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# Association Between Overnight Smartphone Notifications and Daytime Sleepiness Among Undergraduate Medical Students: A Multicenter Cross-Sectional Study

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***Abstract:*** ***Background:*** Overnight smartphone notifications may interrupt sleep continuity through repeated nocturnal awakenings and sleep fragmentation, potentially contributing to excessive daytime sleepiness. However, evidence specifically examining the relationship between overnight smartphone notifications and daytime sleepiness among medical students remains limited, particularly in South Asia. This study aimed to investigate the association between overnight smartphone notifications and daytime sleepiness among undergraduate medical students in Pakistan. ***Methods:*** A multicenter cross-sectional study was conducted between January and May 2025 among 1,000 undergraduate MBBS students enrolled at five medical colleges in Pakistan. Data were collected using a structured self-administered questionnaire. Overnight smartphone notification status (enabled versus disabled during sleep) was considered the primary exposure, while daytime sleepiness was assessed using the validated Epworth Sleepiness Scale (ESS). Sociodemographic characteristics, lifestyle factors, and smartphone-related behaviors were also recorded. Group comparisons were performed using independent-samples t-tests and chi-square tests, and multivariable linear regression analysis was used to identify factors independently associated with daytime sleepiness after adjustment for potential confounders. ***Results:*** The mean age of participants was 21.35 ± 1.42 years, and 51.9% were male. Overall, 65.3% of students reported keeping smartphone notifications enabled during their habitual sleeping period. The mean bedtime smartphone use duration was 93.65 ± 40.39 minutes, and the overall mean ESS score was 8.71 ± 3.07. Students with overnight smartphone notifications enabled demonstrated significantly higher ESS scores than those who disabled notifications (9.04 ± 3.02 vs. 8.09 ± 3.08; $p < 0.001$). The prevalence of excessive daytime sleepiness (ESS ≥11) was also significantly higher among students with notifications enabled (28.3% vs. 21.6%; $p = 0.026$). After adjustment for demographic characteristics, lifestyle factors, and smartphone-related behaviors, overnight smartphone notifications remained independently associated with higher daytime sleepiness ($\beta = 0.92$, $p < 0.001$). Longer bedtime smartphone use, smartphone use after lights-off, night-time smartphone checking, and caffeine consumption were also independently associated with higher ESS scores, whereas greater physical activity was independently associated with lower daytime sleepiness. ***Conclusion:*** Overnight smartphone notifications were independently associated with greater daytime sleepiness among undergraduate medical students. Notification-related smartphone behaviors, including prolonged bedtime smartphone use and night-time smartphone checking, were also associated with increased daytime sleepiness. Promoting healthy nighttime smartphone practices, including limiting unnecessary overnight notifications and strengthening sleep hygiene education, may improve daytime alertness and student well-being. Longitudinal and interventional studies are needed to establish temporal relationships and evaluate the effectiveness of notification-management strategies.

***Keywords:*** daytime sleepiness; Epworth Sleepiness Scale; medical students; overnight smartphone notifications; sleep hygiene; smartphone use.

## INTRODUCTION

Adequate sleep is fundamental for maintaining optimal physical health, cognitive performance, and psychological well-being. Beyond total sleep duration, uninterrupted sleep continuity is increasingly recognized as an essential determinant of normal daytime functioning. Consolidated sleep facilitates memory consolidation, attention, executive functioning, emotional regulation, psychomotor vigilance, and decision-making, whereas repeated nocturnal awakenings and fragmented sleep may impair these neurocognitive processes even when overall sleep duration appears sufficient (1–3). In young adults, particularly university students, disturbed sleep continuity has been associated with reduced alertness, diminished learning capacity, impaired concentration, and decreased productivity (4,5). Medical students constitute a particularly vulnerable population because of demanding academic schedules, prolonged study hours, frequent examinations, clinical responsibilities, and increasing reliance on digital technologies, all of which may compromise healthy sleep habits and daytime functioning (6).

Excessive daytime sleepiness (EDS) is one of the most important functional consequences of disturbed sleep and is characterized by an increased tendency to fall asleep or difficulty maintaining alertness during routine daytime activities. The Epworth Sleepiness Scale (ESS) is a validated and widely used instrument for assessing subjective daytime sleepiness and has been extensively applied in epidemiological studies involving university and medical students (7). Recent evidence suggests that excessive daytime sleepiness affects approximately one-fifth to nearly one-half of medical students worldwide, although prevalence estimates vary according to study populations and diagnostic thresholds (5,8). Persistent daytime sleepiness has important implications for medical education because it has been associated with impaired attention, slower reaction times, reduced psychomotor performance, diminished executive functioning, impaired learning, and poorer clinical decision-making during undergraduate medical training. Furthermore, excessive daytime sleepiness has been linked to burnout, reduced quality of life, emotional distress, and an increased risk of medical errors during clinical practice, highlighting its importance as both an educational and public health concern (6–8).

The widespread availability of smartphones has fundamentally transformed communication, education, and social interaction among young adults. Smartphones have become indispensable educational tools for medical students, providing instant access to online learning resources, lecture materials, medical applications, clinical guidelines, and communication platforms. Consequently, smartphone ownership and use among university students have reached exceptionally high levels worldwide, with many students remaining connected throughout the day and night (9). While previous studies have primarily investigated total daily smartphone use or bedtime smartphone use before sleep, increasing attention has recently focused on overnight smartphone notifications as a potentially important but underexplored behavioral exposure. Notifications generated by messaging applications, social media platforms, emails, and other mobile applications may produce audible alerts, vibration signals, or screen illumination during habitual sleep periods. Unlike voluntary bedtime smartphone use, overnight notifications may interrupt sleep involuntarily by provoking complete awakenings, brief cortical arousals, or habitual smartphone checking behaviors. Consequently, overnight notifications may disrupt sleep continuity independently of total smartphone use, making them a distinct behavioral exposure that warrants separate investigation (9,10).

Several physiological and behavioral mechanisms may explain the potential association between overnight smartphone notifications and excessive daytime sleepiness. Repeated nocturnal notifications may fragment normal sleep architecture through recurrent awakenings and micro-arousals, thereby reducing sleep continuity and limiting the restorative functions of sleep. In addition, anticipatory anxiety regarding incoming messages and conditioned smartphone-checking behaviors may increase nocturnal cognitive arousal, making it more difficult to maintain uninterrupted sleep. Frequent activation of sympathetic nervous system responses following notification alerts may further compromise sleep quality by delaying the return to deeper stages of sleep after awakening. Over time, cumulative sleep fragmentation and reduced restorative sleep may increase daytime sleep propensity, resulting in impaired vigilance, decreased concentration, slower reaction times, and excessive daytime sleepiness. These biologically plausible mechanisms suggest that overnight smartphone notifications represent a potentially modifiable behavioral factor that may influence daytime alertness among medical students.

Despite growing interest in the relationship between smartphone use and sleep-related outcomes, relatively few studies have specifically examined the influence of overnight smartphone notifications on excessive daytime sleepiness. Most previous investigations have evaluated broader measures of smartphone exposure, including total daily screen time, bedtime smartphone use, or smartphone addiction, rather than focusing on notification-related sleep interruptions. Recent systematic reviews and observational studies

consistently report that nighttime smartphone use is associated with poorer sleep outcomes, increased daytime fatigue, and reduced daytime functioning among adolescents and young adults (11–13). Similarly, studies involving medical students have demonstrated that frequent nighttime smartphone engagement, particularly checking mobile devices after awakening, is associated with higher Epworth Sleepiness Scale scores and impaired daytime alertness (14,15). However, because many of these studies combined multiple smartphone behaviors into a single exposure variable, the independent contribution of overnight notifications remains insufficiently understood.

Emerging evidence suggests that overnight notifications may represent a distinct mechanism through which smartphones disrupt sleep continuity. Unlike intentional bedtime smartphone use, notifications may interrupt sleep unexpectedly through audible alerts, vibration, or screen illumination, even when individuals do not actively engage with their devices. Several studies have suggested that anticipation of incoming messages and habitual nocturnal smartphone checking contribute to repeated sleep interruptions, resulting in fragmented sleep and greater daytime sleepiness (16,17). Nevertheless, findings across studies remain heterogeneous. While several investigations have demonstrated significant associations between nighttime smartphone interruptions and daytime sleepiness, others have reported weaker or non-significant relationships after adjustment for psychological stress, sleep duration, chronotype, or overall smartphone dependence (18). These inconsistencies may reflect differences in exposure definitions, outcome measurement, statistical adjustment, and study populations rather than the absence of a true association.

Current evidence is also limited by several important methodological shortcomings. Most published studies have employed single-center cross-sectional designs with relatively small convenience samples, thereby restricting the external validity and generalizability of their findings (19). Considerable heterogeneity exists in the assessment of smartphone exposure, with many investigations focusing on smartphone addiction scales or overall screen time instead of objectively assessing overnight notification-related behaviors. In addition, several studies have not utilized validated instruments such as the Epworth Sleepiness Scale to assess daytime sleepiness, limiting comparability across studies. Evidence from South Asia, particularly Pakistan, remains scarce, and multicenter studies examining notification-specific smartphone behaviors among undergraduate medical students are largely lacking (20,21). Addressing these limitations is essential for improving understanding of how overnight smartphone notifications may influence daytime alertness in this academically demanding population.

Therefore, the present multicenter cross-sectional study was conducted to determine the association between overnight smartphone notifications and daytime sleepiness among undergraduate medical students enrolled at five medical colleges in Pakistan. By recruiting a large multicenter sample and assessing daytime sleepiness using the validated Epworth Sleepiness Scale, this study aims to provide robust evidence regarding the relationship between notification-related smartphone behaviors and daytime alertness. The findings may contribute to the development of evidence-based digital well-being strategies and sleep hygiene interventions that promote healthier smartphone practices and improve student health and academic functioning.

## METHODS

### Study Design and Setting

A multicenter cross-sectional study was conducted among undergraduate medical students enrolled at five medical colleges in Pakistan to investigate the association between overnight smartphone notifications and daytime sleepiness. Data were collected over a six-month period from January 2025 to May 2025 using a structured, self-administered questionnaire. The study was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for reporting cross-sectional studies. The multicenter design was adopted to enhance the diversity of the study population, improve the external validity of the findings, and minimize the influence of institution-specific educational environments on the observed associations.

### Study Population and Sampling

The study population comprised undergraduate Bachelor of Medicine and Bachelor of Surgery (MBBS) students enrolled in the participating medical colleges during the study period. Students from all academic years who were 18 years of age or older, owned a smartphone, and provided written informed consent were eligible for participation. Students who declined participation, submitted incomplete questionnaires, reported previously diagnosed sleep disorders, or were receiving medications known to substantially influence sleep or daytime alertness were excluded from the study.

A multicenter convenience sampling technique was employed to recruit participants from the five participating institutions. Investigators visited classrooms following permission from the respective administrations, explained the objectives of the study,

 

and invited eligible students to participate voluntarily. A total of 1,000 undergraduate medical students completed the questionnaire and were included in the final analysis.

**Data Collection Instrument**

Data were collected using a structured, self-administered questionnaire developed following an extensive review of published literature on smartphone use, sleep behavior, and daytime sleepiness. Prior to implementation, the questionnaire was reviewed by faculty members with expertise in community medicine and medical research to ensure clarity and content validity. A pilot assessment was also performed among a small group of medical students who were not included in the final analysis to evaluate the comprehensibility and feasibility of the instrument.

The questionnaire consisted of four sections. The first section obtained sociodemographic information, including age, gender, academic year, place of residence, and body mass index (BMI). The second section collected lifestyle-related information, including smoking status, caffeine consumption, and physical activity.

The third section focused on smartphone-related behaviors, with particular emphasis on overnight smartphone notification practices. Participants were asked whether smartphone notifications remained enabled during sleep, whether they used their smartphone after lights-off, whether they checked their smartphone following nocturnal awakenings, where they usually kept their smartphone while sleeping (e.g., under the pillow, beside the bed, or away from the bed), and the average duration of smartphone use before bedtime. Information regarding the primary purpose of bedtime smartphone use, including social networking, messaging, educational activities, entertainment, and web browsing, was also collected.

The fourth section assessed daytime sleepiness using the Epworth Sleepiness Scale (ESS). The ESS is a validated eight-item questionnaire that evaluates the likelihood of dozing in common daytime situations. Each item is scored on a four-point scale ranging from 0 (would never doze) to 3 (high chance of dozing), resulting in a total score between 0 and 24. Higher scores indicate greater subjective daytime sleepiness. The ESS has demonstrated excellent validity and reliability in both clinical and epidemiological studies and has been widely used in university student populations.

**Study Variables**

The primary exposure variable was overnight smartphone notification status, categorized according to whether participants kept smartphone notifications enabled or disabled during their habitual sleeping period. Additional smartphone-related behaviors, including smartphone use after lights-off, night-time smartphone checking, bedtime smartphone use duration, and smartphone placement during sleep, were evaluated as secondary behavioral variables.

The primary outcome variable was daytime sleepiness, measured using the total Epworth Sleepiness Scale score. For secondary analyses, excessive daytime sleepiness was defined according to the conventional Epworth Sleepiness Scale cut-off value reported in previous validation studies. Potential confounding variables included age, gender, academic year, body mass index, place of residence, smoking status, caffeine consumption, physical activity, and average bedtime smartphone use duration.

**Statistical Analysis**

Data were entered, cleaned, and analyzed using IBM Statistical Package for the Social Sciences (SPSS) version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized as mean ± standard deviation (SD), whereas categorical variables were presented as frequencies and percentages. Normality of continuous variables was assessed before inferential analyses.

Participants were categorized according to overnight smartphone notification status (enabled versus disabled). Differences in baseline characteristics and mean Epworth Sleepiness Scale scores between the two groups were evaluated using the independent-samples t-test for continuous variables and the chi-square test for categorical variables, as appropriate. Pearson's correlation coefficient was calculated to examine the relationship between bedtime smartphone use duration and daytime sleepiness.

To identify independent predictors of daytime sleepiness, multivariable linear regression analysis was performed with the total Epworth Sleepiness Scale score as the dependent variable. Overnight smartphone notification status constituted the principal independent variable, while age, gender, body mass index, academic year, place of residence, smoking status, caffeine consumption, physical activity, bedtime smartphone use duration, smartphone use after lights-off, and night-time smartphone checking were included as covariates to control for potential confounding. Regression assumptions were assessed before interpretation of the final model. All statistical tests were two-tailed, and a p-value of $<0.05$ was considered statistically significant.

## RESULTS

A total of 1,000 undergraduate medical students from five medical colleges in Pakistan participated in the study and were included in the final analysis. The mean age of the participants was 21.35 ± 1.42 years, while the mean body mass index (BMI) was 23.20 ± 3.06 kg/m². Males constituted 51.9% of the study population, whereas **48.1%** were females. Most participants (62.5%**)** resided in university hostels, and students from all five academic years were represented, with the highest proportion enrolled in the fourth year (**21.3%**). The majority of participants were non-smokers (87.3%**),** 70.3% reported regular caffeine consumption, and 45.3% engaged in a moderate level of physical activity (Table 1).

**Table 1. Baseline characteristics of the study participants (N = 1,000)**

| Characteristic | n (%) or Mean ± SD |
|---|---|
| **Age (years)** | **21.35 ± 1.42** |
| **Body mass index (kg/m²)** | **23.20 ± 3.06** |
| **Gender** | |
| • Male | 519 (51.9) |
| • Female | 481 (48.1) |
| **Residence** | |
| • Hostel | 625 (62.5) |
| • Home | 375 (37.5) |
| **Academic year** | |
| • First year | 196 (19.6) |
| • Second year | 203 (20.3) |
| • Third year | 204 (20.4) |
| • Fourth year | 213 (21.3) |
| • Final year | 184 (18.4) |
| **Smoking status** | |
| • Yes | 127 (12.7) |
| • No | 873 (87.3) |
| **Caffeine consumption** | |
| • Yes | 703 (70.3) |
| • No | 297 (29.7) |
| **Physical activity level** | |
| • Low | 336 (33.6) |
| • Moderate | 453 (45.3) |
| • High | 211 (21.1) |

**Abbreviations:** SD, standard deviation; BMI, body mass index.

Overnight smartphone notification practices are summarized in **Table 2**. Overall, **653 (65.3%)** participants reported keeping smartphone notifications enabled during their habitual sleeping period, whereas **347 (34.7%)** disabled notifications overnight. More than half of the students (**57.4%**) reported using their smartphones after lights-off, while **28.4%** acknowledged checking their smartphones following nocturnal awakenings. Nearly half of the participants (**48.8%**) kept their smartphones under the pillow while sleeping. Social media represented the most frequently reported bedtime smartphone activity (**40.0%**), followed by video streaming (**21.9%**), messaging (**19.2%**), educational activities (**12.4%**), and gaming (**6.5%**). The mean duration of bedtime smartphone use was 93.65 ± 40.39 minutes**.**

**Table 2. Overnight smartphone notification practices among undergraduate medical students (N = 1,000)**

| Variable | n (%) |
|---|---|
| **Overnight smartphone notifications** | |
| • Enabled | 653 (65.3) |
| • Disabled | 347 (34.7) |
| **Smartphone use after lights-off** | |
| • Yes | 574 (57.4) |
| • No | 426 (42.6) |
| **Night-time smartphone checking** | |
| • Yes | 284 (28.4) |
| • No | 716 (71.6) |
| **Phone kept under pillow during sleep** | |
| • Yes | 488 (48.8) |
| • No | 512 (51.2) |
| **Primary bedtime smartphone activity** | |
| • Social media | 400 (40.0) |
| • Videos/streaming | 219 (21.9) |
| • Messaging | 192 (19.2) |
| • Study/educational activities | 124 (12.4) |
| • Gaming | 65 (6.5) |
| **Bedtime smartphone use (minutes)** | 93.65 ± 40.39 |

**Data are presented as frequency (%) or mean ± standard deviation (SD).**

The association between overnight smartphone notification status and daytime sleepiness is presented in **Table 3**. Students who kept smartphone notifications enabled during sleep demonstrated significantly higher daytime sleepiness compared with those who disabled notifications. The mean Epworth Sleepiness Scale (ESS) score was **9.04 ± 3.02** among participants with overnight notifications enabled compared with **8.09 ± 3.08** among those with notifications disabled (**$t = 4.68$, $p < 0.001$**). Similarly, the prevalence of excessive daytime sleepiness (ESS ≥11) was significantly higher among students with overnight notifications enabled (**28.3%**) than among those who disabled notifications (**21.6%**, **$\chi^2 = 4.97$, $p = 0.026$**).

**Table 3. Association between overnight smartphone notification status and daytime sleepiness among undergraduate medical students (N = 1,000)**

| Variable | Notifications Enabled (n = 653) | Notifications Disabled (n = 347) | Test statistic | *p*-value |
|---|---|---|---|---|
| ESS score, Mean ± SD | 9.04 ± 3.02 | 8.09 ± 3.08 | $t = 4.68$ | <0.001 |
| Excessive daytime sleepiness (ESS ≥11), n (%) | 185 (28.3) | 75 (21.6) | $\chi^2 = 4.97$ | 0.026 |

Abbreviations: ESS, Epworth Sleepiness Scale; SD, standard deviation.

Multivariable linear regression analysis was performed to identify factors independently associated with daytime sleepiness after adjustment for demographic characteristics, lifestyle factors, and smartphone-related behaviors (**Table 4**). Overnight smartphone notifications remained independently associated with higher ESS scores (**$\beta = 0.92$, $p < 0.001$**). Longer bedtime smartphone use (**$\beta = 0.023$** per minute, **$p < 0.001$**), smartphone use after lights-off (**$\beta = 1.45$, $p < 0.001$**), night-time smartphone checking (**$\beta = 1.21$, $p < 0.001$**), and caffeine consumption (**$\beta = 0.63$, $p < 0.001$**) were also significant independent predictors of greater daytime sleepiness. Conversely, higher levels of physical activity were independently associated with lower ESS scores (**$\beta = -0.49$, $p < 0.001$**). Age, gender, body mass index, academic year, place of residence, and smoking status were not significantly associated with daytime sleepiness after multivariable adjustment.

**Table 4. Multivariable linear regression analysis identifying factors associated with daytime sleepiness (Epworth Sleepiness Scale score) among undergraduate medical students (N = 1,000)**

| Variable | β Coefficient | Standardized β | *p*-value |
|---|---|---|---|
| Overnight smartphone notifications (Enabled vs Disabled) | 0.92 | 0.14 | <0.001 |
| Bedtime smartphone use (per minute) | 0.023 | 0.31 | <0.001 |
| Smartphone use after lights-off | 1.45 | 0.23 | <0.001 |
| Night-time smartphone checking | 1.21 | 0.18 | <0.001 |
| Caffeine consumption | 0.63 | 0.10 | <0.001 |
| Physical activity | −0.49 | −0.11 | <0.001 |
| Age | −0.05 | −0.02 | 0.429 |
| Gender | 0.19 | 0.03 | 0.218 |
| Body mass index | 0.00 | 0.00 | 0.926 |
| Academic year | −0.00 | −0.00 | 0.949 |
| Residence | −0.15 | −0.02 | 0.356 |
| Smoking | 0.31 | 0.03 | 0.191 |

**Dependent variable**
Epworth Sleepiness Scale (ESS) score.

**Model adjusted for**
age, gender, body mass index, academic year, residence, smoking status, caffeine consumption, physical activity, bedtime smartphone use duration, smartphone use after lights-off, and night-time smartphone checking.

**Abbreviations**
β, regression coefficient; ESS, Epworth Sleepiness Scale.

## DISCUSSION

The present multicenter cross-sectional study investigated the association between overnight smartphone notifications and daytime sleepiness among undergraduate medical students enrolled at five medical colleges in Pakistan. The principal findings demonstrated that nearly two-thirds of participants kept smartphone notifications enabled during their habitual sleeping period, and these students exhibited significantly higher Epworth Sleepiness Scale (ESS) scores than those who disabled overnight notifications. Furthermore, overnight smartphone notifications remained independently associated with greater daytime sleepiness after adjustment for demographic characteristics, lifestyle factors, and other smartphone-related behaviors. Additional independent predictors included longer bedtime smartphone use, smartphone use after lights-off, night-time smartphone checking, and caffeine consumption, whereas higher levels of physical activity were associated with lower daytime sleepiness. Collectively, these findings suggest that overnight smartphone notification practices represent an important behavioral factor associated with impaired daytime alertness among undergraduate medical students (23,24).

The observed association between overnight smartphone notifications and daytime sleepiness is consistent with a growing body of literature indicating that nighttime digital device interruptions are associated with poorer daytime functioning. Previous systematic reviews and observational studies have consistently reported that electronic device use during habitual sleep periods is associated with increased daytime sleepiness, fatigue, and impaired cognitive performance among adolescents and young adults (24–26). Similarly, studies involving university and medical students have demonstrated that frequent nighttime smartphone engagement, particularly repeated checking of mobile devices after bedtime or following nocturnal awakenings, is associated with higher ESS scores and reduced daytime alertness (25,26). Although most earlier investigations focused on overall smartphone use or smartphone addiction rather than notification-specific behaviors, our findings extend the existing evidence by demonstrating that overnight smartphone notifications themselves remained independently associated with daytime sleepiness after controlling for multiple potential confounders. This observation highlights that the manner in which smartphones interrupt sleep may be as important as the overall duration of smartphone use.

Several physiological and behavioral mechanisms may explain the association observed in the present study. Overnight smartphone notifications may interrupt normal sleep architecture by inducing repeated awakenings or brief cortical micro-arousals, thereby reducing sleep continuity even when individuals rapidly return to sleep. Sleep fragmentation has been shown to impair restorative sleep, decrease slow-wave sleep, and reduce rapid eye movement sleep, ultimately contributing to excessive

daytime sleepiness and impaired neurocognitive performance (27,28). In addition, notification alerts may provoke anticipatory anxiety regarding incoming messages, encouraging habitual nocturnal smartphone checking and increasing cognitive arousal before sleep can be re-established. Recurrent activation of sympathetic nervous system responses following notification alerts may further delay the transition back to deeper stages of sleep, thereby compromising sleep efficiency and next-day alertness. Although the cross-sectional nature of the present study precludes causal inference, these well-established physiological mechanisms provide biological plausibility for the observed association between overnight smartphone notifications and greater daytime sleepiness (27–29).

Beyond overnight notifications, several additional smartphone-related behaviors were independently associated with greater daytime sleepiness in the present study. Longer bedtime smartphone use, smartphone use after lights-off, and night-time smartphone checking all remained significant predictors after multivariable adjustment. These findings are consistent with previous studies reporting that cumulative nighttime smartphone exposure, rather than a single isolated behavior, may contribute to progressive sleep disruption and reduced daytime functioning (25,29). Smartphone use after lights-off may prolong sleep onset latency through continued cognitive engagement and exposure to light emitted from electronic screens, whereas habitual smartphone checking during nocturnal awakenings may reinforce conditioned wakefulness and further fragment sleep. Together, these findings suggest that multiple nighttime smartphone behaviors may interact to impair sleep continuity and increase daytime sleepiness among medical students.

Lifestyle-related factors also demonstrated significant associations with daytime sleepiness. Regular caffeine consumption was independently associated with higher ESS scores, whereas greater physical activity was associated with lower daytime sleepiness. Although caffeine is frequently consumed by medical students to combat fatigue and maintain alertness during prolonged study sessions, excessive caffeine intake may delay sleep onset, reduce sleep quality, and disrupt normal sleep architecture, potentially contributing to persistent daytime sleepiness despite its short-term stimulatory effects (30,31). Conversely, regular physical activity has consistently been associated with improved sleep efficiency, enhanced sleep continuity, and better daytime functioning. Exercise may improve circadian rhythm regulation, reduce psychological stress, and promote restorative sleep, thereby lowering the likelihood of excessive daytime sleepiness. These findings underscore the importance of considering lifestyle behaviors alongside smartphone-related factors when designing interventions to improve sleep health among medical students (30,31).

The findings of the present study have important clinical, educational, and public health implications. Medical students experience substantial academic demands that require sustained attention, rapid decision-making, and optimal cognitive performance. Daytime sleepiness may compromise learning efficiency, reduce classroom engagement, impair clinical reasoning, and potentially increase the risk of errors during clinical training. Because overnight smartphone notifications represent a potentially modifiable behavioral factor, simple interventions such as enabling "Do Not Disturb" mode during sleep, silencing non-essential notifications, maintaining smartphones away from the bedside, and promoting healthy digital habits may contribute to improved daytime alertness. Universities and medical colleges should consider incorporating sleep hygiene education and digital well-being strategies into student wellness programs, emphasizing practical approaches to minimize unnecessary nighttime smartphone interruptions while encouraging responsible technology use (32,33).

This study possesses several notable strengths. To our knowledge, it is among the first multicenter studies in Pakistan specifically evaluating the association between overnight smartphone notifications and daytime sleepiness among undergraduate medical students. The inclusion of 1,000 participants from five medical colleges provided a large and diverse sample, thereby enhancing statistical power and improving the external validity of the findings. Daytime sleepiness was assessed using the validated Epworth Sleepiness Scale, facilitating comparison with previous studies and ensuring standardized outcome measurement. Furthermore, the study examined notification-specific smartphone behaviors rather than relying solely on measures of overall smartphone use or smartphone addiction. The use of multivariable regression analysis allowed adjustment for several important demographic, lifestyle, and smartphone-related variables, strengthening confidence in the observed associations.

Several limitations should also be acknowledged. First, the cross-sectional design precludes conclusions regarding temporal or causal relationships between overnight smartphone notifications and daytime sleepiness. Second, smartphone behaviors and daytime sleepiness were assessed using self-reported questionnaires, making the findings susceptible to recall bias and reporting bias. Third, although multiple potential confounders were considered, residual confounding from unmeasured factors such as psychological stress, anxiety, chronotype,

 

academic workload, or pre-existing sleep disorders cannot be excluded. Fourth, objective sleep assessment methods, including actigraphy or polysomnography, and smartphone usage tracking applications were not used to validate self-reported behaviors. Finally, because the study population consisted exclusively of undergraduate medical students, the findings may not be generalizable to students from other academic disciplines or to the general population.

Future longitudinal cohort studies are required to clarify the temporal relationship between overnight smartphone notifications and daytime sleepiness and to determine whether reducing nighttime notifications leads to measurable improvements in daytime alertness. Randomized intervention studies evaluating digital well-being programs, smartphone notification management, and sleep hygiene education would provide stronger evidence regarding effective strategies for improving sleep health among university students. The incorporation of wearable sleep monitoring devices and smartphone usage tracking software may further enhance the accuracy of exposure and outcome assessment in future research.

In conclusion, this multicenter study demonstrated that overnight smartphone notifications were independently associated with greater daytime sleepiness among undergraduate medical students. Additional nighttime smartphone behaviors, including prolonged bedtime smartphone use, smartphone use after lights-off, and night-time smartphone checking, were also independently associated with higher daytime sleepiness, whereas regular physical activity appeared to have a protective association. These findings highlight the importance of promoting healthy nighttime smartphone practices and comprehensive sleep hygiene interventions within medical schools. Prospective studies are warranted to establish temporal relationships and evaluate the effectiveness of interventions aimed at reducing notification-related sleep disruption and improving daytime functioning among medical students (34,35).

## CONCLUSION

This multicenter cross-sectional study demonstrated that overnight smartphone notifications were independently associated with greater daytime sleepiness among undergraduate medical students. Students who kept smartphone notifications enabled during their habitual sleeping period exhibited significantly higher Epworth Sleepiness Scale scores and a greater prevalence of excessive daytime sleepiness than those who disabled notifications. In addition to overnight notifications, prolonged bedtime smartphone use, smartphone use after lights-off, and night-time smartphone checking were independently associated with higher daytime sleepiness, whereas regular physical activity showed a protective association.

These findings highlight overnight smartphone notifications as a potentially modifiable behavioral factor associated with impaired daytime alertness in medical students. Promoting healthy nighttime smartphone practices, including limiting unnecessary notifications during sleep, encouraging appropriate digital device use before bedtime, and incorporating sleep hygiene education into student wellness programs, may contribute to improved daytime functioning and overall well-being. Nevertheless, because of the cross-sectional design, causal relationships cannot be established. Future longitudinal and interventional studies incorporating objective sleep monitoring and smartphone usage tracking are warranted to clarify temporal relationships and evaluate the effectiveness of interventions aimed at reducing notification-related sleep disruption among medical students.

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