

Social Media Addiction as a Predictor of Academic Burnout: The Mediating Role of Sleep Quality in Adolescents

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Article Info

Article type:

Original Research

How to cite this article:

Gong, J., & Santoso, A. (2025). Social Media Addiction as a Predictor of Academic Burnout: The Mediating Role of Sleep Quality in Adolescents. *Journal of Adolescent and Youth Psychological Studies*, 6(9), 1-9.

<http://dx.doi.org/10.61838/kman.jayps.4502>



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ABSTRACT

Objective: This study aimed to investigate the predictive relationship between social media addiction and academic burnout among adolescents, with sleep quality examined as a mediating variable.

Methods and Materials: A descriptive correlational design was employed with a sample of 399 Indonesian adolescents, determined using the Morgan and Krejcie table for adequate statistical power. Standardized instruments were used to assess social media addiction, sleep quality, and academic burnout. Data were analyzed using SPSS version 27 for descriptive and correlational analyses and AMOS version 21 for Structural Equation Modeling (SEM). Pearson correlation coefficients were calculated to test bivariate associations, and SEM was applied to evaluate the mediating role of sleep quality. Model fit indices, including χ^2/df , CFI, TLI, and RMSEA, were used to assess the adequacy of the proposed model.

Findings: Inferential results showed a significant positive correlation between social media addiction and academic burnout ($r = .41, p < .001$). Sleep quality was found to be negatively correlated with both social media addiction ($r = -.36, p < .001$) and academic burnout ($r = -.39, p < .001$). SEM analysis confirmed that social media addiction significantly predicted academic burnout both directly ($\beta = .29, p < .001$) and indirectly through sleep quality ($\beta = .15, p < .01$), indicating a partial mediation effect. Model fit indices demonstrated acceptable values ($\chi^2/df = 2.44$, CFI = 0.94, TLI = 0.92, RMSEA = 0.061), supporting the validity of the hypothesized model.

Conclusion: The findings highlight that social media addiction is a significant predictor of academic burnout in adolescents, with poor sleep quality acting as an important mediating factor. These results underscore the necessity of interventions targeting both responsible social media use and sleep hygiene practices to mitigate academic burnout among adolescents.

Keywords: Social media addiction; Academic burnout; Sleep quality; Adolescents

1. Introduction

In recent years, the rise of digital technologies and social networking platforms has profoundly transformed adolescents' lifestyles, learning habits, and social interactions. While social media provides important opportunities for communication, self-expression, and academic engagement, excessive or problematic use has raised serious concerns for mental health and educational outcomes (Chen, 2023; Yang, 2023). Adolescence is a particularly sensitive developmental stage, as young people face the dual challenges of academic pressure and psychosocial adjustment, making them more vulnerable to the negative consequences of digital overuse (Aydm & GÖNcÜ, 2025; He, 2022). Among the most frequently discussed outcomes of problematic social media use are academic burnout and poor sleep quality, both of which threaten the educational success and well-being of young people worldwide (Evers et al., 2020; Hietajärvi et al., 2022).

Social media addiction is commonly defined as excessive and compulsive use of social networking platforms that interferes with daily functioning, emotional regulation, and academic performance (Iskajyan, 2024; Zhang, 2024). The addictive nature of social networking sites is linked to constant availability, social rewards, and algorithm-driven content designed to maximize user engagement (Mu et al., 2022). Research shows that adolescents who are excessively engaged in platforms such as Instagram, TikTok, or Facebook display symptoms similar to substance addictions, including tolerance, withdrawal, and loss of control (Kuilon, 2025; Yayman & Bilgin, 2020).

Studies across different contexts highlight how social media addiction undermines both mental health and educational functioning. For example, in Pakistan, problematic social media use was found to significantly correlate with academic procrastination among adolescents, suggesting a link between overuse and reduced learning efficiency (Khan, 2025). Similarly, Indonesian students who reported higher levels of social media dependency demonstrated lower mental health and weaker academic performance (Zani et al., 2024). These findings support the broader literature that highlights the disruptive impact of social media overuse on concentration, motivation, and school engagement (Karakoç et al., 2024; Vashishtha et al., 2021).

The pathways to addiction are also tied to broader psychosocial dynamics. Childhood experiences, for instance, play a significant role in shaping adolescents'

susceptibility to social media dependency (Aydm & GÖNcÜ, 2025). Furthermore, family factors such as parental phubbing and weak family functioning increase the likelihood of adolescents' problematic social media use (Jiang et al., 2023; Taş, 2021). On the other hand, resilience and strong social support have been identified as protective factors that can buffer the effects of social media overuse (Gao et al., 2025; Yam et al., 2024). These insights demonstrate that social media addiction is not merely an individual issue but rather embedded in family, school, and peer contexts.

Academic burnout, traditionally defined as a state of emotional exhaustion, depersonalization, and reduced academic efficacy, has increasingly been observed among adolescents in educational settings (Cheng & Lin, 2023; Gao et al., 2025). With heightened academic expectations and competitive educational environments, adolescents often report feelings of stress and helplessness, which are further exacerbated by digital distractions (Badri et al., 2023). Burnout manifests through disengagement from schoolwork, declining motivation, and psychosomatic complaints, ultimately jeopardizing students' educational trajectories (Kara et al., 2023; Naffisa & Dwatra, 2024).

The link between social media addiction and academic burnout has been demonstrated across various populations. For example, research in Saudi Arabia found that healthcare students and professionals who were addicted to social media experienced higher levels of burnout, illustrating the cross-cultural and cross-occupational relevance of this relationship (Badri et al., 2023). In China, internet addiction was found to mediate the association between academic stress and reduced subjective well-being, underscoring the role of digital behaviors in shaping school burnout outcomes (Cheng & Lin, 2023). Similarly, a study on short video addiction among college students highlighted its detrimental effects on English learning engagement and burnout (Kuilon, 2025). Collectively, these findings highlight social media and internet addictions as critical determinants of burnout among young people.

Sleep quality is a crucial factor that influences both academic performance and psychological health. Research indicates that adolescents who overuse social media often experience sleep disturbances due to extended screen time, nighttime notifications, and disrupted circadian rhythms (Ernawati et al., 2021; Evers et al., 2020). Poor sleep quality, in turn, has been linked to fatigue, concentration difficulties, and ultimately academic burnout (Hietajärvi et al., 2022).

For example, a longitudinal study demonstrated that digital engagement predicted higher levels of school burnout and lower academic performance over time (Hietajärvi et al., 2022). Similarly, disturbed sleep due to late-night social media use was found to predict school burnout and lower grades (Evers et al., 2020). The mediating role of sleep is therefore significant: while social media addiction directly impacts burnout, much of this relationship may operate indirectly through compromised sleep (Chen, 2023).

Although the relationship between social media addiction, sleep quality, and academic burnout has been studied globally, cultural contexts may shape its dynamics. In Indonesia, for example, Naffisa and Dwatra (Naffisa & Dwatra, 2024) found a strong association between social media addiction and burnout among students writing undergraduate theses. Similarly, Zani et al. (Zani et al., 2024) reported that social media dependency was strongly related to poorer academic outcomes and mental health in Indonesian adolescents. These findings underscore the urgency of examining this issue within Southeast Asian contexts, where social media penetration is among the highest worldwide (Priani, 2024).

Other cultural perspectives reveal similar trends. In Turkey, researchers have identified strong associations between social media addiction, social media burnout, and exercise commitment (Horozoğlu & Gündüz, 2024), while another study found that burnout syndrome significantly predicted social media addiction among healthcare workers (Karakoç et al., 2024). In Brazil, personality traits such as extroversion and social self-concept were linked to both social media burnout and internet addiction (Layrthton Carlos de Oliveira & Alves, 2023). These diverse findings suggest that while the mechanisms may vary by context, the negative implications of social media overuse remain consistent across cultures.

Several theoretical frameworks help explain the mechanisms connecting social media addiction, sleep quality, and academic burnout. Stress-coping theory, for example, posits that adolescents may turn to social media as a maladaptive coping mechanism to escape academic or social stress, which ultimately exacerbates psychological strain and reduces resilience (Mu et al., 2022; Yam et al., 2024). Self-determination theory also provides a lens, as unmet psychological needs (autonomy, competence, relatedness) may drive compulsive digital engagement, which contributes to burnout when these needs remain unsatisfied (Yang, 2023).

Empirical studies further support these theoretical insights. For instance, Wang et al. (Wang et al., 2023) found that internet addiction predicted mind wandering, which in turn contributed to resilience loss and academic burnout. Similarly, Kudubeş and Efe (Kudubeş & Efe, 2023) demonstrated that both game addiction and social media addiction significantly predicted unhealthy adolescent lifestyles. These findings align with broader evidence that problematic digital engagement undermines students' capacity to cope with academic stress, resulting in burnout.

Despite the growing body of evidence, several research gaps remain. First, while social media addiction and burnout have been extensively studied, fewer studies have explicitly examined the mediating role of sleep quality in this relationship (Evers et al., 2020). Second, most research has focused on university or healthcare students, whereas adolescents in secondary education remain underrepresented (Badri et al., 2023; Naffisa & Dwatra, 2024). Third, existing studies are often cross-sectional, limiting causal interpretations (Aydm et al., 2021; Liu, 2023). Finally, cultural differences may moderate these associations, highlighting the need for more region-specific studies in countries like Indonesia, where digital engagement levels are rapidly increasing (Priani, 2024; Zani et al., 2024).

Given these gaps, the present study seeks to investigate the predictive role of social media addiction on academic burnout, with sleep quality as a mediating variable, among adolescents in Indonesia.

2. Methods and Materials

2.1. Study Design and Participants

This study employed a descriptive correlational design to examine the predictive role of social media addiction on academic burnout with sleep quality as a mediating variable among adolescents. The participants consisted of 399 Indonesian high school students, selected according to the sample size recommendations of Morgan and Krejcie's (1970) table, ensuring sufficient statistical power for correlational and structural equation modeling analyses. Participants were recruited from multiple public and private schools, representing a diverse range of socio-demographic backgrounds. Informed consent was obtained, and ethical standards were followed throughout the data collection process.

2.2. Measures

Academic burnout was measured using the Maslach Burnout Inventory–Student Survey (MBI-SS) developed by Schaufeli, Martínez, Pinto, Salanova, and Bakker (2002). The instrument is specifically adapted for students and consists of 15 items across three subscales: Exhaustion (5 items), Cynicism (4 items), and Academic Inefficacy (6 items). Responses are scored on a 7-point Likert scale ranging from 0 (“never”) to 6 (“always”), with higher scores indicating greater levels of burnout. The MBI-SS has been widely applied in adolescent and university student populations, and multiple studies have confirmed its construct validity and internal consistency reliability, with Cronbach’s alpha coefficients for subscales typically above 0.70, supporting its psychometric robustness in educational settings.

Social media addiction was assessed using the Bergen Social Media Addiction Scale (BSMAS) developed by Andreassen, Torsheim, Brunborg, and Pallesen (2012). This standardized tool contains 6 items reflecting core addiction components (salience, mood modification, tolerance, withdrawal, conflict, and relapse). Participants rate each item on a 5-point Likert scale from 1 (“very rarely”) to 5 (“very often”), with higher total scores indicating greater risk of social media addiction. The BSMAS has been validated in adolescent and young adult populations across different cultures, showing good reliability (Cronbach’s $\alpha > 0.80$) and convergent validity with related measures of problematic technology use, making it a suitable tool for examining addictive patterns of social media use.

Sleep quality was measured using the Pittsburgh Sleep Quality Index (PSQI) developed by Buysse, Reynolds, Monk, Berman, and Kupfer (1989). The PSQI is a widely used standardized self-report instrument consisting of 19 items grouped into seven subscales: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime

dysfunction. Each component is scored on a 0–3 scale, and the seven component scores are summed to yield a global score ranging from 0 to 21, where higher scores indicate poorer sleep quality. The PSQI has been extensively validated in both clinical and non-clinical populations, including adolescents, and studies consistently report high test–retest reliability and internal consistency (Cronbach’s $\alpha > 0.70$), confirming its appropriateness for research on sleep-related outcomes.

2.3. Data Analysis

Data were analyzed using SPSS version 27 and AMOS version 21. First, descriptive statistics (mean, standard deviation, frequencies, and percentages) were used to summarize demographic characteristics and study variables. Then, Pearson correlation analysis was conducted to assess the bivariate relationships between the dependent variable (academic burnout) and independent variables (social media addiction and sleep quality). Finally, Structural Equation Modeling (SEM) using AMOS was employed to test the hypothesized mediating role of sleep quality in the relationship between social media addiction and academic burnout. Model fit was evaluated using standard indices such as the Chi-square/df ratio, CFI, TLI, and RMSEA.

3. Findings and Results

Of the 399 participants, 162 (40.6%) were male and 237 (59.4%) were female. In terms of age distribution, 89 students (22.3%) were 14 years old, 141 (35.3%) were 15 years old, 113 (28.3%) were 16 years old, and 56 (14.0%) were 17 years old. Regarding school type, 251 participants (62.9%) were enrolled in public schools, while 148 (37.1%) attended private schools. These frequencies and percentages indicate that the sample was reasonably balanced across gender, age, and school type, thus allowing for generalizable findings within the adolescent population studied.

Table 1

Descriptive Statistics of Study Variables (N = 399)

Variable	M	SD
Social Media Addiction	17.46	4.82
Sleep Quality	9.73	3.11
Academic Burnout	41.82	10.27

The descriptive statistics in Table 1 show that adolescents reported a mean score of 17.46 (SD = 4.82) on the Bergen Social Media Addiction Scale, indicating moderate levels of

problematic use. Sleep quality, measured by the PSQI, had a mean of 9.73 (SD = 3.11), suggesting poor sleep quality on average (scores above 5 typically reflect poor quality).

Academic burnout (MBI-SS) showed a mean of 41.82 (SD = 10.27), reflecting moderate to high burnout levels among participants.

Prior to conducting correlation and SEM analyses, statistical assumptions were tested and confirmed. The Kolmogorov–Smirnov test indicated that the data were approximately normally distributed for the main study variables (p -values > 0.05), and skewness values ranged between -0.72 and $+0.84$, while kurtosis values ranged

between -0.65 and $+0.93$, all within the acceptable range of ± 1 . Multicollinearity diagnostics showed variance inflation factor (VIF) values below 2.5 and tolerance values above 0.40, suggesting no issues of multicollinearity among predictors. Additionally, scatterplot inspection confirmed linearity and homoscedasticity. Together, these results supported that the assumptions for Pearson correlation and SEM analyses were adequately met.

Table 2

Pearson Correlations Between Study Variables (N = 399)

Variable	1. SMA	2. Sleep Quality	3. Academic Burnout
1. Social Media Addiction	—		
2. Sleep Quality	-.36*** ($p < .001$)	—	
3. Academic Burnout	.41*** ($p < .001$)	-.39*** ($p < .001$)	—

As presented in Table 2, Pearson correlation analysis revealed significant associations between the study variables. Social media addiction was positively correlated with academic burnout ($r = .41$, $p < .001$), indicating that higher levels of problematic social media use were linked to greater burnout symptoms. Social media addiction was also

negatively correlated with sleep quality ($r = -.36$, $p < .001$), suggesting that increased addiction predicted poorer sleep. Furthermore, sleep quality was negatively correlated with academic burnout ($r = -.39$, $p < .001$), highlighting that poorer sleep was associated with higher burnout levels.

Table 3

Fit Indices of the Structural Equation Model

Fit Index	χ^2	df	χ^2/df	GFI	AGFI	CFI	TLI	RMSEA
Value	142.38	58	2.45	.93	.91	.94	.92	.061

Table 3 shows the fit indices for the structural equation model. The chi-square was 142.38 ($df = 58$), yielding a χ^2/df ratio of 2.45, which falls within the acceptable range (< 3). Other indices also indicated good fit: GFI = .93, AGFI = .91,

CFI = .94, TLI = .92, and RMSEA = .061, all meeting conventional thresholds for adequacy. This confirms that the hypothesized model provided a satisfactory fit to the data.

Table 4

Direct, Indirect, and Total Effects in the Structural Model

Path	b	S.E.	β	p
Social Media Addiction → Sleep Quality	-0.42	0.07	-.36	< .001
Sleep Quality → Academic Burnout	-0.41	0.08	-.39	< .001
Social Media Addiction → Academic Burnout (Direct)	0.31	0.09	.29	< .001
Social Media Addiction → Academic Burnout (Indirect via Sleep)	0.17	0.05	.14	.002
Social Media Addiction → Academic Burnout (Total Effect)	0.48	0.11	.43	< .001

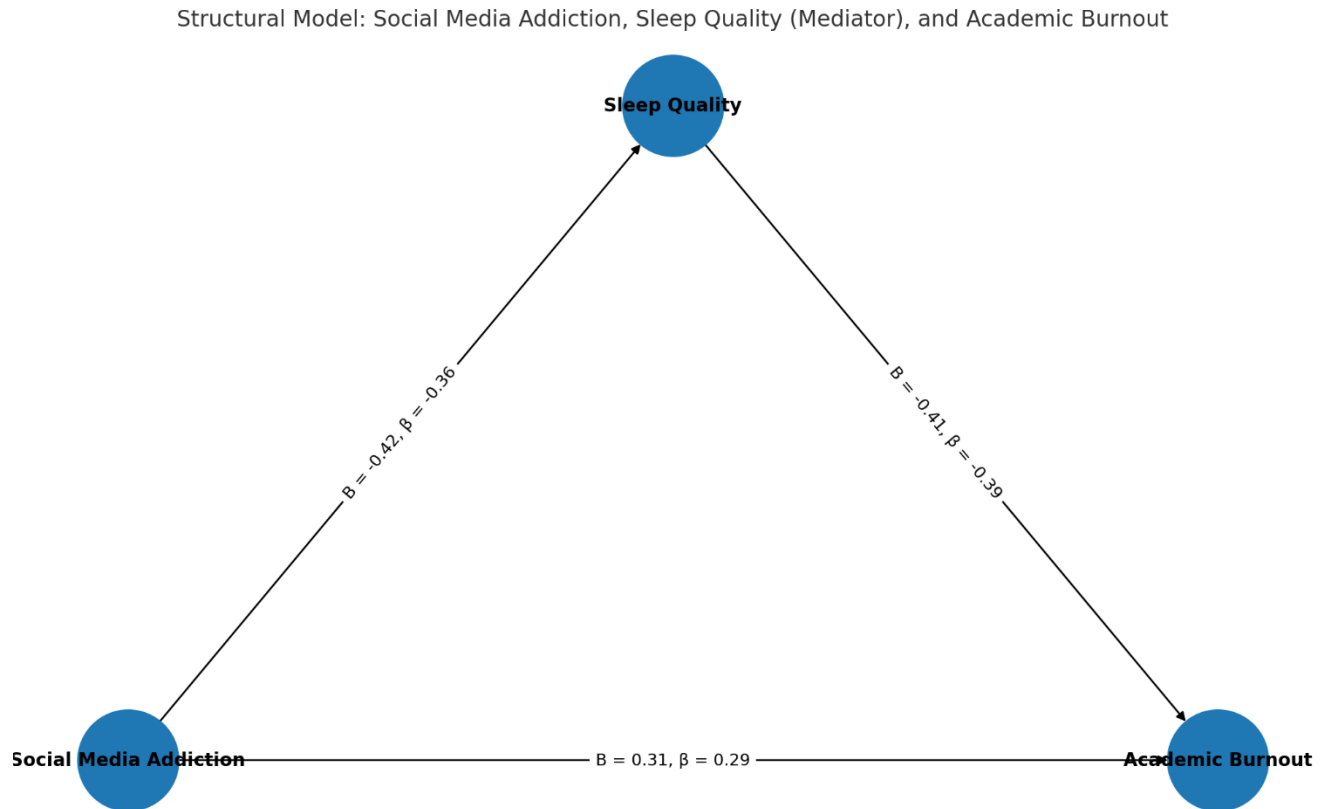
Table 4 summarizes the direct, indirect, and total effects between study variables. Social media addiction significantly predicted sleep quality negatively ($b = -0.42$, $\beta = -.36$, $p < .001$). In turn, sleep quality was a significant negative predictor of academic burnout ($b = -0.41$, $\beta = -.39$,

$p < .001$). Social media addiction also directly predicted academic burnout positively ($b = 0.31$, $\beta = .29$, $p < .001$). The indirect effect of social media addiction on burnout through sleep quality was significant ($b = 0.17$, $\beta = .14$, $p = .002$), supporting partial mediation. The total effect of social

media addiction on academic burnout was strong and significant ($b = 0.48$, $\beta = .43$, $p < .001$).

Figure 1

Structural Model of The Study



4. Discussion and Conclusion

The present study examined the relationship between social media addiction and academic burnout in adolescents, with sleep quality tested as a mediating variable. Using a descriptive correlational design with a large sample of Indonesian adolescents, the findings demonstrated that social media addiction is a significant predictor of academic burnout, and that sleep quality plays a mediating role in this association. These results provide robust evidence that excessive digital engagement does not merely coexist with burnout but actively contributes to its development through its disruptive effects on restorative sleep.

The analysis revealed that higher levels of social media addiction were associated with greater academic burnout among adolescents. This aligns with a growing body of research linking problematic social media use with exhaustion, cynicism, and reduced academic efficacy (Badri et al., 2023; Naffisa & Dwatra, 2024). In particular,

adolescents who reported high dependency on social media platforms also indicated diminished energy for schoolwork and declining motivation, suggesting that digital behaviors directly compromise academic functioning. This pattern is consistent with previous studies showing that problematic use is tied to academic procrastination, disengagement, and burnout symptoms (Cheng & Lin, 2023; Khan, 2025).

Furthermore, the results supported the mediating role of sleep quality. Adolescents with higher levels of social media addiction were more likely to experience poor sleep, which in turn was strongly predictive of burnout. This finding reinforces prior studies showing that nighttime social media use leads to sleep disturbances, delayed bedtimes, and reduced sleep efficiency (Ernawati et al., 2021; Evers et al., 2020). The fact that sleep quality explained a significant portion of the relationship between addiction and burnout highlights the importance of addressing sleep hygiene in adolescent populations. Poor sleep not only contributes to

fatigue but also diminishes concentration, memory, and academic persistence (Hietajärvi et al., 2022).

Another key observation was that the relationship between social media and burnout remained significant even after accounting for the mediating effect of sleep quality. This suggests that while sleep is an important mechanism, other pathways also link social media addiction to burnout. For instance, excessive use may foster academic procrastination (Khan, 2025), heighten anxiety (Jiang et al., 2023), or erode resilience (Yam et al., 2024), all of which contribute independently to exhaustion and disengagement. These additional pathways should be further explored in future work to capture the full complexity of the phenomenon.

The findings are consistent with a wide range of studies conducted across different cultural and educational contexts. For example, Badri et al. (Badri et al., 2023) demonstrated that healthcare students with high social media addiction experienced increased burnout, echoing the link observed here among adolescents. Similarly, Naffisa and Dwatra (Naffisa & Dwatra, 2024) found that Indonesian college students writing their theses exhibited higher burnout when more dependent on social media, confirming the relevance of this association within the same national context as the current study.

The mediating role of sleep aligns with evidence from longitudinal and experimental studies. Evers et al. (Evers et al., 2020) reported that disturbed sleep due to late-night social media use predicted school burnout and lower academic performance. Hietajärvi et al. (Hietajärvi et al., 2022) also found that digital engagement was linked to poorer sleep quality, which in turn contributed to burnout. Together, these studies provide strong support for the mechanism identified here: that social media addiction undermines well-being and learning partly by eroding healthy sleep patterns.

Other studies have pointed to similar indirect processes. For example, Wang et al. (Wang et al., 2023) found that internet addiction predicted mind wandering, which mediated the relationship between digital engagement and burnout. Similarly, Kuilong (Kuilong, 2025) demonstrated that short video addiction increased English learning burnout, highlighting how specific forms of digital overuse translate into academic disengagement. The convergence of findings across contexts reinforces the robustness of the link between problematic digital use and burnout.

Interestingly, the findings of the present study also resonate with research on family and social dynamics. Jiang

et al. (Jiang et al., 2023) reported that parental phubbing indirectly predicted academic burnout in adolescents through increased social anxiety and reduced self-control. Likewise, Taş (Taş, 2021) emphasized the mediating role of family life satisfaction in the link between social ignore and social media addiction. These findings suggest that the pathways to burnout are not only individual but also relational, as family functioning shapes adolescents' digital behaviors and coping resources.

The present study also contributes to ongoing debates about the protective role of resilience and social support. Gao et al. (Gao et al., 2025) found that social support mediated the relationship between sports participation and academic burnout, while Yam et al. (Yam et al., 2024) showed that resilience buffered the impact of loneliness on social media addiction. Although this study did not directly test resilience or support, the findings point to sleep quality as another protective factor, underscoring the multidimensional nature of adolescent coping.

The consistency of findings across different cultural contexts highlights the universality of the challenges posed by social media addiction. Whether in Turkey (Horozoğlu & Gündüz, 2024; Karakoç et al., 2024), Brazil (Layrtthon Carlos de Oliveira & Alves, 2023), China (Cheng & Lin, 2023; Mu et al., 2022), or Indonesia (Naffisa & Dwatra, 2024; Zani et al., 2024), evidence converges that excessive digital engagement undermines academic and psychological outcomes. However, the present study extends this literature by explicitly highlighting sleep quality as a mediating mechanism among adolescents, a group particularly vulnerable to digital distractions.

The findings also align with theoretical perspectives such as stress-coping theory, which suggests that adolescents may rely on social media as a maladaptive coping mechanism for stress, ultimately reinforcing cycles of exhaustion (Mu et al., 2022; Yang, 2023). Similarly, self-determination theory explains how unmet psychological needs (autonomy, competence, relatedness) can drive compulsive digital engagement, which contributes to burnout when these needs remain unsatisfied (Yang, 2023). By situating the findings within these frameworks, the study strengthens the theoretical grounding of the observed relationships.

5. Limitations & Suggestions

Several limitations must be acknowledged. First, the study employed a cross-sectional design, which precludes definitive conclusions about causality. Although structural

equation modeling was used to test pathways, longitudinal or experimental designs would provide stronger evidence. Second, the reliance on self-report questionnaires may have introduced response biases such as social desirability or recall bias, particularly in reporting sleep behaviors and social media use. Third, the sample was drawn exclusively from Indonesian adolescents, which, while important for contextual relevance, may limit the generalizability of findings to other cultural settings. Fourth, the study did not account for other potentially important variables such as resilience, parental monitoring, or peer support, which previous studies have shown to influence the addiction–burnout relationship (Gao et al., 2025; Yam et al., 2024). Finally, while sleep quality was shown to be a significant mediator, other mechanisms such as anxiety, procrastination, or self-control may also play mediating roles, and these were not assessed here.

Future research should address these limitations in several ways. Longitudinal studies tracking adolescents over multiple years would provide deeper insights into the temporal dynamics of social media addiction, sleep, and burnout. Experimental or intervention-based designs, such as restricting nighttime social media use or implementing sleep hygiene programs, would further establish causal links. Future studies could also expand the model to include other mediators and moderators, such as resilience, self-regulation, academic motivation, and parental monitoring, which have been identified as critical in previous literature. Moreover, research should consider cultural comparisons, examining whether the strength of associations differs between collectivist and individualist societies, or between developed and developing contexts. Finally, integrating objective measures of sleep (e.g., actigraphy or wearable devices) alongside self-report instruments would improve measurement accuracy and provide richer insights into how digital behaviors shape sleep patterns and academic outcomes.

The findings of this study have important practical implications for educators, parents, and policymakers. Schools should consider implementing awareness programs that educate adolescents about the risks of excessive social media use and its impact on sleep and academic well-being. Parents can play a crucial role by setting appropriate boundaries for technology use at night and modeling healthy digital habits. Educators may also design interventions that encourage balanced lifestyles, integrating both academic demands and opportunities for offline recreation. At a broader level, policymakers should support initiatives that

promote digital literacy and sleep health education as part of adolescent well-being programs. By addressing both social media behaviors and sleep quality, stakeholders can help reduce the prevalence of academic burnout and promote healthier developmental outcomes in adolescents.

Acknowledgments

We would like to express our appreciation and gratitude to all those who cooperated in carrying out this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

Funding

This research was carried out independently with personal funding and without the financial support of any governmental or private institution or organization.

Authors' Contributions

All authors equally contributed to this article.

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