

Smartphone Addiction and Working Memory in Undergraduate Medical Students: A Cross-sectional Study Examining the Mediating Role of Sleep

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ABSTRACT

Introduction: Excessive smartphone usage is recognised as a behavioural addiction that can interfere with sleep and hinder cognitive abilities like working memory. Medical students, because of their academic pressure and dependence on digital gadgets, constitute a notably susceptible population.

Aim: To evaluate the link between smartphone addiction and working memory performance and to assess if sleep duration acts as a mediator in this connection among undergraduate medical students.

Materials and Methods: The present cross-sectional study was conducted among 170 undergraduate medical students from April to September 2025 at Bhaarith Medical College and Hospital, Chennai, Tamil Nadu, India. Students aged 18-24 years of either gender who provided written informed consent, owned a smartphone and had been using it regularly for at least one year were included in the study. Smartphone addiction was assessed with the Smartphone Addiction Scale-Short Version (SAS-SV), while sleep duration was determined from a 7-day sleep diary. The objective evaluation of working memory was

conducted through a computerised 3-back task that provided data on accuracy rate, reaction time, sensitivity index (d') and response bias (c). Data analysis involved Pearson correlation, multiple linear regression and mediation analysis.

Results: The study included 170 undergraduate medical students with mean age: 19.18 ± 1.25 years, of whom 55% were males and 45% were females. Increased smartphone addiction scores were strongly correlated to reduced sleep duration ($r = -0.46$, $p < 0.001$) and diminished working-memory performance, indicated by lower d' ($r = -0.55$, $p < 0.001$) and accuracy, along with longer reaction times. Sleep duration partially mediated the adverse relationship between smartphone addiction and working memory (indirect effect = -0.030 ; 95% CI: -0.043 to -0.019), representing around 47% of the overall effect.

Conclusion: Smartphone addiction negatively impacts working memory in medical students, in part due to decreased sleep duration. Focused strategies emphasising healthy sleep practices and responsible smartphone usage could alleviate cognitive decline and improve academic outcomes in this group.

Keywords: Behavioural addiction, Cognition, N-back task, Neurocognitive function, Sleep deprivation

INTRODUCTION

Smartphones have become an essential component of modern life, especially among young adults. Its functionality is multifaceted that they provide instant access to academic resources, communication platforms and social media. These properties have made smartphone indispensable in the academic and personal domains of medical undergraduates. However, it is alarming that excessive and uncontrolled use of smartphones causes a form of behavioural addiction, similar to substance-related disorders resulting in craving, tolerance and withdrawal like symptoms [1]. This condition is termed as smartphone addiction [2]. It has been associated with a variety of harmful health consequences including sleep disturbances, impaired concentration causing reduced academic productivity and psychological distress [3].

Sleep plays a crucial role in neurocognitive performance and health [4]. Adequate daily sleep is mandatory for learning, attention and memory consolidation [5]. Working memory, one of the various cognitive domains, refers to the ability to hold and manipulate information for goal-directed behaviour. It is particularly influenced by the quality and duration of sleep [6]. Studies on neuroimaging and electrophysiology have demonstrated that sleep promotes synaptic plasticity and the reorganisation of memory traces in the prefrontal cortex and hippocampus, which are essential for working memory processes [7-9]. Sleep restriction and irregular sleep patterns result in reduced accuracy, longer reaction times and impaired executive

control during working memory tasks [10]. Recent studies have confirmed that both total and partial sleep deprivation negatively affect memory formation and working memory efficiency [11,12].

In this sense, medical students are particularly at risk. They are more likely to engage in unhealthy sleep habits due to the demands of their curriculum, erratic schedules and academic stress. Long-term smartphone use, especially at night, has also been found to be a significant factor in both the duration and quality of poor sleep [13]. According to recent research conducted on both Indian and foreign cohorts, smartphone addiction is very common among undergraduates and there exists a correlation between excessive smartphone use, disturbed sleep and poor cognitive function [14,15].

While the connection between smartphone addiction and sleep, the adverse effects of sleep deprivation on working memory are well acknowledged, little research has sought to investigate the combined association between smartphone addiction, objectively measured sleep duration and working memory performance [16-18]. Prior research has often focused on sleep or cognition in isolation without considering the function of sleep as a potential mediator between smartphone addiction and working memory [19,20]. This identifies an interesting gap in the literature.

From the rationale mentioned above, the null hypothesis was that there will be no significant association between smartphone addiction severity and working memory performance and that sleep duration does not mediate this relationship. Alternatively, it

was hypothesised that increased severity of smartphone addiction would be associated with lower working memory performance and that this association would be partially mediated by shorter sleep duration.

Hence, the aim of this study was to assess the relationship between smartphone addiction, duration of sleep and working memory in undergraduate medical students and to determine whether sleep duration mediates the association between smartphone addiction and working memory.

MATERIALS AND METHODS

The present cross-sectional study was conducted including the undergraduate medical students from all years (MBBS I-IV), in the Department of Physiology, Bhaarith Medical College and Hospital, Bharath Institute of Higher Education and Research (BIHER), Chennai, Tamil Nadu, India between April and September 2025. Study was commenced after obtaining approval from the Institutional Ethical Committee (IEC) (CDSCO Reg No: ECR/1551/Inst/TN/2021).

Inclusion criteria: A total 170 undergraduate medical students who provided written informed consent, of either gender, aged 18-24 years who owned a personal smartphone and had been using it for at least one year were included in the study.

Exclusion criteria: Students with known neurological or psychiatric disorders, chronic systemic illnesses, currently on medications known to affect cognition or sleep, acute illness, fever, or sleep deprivation during the week of assessment were excluded from the study.

Sample size: The sample size was calculated using a previously reported prevalence of smartphone addiction in student population [21]. A minimum sample of 147 is required with assumption of 10% precision and 95% confidence interval. Therefore a sample of 170 was taken after allowing 12-15% non-response or incomplete data. The sample size was calculated using the formula: $n = Z^2 \cdot p(1-p) / d^2$ where, p: Expected proportion, d: Absolute precision, 1-a/2: Desired confidence level. With n=170 ($\alpha=0.05$), the study has 91% power to detect $r=0.25$ and 75% power for $r=0.20$ for the primary association.

Data collection: Smartphone Addiction Scale-Short Version (SAS-SV): A validated 10-item instrument scored on a Likert scale, used to assess the severity of smartphone addiction [22]. This validated 10-item instrument measures smartphone addiction across six domains: daily life disturbance, positive anticipation, withdrawal, cyberspace-oriented relationship, overuse, and tolerance. Each item is rated on a six-point Likert scale (1=strongly disagree; 6=strongly agree). Total scores range from 10 to 60, with validated gender-specific cut-offs of ≥ 31 for males and ≥ 33 for females indicating addiction 7-day Sleep Diary [23].

Working memory was assessed using a computerised 3-back task administered via PsyToolKit software [24]. In this task, a sequence of letters was presented on the screen, and participants were required to indicate whether the current stimulus matched the one presented three trials earlier. The n-back task is a widely used and well-validated experimental paradigm for assessing working memory and executive function. It has demonstrated good construct and convergent validity across behavioural and neuroimaging studies [25,26]. The task recorded the following parameters:

- Accuracy (%) - Proportion of correct responses a participant makes during the task.
- Reaction time (ms) - Latency between the presentation of a stimulus and the participant's response.
- Sensitivity index (d') - A measure that quantifies a participant's ability to distinguish between target and non-target stimuli. A higher d' indicates better working memory performance.

- Response bias (criterion c) - Reflects a participant's tendency in responding, independent of their actual sensitivity (i.e.,) whether they are tending to respond "yes"/target often leading to more hits but also more false alarms (liberal bias) or tending to respond "no"/non-target often leading to fewer false alarms but also more misses (conservative bias).

Sensitivity index (d') and response bias (c) were computed using standard signal detection theory parameters derived from hit and false alarm rates [27,28].

After obtaining IEC clearance, all the MBBS students were invited to participate in the study through class announcements. Written informed consent was obtained from willing participants. The demographic and anthropometric parameters like age, sex, year of study, height, weight, Body Mass Index (BMI) were recorded. On day 1, participants completed the SAS-SV along with demographic details and were classified based on established gender specific cut-offs as a score of ≥ 31 for males and ≥ 33 for females indicating smart phone addiction, while lower scores were considered normal [15]. From Day 2 to Day 8, the students were instructed to maintain a 7-day sleep diary in which they noted the time at which they went to bed at night, time they woke up which has to be done within one hour of waking up. And were also asked to note down the duration of any day-time nap. The average sleep duration from all seven days was calculated [23]. On Day 9, participants underwent assessment of working memory in the Physiology lab using the computerised 3-back task which was administered individually under quiet conditions. The task was explained and participants were presented with a sequential series of uppercase letters on a computer screen. They were instructed to indicate whether the current stimulus matched the one presented three trials earlier. Each stimulus was displayed for a fixed duration of 500 ms with a brief inter-stimulus interval. A 20-trial practice block was administered prior to the test phase to ensure task familiarity. The test phase consisted of 60 trials presented in five blocks, with target and non-target stimuli randomly distributed.

Performance measures including hit rate, false alarm rate, accuracy (% correct responses), and reaction time (ms) were recorded. Signal detection theory parameters were computed from hit and false alarm rates. The sensitivity index (d') was calculated as the standardised difference between the z-transformed hit rate and false alarm rate using the inverse cumulative normal transformation. Response bias (criterion c) was derived as a measure of decision tendency independent of sensitivity. A log-linear correction was applied to adjust extreme proportions prior to z-transformation to avoid infinite values [27]. Higher d' values indicate better working memory discrimination, while positive c values reflect a more conservative response tendency. As the 3-back task is a cognitive performance measure, no predefined clinical cut-off was applied and all variables were analysed as continuous measures.

STATISTICAL ANALYSIS

The data was recorded and analysed using Microsoft Excel R, Statistical Package for Social Sciences (SPSS) Version 26.0 for windows software to express the mean $\pm$ SD for continuous variables and proportions for categorical variables. Correlations between smartphone addiction, sleep duration, and working memory indices were examined using Pearson's correlation, with Spearman's rank correlation as a sensitivity check. A multiple linear regression model was applied with working-memory sensitivity (d') as the dependent variable and SAS-SV score, sleep duration, accuracy, reaction time, and response bias as predictors. Mediation analysis was performed to test the indirect effect of smartphone addiction on d' through sleep duration using non-parametric bootstrapping (5,000 resamples). A $p < 0.05$ was considered statistically significant.

RESULTS

This study was conducted on 170 undergraduate medical students with a mean age of 19.18±1.25 years. Majority of the students had a normal body mass index. The average sleep duration was 6.7±1.3 hours/day. The 3-back working memory task displayed a mean accuracy of 80.9±14.5%, a mean sensitivity index of 1.84±0.91 and a mean reaction time of 737±206 ms [Table/Fig-1].

Variables	Mean±SD (n=170)
Age (years)	19.18±1.25
BMI (kg/m²)	21.96±2.93
Duration of sleep (h/day)	6.65±1.27
SAS-SV score	27.89±7.71
Working memory accuracy rate (%)	80.91±14.49
Sensitivity index (d')	1.84±0.91
Mean RT (ms)	736.97±205.9
Response bias (c)	0.14±0.19

[Table/Fig-1]: Baseline characteristics of study participants. BMI: Body mass index; SAS-SV: Smartphone addiction scale- Short version; RT: Reaction time

As shown in [Table/Fig-2], the cohort was predominantly from first and second year (n=147). Only a smaller proportion of participants were classified as overweight or obese (n=29, 17.1%). About 19.4% (n=33) of students were sleep deprived (<6 hours/day). The mean SAS-SV was 27.9±7.7. About 32.4% (n=55) of students showed higher scores for smartphone addiction.

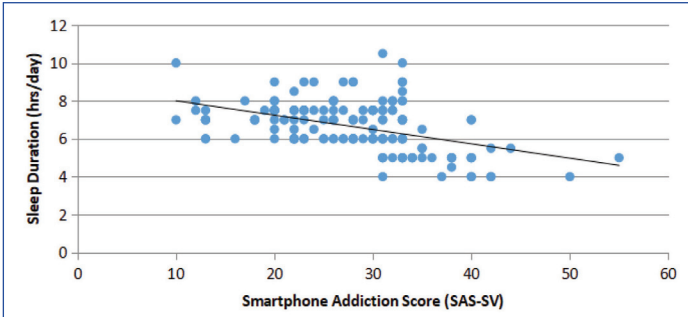
Variables	n (%) (Total n=170)
Gender (Male/Female)	
M	93 (55)
F	77 (45)
Year of study (I/II/III/IV)	
I	83 (48.8)
II	64 (37.6)
III	18 (10.6)
IV	5 (2.9)
BMI category	
Normal	141 (82.9)
Overweight	26 (15.3)
Obese	3 (1.8)
Sleep duration	
Adequate (≥6 hrs/day)	137 (80.6)
Sleep-deprived (<6 hrs/day)	33 (19.4)
SAS-SV interpretation	
Normal	115 (67.6)
At-risk	55 (32.4)

[Table/Fig-2]: Descriptive statistics of continuous variables among study participants (n=170). BMI: Body mass index; SAS-SV: Smartphone addiction scale- Short version

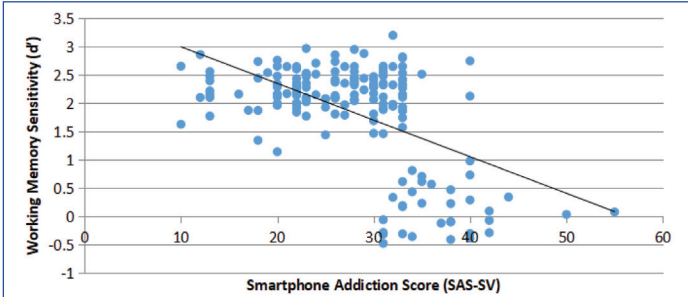
Pearson correlation analysis demonstrated a significant negative correlation between smartphone addiction scores and sleep duration (r=-0.46, p<0.001), indicating that higher smartphone addiction scores were associated with shorter sleep duration [Table/Fig-3].

Pearson correlation analysis demonstrated a significant negative correlation between smartphone addiction scores and working memory sensitivity (r=-0.55, p<0.001) indicating students scoring higher on the SAS-SV exhibit lower working memory performance [Table/Fig-4].

Pearson correlation analysis showed a significant positive correlation between sleep duration and working memory sensitivity (r=0.69, p<0.001) suggesting that students with longer sleep exhibited

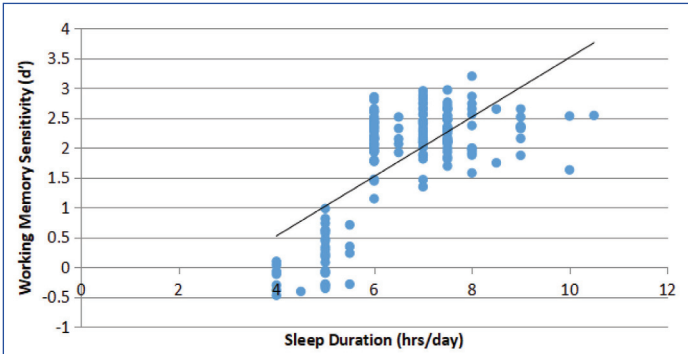


[Table/Fig-3]: Scatterplot showing correlation between smartphone addiction scores and sleep duration.



[Table/Fig-4]: Scatterplot showing correlation between smartphone addiction scores and working memory sensitivity.

higher working memory performance as evident in this scatterplot [Table/Fig-5].



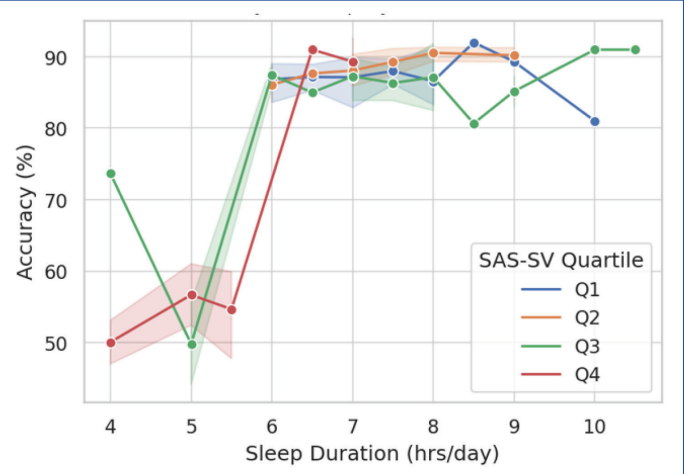
[Table/Fig-5]: Scatterplot showing correlation between sleep duration and working memory sensitivity index.

Group comparisons were performed using independent samples t-test. A p-value <0.05 was considered statistically significant. Working memory sensitivity (d') was significantly higher among students with adequate sleep duration (≥6 hours/day) compared to sleep-deprived students (<6 hours/day). Similarly, students classified as at risk for smartphone addiction demonstrated significantly lower working memory sensitivity compared to normal smartphone users. Students with sleep deprivation demonstrated significantly lower accuracy and prolonged reaction time compared to those with adequate sleep (p<0.001). Similarly, participants at risk for smartphone addiction showed significantly reduced accuracy and increased reaction time compared to normal users (p<0.001). Students with adequate sleep exhibited significantly high response bias (p<0.001) and those with less SAS-SV scores showed significantly high response bias (p<0.023) indicating a more conservative response strategy, reflecting greater caution in identifying target stimuli [Table/Fig-6].

This line plot shows that accuracy on the working memory task improved with longer sleep duration across all quartiles of smartphone addiction. Students in the lowest quartile of smartphone addiction (Q1) consistently showed higher accuracy across sleep durations, while those in the highest quartile (Q4) demonstrated the greatest impairment, particularly when sleep was reduced [Table/Fig-7].

Grouping variable	Sleep duration			Smartphone addiction status		
	Adequate sleep (≥6 h/day) n=137 (Mean±SD)	Sleep-deprived (<6 h/day) n=33 (Mean±SD)	p-value	Normal users n=115 (Mean±SD)	At-risk users n=55 (Mean±SD)	p-value
Accuracy %	87.48±4.34	53.65±8.79	<0.001	86.60±7.20	69.02±18.29	<0.001
Reaction time (ms)	646.04±82.98	1114.45±110.87	<0.001	660.20±105.49	897.49±265.32	<0.001
Sensitivity (d')	2.01±0.85	1.12±0.74	<0.001	2.03±0.82	1.44±0.93	<0.001
Response bias (c)	0.18±0.18	0.01±0.17	<0.001	0.17±0.20	0.10±0.18	0.023

[Table/Fig-6]: Comparison of working memory indices based on sleep duration and smartphone addiction status.
n: No. of students



[Table/Fig-7]: Accuracy vs sleep duration, stratified by SAS-SV quartiles.

Our study showed that students with higher scores in SAS-SV had significant correlation with shorter sleep duration ($r=-0.46$, $p<0.001$), poor working memory performance indices like lower sensitivity index ($r=-0.55$, $p<0.001$), lower accuracy rate ($r=-0.56$, $p<0.001$) and longer reaction time ($r=-0.58$, $p<0.001$) as analysed by bivariate correlation. Moreover students with smart phone addiction revealed a weak but statistically significant negative correlation ($r=-0.19$, $p=0.014$). Students with greater smartphone addiction were more likely to respond “target” even when unsure, leading to more hits but also more false alarms (liberal bias). Pearson and Spearman correlation analyses demonstrated a significant positive association between sleep duration and accuracy, and a significant negative association with reaction time ($p<0.001$ for both). Sleep duration also showed a weak but significant positive correlation with response bias [Table/Fig-8].

Variables	Pearson r (p-value)	Spearman rho (p-value)
SAS-SV vs d'	-0.545 (<0.001)	-0.415 (<0.001)
SAS-SV vs Sleep (hrs/day)	-0.460 (<0.001)	-0.458 (<0.001)
SAS-SV vs Accuracy (%)	-0.558 (<0.001)	-0.427 (<0.001)
SAS-SV vs Reaction time (ms)	0.579 (<0.001)	0.417 (<0.001)
SAS-SV vs Response bias (c)	-0.188 (0.014)	-0.254 (0.001)
Sleep duration vs Accuracy (%)	0.675 ($p<0.001$)	0.525 ($p<0.001$)
Sleep duration vs Reaction time (ms)	-0.622 ($p<0.001$)	-0.477 ($p<0.001$)
Sleep duration vs Response bias (c)	0.195 ($p=0.011$)	0.163 ($p=0.034$)

[Table/Fig-8]: Correlation analysis (SAS-SV vs working memory and sleep duration, Sleep duration vs accuracy, reaction time, response bias).
SAS-SV: Smartphone addiction scale- Short version; d': Sensitivity index

In the regression model with working memory performance (d') as the outcome, accuracy emerged as the strongest positive predictor, while response bias (c) was a significant negative predictor. Sleep duration showed a modest positive association that approached but did not reach statistical significance. In contrast, smartphone addiction scores did not independently predict d' after accounting for other factors. The model explained 95.5% of the variance in d' ($R^2=0.955$) [Table/Fig-9].

Predictor	Coefficient (β)	Std. Error	t-value	p-value
Constant (Intercept)	-3.500	0.261	-13.389	<0.000
SAS-SV	0.001	0.002	0.493	0.622
Sleep duration	0.031	0.017	1.855	0.065
Accuracy	0.063	0.002	28.509	<0.000
RT	0.000	0.000	0.448	0.654
Response bias	-0.389	0.093	-4.197	<0.0001

[Table/Fig-9]: Multiple linear regression analysis (Outcome: Working memory d').
Model summary: $R^2=0.953$, Adjusted $R^2=0.952$, $F(5,163)=665.8$, $p<0.001$
SAS-SV: Smartphone addiction scale- Short version; RT: Reaction time

Bootstrapped mediation analysis demonstrated that sleep duration partially mediated the relationship between smartphone addiction and working memory (d'). The indirect effect of SAS-SV on d' via sleep duration was statistically significant ($\beta=-0.014$, 95% CI: -0.028 to -0.002, $p<0.05$). The direct effect of SAS-SV on d' became non-significant when sleep duration was included, suggesting partial mediation [Table/Fig-10].

Effect	Estimate	Boot 95% CI (Lower)	Boot 95% CI (Upper)
Total effect (c)	-0.065	-0.080	-0.049
Direct effect (c')	-0.034	-0.046	-0.022
Indirect effect (a×b)	-0.030	-0.043	-0.019

[Table/Fig-10]: Mediation of the Association between Smartphone Addiction (SAS-SV) and Working Memory (d') by Sleep Duration (n=170).
Notes: Outcome=d'. Exposure=SAS-SV score. Mediator=Average sleep duration. 5,000 bootstrap resamples. Proportion mediated=47%

DISCUSSION

The authors assessed the relationship between smartphone addiction, duration of sleep, and working memory performance in undergraduate medical students, concentrating on the mediating role of sleep. The present study findings revealed that higher smartphone addiction scores were significantly associated with shorter sleep duration, reduced working memory sensitivity, lower accuracy, and longer reaction times. The mediation analysis demonstrated that sleep duration partially mediated the negative association between smartphone addiction and working memory, highlighting the pivotal role of sleep in cognitive functioning of medical students.

The present study findings are consistent with several recent studies [Table/Fig-11] [15,17,18,29-35]. Gunasekar A et al., in India reported that smartphone addiction was strongly associated with poor sleep quality and higher BMI among medical students [29]. Similarly, Failoc-Rojas VE et al., in Peru demonstrated that high smartphone dependence was linked with insomnia symptoms [30]. Rafique N et al., from China also found that smartphone use before sleep worsened sleep quality as measured by the PSQI [31]. In Indian cohorts, Pradeep C et al., observed a high prevalence of smartphone addiction among medical undergraduates, linking directly with poor sleep [15], while Zeerak Q et al., (2024) showed that addiction negatively associated with academic performance, indirectly pointing toward impairments in cognitive domains such as working memory [32].

The authors have used an objective measure of working memory (3-back task) and sleep duration (7-day diary) rather than relying

Authors name, publication year	Place of study	Sample population	Sample size	Findings
Gunasekar A et al., [29], 2025	India	Medical students	300	Smartphone addiction associated with poor sleep and BMI differences.
Failoc-Rojas VE et al., [30], 2025	Peru	Medical students	600	High smartphone dependence linked with insomnia.
Rafique N et al., [31], 2020	Saudi Arabia	College students	1925	Excessive mobile phone use was associated with poorer subjective sleep quality.
Pradeep C et al., [15], 2025	India	Undergraduate medical students	300	High prevalence of addiction among medical students.
Zeeraq Q et al., [32], 2024	India	Undergraduate medical students	367	Addiction negatively predicted academic performance (cognitive outcomes).
Tu Z et al., [18], 2023	China	University students	150	Reducing bedtime use improved sleep and WM performance.
He JW et al., [17], 2020	China	Young adults (trial participants)	43 (RCT)	Restricting bedtime phone use increased sleep duration and WM.
Al-Amri A et al., [34], 2023	Saudi Arabia	University students	300	Addiction associated with cognitive impairments (attention/WM).
Yang LL et al., [35] 2023	China	College students	500	Sleep quality mediated link between addiction and mental health.
Akkurt L and Aksoy CC [36], 2025	Turkey	Physiotherapy/Rehab students	200	Addiction linked with reduced WM and higher fatigue.
Present study, 2025	India	Undergraduate medical students	170	Smartphone addiction associated with shorter sleep and poorer working memory; sleep duration partially mediated this relationship.

[Table/Fig-11]: Comparison of present study with other studies [15,18,29-36].

solely on self-reported measures. Prior research has often assessed sleep quality using scales such as the Pittsburgh Sleep Quality Index (PSQI), or working memory through questionnaires, which may be subject to recall and reporting bias. The present study thus provides a more substantial evidence linking smartphone addiction to working memory deficits by using performance-based cognitive measures.

The partial mediation by sleep duration supports the neuro-physiological evidence that sleep plays an important role in working memory processes [36]. Sleep enhances hippocampal-prefrontal interactions and synaptic plasticity, both essential for updating and manipulating information in working memory [37]. Sleep restriction has been persistently shown to reduce accuracy and increase reaction times in working memory tasks [10]. The current study's mediation results indicate that reduced sleep is one pathway through which smartphone addiction impairs cognition, although other mechanisms (e.g., attentional capture, emotional dysregulation) may also contribute [35].

Not all studies have demonstrated a direct impact of smartphone addiction on working memory after accounting for confounders. For instance, Demirci K et al., found significant associations between smartphone use and depressive symptoms, but the direct relationship with cognitive performance diminished after adjusting for psychological distress [38]. In the regression model, smartphone addiction scores did not independently predict d' after accounting for accuracy and response bias, suggesting that the effect may be indirect and multifactorial.

The implications of our findings are particularly relevant for medical education and student well-being. Academic pressures, irregular schedules, and excessive smartphone use expose them to high risk for both sleep deprivation and cognitive impairments. The awareness on the impact of smartphone addiction on sleep and working memory can help designing interventions (e.g., digital hygiene plans) integrated into health programs aimed at educating students about sleep and time management. This would not only increase cognitive efficiency and academic achievement, but also long-term mental well-being and career competence in future doctors.

Limitation(s)

The cross-sectional design limits causal inference, and sleep duration was self-reported rather than objectively measured using actigraphy or polysomnography. The single-centre sample may restrict generalisability to broader populations.

CONCLUSION(S)

Smartphone addiction is linked to reduced sleep duration and compromised working memory performance in medical students. Sleep partially mediates the relationship, highlighting it as a modifiable risk factor. The present study results, suggest that interventions to

limit pre-sleep smartphone use and improve sleep hygiene may temper cognitive deficits and enhance academic functioning in medical students. Longitudinal and interventional studies in the future are required to confirm causality and assess the effect of systematic digital hygiene and sleep interventions on cognitive functions in this population.

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