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Sleep quality, screen time, and verbal episodic memory in adolescents from Brazil, South America: a cross-sectional study

Qualidade do sono, tempo de tela e memória episódica verbal em adolescentes do Brasil, América do Sul: um estudo transversal

Calidad del sueño, tiempo de pantalla y memoria episódica verbal en adolescentes de Brasil, América del Sur: un estudio transversal

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ABSTRACT:

Introduction: Sleep plays a fundamental role in memory consolidation. Adolescents are especially vulnerable to poor sleep quality. Although there is evidence of the effects of sleep deprivation on memory, few studies have examined the relationship between subjective sleep quality, screen use, and verbal episodic memory performance in this age group. **Objective:** Investigate the relationship between subjective sleep quality, screen time before bed, and verbal episodic memory in adolescents. **Methods:** This cross-sectional study included 21 high school students aged 15 to 17. Participants completed the Pittsburgh Sleep Quality Index (PSQI), the Rey Auditory Verbal Learning Test (RAVLT), an additional questionnaire on screen habits, and the Matrix Reasoning subtest of the Beta-III. Spearman correlation, Mann-Whitney test, and linear regression were performed. **Results:** A significant correlation was found between screen time before sleep and forgetting speed ($\rho = 0.540$; $p = 0.012$), as well as between poor sleep quality and retroactive interference ($\rho = 0.467$; $p = 0.033$). Regression analysis showed that screen time predicted forgetting speed ($R^2 = 0.511$; $p = 0.024$), and sleep quality predicted retroactive interference ($R^2 = 0.560$; $p < 0.011$). Gender differences were observed but not statistically significant. **Conclusion:** Poor sleep quality and nighttime screen use were associated with impairments in verbal episodic memory among adolescents.

Keywords: sleep, sleep quality, screen time, verbal episodic memory, adolescentes, Brazil, South America

RESUMO:

Introdução: O sono exerce papel fundamental na consolidação da memória. A adolescência possui maior vulnerabilidade à má qualidade do sono. Embora existam evidências do impacto da privação de sono na memória, são escassos os estudos que relacionam a qualidade subjetiva do sono e o uso de telas ao desempenho em memória episódica verbal nessa faixa etária. **Objetivo:** Investigar a relação entre qualidade subjetiva do sono, tempo de tela antes de dormir e memória episódica

verbal. **Métodos:** Foi feita assinatura do Termo de Consentimento Livre e Esclarecido (TCLE) pelos pais e do Termo de Assentimento Livre e Esclarecido (TALE) pelos adolescentes. Parecer CEP: Universidade FUMEC. CAAE: 65494822800005155. Estudo transversal com 21 estudantes do ensino médio (15 a 17 anos). Foram aplicados o Índice de Qualidade do Sono de Pittsburgh (PSQI), o Teste Auditivo Verbal de Rey (RAVLT), um questionário adicional e o subteste Raciocínio Matricial do Beta-III. As análises incluíram correlação de Spearman, teste de Mann-Whitney e regressão linear. **Resultados:** Houve correlação entre tempo de tela antes de dormir e velocidade de esquecimento (ρ=0,540; p=0,012), além de associação entre má qualidade do sono e interferência retroativa (ρ = 0,467; p = 0,033). A regressão mostrou que o tempo de tela previu a velocidade de esquecimento (R^2 = 0,511; p = 0,024), e a qualidade do sono previu a interferência retroativa (R^2 = 0,560; p = 0,011). Diferenças entre sexos foram observadas, sem significância estatística. **Conclusão:** A má qualidade do sono e a utilização de telas à noite associaram-se a prejuízos na memória episódica verbal.

Palavras-chave: sono, qualidade do sono, tempo de tela, memória episódica verbal, adolescentes, Brasil, América do Sul

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RESUMEN:
Introducción: El sueño desempeña un papel fundamental en la consolidación de la memoria. La adolescencia presenta una mayor vulnerabilidad a la mala calidad del sueño. Aunque existen evidencias sobre el impacto de la privación del sueño en la memoria, son escasos los estudios que relacionan la calidad subjetiva del sueño y el uso de pantallas con el rendimiento en la memoria episódica verbal en esta etapa. **Objetivo:** Investigar la relación entre la calidad subjetiva del sueño, el tiempo de pantalla antes de dormir y la memoria episódica verbal. **Métodos:** El Formulario de Consentimiento Informado (FCI) fue firmado por los padres y el Formulario de Asentimiento Informado (FAI) por los adolescentes. Estudio transversal con 21 estudiantes de enseñanza media (15 a 17 años). Se aplicaron el Índice de Calidad del Sueño de Pittsburgh (PSQI), la Prueba Auditiva Verbal de Rey (RAVLT), un cuestionario adicional y el subtest de Razonamiento Matricial del Beta-III. Los análisis incluyeron correlación de Spearman, prueba de Mann-Whitney y regresión lineal. **Resultados**: Se observó una correlación entre el tiempo de pantalla antes de dormir y la velocidad de olvido (ρ = 0,540; p = 0,012), además

de una asociación entre mala calidad del sueño e interferencia retroactiva (ρ = 0,467; p = 0,033). La regresión mostró que el tiempo de pantalla predijo la velocidad de olvido (R^2 = 0,511; p = 0,024), y que la calidad del sueño predijo la interferencia retroactiva (R^2 = 0,560; p = 0,011). Se observaron diferencias entre sexos, sin significación estadística. **Conclusión:** La mala calidad del sueño y el uso nocturno de pantallas se asociaron con perjuicios en la memoria episódica verbal.

Palabras clave: sueño, calidad del sueño, tiempo de pantalla, memoria episódica verbal, adolescentes, Brasil, América del Sur

Introduction

Over recent decades, scientific understanding of sleep has advanced significantly, accompanied by growing interest in elucidating its role in cognitive processes, overall health, and quality of life. Historically, sleep was considered merely a state of cerebral inactivity aimed at conserving and restoring energy [1].

However, since the early 20th century, it has become clear that sleep is a neurophysiologically active phenomenon characterized by distinct patterns of brain activity. These patterns are associated with critical functions, including emotional regulation, physical recovery, and various cognitive aspects, notably memory consolidation [2].

Since then, numerous studies employing molecular, physiological, and behavioral paradigms have robustly established the connection between sleep and different types of memory, particularly declarative memory, which encompasses the recall of events and factual information, known as episodic memory [3 – 4 - 5].

Research findings indicate that good sleep quality facilitates the consolidation of newly acquired memories, making them more stable and resistant to forgetting [6]. Additional studies have reinforced these findings by demonstrating that sleep deprivation, whether occurring before or after learning tasks, negatively impacts mnemonic performance in declarative memory tasks [5, 7].

From a neurobiological perspective, several mechanisms explain sleep's contribution to memory consolidation. At the cellular level, the reactivation of firing patterns in hippocampal neurons generates more stable memory representations in extra-hippocampal networks, predominantly within the neocortex, during sleep [1, 6]. This process occurs mainly during slow-

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wave sleep (SWS), characterized by large, slow-wave oscillations (0.5–4 Hz) [8].

As seen across various animal species, sleep regulation patterns vary according to developmental stages. During early life, from birth to early childhood, significant changes occur in sleep architecture, with progressive alterations in the proportion and distribution of NREM and REM sleep stages [4].

Adolescence, in particular, is marked by significant sleep-related changes that predispose individuals to sleep loss, driven by both biological and behavioral factors [9]. Longitudinal electroencephalogram (EEG) studies have shown that slow-wave sleep in the NREM phase, specifically activities in delta and theta frequencies, significantly decrease between approximately 12 and 16 years of age [10 – 11 - 12].

Research [4, 11] highlights that the steepest decline in slow-wave power occurs precisely during this age range, following by about one year the peak of pubertal maturation. Additionally, these studies report an average annual decrease in total sleep duration of about 10 minutes per year during adolescence, attributed exclusively to reduced NREM sleep.

Physiological delays in circadian rhythms are observed during adolescence, including delayed melatonin secretion, causing teenagers to experience later sleep onset [9]. This developmental stage is also marked by puberty, which initiates complex hormonal and sexual changes affecting adolescent brain and behavior [13].

These alterations, coupled with the hyperactivation of dopaminergic circuits, may increase vulnerability to mental health disorders [9], potentially negatively impacting sleep. Furthermore, contextual factors, such as electronic media usage, can also influence sleep patterns [14, 15, 16].

Excessive use of electronic media among adolescents constitutes an environmental factor significantly associated with poor sleep quality [17]. Although the mechanisms underlying this relationship are not fully understood, some authors suggest that stimulating content increases physiological arousal, making relaxation necessary for sleep initiation difficult [17].

Moreover, engaging in stimulating activities through screen devices can inhibit nighttime melatonin secretion, disrupting circadian rhythms [16]. Consequently, studies have documented shorter and fragmented sleep [14, 16], sleep disturbances [15], prolonged sleep onset latency, poorer sleep efficiency, and increased daytime dysfunction [18]. Poor sleep quality, often mediated by screen use, directly impacts various aspects of adolescents' lives.

Some studies [6, 8] also indicate that poor sleep quality can impair fundamental cognitive functions necessary for learning, including attention, decision-making, and behavioral self-regulation. Emotionally, sleep deprivation or poor sleep quality has been linked to increased depressive symptoms, irritability, impulsivity, and risk-taking behaviors [2, 19]. Academically, adolescents with insufficient or fragmented sleep exhibit greater difficulty concentrating and deficits in declarative, procedural, and working memory performance, negatively affecting school performance [1, 5].

Despite significant advances in sleep and memory research, many studies focus on individuals with sleep disorders or partial or total sleep deprivation [4 - 5, 9, 20 - 21]. Such experiments often occur in laboratory settings, overlooking subjective sleep quality in naturalistic conditions. Subjective sleep quality encompasses satisfaction with sleep initiation, maintenance, duration, and restfulness upon awakening [22]. This distinction is crucial, as these variables appear to affect memory consolidation even without objectively reduced sleep duration.

Additionally, many studies focus on adult or middle-aged populations, highlighting the need for more adolescent-focused research given the significant behavioral, emotional, and hormonal changes during this developmental phase. Understanding how sleep-related variables impact episodic memory and academic performance during adolescence is therefore essential [3, 18, 21].

Furthermore, few studies explore how specific aspects of sleep quality, such as, latency, sleep duration, and daytime sleepiness, relate to variables involved in verbal episodic memory tasks, including forgetting speed, retroactive interference, proactive interference, and learning indices. Given the importance of sleep for cognitive functioning and the prevalence of sleep-disruptive behaviors during adolescence, this study aims to understand these relationships. The hypothesis is that individuals

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with poorer sleep quality or less healthy habits will exhibit impaired performance on measures of verbal episodic memory.

Methods

This study aimed to investigate the relationship between sleep quality, screen time exposure, and performance on verbal episodic memory tasks in adolescents.

The investigation sought to analyze possible associations between subjective sleep indicators, such as the Pittsburgh Sleep Quality Index (PSQI), and cognitive performance measures assessed by the Rey Auditory Verbal Learning Test (RAVLT). Screen time reported during nighttime was also considered a relevant behavioral variable. This approach aims to enhance understanding of the effects environmental factors and daily habits have on cognitive functions critical during adolescence.

This cross-sectional, observational study was approved by the Ethics Committee of Fundação Mineira de Educação e Cultura, Universidade FUMEC, CAAE: 65494822800005155. Data collection occurred in a private educational institution located in Lagoa Santa, Minas Gerais, which consented to its execution.

Inclusion criteria required healthy participants, following the exclusion criteria listed in the procedures. The study initially included 31 students; however, only 21 (8 males and 13 females) were selected based on these established criteria.

Instruments Used

Pittsburgh Sleep Quality Index (PSQI) [23]

The PSQI assesses subjective sleep quality over the past month and comprises 19 items grouped into seven components: sleep latency, subjective sleep quality, habitual sleep efficiency, sleep medication usage, sleep disturbances, sleep duration, and daytime dysfunction related to sleep-wake cycles. Each component is scored from 0 to 3, with total scores ranging from 0 to 21. Scores between 0-5 indicate good sleep quality, 6-10 suggest poor sleep quality, and scores above 10 suggest a possible sleep disorder. The PSQI is psychometrically valid for Brazilian adolescents, having been validated within the Brazilian Psychological Test Assessment System (SATEPSI). It is recommended for research due to its ease and quick administration.

Revised Beta Examination (Beta-III) [24]
The Beta-III is a non-verbal test assessing general intelligence. Specifically, this study utilized the Matrix Reasoning subtest to ensure participants met inclusion and exclusion criteria through a rapid assessment of reasoning ability and pattern identification, with a maximum duration of 2 minutes. This subtest is accurate, efficient for rapid screening of adolescents in clinical and academic research, and has been validated and standardized in Brazil according to SATEPSI guidelines.

Rey Auditory-Verbal Learning Test (RAVLT) [25]
The RAVLT assesses auditory-verbal learning and episodic declarative memory. Participants hear and recall a list of words following standardized application, recording, scoring, and interpretation guidelines, with age-specific norms. The test duration is approximately 40 minutes, comprising 20 minutes of initial learning phases and an additional 20 minutes for delayed recall. The RAVLT is psychometrically precise and sensitive in detecting memory performance variations, validated and recommended for use in Brazilian adolescent research according to SATEPSI.

Data Collection Procedures
Participants were invited through classroom announcements that outlined the objectives and procedures of the study. Following the signing of the Free and Informed Consent Form by parents and the Free and Informed Assent Form by adolescents, demographic data were collected via electronic questionnaires completed by parents using Google Forms. Subsequently, participants were individually scheduled for an in-person assessment conducted in a private room provided by the school.

The assessment instruments were administered in a structured, single-day session divided into five primary stages. Initially, participants completed the Rey Auditory-Verbal Learning Test (RAVLT) up to the distractor phase. During the 20-minute interval required by the RAVLT, participants completed the Pittsburgh Sleep Quality Index (PSQI), the Matrix Reasoning subtest of the Beta-III for cognitive control, and an additional questionnaire regarding electronic device use before sleep, medication use, and psychiatric diagnoses. After the interval, the RAVLT was completed with delayed recall and recognition tasks, fully assessing verbal episodic memory.

Each instrument was individually administered by one of five trained researchers, adhering strictly to technical and ethical standards for

neuropsychological testing. Responses were manually verified before statistical analysis, ensuring accuracy and confidentiality.

Data were initially organized in Microsoft Excel spreadsheets and subsequently exported to IBM SPSS Statistics software for statistical analyses. Spearman correlation coefficients were employed for associations between continuous variables. Non-parametric tests (Mann-Whitney U and Kruskal-Wallis) compared groups, and simple linear regression models assessed predictive relationships. A significance level of 5% ($p < 0.05$) was adopted. Complementary graphical and data visualizations were generated with the support of the OpenAI platform to facilitate detailed analysis and interpretation of sleep quality indicators and cognitive performance scores.

Results

The study sample comprised 21 adolescents aged between 15 and 17 years ($M = 15.8$; $SD = 1.01$), consisting of 13 females (61.9%) and 8 males (38.1%), all regularly enrolled in a private school in Lagoa Santa, Minas Gerais.

Spearman correlation analysis revealed a moderate and statistically significant positive correlation between nighttime screen time and forgetting speed on the RAVLT ($\rho = 0.540$; $p = 0.012$). This result suggests that adolescents reporting higher exposure to electronic devices at night showed increased loss of previously learned information after interference. This finding implies a potential negative impact of screen time on mnemonic consolidation processes. Additionally, a significant positive correlation was observed between PSQI scores and retroactive interference ($\rho = 0.467$; $p = 0.033$), indicating poorer subjective sleep quality was associated with greater difficulty retrieving information following the introduction of new stimuli.

Figure 1 illustrates the correlation matrix, including Rey Auditory-Verbal Learning Test (RAVLT) scores, Pittsburgh Sleep Quality Index (PSQI) scores, average nighttime screen time in minutes, Matrix Reasoning subtest scores (Beta-III), and sociodemographic variables.

Several additional associations approached the threshold for statistical significance, notably the correlation between PSQI and forgetting speed ($\rho = 0.441$; $p = 0.053$) and between screen time and retroactive interference ($\rho = 0.336$; $p = 0.092$). Although these correlations did not reach

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conventional significance criteria, they suggest trends consistent with the theoretical hypotheses of this study, warranting further investigation with larger samples.

Overall, the findings support the hypothesis that behavioral variables such as electronic device use and aspects of sleep quality systematically relate to performance on verbal episodic memory tasks in adolescents. Based on these correlational results, simple linear regression analyses were conducted to examine the predictive capacity of these variables regarding episodic memory performance. Two independent models were constructed, both achieving statistical significance.

The correlational results revealed statistically significant associations between average screen exposure time before sleep and forgetting speed ($\rho = 0.540$; $p = 0.012$), and between subjective sleep quality assessed by PSQI and retroactive interference in verbal episodic memory ($\rho = 0.467$; $p = 0.033$). Forgetting speed was calculated as the ratio between delayed recall and final learning on the RAVLT, while retroactive interference corresponded to the difficulty in recalling information following the presentation of new stimuli. These findings suggest that higher screen exposure times and poorer subjective sleep quality significantly correlate with specific impairments in verbal episodic memory.

Additionally, Spearman correlation coefficients calculated between behavioral and cognitive variables confirmed the previously mentioned statistically significant associations: nighttime screen time positively correlated with forgetting speed ($\rho = 0.540$; $p = 0.012$), and subjective sleep quality (PSQI) was associated with retroactive interference ($\rho = 0.467$; $p = 0.033$). These findings indicate that both nighttime electronic device use and poor sleep quality indicators are positively related to increased vulnerability to interference effects on mnemonic consolidation.

In the first regression model, average nighttime screen time was used as a predictor variable for forgetting speed observed on the RAVLT. Results showed that screen time significantly predicted the forgetting rate ($\beta = 0.815$; $p = 0.001$), accounting for approximately 51% of the variance in memory performance ($R^2 = 0.511$). The positive β coefficient indicates that greater screen exposure is associated with faster forgetting rates, representing greater episodic memory impairment. This effect is visually represented in Figure 2, showing the scatter plot with the adjusted regression line.

In the second model, sleep quality assessed by PSQI served as a predictor for retroactive interference. A significant effect was found, with higher PSQI scores (indicating poorer sleep quality) linked to greater interference from new information on previously learned content ($\beta = 0.810$; $p < 0.001$), explaining 56% of the variance ($R^2 = 0.560$). Data distribution and model adjustment are depicted in Figure 3.

Analysis of sex differences regarding behavioral variables revealed relevant patterns. Boxplots in Figures 4A and 4B illustrate subjective sleep quality scores (PSQI) and average nighttime screen exposure time, stratified by sex.

Figure 4A shows that female adolescents reported higher nighttime screen exposure compared to males, although this difference was not statistically significant (Mann-Whitney test, $p = 0.051$). Despite not reaching statistical significance, the trend suggests greater digital engagement among girls.

Figure 4B presents PSQI scores, with females demonstrating broader variability and slightly higher median scores, indicating poorer subjective sleep quality compared to males. This finding aligns with literature suggesting higher prevalence of sleep complaints among female adolescents, potentially associated with hormonal, emotional, and behavioral factors [26].

Although statistical tests did not identify significant differences between sexes regarding cognitive variables (total RAVLT score, forgetting speed, and interference indices), it is important to highlight that the limited sample size, particularly in the male group ($n = 8$), may have reduced the statistical power needed to detect true effects.

Nevertheless, the trends toward greater screen time and poorer sleep quality among females warrant attention, especially considering previous findings indicating relationships between these variables and mnemonic performance. These data reinforce the need for future investigations with larger samples and stratified analyses to explore possible interactions between sex, sleep, and memory.

Discussion

Advances in neuroscience have consistently shown that sleep is not merely a state of physiological rest, but an active period for processing and reorganizing information learned throughout the day. As highlighted in the

introduction, the consolidation of declarative memory, particularly episodic memory, heavily relies on sleep quality, especially slow-wave sleep (SWS), which facilitates coordinated communication between the hippocampus and neocortex [20].

In this context, adolescence represents a particularly critical phase. The brain undergoes intensive synaptic and hormonal reorganization [13], coinciding with increased behaviors detrimental to sleep quality, notably excessive nighttime screen usage [15, 17].

Findings from the present study reinforce and extend the understanding that adolescents with poorer scores on the Pittsburgh Sleep Quality Index (PSQI) demonstrate higher levels of retroactive interference in verbal episodic memory tasks ($\rho = 0.467$; $p = 0.033$).

Furthermore, average exposure to electronic devices before sleep was significantly correlated with forgetting speed ($\rho = 0.540$; $p = 0.012$), indicating that nighttime screen use may impair the consolidation of newly acquired memories. These results confirm the central hypothesis of the study, suggesting that often overlooked daily behavioral variables directly influence cognitive processes essential to academic performance and adolescent learning. These associations become even more relevant when interpreted in light of neurobiological models outlined in the introduction.

Exposure to blue light emitted by screens, cognitive overload from digital content, and fragmented sleep contribute to reduced deep sleep and melatonin suppression, effects particularly detrimental during adolescence—a period marked by accelerated brain development [17, 27].

Episodic memory, reliant on the integrity of these processes, becomes vulnerable to external interference and accelerated information loss. Consequently, the data from this study align with contemporary literature, underscoring that not only sleep duration but also subjective sleep quality and the behavioral context significantly impact cognitive performance among school-aged youth [6, 22].

Another notable aspect involves observed behavioral differences between sexes. Although statistical analyses did not reach significance between groups, female adolescents reported higher average nighttime screen time ($p = 0.051$) and higher PSQI scores, suggesting a tendency toward poorer subjective sleep quality. This finding is consistent with previous literature

highlighting gender-based differences in sleep quality among adolescents, potentially related to hormonal, emotional, and behavioral factors [26].

Gender Differences and Predictive Behavioral Variables

These findings, though preliminary, align with previous studies indicating higher prevalence of sleep complaints, insomnia, and emotional symptoms among girls during puberty and adolescence [12, 14]. This trend may reflect not only hormonal factors but also distinct digital usage patterns, with greater engagement in social networks, instant messaging, and emotionally stimulating content, all potentially detrimental to sleep hygiene [14].

Beyond bivariate correlations, linear regression analyses conducted in this study reinforce the predictive role of behavioral variables on memory performance. Nighttime screen exposure explained approximately 51% of the variance in forgetting speed ($R^2 = 0.511$; $\beta = 0.815$; $p = 0.001$), while sleep quality assessed by PSQI accounted for 56% of the variance in retroactive interference ($R^2 = 0.560$; $\beta = 0.810$; $p < 0.001$). These findings suggest that even in a small sample, variables such as electronic device use and subjective sleep quality demonstrate a strong explanatory capacity regarding specific components of verbal episodic memory.

Similar results have been reported in literature, indicating that variables related to sleep architecture and nighttime digital behavior significantly impact the consolidation and retrieval of declarative memories [1, 5, 7]. Previous studies also suggest that sleep deprivation or fragmentation, particularly when occurring after learning, may compromise synaptic consolidation processes and increase retroactive interference [5, 20]. These findings strengthen the hypothesis that interventions targeting these factors could directly influence cognitive processes critical for academic performance [12, 22].

However, it is essential to acknowledge the methodological limitations of this study. The small sample size (n = 21), composed exclusively of students from a private school in a region with high human development index, limits generalizability. Additionally, the absence of objective sleep measures, such as polysomnography or actigraphy, restricts precision in identifying actual sleep architecture. Formal academic indicators, such as grades or school reports, were also not considered, potentially limiting deeper analyses of the impact of poor sleep quality on academic performance [28 - 29].

Despite these limitations, the data presented here provide robust preliminary evidence that could guide public policies and educational actions. Simple interventions, such as restricting nighttime screen usage, adjusting school schedules to better align with adolescents' biological rhythms, and implementing sleep education programs, may directly impact learning and student well-being [15, 30]. Such strategies become even more relevant when combined with interdisciplinary school actions involving health professionals, psychologists, and educators.

To deepen understanding of these issues, future studies should adopt longitudinal and experimental designs incorporating objective sleep measures and more rigorous variable controls. Research testing psychoeducational interventions (such as limiting screen usage one hour before bedtime) should be prioritized, measuring effects on cognitive, emotional, and academic variables. Additionally, multivariate analyses including hormonal, emotional, and social aspects, particularly regarding possible gender differences in the relationship between sleep and cognition, will be essential [12, 22].

Conclusion

The findings of this study suggest that adolescents with higher nighttime exposure to screens exhibit increased forgetting speeds, indicating potential impairments in the consolidation of newly acquired memories. Concurrently, poorer subjective sleep quality was associated with heightened retroactive interference in verbal episodic memory tasks. These results reinforce existing evidence linking suboptimal sleep patterns and excessive use of electronic devices to detrimental effects on mnemonic processes critical for effective learning and memory retention.

Furthermore, these data underline the critical role of behavioral factors in determining sleep quality and subsequent cognitive performance among adolescents. The insights gained highlight the urgency for targeted educational interventions aimed at improving sleep hygiene and reducing nighttime electronic device usage. Implementing such interventions could significantly enhance cognitive outcomes and overall academic performance in this vulnerable age group.

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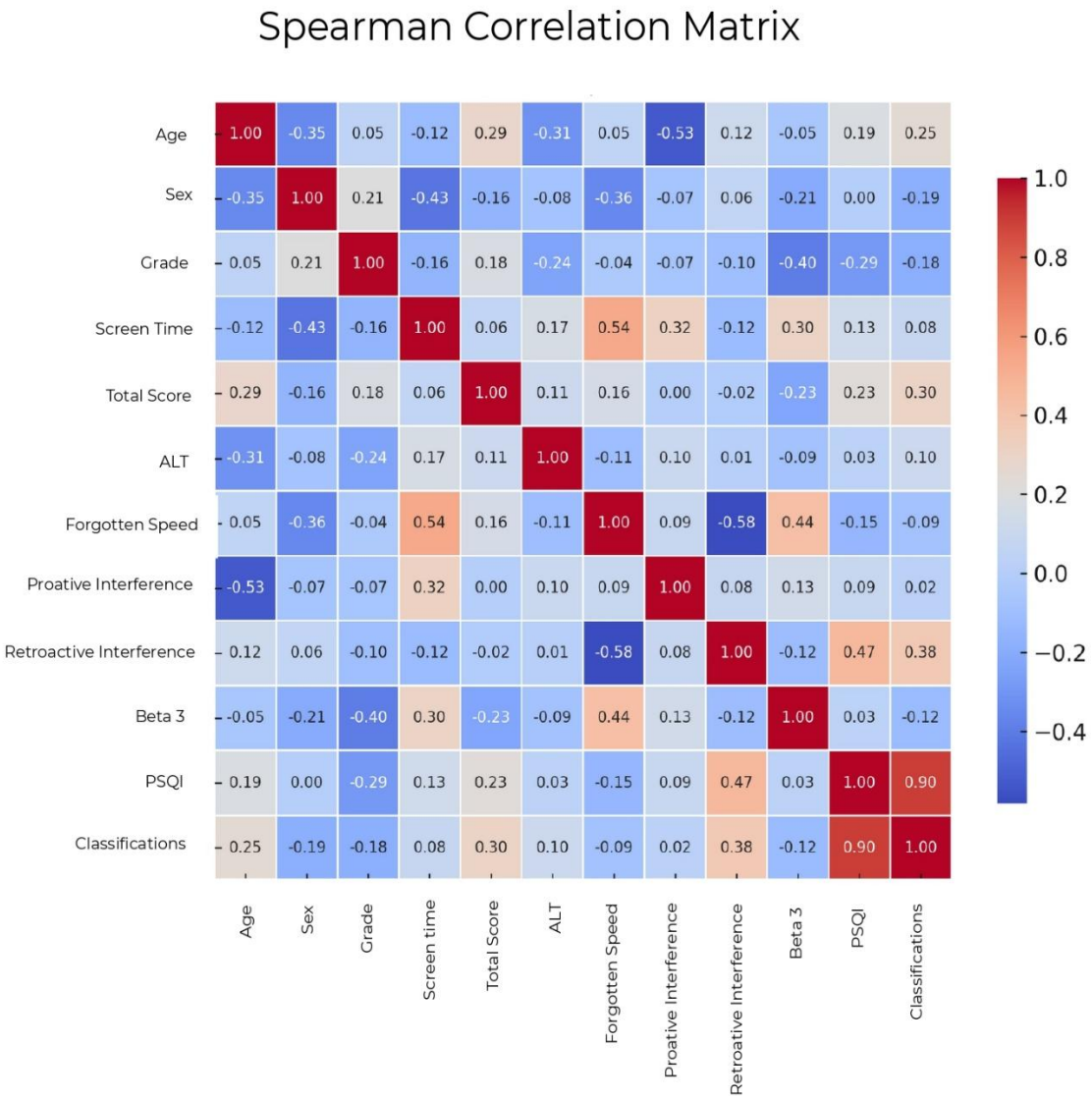

Figure 1. Spearman correlation matrix between behavioral, cognitive, and sleep variables (n = 21)
Source: The authors
Legend: The presented Spearman correlation heatmap explores the relationships among behavioral variables (average screen time during the night, PSQI score and its classification), cognitive variables (indicators derived from the Rey Auditory Verbal Learning Test – RAVLT), and sociodemographic variables (age and school grade). **Explanatory note**: Among the cognitive variables, the Total Score represents the sum of correctly recalled words in the first five trials of List A, reflecting initial learning; ALT (Across-List Learning) corresponds to the gain obtained between the first and fifth trials; Forgetting Speed indicates the rate of

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information loss between the moment of peak learning and delayed recall; Proactive Interference evaluates the impact of previously learned information on new learning (List B); and Retroactive Interference measures how much the new information interfered with the retrieval of previously learned content (List A). The variable Beta 3 refers to performance on the Matrix Reasoning subtest, used to control for intellectual capacity. The PSQI (Pittsburgh Sleep Quality Index) represents subjective sleep quality, with higher scores indicating worse quality. The Sleep Classification variable categorizes the PSQI into three levels: good sleep quality (01), poor sleep (02), and sleep disorder (03). Statistically significant correlations ($p < 0.05$) indicate relevant associations between the evaluated domains.

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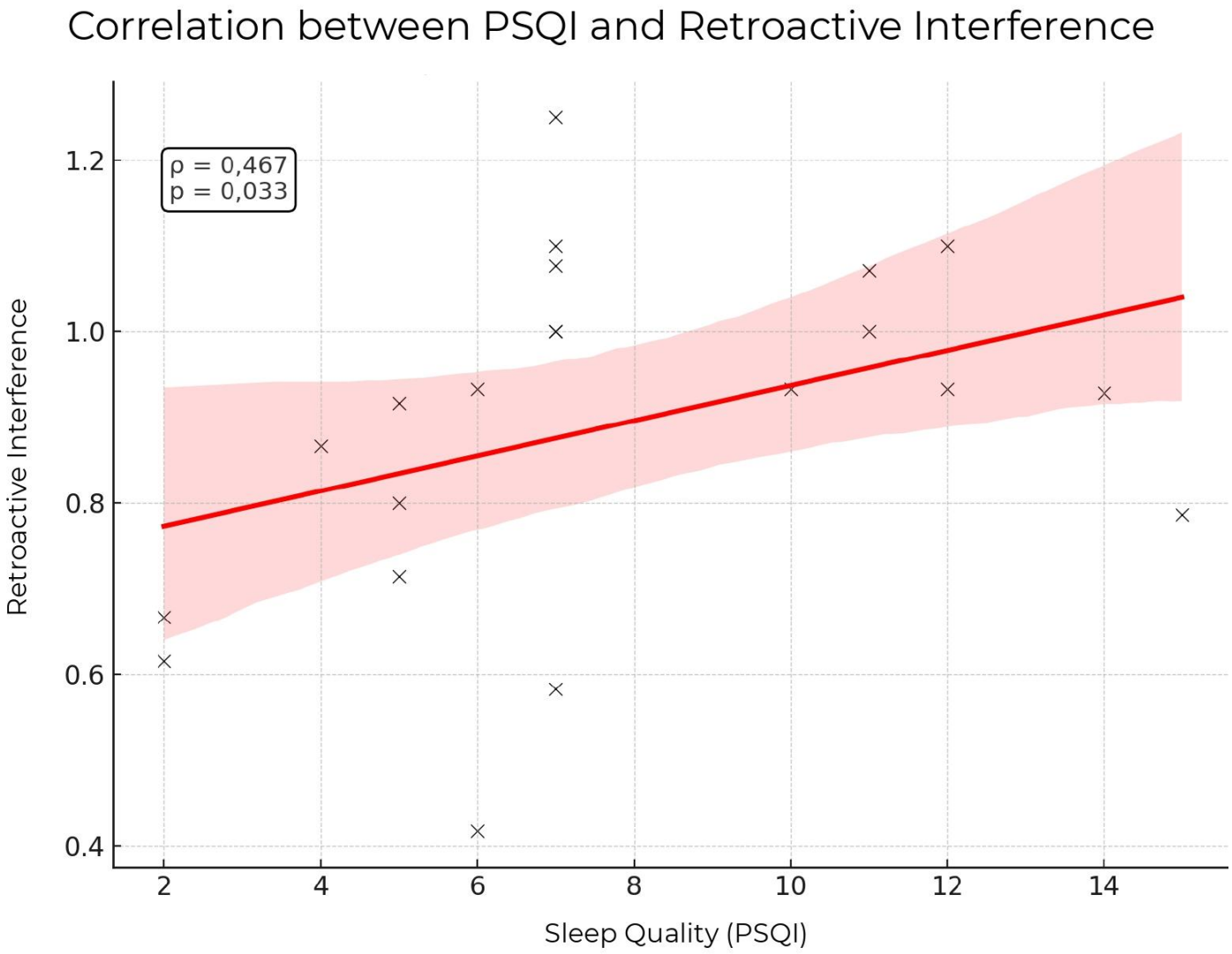

Figure 2. Linear regression between screen time and forgetting speed
Source: The authors
Legend: Scatter plot with linear regression trend line, indicating a positive correlation between the self-reported average time spent using electronic devices before bedtime (in minutes) and forgetting speed on the RAVLT. Forgetting speed was calculated as the ratio between performance at the final learning phase and delayed recall. The Spearman coefficient (ρ = 0.540; p = 0.012) suggests that longer screen time is associated with greater loss of previously learned information.

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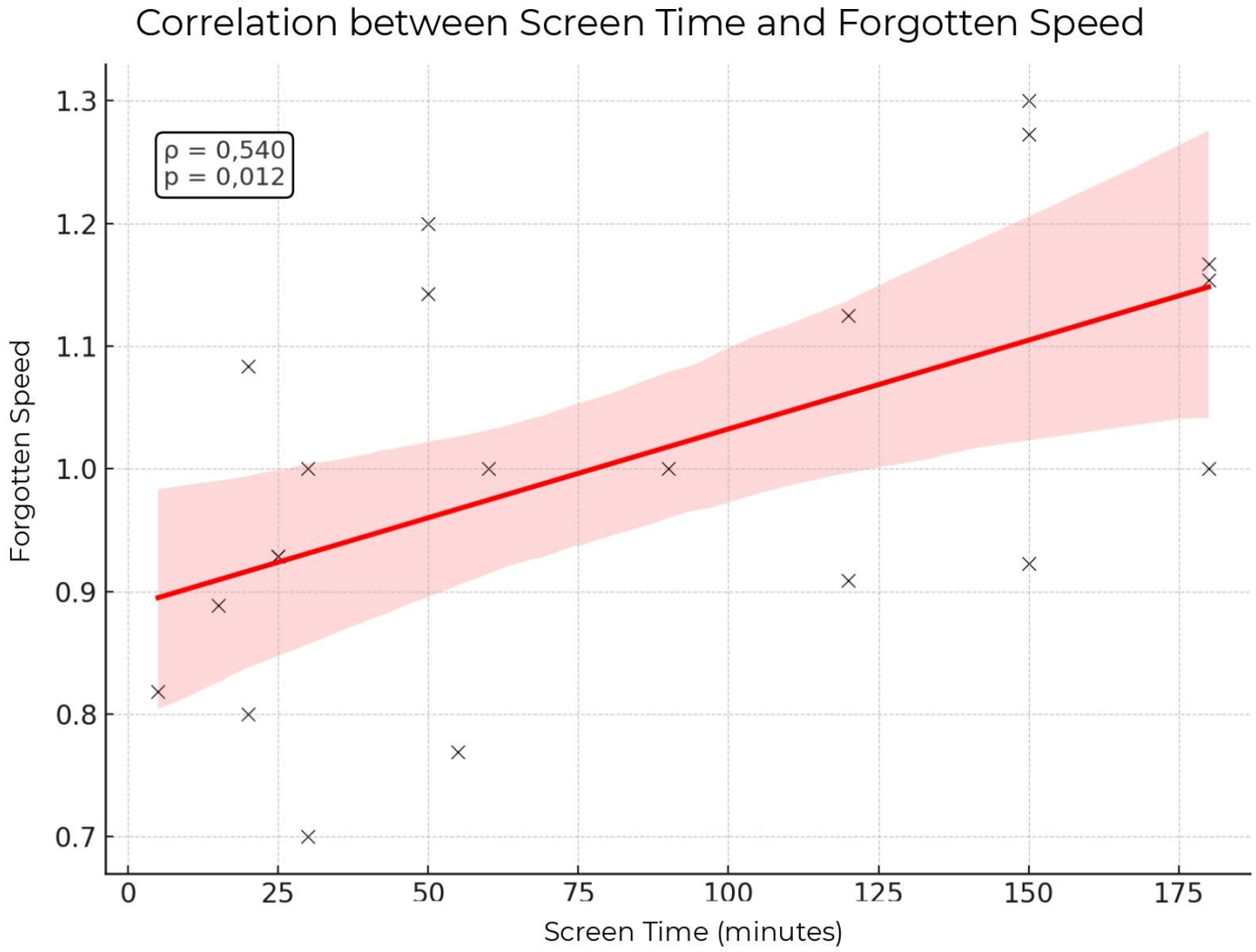

Figure 3. Linear regression between PSQI and retroactive interference

Source: The authors.

Legend: Scatter plot with a linear regression trend line, illustrating the positive association between scores on the Pittsburgh Sleep Quality Index (PSQI) and retroactive interference, measured as the ratio between performance on delayed recall of List A and the interfering item (List B) from the RAVLT. The Spearman coefficient (ρ = 0.467; p = 0.033) indicates that poorer subjective sleep indicators are associated with greater vulnerability to interference from new information on previously acquired memories.

Note: Overlapping points (marked with "x") represent participants who obtained identical scores on both analyzed variables.

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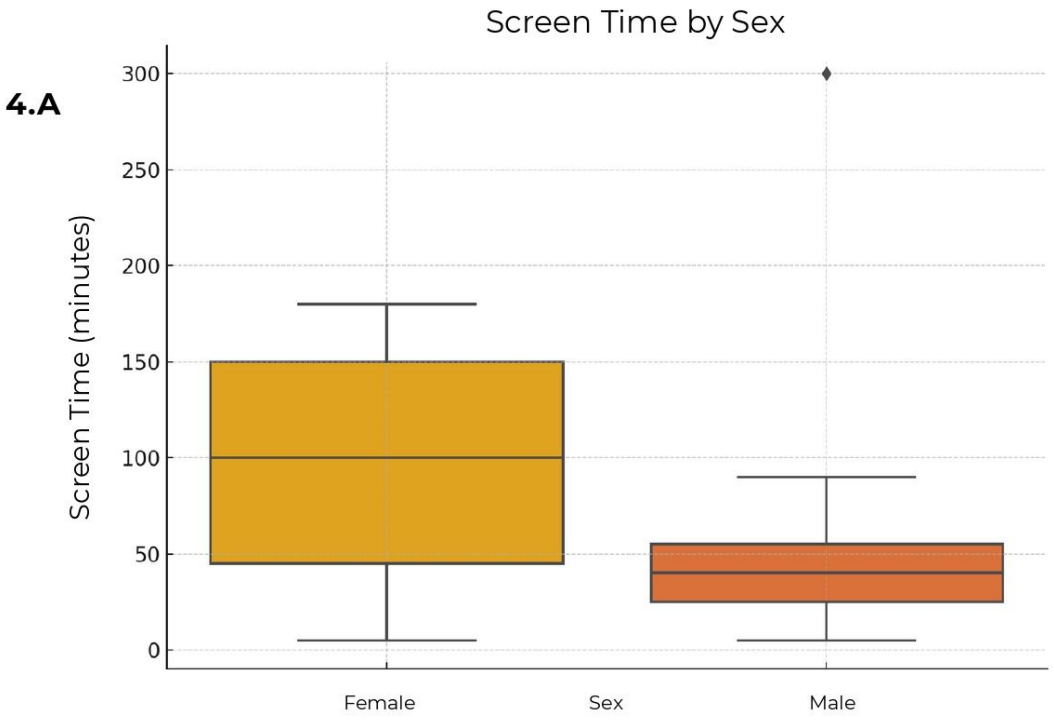

Figura 4A. Screen Time by Sex
Source: The authors.
Legend: Boxplot showing the average screen exposure time (in minutes) by sex. A higher median and range are observed in the female group, indicating a tendency for greater use of electronic devices before bedtime among girls.

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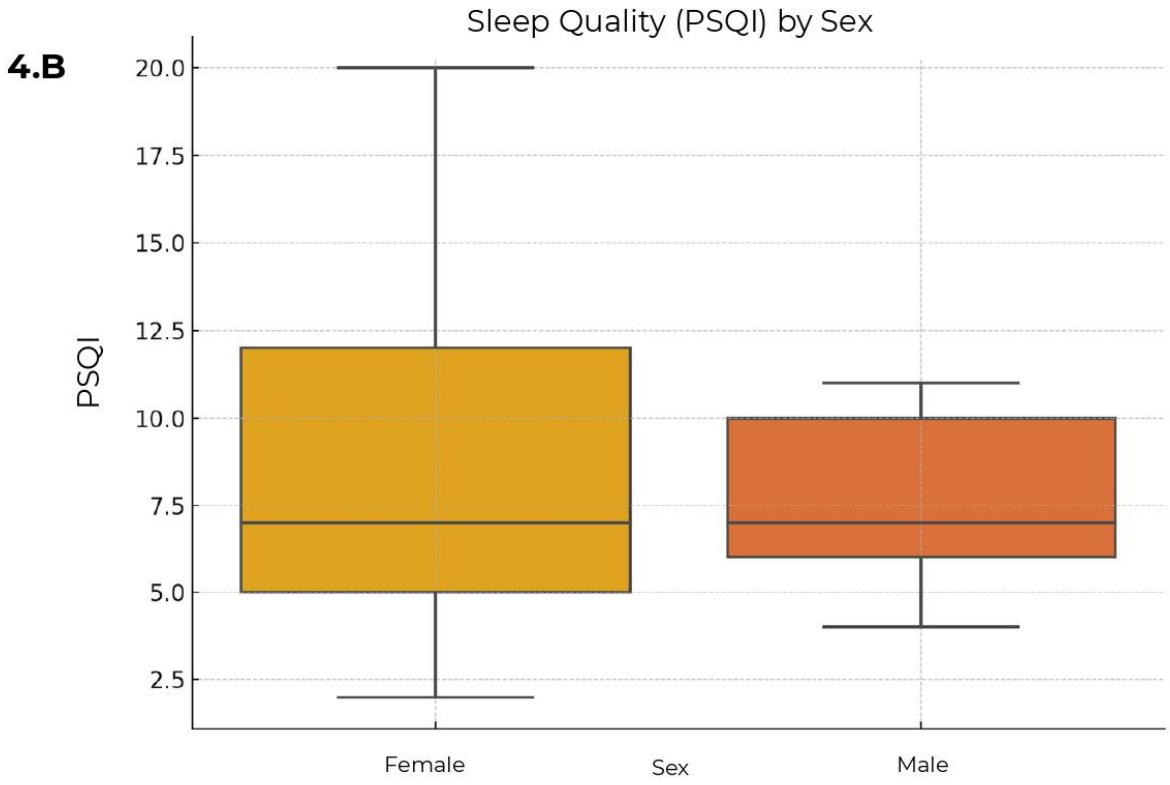

Figure 4B. Sleep Quality (PSQI) by Sex
Source: The authors
Legend: Boxplot showing the distribution of Pittsburgh Sleep Quality Index (PSQI) scores, comparing female and male participants. Greater variability and a tendency toward higher scores (poorer sleep quality) are observed among girls.

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