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Bedtime smartphone use and academic performance: A longitudinal analysis from the stressor-strain-outcome perspective

Yanqing Lin [a], Xun Zhou [b,*]

[a] Department of Information and Service Management, Aalto University School of Business, Ekonominaukio 1, Espoo 02150, Finland
[b] Department of Environment and Geography, University of York, 290 Wentworth Way, York YO10 5NG, United Kingdom

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ABSTRACT

The penetration of smartphones into human life finds expression in problematic smartphone use, particularly under the Covid-19 home confinement. Problematic smartphone use is accompanied by adverse impacts on personal wellbeing and individual performance. However, little is known about the mechanism of such adverse impacts. Motivated by this, the present study strives to answer (i) how bedtime smartphone use impacts students' academic performance through wellbeing-related strains; (ii) how to mitigate the adverse consequences of bedtime smartphone use. Drawing upon the stressor-strain-outcome paradigm, the current work presents a comprehensive understanding of how smartphone use indirectly deteriorates college students' academic performance through the mediators of nomophobia — "*the fear of being unavailable to mobile phones*" (Lin et al., 2021) — and sleep deprivation. This allows a more flexible remedy to alleviate the adverse consequences of smartphone use instead of simply limiting using smartphones. This study collects a two-year longitudinal dataset of 6093 college students and employs the structural equation modeling technique to examine the stressor-strain-outcome relationship among bedtime smartphone use, nomophobia, sleep deprivation, and academic performance. This study finds robust evidence that wellbeing-related strains (i.e., nomophobia and sleep deprivation) mediate the negative relationship between bedtime smartphone use and academic performance. Furthermore, engaging in physical activity effectively mitigates the adverse effects of bedtime smartphone use upon nomophobia and sleep deprivation. This study not only enriches the current literature regarding the indirect effect mechanism of smartphone use but also provides valuable insights for academics and educational policymakers.

1. Introduction

Smartphones have become a ubiquitous and indispensable part of our daily lives and professional activities [1,2]. However, the increasing penetration of smartphones into people's lives gives rise to public concern about problematic smartphone use. Problematic smartphone use finds expression in excessive and uncontrolled smartphone use that fuels a number of physical and mental problems [3,4]. As a significant indicator of problematic smartphone use, bedtime smartphone use has been found prevalent among users [4]; related statistics by Alshobaili and AlYousefi [5] document that nine out of ten respondents have bedtime smartphone use habits in Saudi Arabia. An increasing amount of time spent on the smartphone before sleep directly makes the user more susceptible to sleep disorders and psychological unease [5,6]. It is particularly noteworthy that the adverse consequences of smartphone use would be further intensified under the Covid-19 pandemic home confinement (see, [7,8]).

Discussions regarding the potential outcomes of (problematic) smartphone use have occupied an increasingly important place in either societal debates [9] or academic research [10]. Bedtime smartphone use leads to a growing public health concern and an urgent need to understand its impacts on personal wellbeing and individual performance [11, 4]. A vast majority of the existing literature has focused on the direct impacts of smartphone use based on cross-sectional analysis. Evidence has been found that the general use of smartphones or the use of specific mobile applications can cause users' physical and mental discomfort (e.g., [12,13]), as well as impaired academic performance (e.g., [14,15]). However, few studies have examined the indirect impacts of bedtime smartphone use on individual performance via potential mediators. This is clearly a research gap to be bridged, as a comprehensive understanding of the effect mechanism of smartphone use is critically important for both individual and organizational performance.

* Corresponding author.
E-mail addresses: yanqing.lin@aalto.fi (Y. Lin), xun.zhou@york.ac.uk (X. Zhou).

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Furthermore, by addressing this research gap, this study also echoes the call for disentangling how smartphone use interferes with students' educational life, especially in light of health indicators, as indicated in the systematic literature review by Amez and Baert [10].

Under such circumstances, we employ the stressor-strain-outcome (SSO) theory to consolidate bedtime smartphone use, wellbeing-related variables, and academic performance in an integrated manner. This offers a complete view of the indirect effect of bedtime smartphone use on students' academic performance through wellbeing-related factors. In contrast with cross-sectional results in most past studies, the present work seeks longitudinal evidence to empirically verify the mediating effects of wellbeing-related strains on the relationship between the external stressor (i.e., bedtime smartphone use) and its outcome (i.e., academic performance). The wellbeing-related strains considered here include two indicators related to bedtime smartphone use — nomophobia, referring to "*the fear of being out of mobile phone contact*" ([16], p. 1322), and sleep deprivation, conceptualized as no sleep or reduced sleep time than required to keep the individual awake and alert [17] — as discussed in prior works (e.g., [18,19]).

The present study also contributes to effective interventions to mitigate the adverse impacts of bedtime smartphone use on college students' wellbeing and academic performance. Heated discussions have emerged that people, particularly students, should restrict or even ban their access to smartphones (e.g., [20,21]). Furthermore, past studies also offer quasi-experimental evidence on the favorable effects of banning smartphones in schools on students' academic outcomes [22, 23]. However, merely limiting smartphone use could not be feasible for alleviating the adverse effects because of the indispensable role the smartphone plays in social and professional lives. A failed trial can exemplify this by teens in Finland who tried to cut back on their smartphone use [24]. Are there any possible practical treatments for adverse consequences derived from bedtime smartphone use beyond simply cutting off smartphone use? This study aims to tackle this issue, which is valuable to academics and educational policymakers.

In sum, to answer the call for unraveling the indirect effect mechanism of smartphone use on academic performance [10,25] and exploring feasible ways to mitigate the adverse consequences of smartphone use (see, [26,27]), this study strives to answer the following questions:

Research question 1: How does bedtime smartphone use impact academic performance through health indicators, i.e., nomophobia and sleep deprivation?

Research question 2: How to alleviate the adverse effects of bedtime smartphone use?

1.1. The dark side of smartphone use

The use of smartphones has dramatically changed the way we live, learn, and work. On the bright side, for example, the smartphone acts as an essential channel for mobile learning and social interactions [28,29] as well as remote working [30]. Everyday smartphone use among organizational employees for social, informative, and entertainment purposes benefits their affective wellbeing at the end of workdays [31]. Despite the benefits deriving from smartphones, a large body of the current literature has documented adverse outcomes of smartphone use on personal wellbeing (e.g., [12,32]), as well as academic performance of student groups (e.g., [15,33]). Appendix A summarizes previous studies over the past five years investigating the adverse impacts of smartphones, the *so-called* dark side of smartphone use.

Scholars have identified that problematic mobile phone use significantly contributes to decreased physical fitness. For instance, time spent on mobile phones is found to be positively linked to college students' worse cardiorespiratory status, increased sedentary behavior, and decreased health status [34]. Night-time use of mobile phones is identified as a cause of obesity [35]. Many other pieces of evidence support that mobile phone use before sleep is capable of triggering insomnia [36], delaying bedtime [37], increasing sleep latency [38], and decreasing sleep duration [39,37].

Further, the existing literature indicates that smartphone use is a precondition for cultivating *nomophobia* (e.g., [15,40]). Nomophobia, or no-mobile-phobia, conceptually similar to mobile phone addiction, has been identified as one of the most direct adverse outcomes of mobile phone use [40,41]. Several researchers have found that nomophobia or smartphone addiction contributes to the development of psychological unease, including anxiety [42,43], stress ([44]; [45]), depression [46, 47], loneliness ([42, 48]), to name but only a few.

While several studies subscribe that using mobile devices affords several advantages for students' academic achievement, numerous adverse consequences also come with its use (e.g., [49,50]). When used appropriately, smartphones can positively contribute to students' academic performance [10]. For instance, the high degree of flexibility afforded by smartphones enables students to bridge the learning gap due to diverse geographical locations [28] and easily access network-based learning materials and services anytime and anywhere [51]. Further, the smartphone is a multi-platform hub with rich functionalities, allowing individuals to quickly access and share information and efficiently interact and collaborate with peers and teachers [52,53]. On the contrary, more researchers endorse that smartphone use can cause distraction during students' learning process, leading to a detrimental impact on their academic achievements (e.g., [54,55]). For instance, cell phone use can deteriorate students' concentration and the amount of information received during a specific class [51], develop distracted behaviors, and further cause worse learning outcomes and academic performance [56,57]. The work by Tossell et al. [58] reveals that even though students thought smartphones use for studying purposes was beneficial before use, unfortunately, they later viewed smartphone use as harmful to their academic development. This is because respondents self-reported that their smartphones were more like a distraction than a helpful tool, and it was easy to develop nomophobic symptoms such as habitually checking their smartphones though without any purpose. Students with smartphone overuse in-class sessions are more likely to spend more time on non-academic uses (e.g., improper social media use during class) [59] and suffer from distraction [60], thereby being distracted from their academic tasks [61]. The empirical literature also has shown that smartphone addiction is negatively associated with university students' academic performance evaluated by their grade point averages (GPAs) [62,63]. Even outside class sessions, students with smartphone addiction tend to develop procrastination on extra-curricular learning and homework [64].

1.2. Stressor-strain-outcome (SSO) theory

The SSO theory offers accounts for the process that environmental stimuli influence users' psychological and behavioral outcomes via generated strain(s) [65]. Notably, the SSO model indicates that a stressor indirectly impacts the outcome, and the strain typically plays a mediating role between stressors and outcome variables [65]. *Stressor* refers to an external/environmental stimulus that an individual encounters and influences individual internal states [66], which is generally perceived as troublesome, disruptive, and irksome [67,68]. *Strain* can be conceptualized as both the internal processes and consequences resulting from external stimuli, whereby *outcome* acts as the final consequence of stressor and strain [67]. Accordingly, strain arises from stressors and predisposes the subject being stimulated to adverse outcomes [69]. Both strain and outcome can be defined as individual psychological and/or behavioral responses to stressors [70,71].

The SSO paradigm has been adopted as an underlying theory to explore the social impacts of information technologies on human activities. Specifically, Shi et al. [72] find that social media-oriented overload (i.e., information overload, communication overload, and social overload) acts as a significant stressor to induce technostress, thereby further exerting a negative impact on academic achievement. By applying the SSO model, the work by Cao et al. [67] manifests that overuse of mobile social networks causes psychological strain (e.g., life invasion, techno-exhaustion, and privacy invasion), and in turn, deteriorates academic performance as an outcome. Malik et al. [73] show evidence that three types of external stressors, including intensity of mobile instant messaging (MIM) apps use, social comparison, and self-disclosure, significantly yield the strain of MIM fatigue, which further results in academic performance decrement. Likewise, excessive social networking site (SNS) use significantly decreases students' academic performance by inducing cognitive distraction [74]. Late-night use of smartphone-based SNS negatively affects academic performance through the intervening effect of worse sleep quality and cognitive function depletion [75]. While the current literature primarily adopts the SSO model as the theoretical underpinning for understanding the impact of improper (e.g., excessive or late-night) social media use, it calls for an extension of the SSO paradigm to examine the impact of overall smartphone use. Given that the smartphone acts as a hub consolidating a variety of functionalities and uses, we stress that scrutinizing the impact of general problematic smartphone use, e.g., bedtime smartphone use, may offer a more comprehensive understanding of smartphone use consequences.

Whereas past studies apply SSO to investigate the adverse outcomes of mobile application use via mediating strains in the educational context, we argue that the SSO paradigm can be applied to explain the effect mechanism of general problematic smartphone use, mental strain, and academic outcomes. As suggested in past studies, substantial environmental inputs play a crucial role in cultivating addictive behaviors [76]; these behaviors are ultimately linked to habitual control by stimuli from the environment [74,77]. With this in mind, bedtime smartphone use can be viewed as an external stimulus deriving from personal experience of using smartphones from an information systems viewpoint. It will affect personal mental states (e.g., triggering psychological fatigue and stress) [72,73], which can further result in behavioral consequences [67,69]. In addition, previous studies have highlighted that smartphone use plays an important role in the cultivation of nomophobia [36,61] and sleep deprivation [35,32]. Accordingly, the present study bases the research model on the SSO paradigm to understand the effect mechanism of bedtime smartphone use and gain insights into the mediating effects of wellbeing-related strains (i.e., nomophobia and sleep deprivation) between bedtime smartphone use and academic performance.

1.3. Hypotheses development and research model

1.3.1. SSO-related hypotheses

The current literature subscribes that cultivating nomophobia is one of the most direct consequences of smartphone use [41]. Not only can general phone use prompt nomophobia (Joel [50,78]), but also particular mobile applications use, e.g., mobile communication and social media, provokes the development of nomophobia [79,80]. There is evidence showing that prolonged bedtime smartphone use is closely linked to the proneness of smartphone addiction [4]. As an important agent of problematic smartphone use [4], the habit of smartphone use before sleep can be a significant antecedent that predicts smartphone addiction [81]. Further, Paik et al. [[4], p. 1] point out that "*prolonged bedtime smartphone use was associated with higher smartphone addiction proneness scale score*" than daytime smartphone use. In this vein, bedtime smartphone use can be a significant precondition to trigger nomophobia. Once a user develops the habit of bedtime smartphone use, there is a high risk that nomophobia will take place. In other words, the inclination toward nomophobia goes up along with growing bedtime smartphone use.

Nomophobia, as a mental strain, can further lead to psychological or behavioral consequences. Students with nomophobic symptoms are more likely to spend more time on non-academic smartphone use daily [15]. The proximity of smartphones is a tempting distraction [10], particularly during students' studying sessions, which deteriorates their academic performance [60]. Furthermore, the symptom of habitually checking smartphones due to nomophobia can cause cognitive costs [82], thereby giving rise to difficulties in studying processes and reducing academic achievements [61]. Accordingly, it is conceivable that students with nomophobia are more dependent on their smartphones, and they would check their smartphones more frequently and gradually develop into habitually compulsive behaviors, even during in-class sessions. As a result, problematic smartphone use distracts students' concentration on studying and increases the possibility of missing critical knowledge, thereby impairing academic performance.

Based on the SSO framework, we contend that nomophobia mediates the negative effect of bedtime smartphone use on academic performance. Specifically, smartphones expose students to frequent communication, social requests, and entertainment applications. However, when smartphone use exceeds students' processing capability, they quickly lose self-control and get addicted [36,83]. Such nomophobic situations can consume their attention [61], induce cognitive costs [82], and result in adverse academic outcomes [15]. The SSO model effectively integrates bedtime smartphone use, nomophobia, and academic performance, highlighting the dark side of external stimulus in influencing college students' psychological states and academic outcomes. We hypothesize that:

Hypothesis 1. Nomophobia mediates the relationship between bedtime smartphone use and academic performance.

Bedtime smartphone use is closely associated with sleep deprivation, such as sleep disturbances [37] and insomnia [49,84]. Many researchers endorse the salient effect of bedtime smartphone use on sleep problems. For example, Dissing et al. [85] suggest that smartphone use during the pre-sleep period, compared with other dimensions of smartphone use (e.g., daytime smartphone use), is the most substantial factor associated with sleep disturbance. Huang et al. [86] conclude that prolonged smartphone use, especially bedtime smartphone use, directly decreases the sleep duration of Chinese college students. Lin et al. [11] find that smartphone use before sleep significantly leads to delayed sleep onset and reduced total sleep time. Likewise, Krishnan et al. [87] reveal that bedtime smartphone use is closely related to increased sleep problems, e.g., drawn-out sleep latency, decreased sleep duration, and sleep inefficiency. Considering sleep quality is necessary for cognition processing, decent sleep quality is beneficial for academic development [88,89]. In other words, sleep deprivation is harmful to students' cognitive abilities and academic development. Previous studies subscribe to this assertion by showing that both insufficient sleep duration and low sleep quality play significant roles in deteriorating students' learning capacity and academic development [90,89].

Along this line of thought, bedtime smartphone use can impair academic performance by inducing sleep deprivation. Evidence emerges that excessive smartphone use impairs individual cognition through its adverse impacts on mood and sleep [91]. College students tend to spend much time on their phones before sleep and have prolonged bedtime [86]. Under the SSO paradigm, such environmental stimulus of smartphone use before sleep (stressor) inevitably compromises sleep and causes sleep deprivation (strain), which in turn weakens students' learning ability and will be reflected in decreased academic performance (outcome). Therefore, we hypothesize that:

Hypothesis 2. Sleep deprivation mediates the relationship between bedtime smartphone use and academic performance.

1.3.2. Moderating effect

The pivotal role of physical activity has been highly acknowledged in improving mental health and physical wellbeing [92,93]. Following the World Health Organization [94], physical activity is conceptualized as "*several entities, including light individual exercise, collective training, individual or team sports participation*" [95]. As numerous researchers assert that physical activity is an excellent practice for consolidating mental and physical resources [96,97], individuals who engage in physical activity more actively tend to have more available resources [98]. In other words, with higher engagement in physical activity, people would be able to gain more psychological resources to maintain dynamic and mental optimism and deal with external interferences [98,99]. More specifically, problematic smartphone use resembles a behavioral activity that consumes physiological and psychological resources [100]. Physical activity engagement, on the one hand, offers individuals an opportunity to divert themselves away from negative stimuli, e.g., problematic smartphone use, and turn to positive stimuli; on the other hand, it helps individuals to accumulate their physiological and psychological resources by building up physical strength [101] and triggering positive emotions [102]. In response to the resource consumption caused by problematic smartphone use, participating in physical activity allows smartphone users to not only bolster resources of availability but also harmonize resource reserve. As such, those negative consequences due to smartphone use, e.g., anxiety and fear, could be mitigated and hardly trigger nomophobic symptoms among individuals with resilience to mental discomfort induced by using smartphones. In this sense, physical activity engagement can be viewed as a favorable external stimulus that can reap benefits or alleviate adverse outcomes from outside stressors [103]. That is, the adverse consequences, including nomophobia and sleep deprivation caused by bedtime smartphone use, can be less salient. Oppositely, with less or without engaging in physical activity, it would be harder for users to remit the adverse impacts of smartphone use on individual psychological states [98]. We argue that engaging in physical activity enables users to mitigate the negative outcomes resulting from bedtime smartphone use. Therefore, we hypothesize the following:

Hypothesis 3. Physical activity engagement weakens the effect of bedtime smartphone use on nomophobia.

Hypothesis 4. Physical activity engagement weakens the effect of bedtime smartphone use on sleep deprivation.

Fig. 1 illustrates the research model based on the SSO framework. Note that this model also concatenates nomophobia and sleep deprivation because past studies explicate that nomophobia (or mobile phone addiction) places a significant burden on decreased sleep duration and sleep quality [104,105]. The proposed research model also considers several control variables. For instance, in line with past studies, daily time spent on the computer [106], smartphone use for learning purposes [15], age [107], and gender [108] of respondents might affect academic performance, and hence are considered as control variables in the present study. Additionally, the grade is also taken into account as a control variable because academic performance may be affected by the year of study, considering such factors as enrollment pressure, course burden, pressure from job-hunting, etc. [44].

2. Method

2.1. Research context and sample

The two-year longitudinal dataset was collected from undergraduates of a top-ranking public university in Central China by distributing a large-scale questionnaire survey twice to the same student group. The survey, aiming to investigate the effects of smartphone use on college students' wellbeing and academic performance, was designed to obtain information concerning students' smartphone use habits, health-related psychology and physiology, and academic records. Considering that the questionnaire was conducted in the local language (Chinese), back-translation was performed for the original English-based measurement items to guarantee translation consistency between different-language versions as suggested by prior work (e.g., [109]). Further, a pilot test with 30 students was conducted before the formal survey to improve the readability and face validity of the measurements. Concretely, an open-ended question was attached at the end of the pilot questionnaire to collect respondents' feedback on the wording and content. As such, we were able to collect questions reported by the respondents (e.g., expressive ambiguity, inappropriate terminology), which were then addressed to produce the final version.

Supported by the university administration, the questionnaires were released via the surveyed universitys' official website. Once students logged into the universitys' web portal using their username and password, the notification for filling out the questionnaire would show. Before filling out the survey questionnaire, consent to participate in the surveys was first sought from respondents, and those who completed the surveys gained access to the data analysis report as compensation. The surveys were advertised, respectively, from December 2017 to January 2018 (Time 1) and from December 2018 to January 2019 (Time 2). The student number of each respondent was required in the surveys for the sole purpose of identifying the same respondent. The first survey had 10,352 students responded to the inquiries. Those incomplete responses with missing values or unmindful responses with almost the same scale chosen for each question were removed. Consequently, we retained 9256 valid records for the first survey. These 9256 students received the notification for participating in the second survey, and 6719 responses were received. As a result, a final sample size of 6093 valid responses remains for preliminary analysis after removing invalid records, just as in the case of the first survey.

The demographic information of the sample cases is presented in Table 1. There are 3501 males (57.5% of the sample) and 2592 females (42.5%). Most participants report their daily smartphone use for more than 2 hours (Time 1: 4355, 71.5%; Time 2: 4517, 74.1%). Notably, delaying bedtime is quite common among the participants: over 40% of respondents (Time 1: 2563, 42.1%; Time 2: 2467, 40.5%) reported a frequency of delaying bedtime 6–7 times per week, indicating that

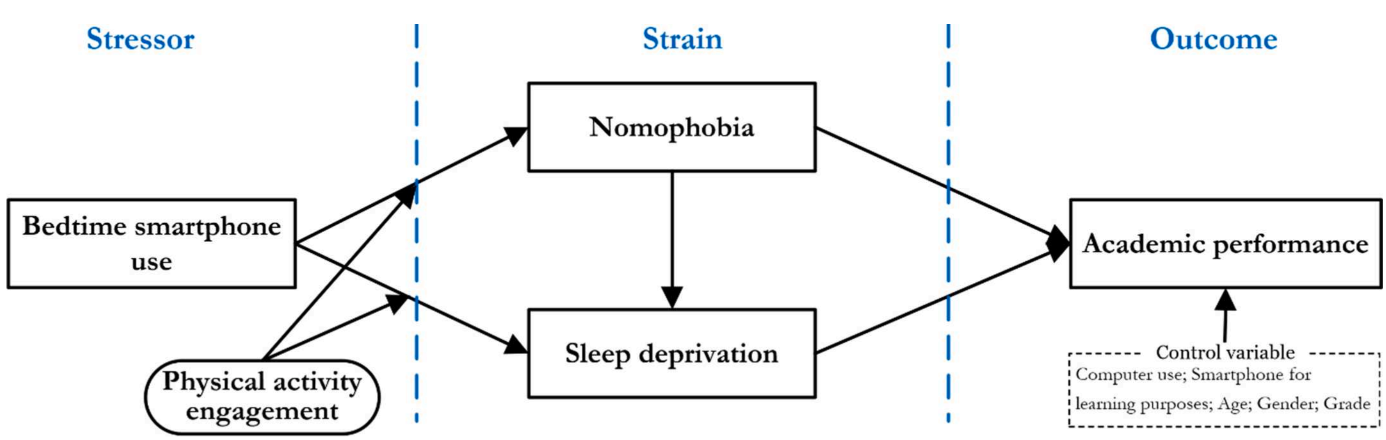

Fig. 1. Research model.

Table 1
Demographic information of participants ($N = 6093$).

Variables	Sample composition Categories	Time 1		Time 2	
Age	Between 16 and 31 (based on the first survey); Mean = 20.03; Std. Dev. = 1.20				
Gender	Male	3501 (57.5%)			
	Female	2592 (42.5%)			
Grade	Enrolled in 2014	82 (1.3%)			
	Enrolled in 2015	1741 (28.6%)			
	Enrolled in 2016	1683 (27.6%)			
	Enrolled in 2017	2587 (42.5%)			
		Frequency	Percentage (%)	Frequency	Percentage (%)
Daily smartphone use in hours	Less than 0.5 h	306	5.0	148	2.4
	0.5–1 h	359	5.9	327	5.4
	1–2 h	1073	17.6	1101	18.1
	2–4 h	1832	30.1	2045	33.6
	4–6 h	1513	24.8	1604	26.3
	7–8 h	410	6.7	452	7.4
	More than 8 h	600	9.8	416	6.8
Daily computer use in hours	Less than 0.5 h	891	14.6	972	16.0
	0.5–1 h	1173	19.3	1451	23.8
	1–2 h	1840	30.2	1618	26.6
	2–4 h	1337	21.9	1218	20.0
	4–6 h	552	9.1	533	8.7
	7–8 h	101	1.7	164	2.7
	More than 8 h	199	3.3	137	2.2
Bedtime smartphone use for non-academic purposes	1 (Never)	426	7.0	222	3.6
	2	331	5.4	379	6.2
	3	480	7.9	451	7.4
	4	752	12.3	684	11.2
	5	680	11.2	790	13.0
	6	793	13.0	845	13.9
	7 (Very often)	2631	43.2	2722	44.7
Smartphone use for learning purposes	1 (Never)	311	5.1	178	2.9
	2	331	5.4	946	15.5
	3	1632	26.8	1331	21.8
	4	2734	44.8	2385	39.1
	5 (Very often)	1085	17.8	1253	20.6
Frequency of delaying bedtime[1]	Never	364	6.0	210	3.4
	1–2 times per month	358	5.9	378	6.2
	1–2 times per week	1398	22.9	1383	22.7
	3–5 times per week	1410	23.1	1655	27.2
	6–7 times per week	2563	42.1	2467	40.5

[1] Delaying bedtime here refers to going to bed after 23:00, given the fact that sharp 23:00 is the regulated lights-out time of student dormitory at most Chinese Universities, including the surveyed university.

staying up and delaying bedtime is typical among Chinese college students.

2.2. Measures

Existing validated scales are adapted to measure the constructs in this study (see Appendix B). Bedtime smartphone use is measured via the frequency of non-academic smartphone use before sleep via a seven-Likert scale from 1 (never) to 7 (very often) [110,111], while sleep deprivation is measured via two dimensions — the frequencies of insomnia and delaying bedtime [112,113]. Nomophobia is measured via the existing scale from Yildirim and Correia [114]. The measurement items of physical activity engagement are adopted from the scale developed by Booth et al. [115]. In line with prior studies [62,116], academic performance is measured by the ranking of academic records self-reported by students. Notably, the university information system allows students to log in via their username and password anytime and check their transcripts, including academic scores and rankings in their classes.

2.3. Data analysis

The current study employs change values to validify our hypotheses. For example, we calculate the first difference (labeled Δ) of bedtime smartphone use as the value of Time 2 minus that of Time 1. The change values are preferred because the first differencing removes the time-invariant individual differences (unobserved heterogeneity) between subjects, thereby promoting the strength of the statistical test [117]. In light of this advantage, change values have been extensively used in existing psychology-related research (see, e.g., [118,119]).

The proposed hypotheses were tested using the structural equation modeling (SEM) technique. More specifically, the partial least squares (PLS)-based SEM has been employed because, according to Gefen et al. [120], it can not only readily handle both reflective and formative constructs, but also simultaneously tackle multiple regressands (namely, dependent variables), mediators, and moderators, just as is the case in the current study. In line with Hulland [121], the measurement model has been first verified by examining the reliability and validity of latent variables. Then the structural model has been assessed with path coefficients and their significance levels.

3. Results

3.1. Reliability and validity

The verification of the measurement model involves estimating the measurement items' reliability and validity in the survey instrument. Because reflective items are capturing the construct's effects under scrutiny [122], we evaluate reliability with three indicators, including standard estimates of Cronbachs' alpha, composite reliability (CR), and average variance extracted (AVE) [123]. As illustrated in Table 2, the values of Cronbach's alpha, CR, and AVEs for either Δnomophobia or

Table 2
Reliability and validity.

Reliability and convergent validity for reflective variables				
Latent variable	**Minimalfactor-loading**	**Cronbach'salpha**	**CR**	**AVE**
ΔNomophobia	0.880	0.873	0.922	0.797
ΔPhysical activity engagement	0.860	0.715	0.875	0.777
Weights and t-statistics for the formative variable				
Construct	**Measurement**	**Weights**	***t*-statistics**	***p*-value**
ΔSleep deprivation	ΔDelaying bedtime	0.733***	29.849	*P* < 0.001
	Δ Insomnia	0.521***	17.830	*P* < 0.001

Notes: Δ means the value difference between Time 1 and Time 2.
*** means the significant level at 0.001.

Δphysical activity engagement are above-suggested thresholds of 0.7, 0.7, and 0.5, respectively [124,125]. Further, the convergent validity and discriminant validity of latent variables are assessed. To determine convergent validity, each constructs' measurement items need to load greatly among these items themselves. As can be seen from Table 2, all the factor loadings of our latent constructs exceed prescribed thresholds of 0.7 [126], confirming sufficient convergent validity. For holding adequate discriminant validity, the AVEs' square root for each construct should be greater than its correlations with any other construct [123]. Under the inter-construct correlation matrix shown in Table 3, all the unique bivariate correlations among all the latent constructs in our measurement model are much lower than the square root of intra-construct AVE for each, suggesting sufficient discriminant validity. This indicates that respondents can differentiate among our research model constructs when responding to the questionnaire. Additionally, the factor loading of every item above 0.5 on its associate construct further confirms discriminant validity and convergent validity (see Table 2).

ΔSleep deprivation is a formative construct measured by Δdelaying bedtime and Δinsomnia. Following Petter et al. [127], we assess the formative items by examining their weights and significant levels. As presented in Table 2, both Δdelaying bedtime and Δinsomnia are highly significant at the 99.9% confidence level, suggesting sufficient measurement reliability [128]. In addition, multicollinearity among all variables is checked through the Variance Inflation Factors (VIFs); all the VIFs are below the suggested threshold of 0.5 [129], indicating multicollinearity is not a concern in this study.

3.2. Hypotheses testing

The test of the structural model involves estimates of both the path coefficients and R^2 values. The path coefficients present relationship strengths between the independent and dependent variables; R^2 values represent the proportion of variance explained by the independent variables on its dependent variable. The path coefficients (including correlations and statistical significance), along with R^2 values, suggest how well the data substantiates the hypothesized model.

Fig. 2 and Table 4 depict the analysis results of the structural model. All four hypotheses are verified by empirical evidence. To begin with, increasing bedtime smartphone use significantly contributes to the development of nomophobia ($\beta = 0.273$, $p < 0.001$), which further causes more sleep deprivation ($\beta = 0.149$, $p < 0.001$) and impaired academic performance ($\beta = -0.120$, $p < 0.001$). Second, time increase in bedtime smartphone use is positively related to sleep deprivation ($\beta = 0.270$, $p < 0.001$), which further exerts a negative effect on academic performance ($\beta = -0.153$, $p < 0.001$). Moreover, physical activity engagement weakly moderates the positive effects of bedtime smartphone use on both nomophobia ($\beta = -0.053$, $p < 0.001$) and sleep deprivation ($\beta = -0.046$, $p < 0.001$), confirming *Hypothesis 3* and *Hypothesis 4*. Taken together, our model explains 10.7%, 25.8%, and 13.3% of the variance in nomophobia, sleep deprivation, and academic performance, respectively. They are all above the suggested threshold of 10%, indicating that the research model is acceptable [130].

The two-step approach prescribed by Nitzl et al. [131] is applied to verify the mediating effects of nomophobia and sleep deprivation. We first need to verify the significance of the particular indirect relationship through the mediators. After confirming a significant result in the first step, we can then test the direct relationship between the independent and dependent variables. If the relationship between the independent variable (bedtime smartphone use) and the dependent variable (academic performance) is insignificant, we can conclude a full mediation; otherwise, it is a partial mediation. Table 5 summarizes the mediation analysis results. The particular indirect effects for both mediators, i.e., nomophobia ($\beta = -0.028$, $p < 0.001$) and sleep deprivation ($\beta = -0.041$, $p < 0.001$) are significant. Further, bedtime smartphone use has a significantly negative direct influence on academic performance ($\beta = -0.140$, $p < 0.001$). As a result, sleep deprivation and nomophobia partially rather than fully mediate the negative effect of bedtime smartphone use on academic performance, supporting *Hypothesis 1* and *Hypothesis 2*. The partial mediation indicates that bedtime smartphone use can not only exert a direct impact on academic performance but also, simultaneously, indirectly affect academic performance through the mediating effects of nomophobia and sleep deprivation. Moreover, the direct impact of bedtime smartphone use on academic performance is more potent than either indirect effect via the mediator of nomophobia or sleep deprivation.

Following Mackinnon and Dwyer [132], the ratio of the specific indirect effects to the total effect is utilized as an agent of the effect size for mediation. Even though a few studies, e.g., Preacher and Kelley [133], criticized this measure, more scholars (e.g., [134,135]) defend this agent and assert that "*if accompanied by the total effect, the ratio of the indirect effect to the total effect is meaningful where the indirect effect and the direct effect have the same sign in a basic mediation model*" ([134], p. 61). As shown in Table 5, we can conclude that the indirect effect size of mediation via sleep deprivation exceeds the effect size of mediation via nomophobia.

The results summarized in Table 4 show that the effects of age and grade on academic performance are insignificant. Gender is a significant factor that affects academic performance, and female academic records are significantly higher than males. Interestingly, the increasing time spent on computer use and smartphone use for learning purposes contribute to decreased academic performance. This is opposite to many studies showing that mobile use for learning can benefit students by improving academic achievements (e.g., [14,136]). A possible explanation for this lies in that mobile information technologies, like smartphones, may have immediate improvement on learning performance. However, the decreased overall performance takes time to reflect. This is consistent with the work of Tossell et al. [58]: albeit students considered smartphone use for tertiary education as beneficial before use, they later deemed it as impaired to their educational goals because of distraction

Table 3
Discriminant validity.

Construct	ΔACP	ΔNOM	ΔPHA	ΔSDE	ΔBSU
ΔAcademic performance (ΔACP)	**1.000**				
ΔNomophobia (ΔNOM)	−0.221	**0.893**			
ΔPhysical activity engagement (ΔPHA)	0.179	−0.155	**0.882**		
ΔSleep deprivation (ΔSDE)	−0.260	0.284	−0.363	–	
ΔBedtime smartphone use (ΔBSU)	−0.290	0.300	−0.142	0.367	**1.000**

Notes: The diagonal row with boldfaced numbers reports AVEs' square roots. As a formative variable, ΔSDE has no AVE value.

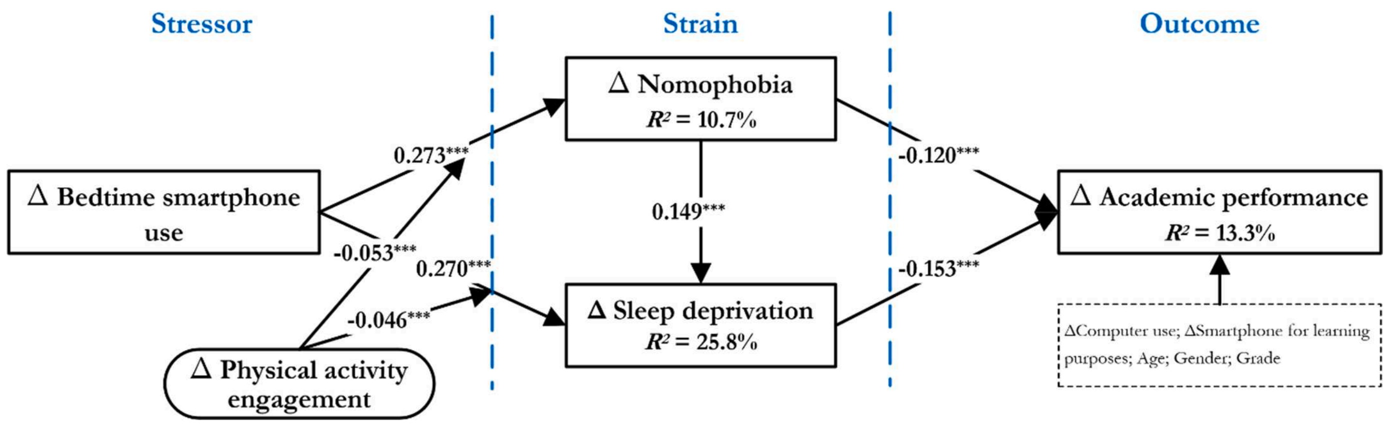

Fig. 2. Model test.
(Notes: Δ means value difference between Time 1 and Time 2; $^{n.s.}$ means correlation is not insignificant at 0.05; *** means correlation is significant at 0.001).

Table 4
Results of hypotheses test.

Relationship	Direct effect	CI [lower, upper]	Indirect effect	Total effect
SSO related effects				
ΔBedtime smartphone use → ΔNomophobia	0.273***	[0.245, 0.299]		0.273***
ΔBedtime smartphone use → ΔSleep deprivation	0.270***	[0.237, 0.303]	0.041***	0.311***
ΔNomophobia → ΔSleep deprivation	0.149***	[0.122, 0.177]		0.149***
ΔNomophobia → ΔAcademic performance	−0.120***	[−0.148, −0.092]	−0.023***	−0.143***
ΔSleep deprivation → ΔAcademic performance	−0.153***	[−0.182, −0.125]		−0.153***
Moderating effects				
ΔBedtime smartphone use * ΔPhysical activity engagement → ΔNomophobia	−0.053***	[−0.078, −0.027]		
ΔBedtime smartphone use * ΔPhysical activity engagement → ΔSleep deprivation	−0.046***	[−0.071, −0.022]		
Control effects				
ΔPhysical activity engagement → ΔNomophobia	−0.105***	[−0.134, −0.077]		
ΔPhysical activity engagement → ΔSleep deprivation	−0.292***	[−0.323, −0.260]		
ΔComputer use → ΔAcademic performance	−0.119***	[−0.146, −0.091]		
ΔSmartphone use for learning purposes→ ΔAcademic performance	−0.154***	[0.182, .0127]		
Gender → ΔAcademic performance	0.044**	[0.021, 0.067]		
Age → ΔAcademic performance	$-0.004^{n.s.}$			
Grade → ΔAcademic performance	$0.013^{n.s.}$			

Notes: Δ means the value difference between Time 1 and Time 2, Δ = Time 2 Time1. CI means confidence interval. $^{n.s.}$ means correlation is not insignificant at 0.05; ** means correlation is significant at 0.01; *** means correlation is significant at 0.001.

and altered habitual behaviors due to smartphone use.

4. Discussion

Despite numerous studies discussing the direct adverse impacts of smartphones, limited studies consolidate improper smartphone-using habits, individual wellbeing, and academic achievement into an integrated model, particularly based on longitudinal analysis. By employing the SSO paradigm, this study illustrates the underlying mechanism of bedtime smartphone use on college students' academic performance, and how to alleviate the adverse effect of bedtime smartphone use on individual wellbeing.

This study verifies the applicability of the SSO paradigm on the indirect effect of bedtime smartphone use on academic performance by demonstrating that both nomophobia and sleep deprivation act as partial in the relationship between bedtime smartphone use and students' academic performance. Specifically, bedtime smartphone use, as a significant index of problematic smartphone use [11], contributes to nomophobia development, thereby resulting in more sleep deprivation and worse academic performance. This evidence resonates with previous findings: nomophobia induces individual anxiety and fatigue, hence reducing self-control [83,137]. The depletion of self-control causes decreased cognitive abilities and academic performance [138,139]. We also find that bedtime smartphone use, as an external stimulus concerning personal experience, directly triggers students' sleep deprivation by causing delaying bedtime habits and insomnia. Deprived sleep subsequently leads to decreased academic performance. In other words, the development of unhealthy behavioral habits with regard to sleep disturbance can easily reflect on impaired academic performance. This finding echoes past studies that improperly using smartphones can lead to prolonged bedtime and sleep disturbance [140,37]; sleep deprivation is significantly associated with academic performance decrement [88, 89].

In addition to the mediating effects, this study empirically confirms that promoting students' participation in physical activity can work well in mitigating the negative consequences of problematic smartphone use, including sleep disorders and psychological addiction. This finding is consistent with the previous study that engaging in physical activity contributes to decreasing university students' mobile phone dependence and increasing their self-control [141]. The situation can be explained as follows: physical activity engagement can be regarded as a favorable external stimulus to consolidate mental or physical resources [96,97]. Through actively engaging in physical activity, individuals reap and reserve more mental capital to maintain an optimal state of mind and withstand external distractions in light of the view of Halbesleben et al. [98]. According to Zhang et al. [100], problematic smartphone use can significantly decrease psychological capital, which in turn leads to

Table 5
Mediation analysis results.

Direct effect without mediators ΔBSU → ΔACP	Mediation analysis Mediator	ΔBSU → ΔACP	ΔBSU → Mediator → ΔACP	Mediation	Effect size
−0.211***	ΔNomophobia	−0.140***	−0.028***	Partial	13.4%
	ΔSleep deprivation	−0.140***	−0.041***	Partial	29.3%

Notes: BSU means bedtime smartphone use; ACP means academic performance. *** means the significant level at 0.001.

decreased academic performance, i.e., learning burnout. By participating in physical activities, people can generate energy by distracting themselves from problematic smartphone use and shift to pleasant stimuli of consolidating and restoring resources by strengthening physical capabilities and engendering psychological optimism. Therefore, engaging in physical activity enables smartphone users to mitigate the adverse consequence of problematic smartphone use on psychological wellbeing. In this vein, increasing physical activity engagement allows college students to bounce from negative psychological experiences deriving from smartphone use [99,103]. On the contrary, decreasing such an advantageous external stimulus prevents individuals' psychological resources acquisition, thus lacking the capability to arm themselves for subsequent adverse outcomes [99,103]. As a result, the adverse health-related consequences due to bedtime smartphone use can be mitigated with higher engagement in physical activity.

5. Conclusion

5.1. Implications

This study offers several theoretical implications. First, by answering the first research question, the current study presents a more comprehensive and robust understanding of the dark side of smartphone use by consolidating bedtime smartphone use, wellbeing-related strains, and academic outcomes. We have quantified the level of smartphone use and impacted variables for two continuous time periods and utilized the first difference of two-year longitudinal data to test the proposed hypotheses. The first-difference estimator can eliminate, to a large degree, the interference of unobserved individual differences and hence yield more accurate results. Despite a relative sparsity in SEM of using first-difference estimators from a longitudinal dataset to deal with this question in the existing literature, its advantages have been understood recently (see, e.g., [142,143]). In particular, when exploring the negative effect of smartphone use on academic performance, Bjerre-Nielsen et al. [143] find that the effect magnitude is substantially lower in a fixed-effects model (identical to the first-difference estimator based on the within transformation (c.f., [144])), where the longitudinal data is leveraged to control for all stable characteristics concerning student background, including those beyond observation by researchers. Accordingly, it is concluded that "*the size of the effect of smartphone usage on academic performance has been overestimated in studies that controlled for only observed student characteristics*" ([143], p. 1351). Using the first-difference estimator based on a longitudinal dataset yields the major virtue of controlling for individual traits out of observation [142,145], thereby eliminating the individual effects [144], which can easily emerge in cross-sectional studies due to without controlling for unobserved fixed traits [143]. This study enriches the state-of-the-art in this realm by answering the call for requiring such research design in the examination of negative effects of smartphone use on learning [60].

Second, this study innovatively employs the SSO paradigm to illustrate the indirect impacts of mobile technology on college students' academic outcomes, especially with regard to deteriorated individual well-being. As indicated in the literature review by Chen and Yan [60], the question of how smartphone use affects students learning deserves sophisticated answers instead of straightforward ones. The present study shows evidence regarding the usefulness of the SSO theory in reasonably explaining the underlying mechanism of problematic smartphone use on academic performance, especially in light of inducing wellbeing-related problems. While the previous studies typically concentrate on investigating the direct effects of general mobile phone use (e.g., [54,55]) or specific mobile applications [146,147] on academic performance or individual fitness, our findings underline the mediating effect of wellbeing-related strains. On the one hand, this study corroborates previous work that identifies smartphone misuse before sleep as an important stressor [,6]. On the other hand, this study enriches the existing literature by echoing the call for more research into the indirect effect of smartphone use on individual performance through health-related indicators [10].

Another contribution of this study is to answer the call for research concerning prevention and intervention strategies that would help students mitigate adverse outcomes of using their smartphones (see, e.g., [148,149]). By addressing the second research question, this study offers and verifies a possible treatment, i.e., engaging in physical activity, for alleviating the adverse impact of bedtime smartphone use on individual wellbeing. Albeit existing studies proposed several solutions to tackle the dark side of mobile information technology use, such as restricting or even forbidding access to mobile devices. However, such solutions inevitably leave users in a dilemma because simply restricting smartphone use is impracticable considering its indispensability in daily life and work scenarios. Notably, this study offers robust empirical evidence in favor that promoting students' engagement in physical activity weakens the adverse consequences of bedtime smartphone use. Promoting participation in physical activity, as a positive external stimulus, can not only directly bring beneficial outcomes, e.g., direct improvement of psychological wellbeing [150] and prevention of chronic diseases [151], but also alleviate adverse consequences caused by outside stressors, e.g., mood instability [152] and depression [153].

A number of practical suggestions can be drawn from this study. First, bedtime smartphone use is closely linked to nomophobia and sleep deprivation. This study proclaims that increasing time on bedtime smartphone use adds to the possibility of smartphone addiction and sleep deprivation, which plays a significant role for educational policymakers to further monitor the mental indications of smartphone usage and its consequence on academic achievement. Accordingly, bedtime smartphone usage would be a visible sign to diagnose nomophobic symptoms, and thus altering college students' sleep habits would significantly mitigate the subsequent adverse impacts of bedtime smartphone use on individual wellbeing and academic performance. Second, taking the mediating effect of nomophobia and sleep deprivation into account, regulating sleep habits and treating nomophobic behaviors may cut off the partial affecting channel of smartphone use on academic performance. Third, the findings of our study on nomophobia and sleep deprivation will provide sufficient awareness regarding the harms caused by smartphone use to the university student group to tertiary education policymakers towards advancing educational policies, as well as feasible solutions at different phases of prevention and intervention. The present study offers educational policymakers and educators helpful knowledge about the effect mechanism on how daily smartphone use harms college students' academic performance through mental wellbeing. More importantly, this study provides educational policymakers with feasible measures to treat students' overdependence on smartphones and its adverse consequence on sleep. Specifically, while it is almost impossible to ban smartphone use in universities, educational institutions should make practical measures to promote students' engagement in various recreational and sports activities, taking physical activity as an example, to alleviate the adverse impacts of smartphone usage. On the one hand, taking part in beneficial activities help to decrease the time that would otherwise be spent on smartphones; on the other hand, engaging in beneficial activities can be viewed as an excellent external stimulus to integrate psychological or physical resources [96,97].

5.2. Limitations and future research

There are a few research limitations that warrant future improvement. First, since all the respondents in this study are from China, we encourage a prospective study extending to multiple cultural backgrounds, as well as a comparison study among various cultural groups. Second, the dataset of this study came from self-reported surveys. Considering that self-reported data is a norm instead of an exception [60], we recommend using smartphone-activity tracking apps or smartphone sensors for more accurate data collection in future studies, consistent with the suggestion from Bjerre-Nielsen et al. [143] and Parry et al. [154]. Furthermore, it is also suggested to make a meta-analysis of the literature regarding the effect of mobile devices on academic outcomes and to have standardized effect measures for future work.

Third, this study investigates only bedtime smartphone use and two main wellbeing-related variables, i.e., nomophobia and sleep deprivation, in the SSO structural equation model. A natural extension would be to apply the SSO framework to other smartphone use scenarios, such as smartphone use after wake-up or during in-class sessions, and many different psychological strains, such as stress and depression. Nevertheless, although the SSO framework proves useful in explaining the effect mechanism of problematic smartphone use on academic performance via mental-orientated strains, its generalization might be limited when considering other smartphone use types, learning tasks, or subject areas. Since the present study concentrates on one crucial measure of problematic smartphone use, i.e., bedtime smartphone use, another fascinating avenue for future research is to take into account the content viewed during bedtime smartphone use and investigate whether the content dimensions of viewing during bedtime smartphone use could moderate the adverse impacts of bedtime smartphone use. Furthermore, in addition to problematic smartphone use, there are other factors that may affect students' sleep quality and academic performance, such as students' psychological and physical indications, which deserve more attention in future research. As indicated by Chen and Yan [60], it is reasonable that multitasking with smartphones does distract students' learning through different mechanisms. Future studies are encouraged to base research frameworks on theories drawn from other fields to disentangle the sophisticated process of how smartphone use affects academic performance via different pathways and mechanisms. Therefore, more reliable strategies would be expected to prevent and intervene in those adverse consequences due to smartphone use.

Fourth, although using the first difference in this longitudinal study has several advantages, as mentioned above in comparison with cross-sectional studies, its usefulness can be largely compromised in the case of reversed causality. Therefore, a longitudinal study spanning more periods is promising to allow more possibilities of causal inference (e.g., difference-in-differences, propensity score matching) and improve the generalization of our findings.

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Appendix A. Summary of critical empirical studies between 2016 and 2021 on the dark side of smartphone use regarding personal wellbeing and academic performance

Source	Sampling	Antecedents	Consequences Psychological wellbeing	Physiological wellbeing	Academic performance
Lin et al. (2021)[15]	Online survey ($N = 9256$); college students in China	Mobile applications use	Nomophobia	Insomnia; Late sleep	Academic ranking
Troll et al. [33]	Surveys (N1 = 446, N2 = 431, N3 = 106); university students from Germany, Switzerland, and Austria	Smartphone use	Trait self-control; Smartphone procrastination		GPA
Abbasi et al. [155]	Survey ($N = 250$); Undergraduates at Universities in Malaysia	Study related/ entertainment related/ SNS related/ game related smartphone use	Smartphone addiction		Cumulative GPA
Fu et al. [36]	Online survey ($N = 6855$); college students in China	Smartphone overuse	Nomophobia	Insomnia; Poor eyesight	Class ranking according to GPAs
Zhang and Wu [32]	Online survey ($N = 427$); university students in China	Smartphone addiction	Self-regulation; Bedtime procrastination	Long sleep latency; Short sleep duration; Poor sleep quality	
Volungis et al. [156]	Survey ($N = 150$); undergraduate college students in the Northeast, U.S.	Smartphone addiction	Social-emotional distress		
Baert et al. [157]	Survey ($N = 696$); first-year university students in Belgium	Smartphone use			Average exam score
Lim et al. [47]	Survey ($N = 140$); patients diagnosed with major depressive disorder in Malaysia	Smartphone use	Smartphone addiction; Depression		
Kim et al. [158]	Web-based nationally representative survey ($N = 62,276$), adolescent in Korean	Smartphone use	Suicide attempts		Academic impairment
Horwood and Anglim [12]	Survey ($N = 539$); an undergraduate psychology unit of an Australian University	Smartphone use	Subjective wellbeing; Psychological wellbeing		
Tan and Arshat [45]	Survey ($N = 400$); undergraduate student in Malaysia	Smartphone Addiction	Stress		
Durak [40]	Survey ($N = 612$); secondary and high school students in Turkey	Smartphone use	Smartphone addiction; Nomophobia		

(continued on next page)

(*continued*)

Source	Sampling	Antecedents	Consequences Psychological wellbeing	Physiological wellbeing	Academic performance
Grant et al. [159]	Survey ($N = 3425$); college and graduate students at Midwestern University, U.S.	Problematic smartphone use	Alcohol use disorders; Attention-deficit hyperactivity disorder; Anxiety; Depression; Post-traumatic stress disorder		Scholastic performance
Winskel et al. [160]	Onsite and online survey ($N = 389$); college students in South Korea and Australia	Smartphone use	Smartphone addiction		Academic performance costs
Demir and Sümer [161]	Survey ($N = 123$); patients who were diagnosed with migraine	Smartphone use		Headache duration and frequency; Poor sleep quality; Daytime sleepiness	
Alhassan et al. [46]	Online survey ($N = 935$); Saudi Arabian population	Smartphone addiction	Depression		
Rod et al. [35]	Survey ($N = 815$); college students in Denmark	Overnight smartphone use		Shorter sleep duration; Higher body mass index	
Elhai et al. [162]	Web survey ($N = 299$); colleges students in U.S.	Smartphone use	Smartphone addiction		
Chung et al. [163]	Survey ($N = 1745$); Korean adolescents	Smartphone use		Sleep quality; Self-perceived health level	School performance
Kim et al. [164]	Web-based survey ($N = 4854$); Korean adults	Smartphone addiction	Depression; Anxiety		
Nayak [63]	Survey ($N = 429$); higher education students in India	Smartphone use	Lack of control; Neglect work; Feeling anxious		Academic performance
Mendoza et al. [61]	Experiments (N1 = 140; N2 = 152); undergraduate in Southeastern Arkansas and west Arkansas, respectively	Cell phone use	Nomophobia; Distraction		Class attention and learning
Fırat et al. [165]	Survey ($N = 150$); adolescents in Ankara	Problematic smartphone use	Depression; Anxiety		
Gezgin et al. [166]	Survey ($N = 818$); pre-service teachers in Turkey	Smartphone use	Nomophobia		
Chen et al. [167]	Survey ($N = 1441$); medical college students in China	Smartphone addiction	Anxiety; Depression	Sleep quality	
Tao et al. [168]	Survey ($N = 4747$); college students.	Problematic mobile phone use	Anxiety; Depression		
Kim et al. [169]	Online survey ($N = 608$); college students in South Korean	Smartphone overuse	Stress; Depression/anxiety symptom/suicidal ideation	Usual health status	
Hawi and Samaha [43]	Online survey ($N = 381$); university students in Lebanon	Smartphone addiction	Anxiety; Problematic family relations		
Lin and Chiang [57]	Web survey ($N = 438$); undergraduate in Singapore	Smartphone activities	Smartphone dependency symptom; Improper phone use; Sociability		GPA
Mohammadbeigi et al. [170]	Survey ($N = 380$); undergraduate students in Iran	Cell-Phone Over-Use		Sleep quality	
Gokçearslan et al. [50]	Online survey via emails ($N = 895$); college students in Ankara	Smartphone use	Smartphone addiction		
Barkley et al. [34]	Survey ($N = 236$); college students in U.S.	Cell phone use		Sedentary activity	
Darcin et al. [42]	Survey ($N = 367$); university students in Turkey	Smartphone use	Smartphone addiction; Social anxiety; Loneliness		
Hawi and Samaha [62]	Survey ($N = 249$); college students in Lebanon	Smartphone use	Smartphone addiction		GPA
Chen et al. [41]	Survey ($N = 1087$); college students in China	Mobile phone addiction	Interpersonal problem; Depression; Social anxiety		
Samaha and Hawi [105]	Survey ($N = 249$); college students in Lebanon	Smartphone addiction	Perceived stress; Satisfaction with life		GPA

Appendix B. Measurement items

Instrument and measurement item	Source/Scale	Source
Bedtime smartphone use		Reich and Subrahmanyam [110]; Rosen et al. [111]
Frequency of non-academic related smartphone use before sleep?	Never 1 2 3 4 5 6 7 Very often	
Sleep deprivation		Edinger et al. [112]; Liu and Liu [113]
"Do you have any insomnia problems?"	Never 1 2 3 4 5 6 7 Very often	
"How often do you stay up at night (that is, going to bed after 23:00)."	A. Never B. 1–2 times a month C. 1–2 times a week D. 3–5 times a week E. 6–7 times a week	
Nomophobia		Yildirim and Correia [114]
"If my mobile phone were low on power or could not connect to the network, I would feel restless, moody, depressed, or irritable."	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
"If I did not have a mobile phone with me, I would feel anxious because my friends would find it hard to get in touch with me."	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
"If I forgot to take my mobile phone with me, I would feel unsettled."	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
Physical activity engagement		Booth et al. [115]
Frequency of engaging in exercising	A. Never B. Less than once per week C. 1–2 times a week D. 3–5 times a week E. 6–7 times a week	
Time spent on exercise per week	A. Less than 0.5 h B. 0.5–1 h C. 1–2 h D. 3–4 h E. 5–6 h F. 7–8 h G. More than 8 h	
Academic performance		Hawi and Samaha [62]; Wong [116]
"What is the ranking of your academic records?"	A. Top 5% B. Top 10% C. Top 25% D. Top 50% E. After 50%	

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