or *n*/SD or % (*N*=40)
Age (years)	28.1 (6.3)
Gender (*n*, % females)	20.0 (50.0)
Educational level	
Elementary-Secondary education (*n*, %)	4 (10.0)
Undergraduate (*n*, %)	15 (37.5)
Higher education (*n*, %)	21 (52.5)
Diet Quality Index score (points)	39.5 (2.8)
Physical activity level (METS/min/week)	1973.1 (1239.5)
Current smokers (*n*, %)	3 (7.5)
Alcohol consumption (g/week)	40.8 (48.1)
Body mass index (kg/m^2)	23.5 (3.6)
Waist circumference (cm)	78.8 (10.1)

Note: Data for qualitative variables are expressed as *n* (%) and quantitative variables as mean±standard deviation (SD).

Table 2 Changes in cognitive performance scores after consumption of each breakfast

	Baseline		60 minutes post-consumption		120 minutes post-consumption	
	Estimated marginal mean	95% CI	Estimated marginal mean	95% CI	Estimated marginal mean	95% CI
Control conditions						
Immediate verbal memory (words)	12.28	11.66–12.89	13.03†	12.47–13.58	11.53‡	10.88–12.18
Delayed verbal memory (words)	9.62	8.80–10.44	9.81	8.80–10.83	7.89†‡	6.89–8.89
Phonological fluency (words)	15.55	14.21–16.89	14.60	13.63–15.57	12.55†‡	11.25–13.85
Attention (seconds)	20.43	18.46–22.39	23.63†	21.80–25.45	18.20‡	16.47–19.93
Executive functions and processing speed (seconds)	42.25	38.24–46.26	38.80	33.34–44.26	40.05	34.40–45.70
HGI breakfast						
Immediate verbal memory (words)	12.38	11.72–13.03	12.43	11.95–12.90	11.58	10.78–12.38
Delayed verbal memory (words)	10.31	9.53–11.09	9.39	8.54–10.23	7.77†‡	6.49–9.05
Phonological fluency (words)	14.88	13.48–16.27	13.80	12.86–14.74	12.95	12.03–13.87
Attention (seconds)	20.20	18.20–22.20	23.43	20.56–26.29	20.03‡	18.09–21.96
Executive functions and processing speed (seconds)	45.93	39.30–52.55	35.78†	31.11–40.44	36.85†	33.33–40.37
LGI breakfast						
Immediate verbal memory (words)	11.93	11.25–12.60	12.68	12.01–13.34	12.23	11.60–12.86
Delayed verbal memory (words)	9.83	8.81–10.84	9.95	9.00–10.91	8.58†‡	7.55–9.60
Phonological fluency (words)	15.00	13.62–16.38	14.88	13.81–15.94	12.43†‡	11.27–13.58
Attention (seconds)	21.25	18.48–24.03	22.75	20.49–25.01	18.60‡	17.00–20.20
Executive functions and processing speed (seconds)	43.65	38.80–48.50	36.43†	32.68–40.17	36.30†	33.21–39.39

Note: Repeated measures ANOVA has been performed stratifying by breakfast condition, with adjustment for age and educational level. Bonferroni test was used for *post hoc* contrasts. HGI: high glycaemic index; LGI: low glycaemic index; CI: confidence interval.
†$P<.05$ from baseline.
‡$P<.05$ between 60 and 120 minutes post-consumption.

Discussion

The findings of this research revealed no significant differences in cognitive outcomes in response to consumption of HGI and LGI breakfasts. However, an HGI breakfast appeared to be less advantageous for delayed and immediate verbal memory, phonological fluency, and attention. Our results therefore suggest that an LGI breakfast might provide more favourable acute cognitive responses than an HGI breakfast in young, healthy adults.

Only a few authors have investigated the impact of breakfast's glycaemic content on adults' cognitive performance. In line with our findings, Lamport *et al.* found that the glycaemic load of breakfast did not impact immediate and delayed verbal memory or executive functions in adults with type 2 diabetes or middle-aged obese females.[11,12] In contrast, other studies provided evidence in support of LGI breakfasts, showing a positive effect on verbal and working memory, selective attention, or executive function.[13–16] Nevertheless, currently available data are inconsistent and insufficient to establish causative connections between breakfast's GI and short-term cognitive functioning.[1,3,5,6,25] Possible explanations for these variable results might stem from the diversity of tests used to assess cognitive abilities, the heterogeneity in participants' ages, differences in the nutritional composition of the experimental meals, and discrepancies in the temporal distribution of the cognitive tests or blood sampling.[6]

In the present study, the observed influence of breakfast's GI on the postprandial cognitive responses was restricted to immediate verbal memory. This is congruent with the work by Nabb and Benton in female undergraduate students, which found that low glycaemic load breakfasts were associated with better memory.[4] Similarly, Benton *et al.* found that verbal memory in young, healthy adults was improved by an LGI breakfast compared to an HGI breakfast.[13] It can be inferred from these data that the stability of glucose, and its resulting insulin profile, affects certain aspects of cognitive function. As evidenced by a prior publication,[26] our study subjects remained normoglycaemic during all test sessions, although postprandial insulin release was found to be more gradual for an LGI compared to an HGI breakfast. Given that insulin has been implicated in modulating cognitive performance,[5] the enhancement of acute insulin sensitivity presumably induced by an LGI breakfast might underlie our observations.[27,28]

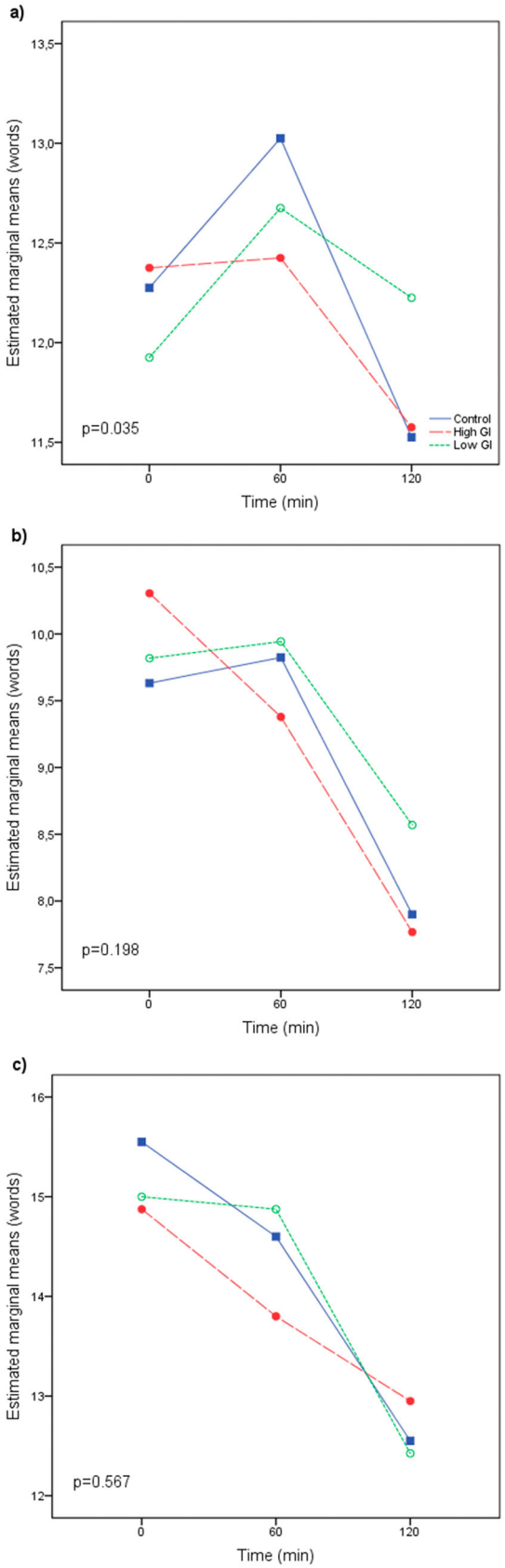

Figure 1 Performance on immediate verbal memory (a), delayed verbal memory (b), and phonological fluency (c) tasks in response to each experimental breakfast. Repeated measures ANOVA has been performed, with adjustment for age and educational level. GI: Glycaemic index.

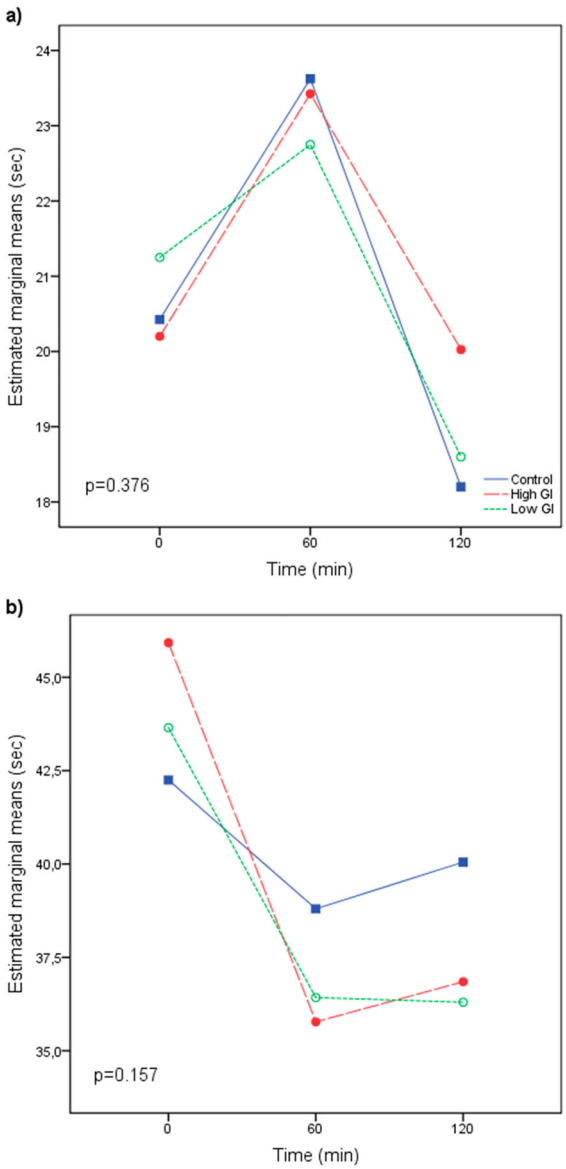

Figure 2 Performance on attention (a) and executive functions and processing speed (b) tasks in response to each experimental breakfast. Repeated measures ANOVA has been performed, with adjustment for age and educational level. GI: Glycaemic index.

There are some limitations to be highlighted in our trial. Firstly, participants could not be blinded because they were provided with real breakfast products. Secondly, the absence of breakfast's influence on cognitive outcomes could be explained by the inclusion of young, healthy adults with good cognitive resources and glucose regulation, thus there may be little room for improvement to observe. Thirdly, differences in volume, energy, and macronutrient distribution among breakfast conditions might mask the effects of GI on short-term cognitive performance.[4] In this regard, breakfast GI is known to have no effect on short-term energy intake among healthy people[29] but

the acute impact of breakfast composition on the subjective feeling of satiety may affect mood, alertness, motivation, and, subsequently, postprandial cognitive responses.[30] Finally, the possibility that the experimental breakfasts induced cognitive changes after 120 minutes remains unexplored.[13–15]

In summary, the results from the current study indicate that breakfast's GI minimally affects cognitive performance in young, healthy adults. Cognitive responses following both experimental breakfasts were similar, although an LGI breakfast appears to confer an advantage in both delayed and immediate verbal memory, phonological fluency, and attention. This suggests that GI manipulation at breakfast might represent a useful dietary tool towards enhancing cognitive function in the postprandial state. Further research is required to clarify whether the influence of breakfast's GI on cognition is reliable and sustainable and the mechanisms responsible.

Geolocation information

40°58′07.6″N 5°39′18.7″W.

Clinical trial registry

ClinicalTrials.gov Identifier NCT02616276 (https://clinicaltrials.gov/ct2/show/NCT02616276).

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Disclaimer statements

Contributors None.

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Conflicts of interest None.

Ethics approval The Clinical Research Ethics Committee (CREC) of the Health Area of Salamanca approved the study on 14 April 2015.

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