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Association of smartphone use with depression, anxiety, stress, sleep quality, and internet addiction. Empirical evidence from a smartphone application

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ABSTRACT

A growing body of evidence has demonstrated an association between problematic smartphone use and psychopathological behavior (e.g., internet addiction, depression, anxiety, stress, and sleep quality). However, little is yet known whether problematic and general smartphone use co-occur with depression and whether internet use, stress, anxiety and sleep quality moderate this relationship. The aim of this study was to examine the psychological mechanisms underlying extensive smartphone use and depression using multiple regression and path analysis (PROCESS macro) in a sample of university students. Our findings demonstrated a negative correlation of smartphone use with anxiety, stress, and sleep quality. Extensive smartphone use is related to depression through the mediation of stress; increased smartphone use tends to reduce stress. Moreover, depression leads to higher levels of smartphone use revealing a bi-directional pathway. Taken together, our findings provide solid evidence for a bi-directional hybrid view considering the association between extensive smartphone use and depression mediated by stress. The present study results may help national health authorities to improve the prevention of depression related to modern technology use.

1. Introduction

Nowadays, smartphone use has become a global phenomenon. Billions of people carry smartphones to connect to other people but also to access cyberspace (Adelhardt, Markus, & Eberle, 2019). Portability and internet availability allow smartphones to be potentially even more distracting than desktop- or laptop-based internet use (Kim, Seo, & David, 2015). A growing body of evidence has shown a positive association between problematic smartphone use and psychopathology symptoms such as depression and anxiety (Demirci, Akgönül, & Akpinar, 2015; Elhai, Dvorak, Levine, & Hall, 2017; Elhai, Levine, Dvorak, & Hall, 2016; Kim et al., 2015). Little is yet known about the psychological mechanism underlying the association between smartphone use and depression, primarily because depression is a multilayered phenomenon that may be modulated bi-directionally by other psychopathological symptoms (e.g., stress, anxiety, and sleep quality), while smartphone use may be associated with technology-related addiction behaviors (e.g., Internet overuse). In line with this consideration, we designed our study aiming to address this issue and fill this gap.

People experiencing depressive mood use smartphones more frequently to alleviate negative emotions, thus potentially causing further social isolation and a possible increase in smartphone overuse (Kim et al., 2015). However, this relationship is complex and appears to be bi-directional, from depression to overuse and from overuse to depression due to decreased face-to-face communication, and the interrelationship of problematic smartphone use with other forms of psychopathology. There are positive correlations between smartphone use and stress (Elhai et al., 2017), a positive correlation between smartphone use and anxiety (Elhai et al., 2017), and a positive correlation between smartphone use and sleep quality (Demirci et al., 2015; Randjelović et al., 2019; Xie, Dong, & Wang, 2018). This relation should be taken seriously since the latest data from the World Health Organization (WHO, 2017) show depression is the leading cause of disability and ill health in the world affecting more than 300 million people globally, tending to become a major contributor to disease

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burden worldwide by 2030. Numerous studies have also demonstrated a rise in depression among children and adolescents (Costello, Copeland, & Angold, 2011; Stojiljković & Stanković, 2018). Data from Southeastern Europe (Serbia) show that the incidence of depression ranging from mild to severe is up to 55.1% in college students (Miletic, Lukovic, Ratkovic, Aleksic, & Grgurevic, 2015), whereas 18% of children and adolescents exhibit depressive symptoms. It is significant to explore to what extent depression symptoms are related to extensive smartphone use in youths. A growing body of evidence demonstrates that extensive smartphone use may share common characteristics with internet addiction, stress, anxiety, and depression (Ben-Yehuda, Greenberg, & Weinstein, 2016; Choi et al., 2015; Kim et al., 2015; Kim, Jang, Lee, Lee, & Kim, 2018). Internet addiction is a behavior pattern of excessive or obsessive online or offline internet use accompanied by loss of control, withdrawal, and escape, whereas smartphones are frequently used for internet access (Kim et al., 2018; Young, 1998). Anxiety is an emotion characterized by the subjective experience of anxious affect, physical changes and anxious thoughts (American Psychiatric Association, 2015; Jovanović, Gavrilov-Jerković, & Lazić, 2019), and stress is related to chronic non-specific arousal, tension, agitation, and irritability, whereas depression is associated with anhedonia, dysphoria, hopelessness, and loss of interest (Jovanović et al., 2019).

There are three prominent views on the causal relation between problematic smartphone use and psychopathology. The first view is that psychopathological phenomena, such as depression and anxiety, may lead to technology overuse (Elhai et al., 2017). Persons with depressive mood use smartphones more frequently to reduce their negative emotions (Kim et al., 2015), thus possibly causing smartphone overuse. The opposite view is that technology overuse may lead to psychopathological behavior. Smartphone addiction is an important risk factor for the development of depression and anxiety, more significant than internet addiction (Kim et al., 2018). Persons, especially women, who tend to overuse online communication may be at higher risk of depression (Nishida, Tamura, & Sakakibara, 2019). Smartphone overuse may cause dysfunctional behavior such as a checking habit: a repetitive action of inspecting notifications on one's own smartphone (Oulasvirta, Rattenbury, Ma, & Raita, 2012). The third hybrid view suggests a bi-directional association in such a way that smartphone use causes psychopathological behavior while conversely, psychopathological behavior causes problematic smartphone use (Elhai et al., 2017).

However, little is yet known under what conditions extensive smartphone use may result in the development of depression given the strong evidence that stress may play a crucial role in depression etiology. A linear relation between extensive smartphone use and the etiology of depression would be a simplified view since prior literature suggests that the inability to control (neutralize) stress is a major pathogenic factor in the etiology of depression (Allen & Badcock, 2006; Hill, Hellemans, Verma, Gorzalka, & Weinberg, 2012; Peterson, Maier, & Seligman, 1993; Seligman, 1972). Stress management may play a crucial role in modeling depression. Hence, the relation between depression and smartphone use should also be considered taking into account psychological models including stress mediators since the stress generation hypothesis (Hammen, 1991, 2006) provides strong evidence that stress plays a fundamental role in the etiology of depression. Stress and depression influence each other in a bi-directional way since the presence of high-stress life events increases depression, whereas depressive symptoms increase the risk of negative interpersonal life events (Liu & Alloy, 2010). As strongly confirmed by the empirical work, in addition to stress, depression is frequently accompanied by increased anxiety (Stojiljković & Stanković, 2018) and sleep disorders (Thase, 2006; Tsuno, Besset, & Ritchie, 2005), thus suggesting that depression is a multilayered construct.

Since extensive smartphone use is quite often associated with stress and anxiety relief, but also the need for relaxation, this may be related to the mechanisms of Compensatory Internet Use Theory (Kardefelt-Winther, 2014). According to the Compensatory Internet Use Theory, people connect to the global network to avoid real-life problems and compensate for dysphoric mood. Elhai, Levine, and Hall (2019) suggested using this theory to interpret problematic smartphone use, since users can browse the Internet, entertain themselves or perform some relaxing activity on their smartphones as a form of compensation for real-life problems. Insufficient social contacts in real life can lead a person to a virtual social space with two possible outcomes: positive- a person feels better due to fulfilling social needs communicating with other people on the Internet and negative- a person is frequently online and avoids real-world social contacts, thus being attached exclusively to virtual social communication in the long run (Kardefelt-Winther, 2014). Recently, an interesting comprehensive Person-Affect-Cognition-Execution (I-PACE) model by Brand, Young, Laier, Wölfling, and Potenza (2016); Brand et al. (2019) has emerged, attempting to explain addictive behavior by integrating psychological and neurobiological (genetic) facts. Brand et al. argue that addictive behavior develops as a consequence of the interaction between predisposing variables, and cognitive and affective responses to specific stimuli, while executive functions significantly contribute to the development of addictive behavior such as inhibitory control and decision making. The I-PACE model may be used for various types of addictive behavior (gambling, gaming, buying-shopping, compulsive sexual behavior disorders, and smartphone overuse).

The aims of this study were to examine: a) whether extensive smartphone use increases depression through the mediation of anxiety, stress, and sleep quality, b) whether depression increases extensive smartphones use through the mediation of anxiety, stress, and sleep quality, c) whether extensive smartphone use increases internet use through the mediation of depression, anxiety, stress, and sleep quality. Based on the theoretical considerations of the stress generation hypothesis and Compensatory Internet Use Theory, we hypothesized that extensive smartphone use would result in increased depression, through the mediation of anxiety, stress, and lack of sleep quality. We expected that, due to increased stress and anxiety, participants would access their smartphones more frequently to immediately reduce dysmorphic mood. Hence, this mediation would be related to depressive outcomes. Considering the I-PACE model, we hypothesized that increased depression would result in extensive smartphone use through the mediation of anxiety, stress, and sleep quality. Hence, the association would be bi-directional. In line with prior studies indicating the relationship between smartphone and internet overuse (Ben-Yehuda et al., 2016; Mok et al., 2014), we hypothesized that extensive smartphone use would result in higher levels of internet use, through the mediation of anxiety, stress, and lack of sleep quality. We expected that increased smartphone access to reduce dysmorphic mood, per se, would be a significant prerequisite for the development of higher levels of internet use since numerous smartphone applications and browsing the Internet require an internet connection. The present empirical study has highlighted the mechanisms underlying the association between extensive smartphone use and depression mediated by anxiety, stress, and sleep quality.

2. Method

2.1. Participants

A total of 92 (female 74) white medical students (M age = 21.05, SD = 1.69) from the University of Niš, Serbia, participated in the study voluntarily. We recruited participants via a public advertisement posted on the university bulletin board. The sample size was calculated a priori employing statistical parameters for multiple linear regression and a cross-sectional study: an alpha level of 0.05, and a medium effect size $f^2 = 0.15$. The calculation was applied using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007). The exclusion criteria were the use of psychoactive substances and sleep medications since the use of

Table 1
Descriptive statistics and inter-correlations for internet addiction, smartphone use, sleep quality, depression, anxiety, and stress.

	Internet addiction	Smartphone use	Sleep quality	Depression	Anxiety	Stress
Internet addiction	–					
Smartphone use	0.141	–				
Sleep quality	0.174	−0.308**	–			
Depression	0.397**	−0.169	0.425**	–		
Anxiety	0.367**	−0.226*	0.533**	0.650**	–	
Stress	0.432**	−0.232*	0.516**	0.686**	0.825**	–
M	14.69	244.29	6.02	4.79	4.21	8.28
SD	8.60	104.10	3.15	4.52	4.11	4.49
Range	1–47	14.68–536.55	1–16	0–19	0–21	0–21

* $p < .05$.
** $p < .01$.

medication can influence instrument scores and psychomotor habits of subjects (smartphone use). The inclusion criterion was the Android operating system smartphone use. The study was approved by the Ethical Committee of the Faculty of Medicine. Participants signed informed consent to take part in the study anonymously and to install and run an Android QT application on their smartphones during a two-week period.

2.2. Instruments and apparatus

Smartphone use. An Android application QT (www.qualitytimeapp.com) was used to monitor user smartphone activity. The application running in the background automatically registers the exact time of accessing a smartphone and the time spent on the Internet.

Internet Addiction Test (IAT; Young, 1998) was used to measure potential internet addiction in medical students. IAT measures behaviors related to compulsive internet use that include escapism and dependency (e.g., "How often do you find that you stay on-line longer than you intended?"). The 20-item questionnaire on a 5-point scale measures normal (0 − 30), mild (31–49), moderate (50–79), and severe (80–100) levels of internet addiction. Scores range from 0 to 100 and a higher score indicates a higher level of internet addiction. Internal consistency Cronbach Alpha (α) in our sample was $\alpha = 0.845$.

Depression, anxiety, and stress scales (DASS-21; Lovibond & Lovibond, 1995) were used to examine depression, anxiety, and stress. We used the Serbian version of the DASS-21 based on prior studies (Jovanović et al., 2019; Jovanovic, Gavrilov-Jerkovic, Zuljevic, & Brdaric, 2014). The DASS-21 include a 7-item scale per each subscale: Depression (e.g., "I found it difficult to work up the initiative to do things"), Anxiety (e.g., "I felt I was close to panic") and Stress (e.g., "I found myself getting agitated"). The scale contains 21-items in total that can be rated on a 4-point scale "0-Did not apply to me at all, 1-Applied to me to some degree, or some of the time, 2-Applied to me to a considerable degree or a good part of time, 3-Applied to me very much or most of the time". Considering the DASS-21 scale, internal consistency Alpha in our sample was $\alpha = 0.902$, for the depression scale, $\alpha = 0.864$, for the anxiety scale, and $\alpha = 0.871$, for the stress scale.

The Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds 3rd, Monk, Berman, & Kupfer, 1989) is a 19- items questionnaire with five questions used to measure sleep quality. We used a validated version of the PSQI translated into Serbian (Popević et al., 2018). The PSQI measures (e.g., "During the past month, how would you rate your sleep quality overall?") seven components of sleep patterns in adults over a 1-month interval: sleep duration, disturbances, latency, daytime dysfunction, habitual sleep efficiency, sleep quality, and the use of sleep medications. The PSQI global score is calculated as a total of seven components ranging from 0 (no difficulty) to 21 (severe difficulties in all areas). Internal consistency for PSQI for our sample was, $\alpha = 0.741$.

2.3. Procedure

Participants were instructed to install and run the QT application on their smartphones as in a prior study (Randjelović et al., 2019). Two weeks later, participants completed all psychological instruments and filled in a table afterward stating average minutes of smartphone use over 24-h, for each of the 14 days. Participants were instructed to take screenshots of their QT application results for each day of the study. This process was administered by an experimenter. We calculated the total average smartphone use in minutes during a two-week period. All of the participants completed our study.

2.4. Statistical analysis

We conducted the Pearson coefficient correlation and a multiple regression analysis to examine the association of smartphone use and internet addiction with depression, anxiety, stress, and sleep quality. In addition, to examine a bi-directional association between extensive smartphones use and psychopathology, we conducted mediation models using PROCESS v3.4 macro (model 4) for IBS SPSS 25.0 (Hayes, 2017) with the 95% confidence interval for indirect effects and 5000 bootstrap samples set up by default (Preacher & Hayes, 2008). An indirect effect is considered statistically significant when the bias-corrected confidence interval does not include zero. In three separate mediation models, we tested: a) the association between smartphone use (a predictor variable) and depression (a criterion variable) through anxiety, stress, and sleep quality (mediators), with controlled internet addiction; b) the association between depression (a predictor variable) and smartphone use (a criterion variable) through anxiety, stress, and sleep quality (mediators), with controlled internet addiction; c) the association between smartphone use (a predictor variable) and internet addiction (a criterion variable) through depression, anxiety, stress, and sleep quality (mediators). Thus, bi-directional associations were tested.

3. Results

Table 1 shows a statistically significant moderate positive correlation between internet addiction and depression, anxiety and stress. Interestingly, results revealed a statistically significant moderate negative correlation between smartphone use and sleep quality, a weak negative correlation between smartphone use and anxiety, and a weak negative correlation between smartphone use and stress, while the correlation between internet addiction and smartphone use was non-significant. A statistically significant moderate positive correlation of sleep quality with depression, anxiety, and stress was found, similar to the correlation among depression, anxiety, and stress. A statistically significant strong positive correlation was found between anxiety and stress.

Table 2. shows that smartphone use, internet addiction, anxiety, and stress are statistically significant predictors of depression, while sleep

Table 2
Multiple regression analysis of smartphone use, internet addiction, anxiety, stress, and sleep quality predicting depression.

		Unstandardized coefficients		Standardized coefficients	
		B	*S.E*	β	t
1	Smartphone use	−0.01	0.00	−0.17	−1.61
2	Smartphone use	−0.01*	0.00	−0.24	−2.54
	Internet addiction	0.23**	0.05	0.44	4.55
3	Smartphone use	−0.00	0.00	−0.07	−0.78
	Internet addiction	0.10*	0.05	0.20	2.21
	Anxiety	0.61**	0.10	0.56	6.12
4	Smartphone use	−0.00	0.00	−0.03	−0.40
	Internet addiction	0.07	0.05	0.13	1.45
	Anxiety	0.27	0.15	0.25	1.81
	Stress	0.42**	0.14	0.42	2.97
5	Smartphone use	−0.00	0.00	−0.02	−0.25
	Internet addiction	0.07	0.05	0.13	1.45
	Anxiety	0.25	0.15	0.23	1.61
	Stress	0.40**	0.14	0.40	2.83
	Sleep quality	0.09	0.13	0.07	0.71

* p < .05.
** p < .01.

quality is non-significant in this statistical model.

In the first mediation model (Fig. 1) smartphone use was a predictor of depression (a criterion variable) through anxiety, stress, and sleep quality (mediators), while internet addiction was controlled (a covariate variable). Results showed that smartphone use was a statistically significant predictor of anxiety, $b = -0.0129, \pm 0.004$, $p = .001$; stress, $b = -0.0141, \pm 0.004$, $p = .001$; and sleep quality, $b = -0.0108, \pm 0.003$, $p = .001$.

Results showed that stress was a statistically significant predictor of depression, $b = 0.4030, \pm 0.142$, $p = .006$, while anxiety, $b = 0.2461, \pm 0.153$, $p = .112$; and sleep quality, $b = 0.0949, \pm 0.133$, $p = .479$, were non-significant predictors.

The total effect of smartphone use on depression was statistically significant, $b = -0.0108, \pm 0.004$, $p = .013$. The direct effect of smartphone use on depression was non-significant, $b = -0.0009, \pm 0.004$, $p = .803$. The indirect effect was statistically significant, $-0.0099, \pm 0.003$, $p < .05$. The indirect effect of anxiety, $b = -0.0032, \pm 0.002$, $p > .05$, and sleep quality, $b = -0.0010, \pm 0.0019$, $p > .05$, was non-significant, while the indirect effect of stress was statistically significant, $b = -0.0057, \pm 0.002$, $p < .05$.

Table 3. shows that internet addiction, depression, and anxiety are statistically significant predictors of smartphone use, while stress and sleep quality are non-significant in this statistical model.

We tested the second mediation model reversibly. Depression was a predictor of smartphone use (a criterion variable) through anxiety, stress, and sleep quality (mediators), while internet addiction was controlled (a covariate variable). Results showed that depression was a

Table 3
Multiple regression analysis of internet addiction, depression, anxiety, stress, and sleep quality predicting smartphone use.

		Unstandardized coefficients		Standardized coefficients	
		B	*S.E*	β	t
1	Internet addiction	2.04	1.24	0.17	1.64
2	Internet addiction	3.36*	1.31	0.28	2.56
	Depression	−6.36*	2.51	−0.28	−2.54
3	Internet addiction	3.85**	1.30	0.32	2.95
	Depression	−2.36	3.03	−0.10	−0.78
	Anxiety	−7.33*	3.27	−0.30	−2.24
4	Internet addiction	4.10**	1.32	0.35	3.10
	Depression	−1.27	3.19	−0.06	−0.40
	Anxiety	−4.05	4.45	−0.16	−0.91
	Stress	−4.70	4.32	−0.21	−1.09
5	Internet addiction	3.88**	1.31	0.33	2.96
	Depression	−0.79	3.16	−0.03	−0.25
	Anxiety	−2.34	4.50	−0.09	−0.52
	Stress	−3.68	4.31	−0.16	−0.85
	Sleep quality	−6.82	3.81	−0.21	−1.79

* p < .05.
** p < .01.

statistically significant predictor of anxiety, $b = 0.5458, \pm 0.080$, $p = .001$; stress, $b = 0.6134, \pm 0.083$, $p = .001$; and sleep quality, $b = 0.2983, \pm 0.074$, $p = .001$.

Neither stress, $b = -3.683, \pm 0.4.30$, $p = .394$, nor anxiety, $b = -2.336, \pm 0.4.50$, $p = .605$, nor sleep quality, $b = -6.81, \pm 0.3.81$, $p = .077$, was statistically significant predictor of smartphone use.

The total effect of depression on smartphone use was statistically significant, $b = -6.361, \pm 2.50$, $p = .013$. The direct effect of depression on smartphone use was non-significant, $b = -0.7929, \pm 3.162$, $p = .802$. The indirect effect of sleep quality, $b = -2.034, \pm 1.40$, $p > .05$, anxiety, $b = -1.27, \pm 2.22$, $p > .05$, and stress, $b = -2.259, \pm 2.19$, $p > .05$, was non-significant.

In the third mediation model we tested the association between smartphone use (a predictor) and internet addiction (a criterion variable) through depression, anxiety, stress, and sleep quality (mediators). Results showed that smartphone use was a statistically significant predictor of anxiety, $b = -0.0099, \pm 0.004$, $p = .020$; stress, $b = -0.0104, \pm 0.005$, $p = .026$; and sleep quality, $b = -0.0095, \pm 0.003$, $p = .003$. Smartphone use as a predictor of depression was non-significant, $b = -0.0075, \pm 0.005$, $p = .111$.

Results showed that neither depression, $b = 0.3601, \pm 0.248$, $p = .150$; nor anxiety, $b = 0.1265, \pm 0.357$, $p = .724$; nor stress, $b = 0.6326, \pm 0.336$, $p = .063$; nor sleep quality,

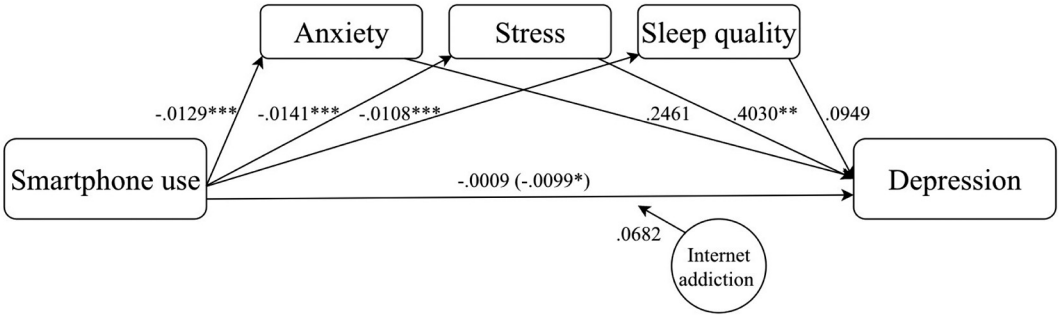

Fig. 1. Mediation statistical model. The indirect effect of smartphone use on depression through the mediation of anxiety, stress, and sleep quality with controlled internet addiction. *$p < .05$, **$p < .01$, ***$p < .001$.

$b = -0.0704, \pm 0.307, p = .819$, was a significant predictor of internet addiction.

The direct effect of smartphone use on internet addiction was statistically significant, $b = 0.0244, \pm 0.008, p = .004$, while indirect effects of smartphone use on internet addiction through the mediation of depression, anxiety, stress, and sleep quality were non-significant.

4. Discussion

The present study demonstrated a bi-directional correlation between smartphone use, and depression. Smartphone use, internet addiction, anxiety and stress were significant predictors of depression, whereas internet addiction, depression, and anxiety were significant predictors of smartphone use. The bi-directional correlation of smartphone use and depression was modulated by the mediating effects of stress. The first hypothesis of this study was that extensive smartphone use would result in increased depression through the mediation of anxiety, stress, and sleep quality, with controlled internet use. The hypothesis was not confirmed since our data revealed that increased smartphone use resulted in reduced depression through the mediating influence of stress, while anxiety and sleep quality as mediators showed a neutral position. The mechanism of the influence of smartphone use on depression has the following features: increased smartphone use is associated with stress reduction, thus resulting in decreased depression. The inability of individuals to control or neutralize stressors is one of the main pathogenic factors in theories of depression (Allen & Badcock, 2006; Hill et al., 2012; Peterson et al., 1993; Seligman, 1972). According to the stress generation hypothesis (Hammen, 1991), negative interpersonal events over a prolonged period of time result in the generation of stress and stress conditions, due to the tendency of the depressed to maintain negative interpersonal relationships, thus leading to further maintenance of depression. Depressed individuals tend to generate stress, consequently causing further development of depression. Hence, this suggests that smartphone use may have a strong compensatory function (Elhai, Levine, et al., 2019; Kardefelt-Winther, 2014), due to reducing stress and anxiety. In addition, smartphone use may be a source of pleasure (Elhai et al., 2017; Robinson & Berridge, 1993). Thus, interpersonal communication serves as positive reinforcement and reduces daily life stress (Elhai et al., 2017) the same as initially in any type of addictive behavior whereby performing a certain activity results in improved mood, pleasure and positive aspects of compulsive behavior (Robinson & Berridge, 1993). One of the main purposes of smartphones may be to facilitate social communication with other people (Choi et al., 2015). This proves that smartphone use should not be over-pathologized (Billieux, Schimmenti, Khazaal, Maurage, & Heeren, 2015) since using a smartphone is neither good nor bad per se; however, the way and context of using this technology is important (Montag & Diefenbach, 2018; Montag, Wegmann, Sariyska, Demetrovics, & Brand, 2019). There is no possible therapeutic effect of smartphone use on depression since these effects are rather immediate and temporary.

The second hypothesis of this study was that increased depression would result in extensive smartphone use through the mediation of anxiety, stress, and sleep quality, with controlled internet use. The hypothesis was partly confirmed since depression and internet addiction successfully predicted higher levels of smartphone use, while the mediation of anxiety, stress, and sleep quality was not confirmed. These findings are in line with the I-PACE model (Brand et al., 2019), indicating that potentially vulnerable individuals, with increased depression and anxiety, are more prone to extensive smartphone use. This suggests a strong association between depression and extensive smartphone use in normal healthy subjects. Interestingly, internet addiction is a significant predictor of smartphone use, however, our findings clearly confirmed that increased (general or problematic) smartphone use does not necessarily belong to the category of internet addiction and as such both may be examined and considered separately. Problematic smartphone use has commonalities but also differences with internet addiction concepts (Elhai et al., 2017; Kuss, Griffiths, Karila, & Billieux, 2014). A recommendation by Montag et al. (2019) to examine Internet use disorder by separately researching accessing the Internet via mobile devices (smartphones, smartwatches, and tablets) and accessing the Internet via nonmobile devices (desktops /laptops) seems very reasonable. Internet use was positively correlated with depression, anxiety, and stress demonstrating that the risk of internet addiction occurs within a range of psychopathology as indicated in the literature (Choi et al., 2015; Dalbudak et al., 2013; Elhai et al., 2017). Thus, the second mediation model was non-significant indicating that depressive symptoms can cause extensive smartphone use in a more directional way compared to extensive smartphone use that leads to depression through the mediation of stress. Taken together, the I-PACE model can be a valid framework to explain mechanisms based on the results obtained in our study.

The third hypothesis of this study was that extensive smartphone use would be positively correlated with internet addictive behavior due to the availability of the Internet on mobile devices, while the presence of depression, anxiety, stress, and low sleep quality would even enhance this association since previous studies have somewhat indicated that smartphone overuse may cause internet addiction (Elhai, Yang, & Montag, 2019) and psychopathology (Elhai et al., 2017; Nishida et al., 2019). The hypothesis was not confirmed since our data revealed no significant correlation between smartphone use and internet use, whereas more frequent smartphone use was correlated negatively with stress, anxiety, and sleep quality. Despite prior research reporting a positive correlation between internet overuse and smartphone overuse (Choi et al., 2015; Randjelovic, Stojiljkovic, Radulovic, Stojanovic, & Ilic, 2020), our data revealed that the higher levels of smartphone applications use are not necessarily related to the Internet and internet browsing. The IAT is a measure related to compulsive internet use including escapism and addiction, while the use of smartphone applications includes internet browsing and additional use of various applications (e.g., games, movies, etc.). Moreover, only a few participants with a mild degree of internet addiction were registered in our sample. Hence, the generalization of results appropriate to a clinical picture of a typical internet addict was not possible. Modern smartphones have a multi-tasking function including a wide range of applications used not only for interpersonal communication, but also for performing business tasks, education, and entertainment (e.g., social networks, playing games). Thus, the capabilities of smartphones go beyond internet browsing. Therefore, higher levels of smartphone use do not necessarily imply tendencies toward internet addictive behavior.

Smartphone use was negatively correlated with sleep quality, anxiety, and stress, indicating that higher smartphone use reduced stress and anxiety whereas decreased sleep quality. This possibly suggests that higher levels of smartphone use are negatively related to sleep quality since a higher sleep quality score indicates sleep disturbances due to increased stress and anxiety. These findings are in line with the Compensatory Internet Use Theory (Kardefelt-Winther, 2014) stating that increased online activities occur to reduce negative emotions and dysphoric mood. This model may be used to explain extensive or problematic smartphone use, as interpreted by Elhai, Levine, et al. (2019). Smartphone overuse is a regulation strategy for reducing negative emotions and anxiety (Elhai, Levine, et al., 2019), as the results of our study clearly confirmed. In line with the Compensatory Internet Use Theory about possible positive (tension reduction) or negative (development of addictive behavior and disturbance in real social interactions) outcomes of increased smartphone use (Kardefelt-Winther, 2014), our findings showed that more frequent smartphone use played a role in positive outcomes. The mediation model showed no association between smartphone use and internet use. In addition, increased or decreased depression, stress, and anxiety did not model this relationship. Hypothetically, a possibility of a strong association between extensive smartphone use and internet use should not be excluded;

however, extensive smartphone use per se does not necessarily contribute to strengthening this association. One might wish to know what applications in smartphones and for what purpose users used during the survey period, given that those data would be very useful to infer the relation between smartphone use and depression. However, such data could not be registered due to a violation of the ethical principles of respecting participants' privacy. Even without those data, we still have a clear insight into the above-mentioned relationships, as we have already discussed.

The limitation of this study may be related to the sample including mostly female Serbian medical students possessing an Android smartphone, thus decreasing the possibility of generalizing results. The results could be mainly generalized to European countries. Further studies should carry out longitudinal research to examine whether long-term smartphone deprivation or at least limited daily use would result in increased stress and consequently in the development of depression. Future research should explore whether certain therapeutic treatments may be provided by smartphones to replace pathological behavior.

In summary, the present study showed a general bi-directional association between extensive smartphone use and depression. First, a bi-directional association may occur through stress as an oscillating factor of everyday life; second, extensive smartphone use may even reduce depression, through the mediating effect of stress reduction. Smartphones are such a powerful technological tool modulating a person's emotional life, even to the extent of potentially opening up a possibility of psychopathological development.

CRediT authorship contribution statement

Miloš Stanković: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Milkica Nešić:**Investigation, Resources.**Svetlana Čičević:**Investigation. **Zhuanghua Shi:**Writing - review & editing.

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