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Cortical arousal and memory modification in different study patterns and beverage consumption in university students

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Abstract

The aims of the present research were: (i) to analyze the cortical arousal and memory modifications associated with different study patterns among university students; (ii) to analyze the effect of different beverage consumption on academic performance, cortical arousal, and memory performance of students. To achieve these aims, we analyzed cortical arousal, operative memory, study patterns, and drink consumption during the study within 84 volunteers' university students from different academic fields before and after an individual study session at the library. We found that long study patterns (> 98.7 min) presented an increased cortical arousal in students without negatively affecting memory performance. These long study patterns also showed that a higher sugary drink consumption was not related to the academic performance of the students. Although most findings were statistically non-significant, the observed trends suggest that prolonged study duration may support cortical arousal without compromising memory, and that common stimulants such as sugary or caffeinated beverages, might not have a measurable

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impact in short study sessions. These preliminary results may inform future studies on optimizing study habits for cognitive performance.

Keywords: education; students; memory; attention; fatigue.

Ativação cortical e modificação da memória em diferentes padrões de estudo e consumo de bebidas em estudantes universitários

Resumo

Os objetivos da presente investigação foram: (i) analisar a ativação cortical e as modificações na memória associadas a diferentes padrões de estudo em estudantes universitários; (ii) analisar o efeito do consumo de diferentes bebidas no desempenho académico, ativação cortical e desempenho da memória. Foram analisadas a ativação cortical, a memória operativa, os padrões de estudo e o consumo de bebidas durante o período de estudo em 84 estudantes universitários voluntários de diferentes áreas académicas, antes e depois de uma sessão individual de estudo na biblioteca. Verificou-se que padrões de estudo mais longos (> 98,7 min) apresentaram uma maior ativação cortical nos estudantes, sem afetar negativamente o desempenho da memória. Estes padrões de estudo mais longos também revelaram um maior consumo de bebidas açucaradas, não estando este consumo relacionado com o desempenho académico dos estudantes. Apesar da maioria dos resultados não apresentar significância estatística, as tendências observadas sugerem que uma maior duração do estudo pode favorecer a ativação cortical sem comprometer a memória, e que estimulantes comuns como bebidas açucaradas ou com cafeína poderão não ter impacto mensurável em sessões de estudo de curta duração. Estes resultados preliminares podem orientar futuras investigações sobre a otimização dos hábitos de estudo para o desempenho cognitivo.

Palavras-chave: educação; estudantes; memória; atenção; fadiga

INTRODUCTION

Research on the learning process has previously focused on the different techniques used by students across different curricular stages, the information acquisition processes, the appropriate environments that engage and optimize learning, study performance, and the implementation of new technologies in the classroom (Henderson et al., 2015; Villota et al., 2015). More recently, some authors analyzed the negative impact of anxiety on operational functions, declarative and procedural memory, and the processing and assimilation of information in university students (Beltran-Velasco et al., 2018; Gulpers et al, 2016; Sharp et al., 2015). In this line, the overstimulation of the sympathetic autonomous nervous system by the anxiety-stress response would modulate the physiological response of the subject, decreasing superior functions such as learning, decision-making processes, self-perception, as well as memory (Beltran-Velasco et al., 2019).

Students use different strategies and techniques that individually differ depending on psychological and emotional factors, either for coping with anxiety and stress or to optimize their study (Johnston et al., 2015). Depending on these intrinsic factors, learning and teaching processes could be highly improved (Arbuthnott, 2015; Nomie-Sato et al., 2022; Sato et al., 2023a; Sato et al., 2023b), as well as controlling factors like the study time (McAndrew et al., 2016), physical activity (Wang et al., 2019), nutritional habits (Grygiel-Gorniak et al., 2016), and the ingestion of central nervous system activators like caffeine (Mahoney et al., 2019).

In this regard, current studies have demonstrated the importance of cortical arousal in cognitive information processing, since decreases in this variable have been linked to fatigue of the Central Nervous System (CNS) (Clemente-Suárez et al., 2010; Clemente-Suárez & Robles-Perez, 2013). The maintenance or increase in cortical arousal levels is essential for consolidating new information (Bellido et al., 2018). However, cortical arousal may suffer alterations depending on several extrinsic factors such as the exposure time to stimuli, the pauses taken, hydration, or the use of xanthines as ergogenic aids (Clemente-Suarez, 2017). All these factors that affect cortical arousal could also be disruptors of study performance and memory in students, but to the best of our knowledge, there is a lack of research on this topic. Despite the growing body of research on cognitive function, relatively few studies have examined how common lifestyle factors, such as beverage consumption (particularly caffeine and sugar intake), interact with study habits to influence cortical arousal and memory. Given the widespread use of these substances among students as study aids, understanding their real effects is essential. By addressing both study patterns and beverage intake, the present study aims to fill this gap and contribute novel data to the field of educational and cognitive neuroscience.

For this reason, we conducted the present study with the aims of: i. to examine the cortical arousal and memory modifications of different study patterns of university students; ii. to investigate the effect of different beverage consumption on academic performance, cortical arousal, and memory performance of students. The initial hypothesis was that students with higher cortical arousal would exhibit higher memory performance, in line with previous findings linking increased arousal to enhanced executive functions and cognitive processing (Delgado-Moreno et al., 2019; Belinchon-deMiguel et al., 2018; Mewborn et al., 2015).

METHOD

Participants

Eighty-four volunteer university students (21.7 ± 3 years old; 52 female and 32 male) from various academic disciplines, including biomedical sciences (*n* = 36) and humanities/social sciences (*n* = 48), were included in this study.

Participants were recruited through announcements on campus bulletin boards, social media platforms of the university, and direct email invitations. A convenience sampling method was used. No monetary or academic compensation was offered for participation; however, students were informed that the study would contribute to ongoing research in cognitive neuroscience and educational psychology. All procedures were conducted by the Declaration of Helsinki (revised in Brazil, 2013) and approved by the university's ethics committee (CIPI/18/074). Data collection was anonymous, and all participants provided written informed consent after being briefed on the objectives and procedures of the study and their right to withdraw at any time.

Procedures

Participants were recruited via advertisements on university bulletin boards, faculty mailing lists, and social media platforms. A convenience sampling method was applied. After expressing interest, students were invited to a scheduled study session in the university library. Upon arrival, they received detailed information about the study and signed a written informed consent form. Participation was voluntary, anonymous, and without any monetary or academic compensation.

Each student underwent a pre-study assessment, which included baseline measures of cortical arousal and operative memory. Participants then proceeded with their individual study sessions under naturalistic conditions in the library. Immediately after studying, the same variables were assessed again, and additional data were collected regarding study behavior and beverage consumption.

MEASURES

Cortical Arousal

Cortical arousal was assessed using the Critical Flicker Fusion Threshold (CFFT) via a Lafayette Instrument Flicker Fusion Control Unit (Model 12,021), following validated procedures (Clemente-Suarez & Robles-Perez, 2015; Clemente-Suarez & Diaz-Manzano, 2019). The test measures the threshold frequency at which a flickering light is perceived as steady, with higher values indicating greater cortical activation and information processing efficiency. Each participant completed the test in a quiet, dimly lit room before and after the study session.

Operative Memory

Memory performance was measured through a serial number recall task adapted from previous studies (Stroup et al, 2003; Clemente-Suarez, 2011). Participants were shown a rapid sequence of digits for 10 seconds and asked to recall and write down as many digits as possible in the correct order after a 15-second delay..The score was the total number of digits correctly recalled in the correct sequence

Study Pattern and Beverage Consumption

Following the study session, participants self-reported their total study time (in minutes), the number of breaks taken, and the duration of each break. They also reported their intake (in mL) of water, sugary drinks, coffee, and energy drinks consumed during the study period. These self-reports were used to explore the influence of consumption patterns on cognitive outcomes.

Statistical analysis

Data are presented as mean ± SD. The Shapiro–Wilk test was used to confirm the normal distribution of data. Paired-samples t-tests were used for pre- and post-intervention comparisons within participants, and independent-samples Student's t-tests were used for simple comparisons between groups. A mixed-design ANOVA was conducted to analyze differences across time (repeated measures) and between groups for all variables. Following a significant *F* ratio (Greenhouse–Geisser adjustment for sphericity), Vertical multiple comparisons among pairwise group means were performed with a Bonferroni correction for type I error when the time x group interaction was significant. The level of significance was set at $p< .05$. Data analysis was performed using SPSS software v. 21 (IBM, Chicago, IL, USA).

RESULTS

We found no significant differences in CFFT and memory after studying (Table 1). The number of study pauses was 0.53±0.64; the average duration of study pauses was 5.04±7.66 minutes; water intake was 145.51±166.64 ml; sugary drink intake was 4.18±37.13 ml; coffee intake was 19.00±45.50 ml; and no energy drinks were consumed.

Table 1

Critical Flicker Fusion Threshold (CFFT) and memory (remembered numbers) before and after studying in all participants

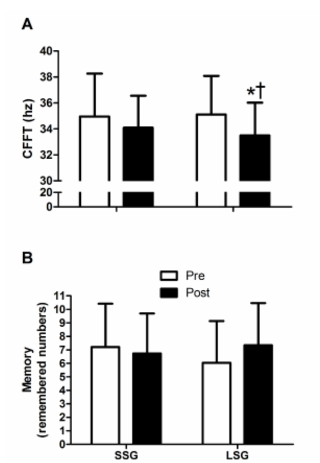
CFFT (hz)			Memory (remembered numbers)		
Pre	Post	% Δ	Pre	Post	% Δ
35.78±7.76	33.56±4.47	6.2±42.4	6.77±3.24	6.82±3.05	0.67±5.85

Note: Data presented are mean±SD.

Figure 1

(A) Critical Flicker Fusion Threshold (CFFT) before and after studying in the Short Study Group (SSG) and Long Study Group (LSG). (B) Number of digits remembered before and after studying in both groups. Values are means ± SD. * indicates significant difference from Pre (p = .001); † indicates significant difference between groups (p = .001).

Note: Abbreviations: SSG = Short Study Group (≤98.7 min), LSG = Long Study Group (>98.7 min).



When participants were divided by sex and by study area (humanities/social sciences vs. biomedical sciences), no significant differences were found in any other variable. The accumulated studying time was 98.70±45.37. Participants were divided into two groups based on their accumulated study time: below or above mean time of study in a large study group (LSG, time >98.7 min) and a small study group (SSG, time <98.8 min). According to this division, accumulated studying time was significantly different, but not age or average grades (Table 2). In addition, no differences were found between groups in the number of study pauses, study pauses meantime, or consumption of water, sugary drinks, or coffee. Comparing pre- and post-studying time, CFFT significantly decreased (p= .001) in the LSG and was significantly different from the SSG (p= .001; Figure 1A). However, memory performance did not show significant differences among groups, although there was a trend (p= .07) for the LSG to remember more numbers after studying (Figure 1B).

Table 2

Participant characteristics and study variables by study group (SSG = Short Study Group, LSG = Long Study Group)

Variable	SSG (n = 56)	LSG (n = 23)	p-value
Study time (min)	76.75 ± 20.72	152.17 ± 44.81	< .001
Age (years)	21.67 ± 3.54	22.34 ± 4.30	.425
Average grades (0–10)	6.84 ± 0.82	7.06 ± 0.80	.214
Water consumption (mL)	133.04 ± 149.63	176.09 ± 202.75	.309
Sugary drink consumption (mL)	0.00 ± 0.00	14.35 ± 68.81	< .001
Coffee consumption (mL)	19.64 ± 48.32	17.43 ± 38.74	.811

Note: Data are presented as mean ± SD. p-values are based on independent sample t-tests.

DISCUSSION

The present study revealed that longer study durations were associated with significantly higher cortical arousal, as measured by the Critical Flicker Fusion Threshold (CFFT), compared to shorter sessions. However, this increase in arousal did not translate into statistically significant improvements in memory performance, although a non-significant trend toward better recall was observed in the long study group. Furthermore, while sugary drink consumption was significantly higher among students who studied longer, no associations were found between beverage consumption (sugary drinks or caffeine) and memory or academic performance. These results suggest that while extended study time may enhance arousal, its effect on cognitive outcomes such as memory is less conclusive and may require further investigation with larger or more homogeneous samples.

Analyzing the cortical arousal, we found a non-significant decrease in CFFT that is linked with a small increase in cortical arousal and information processing (Delgado-Moreno & Robles-Pérez, 2017; Jambaqué et al., 2007). The absence of a general effect of the study on cortical arousal indicates that the average study time of the students may represent an operative strategy to maintain or even improve cortical arousal and information processing.

In this line, we found that studying for more than 98.7 minutes produced a significantly higher cortical arousal. This may potentially improve academic performance, as enhanced information processing is generally associated with better outcomes (Hormeño-Holgado & Clemente-Suarez, 2019). We expected that this response would improve the memory of students (as measured by the numbers recall task), but the large *SD* of the sample would prevent this result, despite the increase in recalled numbers. Previous studies have found that improvements in CFFT are associated with greater visual accuracy, executive functions, reasoning capacity, and memory (Belinchon-deMiguel et al., 2019; Delgado-Moreno et al., 2019; Williams et al., 2015), all of which are cognitive abilities that can positively influence study performance. The increased cortical arousal of LSG could be related to the time students need to become focused on the task, allowing interferences. Previous authors indicated that at least 23 minutes are necessary to focus on the task being conducted. Consequently, the study time of LSG allows them to reach this operative arousal for the study, even if they have had some distraction (Lovden & Wahlin, 2005). Regarding study time, it would be interesting to know the point at which the cortical arousal decreases, thereby limiting the information processing. Future research should analyze longer study times to delimit this.

When analyzing additional factors that could influence information processing and performance during study periods, no significant differences were found between students who consumed caffeinated beverages and those who drank water or no beverage at all. These findings suggest that a higher dose of caffeine, greater than 19.00 ± 45.50 ml of coffee, is required to produce a measurable increase in cortical arousal. Previous studies indicate that the ingestion of high caffeine doses (i.e., from energy drinks) produces an increase in the alert state at the physiological level, a decrease in mental fatigue, and the reduction of the cognitive deficit, among others (Curtis et al., 2022; Mewborn et al., 2015). To maintain these parameters of intellectual performance and CNS stimulation, the dose of caffeine should be at least 9 mg/Kg body weight, which means five cups of coffee or about 700 mg of caffeine for an average adult (Davis et al., 2003). Furthermore, the maximal effect of caffeine is expected in longer duration activities (~5 hours) (Champlin et al., 2016; Kamimori et al., 2002; Souza et al., 2017), thus, future research should assess longer study periods. On the other hand, we found a significantly higher consumptionof sugary drinks in LSG than SSG, fact that could be related with the higher cortical arousal of these groups, even the dose consumed (14.35±68.81 ml) was previously reported as not enough to improve brain performance (Riby et al, 2011; Stollery & Christian, 2016).

Focusing on students' degree marks, we found no significant differences between the groups, indicating that academic performance was not differentiated by the chosen study patterns.

Academic performance is a multidimensional concept determined by factors such as the acquisition of specific competencies of each degree, the completion of practical assignments, and personal variables such as motivation or self-concept (Bunce at al., 2017; Khalaila, 2015). Due to the multifactorial nature of this construct, it seems that the choice of different study durations does not have a significant impact on it. Finally, no significant differences between the groups (SSG and LSG) in the number of breaks during the study time and the duration of these breaks were found. It seems that for the study times analyzed in the present research, these variables do not significantly impac students; probably in longer study times, these variables would directly impact cortical arousal and memory performance, but future studies should confirm this fact.

LIMITATIONS

This study presents several limitations that should be considered when interpreting the findings. First, the sample size was relatively small and drawn from a single university, which may limit the generalizability of the results to broader student populations. Second, beverage consumption and study time were self-reported, potentially introducing recall or reporting bias. Third, the cross-sectional nature of the study prevents the establishment of causality between study behaviors and cognitive outcomes. Finally, the variability in students' academic disciplines and prior study habits may have introduced uncontrolled confounding effects. Future research should aim to include larger and more diverse samples, utilize objective measures of behavior and cognition, and explore longer-term study effects through longitudinal designs.

FUTURE DIRECTIONS AND IMPLICATIONS

Although the study did not yield statistically significant effects in memory performance, the observed trends offer relevant insights for the field. The increase in cortical arousal with longer study durations, without concurrent memory impairment, suggests that sustained attention and engagement may be maintained over time without cognitive detriment. Future research should explore longer and more ecologically valid study periods, include neurophysiological and behavioral measures of engagement, and control for variables such as study content, time of day, and baseline cognitive capacity. Additionally, randomized experimental designs could help establish causal relationships between beverage consumption and cognitive performance, as well as determine optimal conditions for enhancing academic efficiency. These efforts will help refine educational strategies and inform guidelines for effective study habits.

CONCLUSIONS

In conclusion, we found that long study patterns (> 98.7 minutes) presented an increased level of cortical arousal in students, without negatively affecting memory performance. This long study pattern also showed that a higher sugary drinks consumption was not related to the academic performance of the students. The same for caffeine consumption, which may need longer study time in order to benefit from its mental ergogenic effects.

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