*Applied Human Factors and Ergonomics (AHFE2025),* Vol. 199, 2025, 1638–1643
https://doi.org/10.54941/ahfe1006974

# Neuroergonomics of Nutrition: Comparing Natural and Synthetic Sugars on Brainwave Activity and Cognitive Performance Through EEG

**Nithya Varma Madiraju**

The Pennsylvania State University, College of Health and Human Development, University Park, PA 16802, USA

## ABSTRACT

An important area of study within neuroergonomics, nutrition plays a fundamental role in supporting brain function, cognition, and performance. For example, the brain is heavily reliant on natural sugars such as glucose and sucrose, which serve as its primary sources of energy. Glucose, in particular, supports brain activity by fueling the electrical impulses that enable communication between neurons, facilitating cognitive processes, and serving as a key component in the creation of neurotransmitters. Past research shows that the intake of glucose improves attention, memory, and problem-solving. However, synthetic sugars, including aspartame, saccharin, and sucralose, can provide the same degree of sweetness without the significant added caloric value. Although synthetic sugars are often considered substitutes for the purpose of reducing calorie intake and for being a healthier alternative with less impact on weight and blood glucose levels, their influence on cognition and brain activity is not as widely understood. This study aims to dive deeper and investigate the effects of natural vs. synthetic sugars on brainwave activity and mental efficiency using electroencephalography (EEG).

**Keywords:** Neuroergonomics, Nutrition, Synthetic sugars, Natural sugars, EEG, Neuroscience, Cognition, Diet, Glucose

## INTRODUCTION

In the realm of neuroscience, cognitive performance is affected by a multitude of factors, notable ones including sleep, diet, and surrounding environmental conditions. Among the listed, diet has been proven to play an essential role in supporting cognition (Stevenson, 2014), as the brain relies primarily on glucose as its main energy source. Glucose, which is a natural sugar, fuels neuronal communication, supports neurotransmitter synthesis, and encourages higher-order cognitive processes such as memory/active recall, attention, and problem solving. While natural sugars provide metabolic energy to support such functions, the effects of synthetic sugars on brain function and neural activity are less understood as they provide a readily available substitute for natural sugars without the additional caloric value. Furthermore, given the widespread use of synthetic sweeteners in beverages

 

and food products, it is essential to understand whether they can replicate or substitute the cognitive benefits of natural sugars. Therefore, gaining awareness into how several types of sugars influence cognitive performance can help populations who rely on mental endurance and stamina in their daily routines, including students, professionals, athletes, and many more. This study investigates the effects of natural versus synthetic sugars on cognitive performance and brain activity, providing the rationale for the more detailed review presented in the following sections.

## BACKGROUND

### Nutrition's Role in Cognition

Nutrition plays a crucial role in supporting brain function and cognitive performance. The human brain depends on glucose as its primary source of energy, which fuels neuronal activity, supports neurotransmitter synthesis, and facilitates processes such as attention, enhanced memory, and problem-solving (Korol & Gold, 1998). Glucose ingestion has been shown to improve performance on tasks requiring sustained attention and executive function, highlighting the direct link between energy availability and cognitive efficiency.

### Natural Sugar Vs. Synthetic Sugar

Natural sugars, such as glucose, sucrose, and lactose, provide the metabolic energy necessary to sustain neural activity. In contrast, synthetic sweeteners: including aspartame, sucralose, and saccharin, provide the taste of sweetness without utilizing additional calories. These artificial sweeteners are commonly used to reduce calorie intake or manage existing blood glucose levels. However, because artificial sweeteners do not supply metabolic energy, they may be limited in their ability to support optimal attention, memory, and cognitive control. Few studies have directly compared their effects with natural sugars on cognitive performance and neural activity.

### Neuroergonomics Within Nutrition

Neuroergonomics, the study of the brain in relation to everyday tasks and performance, provides a framework for understanding how diet influences cognition in applied settings. Electroencephalography (EEG) offers a non-invasive means to assess real-time neural activity during cognitive tasks. Key EEG frequency bands include theta (4–7 Hz), associated with working memory load; alpha (8–12 Hz), associated with relaxation; and beta (13–30 Hz), associated with alertness and cognitive processing (Gashaj *et al.*, 2024). Investigating the impact of sugar consumption on these bands can provide insights into mechanisms underlying cognitive performance.

### Purpose

The present study aims to compare the effects of natural sugar, synthetic sweeteners, and water on cognitive performance and EEG activity using a within-subject, single-blind design. Participants will complete attention and working memory tasks while EEG is recorded using an Emotiv Insight headset.

### Hypotheses

Participants consuming natural sugars will demonstrate faster reaction times and higher beta band activity, indicating enhanced alertness and cognitive function. Additionally, participants consuming synthetic sweeteners will show minimal changes in behavioral performance and EEG activity compared to water control.

## METHODS

Healthy college-aged adults (ages 18–25) were recruited. Inclusion criteria required that participants were not diagnosed with neurological or metabolic disorders and not currently taking medications that could affect cognition or glucose intake/metabolism. However, the study did account for factors such as caffeine sensitivity, sleep deprivation, or any known neurological conditions that could affect the results. Additionally, participants provided informed consent prior to participation and were compensated for their time. The study employed a single-blind, within-subjects design, in which each participant received all three beverage conditions: (1) Natural sugar (8 oz orange juice), (2) Synthetic sugar (8 oz diet coke), (3) Synthetic sugar (diet coke) and (4) Control (8 oz water). The order of beverage administration was randomized across participants to minimize order effects. Each session was separated by at least 24 hours to minimize carryover effects and held in a quiet room with no distractions. Participants were blinded to the beverage type to reduce expectancy bias. However, experimenters were aware of which beverage was assigned for each individual session. For each participant and drink trial, cognitive performance was assessed using a Stroop test to measure attention and alertness, along with a jigsaw puzzle task to assess higher-order thinking and focus. Neural activity was recorded using an Emotiv Insight EEG headset (14-channel), which captures electrical signals at a sampling rate of 128 Hz. EEG data was collected and exported using the EmotivPRO software with analysis focused on three frequency bands: theta (4–7 Hz), associated with working memory load; alpha (8–12 Hz), associated with relaxation; and beta (13–30 Hz), associated with alertness and cognitive processing.

### Procedure

1. Participants avoided any beverages for at least two hours prior to each session.
2. A 5-minute resting baseline EEG was recorded at the start of each session.
3. Participants consumed the assigned beverage for that session and waited 10–15 minutes for absorption.
4. Simple and complex Stroop tests were completed while EEG was recorded continuously.
5. Behavioral and EEG data were collected separately for each beverage session.
6. Sessions for each participant were scheduled for over three days to ensure adequate data collection and results.

## RESULTS

**Table 1:** EEG data for control group, natural sugar group, and synthetic sugar groups (Mean + SD in %).

| EEG Metric | Control (Water) | Orange Juice (Natural Sugar) | Sprite Zero (Synthetic Sugar 1) | Diet Coke (Synthetic Sugar 2) |
|---|---|---|---|---|
| **Attention** | 51.4 ± 16.6 | 57.4 ± 18.9 | 57.0 ± 15.4 | 59.9 ± 17.3 |
| **Engagement** | 53.2 ± 17.7 | 55.3 ± 13.1 | 56.9 ± 6.3 | 52.8 ± 14.5 |
| **Excitement** | 32.8 ± 13.7 | 45.1 ± 21.4 | 33.7 ± 16.7 | 29.4 ± 9.4 |
| **Interest** | 47.8 ± 3.4 | 49.8 ± 1.7 | 49.7 ± 1.5 | 50.2 ± 1.4 |
| **Relaxation** | 34.6 ± 7.7 | 38.8 ± 8.2 | 37.9 ± 8.7 | 40.9 ± 12.4 |

### Within-Condition Comparisons

Participants who consumed the natural sugar beverage (orange juice) displayed an increase in attention (from 51.4% to 57.4%) and engagement (from 53.2% to 55.3%) compared to the control condition. Both synthetic sugar beverages showed similar levels in attention and interest, though their effects were slightly less consistent across individuals, as reflected by the smaller standard deviations. Excitement scores were highest in the natural sugar group and decreased in all other sweetened conditions and in the control, suggesting that sugar consumption is more linked to heightened focus and alertness rather than emotional arousal.

### EEG Pattern Observations

Across all beverage types, the attention and engagement data tended to be very close to each potentially suggesting the co-activation of neural circuits related to mental efforts and task focus. In contrast, relaxation levels increased slightly across all beverage conditions compared to the control (34.6 ± 7.7%), with the highest values following Diet Coke (40.9 ± 12.4%), followed by orange juice (38.8 ± 8.2%) and Sprite Zero (37.9 ± 8.7%). The small but steady increase in relaxation may reflect psychological comfort associated with drinking a pleasant beverage rather than direct metabolic changes. Although no inferential statistical tests were performed, the descriptive data revealed no crucial differences between natural and synthetic sugar conditions across most EEG measures. Attention, engagement, and interest remained within similar ranges for orange juice, Sprite Zero, and Diet Coke, suggesting that both sugar types may produce comparable short-term effects on neural activation and cognitive engagement.

## DISCUSSION

This study explored how natural and synthetic sugars influence EEG-based measures of cognitive and emotional engagement, including attention, excitement, interest, and relaxation. Although the original hypothesis proposed that natural sugars (such as glucose in orange juice) would yield higher brain activation and performance compared to synthetic sweeteners,

the data did not show significant differences between conditions. Instead, the findings suggest that both natural and artificial sugars may elicit similar short-term neural and cognitive responses.

### Interpretation of Findings

Participants who consumed the natural sugar beverage displayed higher mean attention and engagement levels in comparison to the control condition, suggesting that glucose availability still enhances cortical activation and mental alertness. In contrast, the synthetic sugar beverages (Sprite Zero and Diet Coke) produced similar effects. This introduces that artificial sweeteners can lead to the similar amounts of cognitive efficiency despite lacking the supply of metabolic energy. Slight increases in relaxation scores across all sweetened conditions suggest that beverage consumption, whether naturally or artificially sweetened may have influenced underlying alpha and theta wave activity, which are typically associated with relaxed but attentive mental states. Rather than reflecting heightened cognitive load, this pattern points to a state of calm alertness, potentially linked to psychological satisfaction after beverage intake. The absence of strong differences in beta activity, which is generally tied to focused attention and task engagement, supports the idea that sugar type did not alter overall neural arousal. The observed variability in results (SDs ranging from 6–21%) likely reflects individual differences in metabolism, attentional state, and EEG signal sensitivity.

### Relation to Previous Research

These results extend prior findings that glucose supplementation can improve performance on attention and memory tasks, particularly under cognitively demanding conditions. The modest improvements observed after consuming natural sugars are consistent with studies showing that glucose availability facilitates neurotransmitter synthesis and energy production required for sustained attention. Conversely, the limited effects of synthetic sweeteners align with prior evidence suggesting they primarily stimulate taste pathways and reward perception rather than directly fueling neuronal activity. These findings support the principle that nutritional inputs modulate brain efficiency in ways relevant to daily performance. For students, athletes, and professionals requiring sustained focus, natural sugars and synthetic sugars will temporarily improve attention and engagement when consumed in moderation.

### Limitations

Several limitations should be acknowledged. The study's sample size was small, and EEG data were collected using a consumer-grade Emotiv headset, which, while effective for general trends, has a lower spatial resolution than established research-grade systems. Additionally, no inferential statistical analyses were conducted, limiting the ability to draw firm conclusions about significance. Future research should employ larger samples, double blind experimentation, and direct EEG spectral analysis to confirm and expand on these findings.

### Future Directions

Future studies should incorporate blood glucose monitoring or markers to link metabolic changes with EEG outcomes. Including more complex cognitive tasks, such as working memory or decision-making under load, may also reveal stronger performance differences between natural and synthetic sugars. Comparing short-term versus long-term effects could clarify whether repeated artificial sweetener use leads to neural adaptation or reduced sensitivity to sweetness cues.

## CONCLUSION

Overall, this study found that both natural and synthetic sugars produced comparable short-term effects on EEG measures of attention, engagement, excitement, interest, and relaxation. Although orange juice (natural sugar) showed slightly higher averages in certain metrics, these differences were not substantial. The results suggest that the perceived sweetness of a beverage may play a more significant role in short-term cognitive and emotional responses than its caloric or metabolic content. From a neuroergonomic perspective, these findings emphasize that subjective experience and sensory stimulation can influence brain activity even in the absence of measurable metabolic changes. While glucose remains the brain's primary energy source, synthetic sweeteners may evoke similar neural engagement through reward-related pathways tied to taste perception. Future research should incorporate larger sample sizes, longer absorption periods, and more precise EEG tools to determine whether metabolic and perceptual effects can be more clearly differentiated.

## REFERENCES

Gashaj, V., Trninić, D., Formaz, C., Tobler, S., Gómez-Cañón, J. S., Poikonen, H., & Kapur, M. (2024). Bridging Cognitive Neuroscience and Education: Insights from EEG recording during Mathematical Proof Evaluation. *Trends in Neuroscience and Education*, *35*, 100226. https://doi.org/10.1016/j.tine.2024.100226.

Korol, D., & Gold, P. (1998). Glucose, memory, and aging. *The American Journal of Clinical Nutrition*, *67*(4). https://doi.org/10.1093/ajcn/67.4.764s.

Peters, R., White, D., Cleeland, C., & Scholey, A. (2020). Fuel for thought? A systematic review of neuroimaging studies into glucose enhancement of cognitive performance. *Neuropsychology Review*, *30*(2), 234–250. https://doi.org/10.1007/s11065--020-09431-x.

Stevenson, R. J., & Prescott, J. (2014). Human diet and cognition. *WIREs Cognitive Science*, *5*(4), 463–475. https://doi.org/10.1002/wcs.1290.