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2021

Fu, S., Chen, X. & Zheng, H. (2021). Exploring an adverse impact of smartphone overuse on academic performance via health issues : a stimulus-organism-response perspective. *Behaviour & Information Technology*, 40(7), 663-675.
<https://dx.doi.org/10.1080/0144929X.2020.1716848>

<https://hdl.handle.net/10356/151768>

<https://doi.org/10.1080/0144929X.2020.1716848>

This is an Accepted Manuscript of an article published by Taylor & Francis in *Behaviour & Information Technology* on 21 Jan 2020, available online:
<http://www.tandfonline.com/10.1080/0144929X.2020.1716848>

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**Exploring an adverse impact of smartphone overuse on academic performance via
health issues: A stimulus-organism-response perspective**

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Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work is jointly supported by the China Scholarship Council (CSC No.201806270048) and the National Natural Science Foundation of China (Grant No. 71974149).

Acknowledgments

The paper has benefited from the oral presentation at the 2019 Zhejiang University-Nanyang Technological University Joint Ph.D. Symposium. The authors acknowledge the valuable feedback of Dr. Siyue Li and Dr. Edson C. Tandoc Jr. on the earlier version of this manuscript. The authors would like to thank Associate Editor—Dr. Eunil Park, and two anonymous reviewers for their excellent comments and suggestions throughout the review process that have tremendously improved the quality of this paper. Also, assistance from the Physical Education Department of Wuhan University in data collection is much appreciated.

Data availability statement

Data that support the findings of this paper are not publicly available due to the data confidentiality agreement with the Physical Education Department of Wuhan University. However, the data can be available from the first author on reasonable request (S. Fu, contact email: fu_shaoxiong@163.com).

Citation format

Fu, S., Chen, X., & Zheng, H. (2020). Exploring an adverse impact of smartphone overuse on academic performance via health issues: a stimulus-organism-response perspective. *Behaviour & Information Technology*. <https://doi.org/10.1080/0144929X.2020.1716848>

Exploring an adverse impact of smartphone overuse on academic performance via health issues: A stimulus-organism-response perspective

Abstract

While previous research suggests that smartphone overuse relates to users' adverse health issues such as insomnia, nomophobia, and poor eyesight, few studies have explored the mediating role of such health issues in the relationship between smartphone overuse and academic performance. Guided by the Stimulus-Organism-Response (S-O-R) framework, this study develops a model to understand the relationships among students' smartphone overuse, health issues (i.e., insomnia, nomophobia, and poor eyesight), and academic performance. Moreover, we introduce a moderating role of health information literacy in the relationship between smartphone overuse and health issues. To validate the model, we collect representative data through a large-scale field survey at a public university in China. 6,855 valid responses are retained for data analysis using a structural equation modeling technique. The main results are: (1) health issues—insomnia, nomophobia, and poor eyesight—*partially* mediate the relationship between smartphone overuse and students' academic performance; (2) health information literacy can moderate the relationship between smartphone overuse and the health issues including insomnia and poor eyesight, while the relationship between smartphone overuse and nomophobia is not affected. Finally, we draw related theoretical and practical implications.

Keywords: Academic performance; Health information literacy; Insomnia; Nomophobia; Smartphone overuse; Stimulus-Organism-Response (S-O-R)

1 Introduction

Smartphones, with their pervasive acceptance and powerful functionality, have undoubtedly become an integral part of students' daily activities (Škařupová *et al.*, 2016). Smartphones enable them not only to access the mobile internet but also enjoy a wide variety of apps, including gaming, videos, and social networking (Kim *et al.*, 2015). According to Campus Technology (2018), smartphones are one of the top favorite devices for students. Another investigation conducted by the Pew Research Center (2018) found that 95% of university students have used smartphones. Smartphones may benefit them in terms of online learning, such as integrating digital platforms into lessons, supplying useful information for active learning, supplementing lessons with digital materials, and utilizing educational learning apps.

On the flip side, since an increasing number of features are explored in smartphones, it is unsurprising to see that students have spent considerable time on smartphones every day, which may further lead to *smartphone overuse* (e.g., Hwang *et al.*, 2012; Lee *et al.*, 2014). Smartphone overuse, as a typical form of behavioral addiction, refers to people's heavy dependence on smartphones. Because of individual differences, there are no specific criteria or time cutoff illustrating the boundary of smartphone overuse (Roberts *et al.*, 2014). However, excessive usage of smartphones can be reflected by its negative impact on users' well-being (Darcin *et al.*, 2016; Demirci *et al.*, 2015; Samaha and Hawi, 2016). For example, those who overuse smartphones often suffer from solitary life, anxious emotion, and even irregular eating habits (Choi *et al.*, 2018; Liu *et al.*, 2017).

Over-reliance on smartphone may affect students' learning activities and even their academic performance in schools (McCoy, 2016; Dewi *et al.*, 2018). Such situations would be more severe for those in universities as they have more freedom to determine when and

how to use smartphones (Hawi and Samaha, 2017). In addition to negatively affecting university students' academic performance (Kibona and Mgaya, 2015; Puspitasari and Ishii, 2016), smartphone overuse may lead them to hold some adverse health issues as well. For example, excessive use of smartphones can cause blurred vision and wrist pain (Soror *et al.*, 2015). The increasing use of smartphones has effects on sleep disorders and fatigue (Holbein *et al.*, 2019). Meanwhile, smartphone overuse is positively associated with autism and depression (Hwang *et al.*, 2012). Therefore, it is essential to emphasize the harmful effects of smartphone overuse on students' health-related problems, which could further influence their academic performance.

However, the health issues and students' academic performance associated with smartphone overuse are not considered under one umbrella. While previous research suggests that smartphone overuse relates to users' adverse health issues such as insomnia, nomophobia, and poor eyesight (e.g., Cao et al., 2018; Darcin et al., 2016; Kara et al., 2019), few studies have explored the mediating role of such health issues in the relationship between smartphone overuse and academic performance. For instance, although Samaha and Hawi (2016) found that both health issue (i.e., perceived stress) and academic performance mediate the relationship between smartphone overuse and satisfaction with life, whether health issues can play a mediating role in the relationship between smartphone overuse and academic performance is still unclear. This mediating effect exists in daily life because students' learning activities are readily influenced by their unhealthy or semi-healthy conditions that relate to their smartphone overuse. For example, using a smartphone to play online games until midnight may lead to insomnia, which further affects the students' learning in class the next day.

To understand how smartphone overuse affects students' health issues and their academic performance, we adopt the *stimulus-organism-response* (hereafter referred to as S-

O-R) framework (Jacoby, 2002) to explain the relationships among students' smartphone overuse, health-related issues, and academic performance (S-O-R framework is explained in detail in Section 2.3). Guided by the S-O-R framework, this study seeks to empirically test the mediating effect of the organism (i.e., health issues of students) on the relationship between stimulus (i.e., smartphone overuse) and response (i.e., academic performance). In particular, we focus on three main health issues related to smartphone overuses that have been discussed often in prior works (e.g., Chang *et al.*, 2015; Coyle *et al.*, 2017; Curcio *et al.*, 2006; Kara *et al.*, 2019; King *et al.*, 2013), namely, *insomnia*, *nomophobia*, and *poor eyesight*. Insomnia is a sleep disorder that is characterized by difficulty falling and/or staying asleep (Scott and Judge, 2006). Nomophobia is the irrational fear of being without using a smartphone or being unable to use the phone for some reason, such as the absence of a signal or running out of minutes or battery power (Yildirim and Correia, 2015). Poor eyesight reflects users' vision concerns such as nearsightedness, which may be caused by excessive smartphone usage (Sadagopan *et al.*, 2017).

Furthermore, the literature in Health Informatics has pointed out the role of health information literacy in people's self-care (e.g., Chen *et al.*, 2019; Eriksson-Backa *et al.*, 2012; Niemelä *et al.*, 2012). Health information literacy refers to the degree to which people can obtain and process health information for making health-related decisions (Ivanitskaya *et al.*, 2006). Previous research suggests that training the students' health information literacy helps promote their self-awareness of healthcare and then motivate them to adopt some interventions to alleviate the adverse aspects of their health status (e.g., Eriksson-Backa *et al.*, 2012;). Accordingly, for this study, we also examine the role of health information literacy in moderating the relationship between smartphone overuse and students' health issues (i.e., insomnia, nomophobia, and poor eyesight).

This study is based on a cross-sectional survey with 6,855 undergraduates in China, a nation with one of the highest rates of smartphone usage in the world, where university students have broad access to smartphones in their campus lives (CNNIC, 2019). This study seeks to answer a specific question that current scholars have not paid much attention to—*how does smartphone overuse affect students' academic performance by considering the mediating role of health issues?* Conceptualizing such mediating effects guided by the S-O-R framework is consistent with the reality that being addicted to smartphones is harmful to students' well-being. On the practical front, this study may inform educators how to conduct appropriate intervention strategies—such as improving the students' health information literacy—that enhance their awareness of the health issues caused by smartphone overuse and further mitigate these negative impacts on their academic performance.

2. Literature review and theoretical framework

In this section, we review related literature on the dark side of smartphone overuse—students' poor academic performance and their adverse health issues, respectively. After that, we introduce a possible moderating role of health information literacy in alleviating the adverse impact of smartphone overuse on health issues. Finally, we construct a research model guided by the S-O-R theoretical framework.

2.1 Dark side of smartphone overuse

For this study, the dark side relevant to smartphone overuse involves two-fold. First, smartphone overuse affects users' academic performance negatively. Second, smartphone overuse affects users' health-related issues, including insomnia, nomophobia, and poor eyesight significantly. In particular, we also argue that smartphone overuse may lead to users'

poor academic performance through the negative impacts of nomophobia, insomnia, and poor eyesight.

Evidence supports that smartphone overuse may affect students' learning process, thereby yielding an adverse effect on their academic performance. For example, Mendoza et al. (2018) found that smartphone overuse may distract students' attention in the classroom and decrease their efforts put into their learning. Likewise, Kibona and Mgaya (2015) argued that students who excessively use smartphones in the class tend to do something irrelevant to studying, and thus it is necessary to regulate students' smartphone usage during the class. Also, outside the class, students who are addicted to using smartphones tend to delay their related study tasks such as reviewing and previewing courses and doing homework (King et al., 2013). Hawi and Samaha (2016) argued that, when exposure to smartphone overuse, the magnitude of academic performances among students can be attributed to the electronic multitasking factor, also known as *em-factor*. The *em-factor* refers to the odds ratio for achieving high academic performance by students who multitask in learning contexts (Hawi and Samaha, 2016). In short, those who cannot multitask effectively on smartphones tend to achieve poor academic performance.

However, limited research focused on the relationships among smartphone overuse, health issues, and academic performance. Among the few studies, for example, Mendoza et al. (2018) found that smartphone overuse may cause students' nomophobia—the fear of being without touching their phones—and makes them perform worse on the following quizzes than the others. To deepen the understanding of the association between health issues related to smartphone overuse and students' academic performance, this study focuses on three primary health aspects related to smartphone overuse, namely, insomnia, nomophobia, and poor eyesight. First, people who use smartphones frequently are very likely to have insomnia because accessing phones makes them challenging to fall asleep or go back to

sleep. Accordingly, if someone wakes up very often during sleeping time, he or she may hold a severe degree of insomnia. Second, people using a smartphone before sleep or in class may have nomophobia as they cannot help controlling themselves to leave the phones. Such psychological attachments affect their studies or regular rests. Third, smartphone overuse also means overusing eyes. Thus, it is also common for those who overuse smartphones to get several eyesight concerns, such as refractive errors. As such, insomnia, nomophobia, and poor eyesight are the three common health symptoms caused by smartphone overuse among students.

2.2 Moderating role—health information literacy

Generally, health information literacy concerns one's capacity in making informed health decisions, depending on a series of health information activities, such as health information-seeking, information acquisitions, and information uses (Medical Library Association, 2003). We think that students' health information literacy can alleviate the negative effect of smartphone overuse on their health issues. This is because health information literacy can help students to be aware of the harms of smartphone overuse. For example, when individuals have symptoms such as insomnia, nomophobia, and poor eyesight due to excessive use of smartphones, those who hold qualified health information literacy may consciously decrease the smartphone usage or find out relevant medical knowledge that can be used to relieve such symptoms. Therefore, health information literacy could play a moderating role in the relationship between smartphone overuse and health issues.

2.3 Stimulus-Organism-Response (S-O-R) framework

According to the S-O-R theoretical framework, the stimulus refers to an external factor influencing the physical and psychological well-being of individuals (Cui *et al.*, 2016;

Peng and Kim, 2014). The organism refers to the internal processes and outcomes of the stimulus, usually mediating the relationship between stimulus and response. The response can be conceptualized as the outcome of stimulus and organism (Zhang *et al.*, 2019). In particular, the S-O-R framework emphasizes the mediating role of organism on the relationship between the stimulus and response (Dashti *et al.*, 2019; Jacoby, 2002).

The S-O-R framework has been applied extensively to study the social impacts of digital technologies on people's daily activities. For instance, when using social networking sites, Zhang *et al.* (2019) found that affective social distance (O) can mediate the effects of community reciprocity and community receptivity (S) on product recommendation (R). Cao *et al.* (2018) indicated that information overload, communication overload, and social overload (S) exert positive effects on exhaustion and regret (O), which further affect discontinuous usage intentions (R). When using e-commerce sites, Cui *et al.* (2016) found that consumer perceptions (O) in online auction websites partially mediate the relationship between brand stimuli (S) and bidder loyalty (R), but fully mediate the relationship between technological stimuli (S) and bidder loyalty (R). Additionally, Dashti *et al.* (2019) indicated that application or website quality, perceived interactivity, social commerce constructs and subjective norms (S) in social commerce could positively influence social commerce intention (R) through social support, attitude to social commerce and relationship quality (O).

However, few studies have employed the S-O-R framework to investigate students' usage of smartphones. This is perhaps because past research has paid much attention to *direct* benefits and/or risks of individuals' smartphone usage (e.g., Chen *et al.*, 2018; Choi *et al.*, 2018; Christensen *et al.*, 2016; Mendoza *et al.*, 2018). Unfortunately, potential mediators between smartphone usage and individuals' achievements are not well explored. For this reason, we focus on health issues as mediators between smartphone overuse and academic performance. One advantage of the S-O-R framework is to highlight the mediating effect

(i.e., organism) on the relationship between stimulus and response. In this study, the stimulus refers to smartphone overuse; the organism refers to students' health issues including insomnia, nomophobia, poor eyesight; the response refers to their academic performance. As shown in Figure 1, we propose the research model that articulates how smartphone overuse affects individuals' health issues (i.e., insomnia, nomophobia, poor eyesight), which further affects individuals' academic performance.

-- Insert Figure 1 here --

3. Hypotheses development based on the S-O-R framework

3.1 Stimulus to the organism

Smartphone overuse may result in later bedtimes (Lemola *et al.*, 2015) and sleep disturbance (Dewi *et al.*, 2018), which further leads to sleep disorders like insomnia (Demirci *et al.*, 2015). In particular, the bright light of a smartphone screen may suppress melatonin secretion, which is critical for maintaining high sleep quality and thus delay the onset of awake (Higuchi *et al.*, 2003). We thus hypothesize that:

H1a: Smartphone overuse positively relates to students' insomnia.

Smartphone overuse may be a possible precursor to nomophobia (Kara *et al.*, 2019; Mendoza *et al.*, 2018). Users who are addicted to playing smartphones tend to use them very often and then gradually rely heavily on such digital devices. If they leave their smartphones for a certain period, they may feel lonely and anxious. They even cannot control themselves to giving up these devices, thereby showing the symptom of nomophobia. We thus hypothesize that:

H1b: Smartphone overuse positively relates to students' nomophobia.

Smartphone overuse also affects users' eyes. For instance, eye dryness, burning sensation, and fatigue of individuals showed significant increases before and after use for one and four hours of smartphone use (Choi *et al.*, 2018). Smartphone overuse constantly stimulates the eyes and ultimately leads to poor eyesight. We thus hypothesize that:

H1c: Smartphone overuse positively relates to students' poor eyesight.

Among these health issues caused by smartphone overuse, nomophobia also affects the other two symptoms. For example, students who hold nomophobia are vulnerable to sleeping concerns such as lack of enough rests and insomnia (King *et al.*, 2013; Samaha and Hawi, 2016). Similarly, nomophobia can cause eyesight problems as students keep using their smartphones for a long time until their nomophobia vanishes, which increases the risk of developing cellphone vision syndrome (Ratnayake *et al.*, 2018; Sadagopan *et al.*, 2017). We thus hypothesize that:

H2a: Nomophobia positively relates to students' insomnia.

H2b: Nomophobia positively relates to students' poor eyesight.

3.2 Organism to response

Sleep plays an essential role in students' memory processing during learning, and thus influences their academic performance (Dewald *et al.*, 2010; Piro *et al.*, 2018). Sleep loss was found to be related to sparse procedural and declarative learning among students (Curcio *et al.*, 2006). Specifically, increased sleep fragmentation, early awakenings, poor sleep, and late bedtimes caused by insomnia can prevent memory or learning consolidation during sleep (Curcio *et al.*, 2006). The weakening of learning ability is ultimately reflected in decline in academic performance (Dewald *et al.*, 2010; Piro *et al.*, 2018). We thus hypothesize that:

H3a: Insomnia negatively relates to students' academic performance.

Students who develop nomophobia are likely to check their smartphones frequently for non-class related purposes. This makes students unable to concentrate in the classroom and increases the risk of missing significant knowledge (Drew *et al.*, 2013). Moreover, checking smartphones frequently can induce cognitive costs concerning the time and effortful consumption processes of switching from playing smartphones to taking notes in class (Mendoza *et al.*, 2018). Considering the distraction in class caused by nomophobia, we thus hypothesize that:

H3b: Nomophobia negatively relates to students' academic performance.

Eyesight is positively associated with reading ability (Kulp *et al.*, 2016), visual information processing abilities like visual-spatial, visual-motor integration and visual analysis (Chen *et al.*, 2011), which further facilitate the learning process and promote academic performance. Eyesight is essential for users to timely access information in class. Students with poor eyesight could have difficulties in seeing the blackboard. We thus hypothesize that:

H3c: Poor eyesight negatively relates to students' academic performance.

3.3 Moderating effect

As mentioned in Section 2.2, we posit that students' health information literacy can alleviate the adverse impacts of smartphone overuse on their health issues. Therefore, we hypothesize as follows:

H4a: Health information literacy moderates the adverse impact of smartphone overuse on insomnia.

H4b: Health information literacy moderates the adverse impact of smartphone overuse on nomophobia.

H4c: Health information literacy moderates the adverse impact of smartphone overuse on poor eyesight.

4 Methodology

4.1 Measurement

We adapted existing validated scales to measure the constructs of our research model. Specifically, nomophobia was measured via the scales developed and validated by Yildirim and Correia (2015) and Yildirim et al. (2016). Health information literacy was measured based on the items provided by Niemelä et al. (2012) and the Medical Library Association (2003). Smartphone overuse was measured via two dimensions—one is the frequency of smartphone use in class for non-class purposes, and the other is phone usage before sleep (Chang *et al.*, 2015; Christensen *et al.*, 2016; McCoy, 2016). In line with earlier studies in the healthcare domain (e.g., Coyle *et al.*, 2017), a single-item scale was adopted to measure the students' eyesight. Following the suggestions of American Academy of Sleep Medicine (Edinger *et al.*, 2004) and Liu's work (Liu and Liu, 2005), insomnia was measured based on the frequency of having an insomnia problem like having trouble sleeping within a half-hour, night awakenings, and early morning awakening. Academic performance was measured by the ranking of GPA in their class (Hawi and Samaha, 2016).

The detailed information regarding the measurements is presented in Table 1. Informed by prior work (e.g., Chen *et al.*, 2018), our questionnaire was first developed in Chinese and back-translation was performed to ensure the consistency of translation. Afterward, a pretest was conducted to strengthen the readability and face validity of the measurements. Finally, the questionnaire was revised based on the feedback from the pretest and formed the final version.

-- Insert Table 1 here--

4.2 Data collection procedure

We collected the data from a public university in Central China. The questionnaire was released through a questionnaire issuance platform of this university, which can be accessed on the official website of its Department of Physical Exercises (PE). The PE department conducts a mandatory sports examination for undergraduates per academic year. When students log into the official website of the PE department to view their results of sports test, the questionnaire was sent to students randomly. At the beginning of the questionnaire, we indicated that our research purpose and obtained their informed consent. The questionnaire was advertised between April 14, 2017, and December 15, 2017. After that, 6,948 questionnaires were returned, of which 6,855 were retained for preliminary analysis after removal of unqualified ones, such as those from users who completed the survey quickly (i.e., less than 1 minute), and those who answered the questions inconsistently in the questionnaire (Goode *et al.*, 2017).

The demographic breakdown of the sample is provided in Table 2. As the table shows, there were 3,790 males (55.29% of the sample) and 3,065 females (44.71%). In total, 5,074 of the participants (74.02%) reported having more than three years of internet experience. 3,047 of the participants (44.45%) reported their class ranking, according to GPAs, was intermediate. Most participants reported using their smartphone phone for 0.5-1 hours per day ($n = 3,094$; 38.18%), whereas only 876 (12.78%) used a computer over three hours a day. Also worthy of note is that smartphone-use in class was quite common among the participants ($n = 5,683$; 82.90%).

-- Insert Table 2 here--

5 Data analysis

5.1 Measurement model

A structural equation modeling (SEM) technique was used to test the research model. In particular, partial least squares (PLS)-based SEM was employed for two reasons. First, as a second-generation SEM technique, PLS can simultaneously assess the weights and loadings of indicators on constructs (Fornell and Bookstein, 1982). Also, this technique is able to deal with multiple regressands (i.e., dependent variables), mediators, and moderators at the same time, whereas stepwise regression and hierarchical regression cannot (Gefen *et al.*, 2011). Second, the PLS technique is a favored statistical analysis to validate the relationships among constructs of interest by maximizing its explained variance (Zha *et al.*, 2015). Therefore, PLS is especially suitable for theory explorations (Hair *et al.*, 2011). In this study, we used a tool called SmartPLS 3.0 (see <https://www.smartpls.com>) to do the PLS-SEM analysis.

We assessed the reliability and validity of each latent-variable measurement as well as the paths between the constructs and their significance level. Measurement reliability refers to the consistency and stability of a tested measurement (Cook *et al.*, 1979), where one can assess it by checking its composite reliability (CR) and average variance extracted (AVE) (Fornell and Larcker, 1981). Table 3 shows that the CR values for all of the constructs were greater than 0.8, and all AVE values were above 0.7, well clear of the suggested threshold values of 0.7 and 0.5, respectively (Fornell and Bookstein, 1982; Fornell and Larcker, 1981). Cronbach's alpha values were above 0.6, implying acceptable or moderate reliability of the related measurements (Hinton *et al.*, 2014; Moss *et al.*, 1998). In Table 4, we also offer a correlation matrix for the critical latent variables.

The validity of latent variables was examined by convergent validity and discriminant validity. Table 3 shows the item loadings for all latent variables were above 0.8, indicating a

good convergent validity. Guided by Barclay et al. (1995), we evaluated the discriminant validity of all latent constructs. As shown in Table 3 and 4, the discriminant validity held since the square root of the AVE of each construct surpassed its correlation with any other constructs. This implies that each construct possessed a more distinctive variance compared to its shared variance with other constructs (Fornell and Larcker, 1981). Table 5 shows that all items loaded with higher respective constructs than others, which offers additional evidence for discriminant validity. Taken together, our measurement model thus exhibited sufficient convergent as well as discriminant validity. Meanwhile, the Variance Inflation Factors (VIFs) for all focal constructs in our study fell below 10, eliminating the potential multicollinearity issue (Neter *et al.*, 1996). Common method bias did not exist in our study because the measurements of independent variables (IVs) are self-reported while the measurements of dependent variables (DVs) follow actual outcomes (Podsakoff *et al.*, 2003).

-- Insert Table 3 here --

-- Insert Table 4 here --

-- Insert Table 5 here --

5.2 Structural model

As shown in Figure 2, the full model explained 15.4% of the variance in insomnia, 28.5% of the variance in poor eyesight, and 34.1% of the variance in nomophobia, and 14.9% of the variance in academic performance. The results of the hypotheses tests are shown in Table 6. First, smartphone overuse exhibited a strong positive effect on insomnia ($\beta=0.302$, $p<0.001$), which further negatively influenced academic performance ($\beta= -0.122$, $p<0.001$). Consequently, hypotheses 1a and 3a were both supported. Second, smartphone overuse was positively associated with nomophobia ($\beta= 0.309$, $p<0.001$), which further exerted a weak

positive effect on insomnia ($\beta = 0.093$, $p < 0.001$) and poor eyesight ($\beta = 0.074$, $p < 0.001$), and a weak negative impact on academic performance ($\beta = -0.091$, $p < 0.001$), supporting hypotheses 1b, 2a, 2b, and 3b. Third, smartphone overuse positively affected poor eyesight ($\beta = 0.358$, $p < 0.001$), while poor eyesight was negatively associated with academic performance ($\beta = -0.283$, $p < 0.001$). Accordingly, hypotheses 3a and 3c were supported. Fourth, health information literacy weakly and negatively moderated the impact of smartphone overuse on insomnia ($\beta = -0.073$, $p < 0.001$), and mildly and negatively moderated the impact of smartphone overuse on poor eyesight ($\beta = -0.172$, $p < 0.001$). However, it did not moderate the relationship between smartphone overuse and nomophobia. Thus, hypotheses 4a and 4c were supported, while hypothesis 4b was not supported.

-- Insert Table 6 here --

-- Insert Figure 2 here --

5.3 Mediation analysis

Adhering to the guidelines prescribed by Nitz et al. (2016), mediation analysis was performed to ascertain whether insomnia, nomophobia, and poor eyesight were full or partial mediators. Table 7 summarizes the results of the mediation analysis. Specific indirect effects for all mediators—insomnia ($\beta = -0.037$, $p < 0.001$), nomophobia ($\beta = -0.028$, $p < 0.001$), and poor eyesight ($\beta = -0.101$, $p < 0.001$) were significant. Furthermore, based on the suggestions proposed by Nitz et al. (2016), if the relationship between IVs and DVs is insignificant, we can interpret the mediating effect as a full mediation. Otherwise, it should be interpreted as a partial mediation. In our analysis, we found that smartphone overuse had a significant adverse effect on academic performance ($\beta = -0.434$, $p < 0.001$). Consequently, our results demonstrated that insomnia, nomophobia, and poor eyesight *partially* mediated the adverse impact of smartphone overuse on academic performance.

-- Insert Table 7 here --

6. Discussion

6.1 Major findings

This study aims to investigate the mediating role of health issues (i.e., insomnia, nomophobia, and eyesight problems) on the relationship between smartphone overuse and academic performance among university students in China. By employing the S-O-R framework, our findings confirm that smartphone overuse stimulates students' health issues, which may further affect their academic performance negatively.

First, smartphone overuse is associated with deterioration in students' sleep quality, thereby corroborating H1a. This finding is consistent with Lemola et al. (2015) and Dewi et al. (2018) that improper use of smartphones will result in later bedtimes and sleep disturbance, which leads to insomnia. Smartphone overuse also relates to nomophobia (supporting H1b). Indeed, nomophobia is a reflection of smartphone overuse (King *et al.*, 2013). Moreover, smartphone overuse is associated with the deterioration in students' eyesight (supporting H1c). Consistent with previous studies (e.g., Moon *et al.*, 2016), excessive smartphone use causes eye fatigue and eye diseases, which are harmful to eyesight.

Second, nomophobia is weakly associated with insomnia and poor eyesight; offering supports to H2a and H2b. Nomophobia may contribute to the increase of the frequency and duration of smartphone usage in the daily lives, thereby reducing normal sleep time and sleep quality but increasing eye burden. The phenomenon of "cellphone vision syndrome" has been confirmed again in our study (Sadagopan *et al.*, 2017).

Third, based on the mediation analysis, health issues play a partial mediating role in the relationship between smartphone overuse and students' academic performance. In brief,

in addition to the direct adverse impact of smartphone overuse on academic performance, it may also induce negative health issues and indirectly affect academic performance. Specifically, insomnia can decrease the sufficient sleep time of students, thus affecting daytime learning (Piro *et al.*, 2018). Nomophobia can lead to a distraction in class (Mendoza *et al.*, 2018). Poor eyesight can prevent students from gaining knowledge effectively in class. All these reasons contribute to reduced academic performance. These findings may inform university educators that they can help students avoid the impact of excessive usage of smartphones on their academic performance by highlighting their affected health issues.

Last, health information literacy plays a moderating role in the adverse impact of smartphone overuse on health issues. In particular, this result indicates that health information literacy can help students who overuse smartphones reduce insomnia and poor eyesight, yet nomophobia is not affected. Students with health information literacy could search for and obtain effective treatments of insomnia and eyesight and apply them to themselves. Interestingly, students' health information literacy cannot moderate the relationship between smartphone overuse and nomophobia. The possible reason is that excessive smartphone use is the primary determinant of nomophobia. In the case of smartphone overuse, even the improvement of health-related cognition and abilities cannot effectively reduce nomophobia.

6.2 Research implications

Despite the abundant availability of studies on smartphone overuse, how smartphone overuse can weaken academic performance by affecting users' health has received limited attention. Our current study holds both theoretical and practical implications.

On the theoretical front, this study is among the first to apply the S-O-R framework to explain the adverse impacts of digital technologies on academic performance. In particular,

while previous studies have shown that smartphone overuse can lead to both negative health issues and poor academic performance (e.g., Holbein *et al.*, 2019; Kibona and Mgaya, 2015), our study focuses more on how health issues mediate the relationship between smartphone overuse and academic performance. Conceptualizing the three elements (i.e., smartphone overuse, health issues, and academic performance) within the S-O-R framework provides a novel theoretical lens to further understand the mechanism by which smartphone overuse influence students' academic performance. Furthermore, it is noteworthy that, while past studies have highlighted the existence of various adverse impacts of smartphone overuse (e.g., Dewi *et al.*, 2018; Lee *et al.*, 2014), little is known of how to “treat” those symptoms. Based on 6,855 questionnaires, our study provides reliable support for the moderating role of health information literacy in alleviating the adverse impact of smartphone overuse on insomnia and poor eyesight. Our study, therefore, advances the existing literature by emphasizing the role of health information literacy in treating adverse symptoms caused by smartphone overuse.

On the practical front, our research provides valuable insights for educators wishing to combat the adverse effect of smartphone overuse on students' academic performance, by explaining the adverse effects from the perspective of health issues. Specifically, educators can limit the use of smartphones in the classroom and tell students about the risks of using smartphones before sleep. Second, physical activities should not just be limited in physical education classes. Setting-up exercise during class break and eye health care should be promoted on campus to alleviate the adverse effects of the technological stimulus. Third, while research on the adverse effect of smartphone overuse abounds, most of the implications proposed by previous research are to reduce the amount of smartphone use (Kibona and Mgaya, 2015). However, in modern society, it is often difficult to reduce smartphone use due

to its wide accessibility. Our study finds a way to treat or reduce the negative impacts of smartphone overuse by improving users' health information literacy.

6.3 Limitations and future research directions

This study has a few limitations. First, while ensuring the parsimony of our research model by adhering to the S-O-R framework and focusing on the mediating effects of insomnia, nomophobia, and poor eyesight, we acknowledge that academic performance is subjected to other physical and psychological mechanisms such as spinal disorders and perceived stress. Since health issues, as a broad concept, can be measured in diverse ways and on many dimensions, meaningful findings can be achieved by including these factors in future studies. Second, the study was based on examining undergraduates in China. Considering the potential impact of cultural background, cautions should be taken when extending the outcomes to the students from other cultural backgrounds. Last but not least, in reality, people are using a variety of digital technologies, such as wearable devices, tablets, and desktop devices, while our study only investigated smartphones. Future work can include these devices to make the findings more generalizable.

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Figures:

Figure 1. Research model

(R^2 : The proportion of the variance for a dependent variable that's explained by independent variables; n.s.: not significant; *** : $P < 0.001$)

Figure 2. Research model with results

Tables:

Table 1. Measurement items

Construct	Item	Measurement	Source
Smartphone overuse	1. Frequency of smartphone use in class for non-class related purposes	A. Never B. Sometimes C. Often	Chang <i>et al.</i> , 2015; Christensen <i>et al.</i> , 2016; McCoy, 2016
	2. Average time of smartphone use before sleep	A. Never B. Less than 0.5 h C. 0.5–1 h D. 1–2 h E. Over 2 h	
Academic performance	The class ranking according to GPAs	A. Low B. Fairly low C. Intermediate D. Fairly high E. High	Hawi and Samaha, 2016
Nomophobia	1. “Running out of battery on my smartphone would scare me.”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	Yildirim and Correia, 2015
	2. “If I were to hit my monthly data limit, I would panic.”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
	3. “If I did not have a data signal or could not connect to Wi-Fi, I would constantly check to see whether I had a signal or could find a Wi-Fi network.”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
	4. “If I did not have my smartphone with me, I would be anxious because I could not keep in touch with my family and/or friends.”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
	5. “If I did not have my smartphone with me, I would be uncomfortable because I could not stay up to date with social media and online networks.”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
Poor eyesight	“Compared with the eyesight test results in the university six months ago, is your vision getting better or worse?”	A. Better B. No change C. Worse	Coyle <i>et al.</i> , 2017
Insomnia	“Do you have an insomnia problem?”	A. Never B. Rarely C. Occasionally D. Often	Liu and Liu, 2005; Edinger <i>et al.</i> , 2004
Health information literacy	1. “I know where to seek health information.”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	Niemelä <i>et al.</i> , 2012; Medical Library Association, 2003
	2. “I like to get health information from a variety of sources.”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
	3. “It is easy to assess the reliability of health information in printed sources (magazines and books).”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
	4. “It is easy to assess the reliability of health information on the Internet.”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	
	5. “I apply health related information to my own life and/or that of people close to me.”	Strongly disagree 1 2 3 4 5 6 7 Strongly agree	

Table 2. Demographic statistics for the sample (N = 6,855)

Measurement	Item values	Total count for item	Percentage (%)
Gender	Male	3790	55.29
	Female	3065	44.71
Age	≤18	141	2.06
	19	678	9.89
	20	1079	15.74
	21	1302	18.99
	22	1428	20.83
	23	1445	21.08
	24	593	8.65
	≥25	189	2.76
Internet experience	Less than half a year	674	9.83
	0.5–1 year	379	5.53
	1–2 years	309	4.51
	Between 2 and 3 years	419	6.11
	Over 3 years	5074	74.02
Academic ranking	Low	180	2.63
	Fairly low	558	8.14
	Intermediate	3047	44.45
	Fairly high	1853	27.03
	High	1217	17.75
Daily pre-sleep smartphone-use time	None	876	12.78
	Less than 0.5 h	1819	26.53
	0.5–1 h	2617	38.18
	1–2 hours	1121	16.35
	Over 2 hours	422	6.16
Smartphone-use in class	Never	1172	17.10
	Sometimes	4196	61.21
	Often	1487	21.69

Table 3. Latent variable reliability

	Minimal factor-loading	Cronbach's alpha	Composite reliability	Average variance extracted
SO	0.863	0.660	0.855	0.746
HIL	0.887	0.945	0.958	0.820
NOM	0.851	0.923	0.942	0.765
Notes : SO means Smartphone Overuse; HIL means Health Information Literacy; NOM means Nomophobia. Except for SO, HIL and NOM, the indicators for other variables are not applicable because they are measured by a single measurement.				

Table 4. Correlation coefficients

Construct	SO	INS	PE	HIL	NOM	AP
SO	1.000					
INS	0.371***	1.000				
PE	0.473***	0.353***	1.000			
HIL	0.317***	0.172***	0.274***	1.000		
NOM	0.438***	0.246***	0.306***	0.505***	1.000	
AP	-0.434***	-0.122***	-0.354***	-0.209***	-0.208***	1.000

Notes: SO means Smartphone Overuse; INS means Insomnia; PE means Poor Eyesight; HIL means Health Information Literacy; NOM means Nomophobia; AP means Academic Performance. ***: $P < 0.001$.

Table 5. Loading and cross-loading matrix

Items \ Constructs	SO	HIL	NOM
SO1	0.863	0.278	0.383
SO2	0.865	0.270	0.375
HIL 1	0.280	0.910	0.443
HIL 2	0.311	0.915	0.459
HIL 3	0.264	0.893	0.447
HIL 4	0.282	0.887	0.469
HIL 5	0.298	0.921	0.468
NOM 1	0.381	0.433	0.884
NOM 2	0.353	0.419	0.851
NOM 3	0.407	0.440	0.881
NOM 4	0.382	0.484	0.882
NOM 5	0.392	0.430	0.875

Notes : SO means Smartphone Overuse; HIL means Health Information Literacy; NOM means Nomophobia. SO1-3 mean the measurement items of smartphone overuse. HIL1-5 mean the measurement items of health information literacy. NOM1-5 mean the measurement items of nomophobia.

Table 6. Results of Hypotheses Tests

	Hypothesis	Coefficient	Value in <i>t</i> -tests
Hypotheses related to Stimulus			
H1a	Smartphone overuse → Insomnia	0.302***	22.448
H1b	Smartphone overuse → Nomophobia	0.309***	24.662
H1c	Smartphone overuse → Poor Eyesight	0.358***	27.027
Hypotheses related to Organism			
H2a	Nomophobia → Insomnia	0.093***	6.372
H2b	Nomophobia → Poor Eyesight	0.074***	5.441
Hypotheses related to Response			
H3a	Insomnia → Academic performance	-0.122***	9.635
H3b	Nomophobia → Academic performance	-0.091***	7.065
H3c	Poor Eyesight → Academic performance	-0.283***	22.450
Moderating effects			
H4a	Smartphone overuse * Health information literacy → Insomnia	-0.073***	7.035
H4b	Smartphone overuse * Health information literacy → Nomophobia	0.000 n.s.	0.006
H4c	Smartphone overuse * Health information literacy → Poor Eyesight	-0.172***	17.907

Notes: Reported coefficient values are based on the results of the model analysis in PLS. n.s. = “not significant”, *** $p < 0.001$.

Table 7. Results of Mediation Analysis

Mediator	SO → AP	SO → Mediator → AP	Mediation effect
Insomnia	-0.434***	-0.037***	Partial Mediation
Nomophobia	-0.434***	-0.028***	Partial Mediation
Poor Eyesight	-0.434***	-0.101***	Partial Mediation
Notes: SO means Smartphone Overuse; NOM means Nomophobia; INS means Insomnia; PE means Poor Eyesight; AP means Academic Performance. *** means $P < 0.001$.			