Mechanisms by Which Smartphone Use Affects Sleep

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Contributor: Santiago Correa-Iriarte , Sergio Hidalgo-Fuentes , Manuel Martí-Vilar

Sleep quality is a person's subjective assessment of how well they feel they have slept. There has been increasing concern about sleep-related problems (e.g., sleep efficiency, sleep latency, or sleep quality) due to the importance of sleep in the general health of the population, especially mental health. Problematic smartphone use (PSU) is defined as smartphone use associated with at least some element of dysfunctional use, such as anxiety when the smartphone is unavailable or abandonment of other activities due to smartphone use. Considering the widespread use of smartphones among the population and their suitability for use in bed, many health professionals have been interested in whether there is a link between increased screen use and sleep problems.

sleep quality | problematic smartphone use | circadian rhythms | increased arousal | bedtime procrastination

1. Introduction

Sleep quality is a person's subjective assessment of how well they feel they have slept [1]. In recent years, there has been growing concern about sleep-related problems (e.g., sleep efficiency, sleep latency or sleep quality) due to the importance of sleep in the overall health of the population, especially in mental health [2]. According to the Spanish Society of Neurology [3], more than 10% of the Spanish population will suffer from a severe chronic sleep disorder. In addition, 20–48% of Spanish adults and 20–25% of children have some difficulty initiating or maintaining sleep. There is no consensus on a gender difference in sleep quality, with some studies claiming that women have poorer sleep quality [4][5][6], while others do not find this relationship [7][8].

According to Stahl [9], disturbances in sleep–wake cycles are associated with an increase in mental disorders (e.g., major depression or anxiety disorders); immune system, cardiovascular and metabolic disorders (e.g., diabetes or stroke); neurological disorders (e.g., Alzheimer's dementia or chronic pain); endocrine dysfunction (e.g., in the hypothalamic–pituitary–adrenal axis); cancer; and other derived economic costs (e.g., loss of productivity or cost of accident repair).

Considering the health risks associated with sleep disturbances, data on the increase in sleep problems since the global COVID-19 pandemic may be cause for concern. A study of 19,267 adults in 13 Asian, American and European countries [10] found a significant increase in sleep and mental health problems since the COVID-19 pandemic. Similar results have been found in studies conducted in China [11], where the prevalence of clinical insomnia has increased by 37% since the COVID-19 pandemic, or in Spain, where 23.9% of a sample of 15,070 people reported having problems initiating or maintaining sleep [12]. Considering that during the confinements the amount of time spent in front of screens increased for people of all age ranges [13], many health professionals have been interested in whether there is a link between increased screen use and sleep problems.

This becomes even more relevant when considering the widespread use of smartphones in the population and their suitability for use in bed [14]. In the case of Spain, and according to data from the National Institute of Statistics (INE) [15], 99.2% of people aged 16–74 used smartphones in the three months prior to the survey (conducted in November 2022). Smartme Analytics [16] reflects in its latest report that Spanish adults use, on average, a smartphone for 3 h and 40 min, a figure that increases to 4 h and 15 min a day in the case of young people between 18 and 24 years old.

Problematic smartphone use (PSU) is defined as the use of a smartphone associated with at least some element of dysfunctional use, such as anxiety when the smartphone is not available or neglect of other activities due to smartphone use [17]. These negative or dysfunctional effects can range from withdrawal to loss of control over phone use, decreased productivity, impaired daily functioning, detriment to social relationships or damage to physical health [18][19][20][21]. PSU is closely related, or even overlapping, with other phenomena such as problematic use of social networks, messaging apps or the internet [22][23][24]. However, there are some differences in terms of risk factors, for example, men tend to develop more problematic internet use, while women are more at risk of manifesting PSU [25]. The terminology related to behavioural addictions when researching smartphones is controversial, as some authors think that this may stigmatise smartphone users [21]. Moreover, PSU is not listed as an addiction in any of the main diagnostic manuals, neither the DSM-5 [26] nor the more recent ICD-11 [27]. Thus, in addition to “problematic smartphone use” and “smartphone addiction” other terms have been used to describe this type of relationship with smartphones: “excessive use”, “compulsive use” and “compensatory use” [28][29][30].

The prevalence of PSU in adults varies in different countries, for example, in Arabia it is 66.9% [31], in Bangladesh 61.4% [32] and in China estimates range from 65.8 to 52.8% [33]. Likewise, in Spain, several studies have placed the prevalence of PSU between 20.5 and 23.75% [34][35]. It is worth noting the difficulty in assessing and comparing the prevalence of PSU due to the inconsistency of diagnostic criteria and assessment methods [36]. Additionally, although some studies have found no sex differences [37], there is some consensus in the scientific evidence that women are at higher risk of developing PSU [38][39][40][41][42][43][44][45]. These differences could be caused by a different pattern of smartphone use, with women using smartphones for social purposes (i.e., social networking or instant messaging) and men for more varied purposes, such as video games, calls, and multimedia content [46][47]. In addition, women (especially younger women) may have a higher prevalence of PSU due to having more malleable and influenceable self-control in social situations than men [48][49].

Several negative consequences of PSU have been found, such as low productivity [50], poor academic performance [51][52], general procrastination [53], academic procrastination [54], low self-esteem [55], increased alcohol consumption [52], anxiety and depression [56][57][58], executive function deficiencies [59][60] and sleep problems [61][62][63][64][65].

2. Disruption of Circadian Rhythms

First, it has been proposed that smartphone use close to sleep time may alter the production of melatonin and/or cortisol, both of which are important hormones in the regulation of circadian rhythms.

Melatonin is a hormone secreted by the pineal gland and regulated by sleep-inducing light/dark cycles. The pineal gland is a neural structure related to the visual system and has retinohypothalamic connections with the suprachiasmatic nuclei that house the internal biological clock and play a crucial role in generating circadian rhythms. It has been shown that light exposure in the evening can delay the phase of the internal clock, resulting in sleep problems, while light exposure in the morning advances melatonin secretion [66].

Cortisol, on the other hand, is a steroid hormone produced in the adrenal cortex, related to sleep arousal and wakefulness [67]. Cortisol shows a circadian rhythm, with a peak at the transition between sleep and wakefulness. After awakening, secretion of the hormone decreases throughout the day, reaching a minimum around midnight, before gradually increasing again to reach a new peak the following morning. Thus, cortisol, like melatonin, serves as a marker of an organism's circadian temporal structure, regulating the sleep/wake cycle.

LED-backlit displays (such as smartphones) emit 3.3 times more light in the blue range (440–470 nm) than non-LED-backlit displays (e.g., some eReaders or displays using cathode ray tubes), as reported by Cajochen et al. [68] This difference is relevant as studies indicate that human circadian physiology and alertness levels are particularly sensitive to short-wavelength light [69][70][71][72].

Night-time exposure to an LED-backlit computer screen has been shown to cause a decrease in salivary melatonin levels [69] and an increase in waking time, along with improved cognitive performance, sustained attention, and working and declarative memory [68][73]. However, any delay in the circadian release of melatonin has negative consequences for sleep induction [74]. Schmid et al. [75] compared the effect on melatonin, cortisol and sleep levels of reading before sleep on a smartphone versus reading a printed book. They found that melatonin and cortisol levels were found to be altered in the smartphone use condition, in addition to a reduction in slow wave sleep. According to a study by Wallenius et al. [76], school children who used digital media for three hours a day showed a decrease in the cortisol increase one hour after waking up, showing an alteration in the circadian rhythm that this hormone follows. In contrast, children who used digital media for less than three hours or not at all showed a typical increase in cortisol in the morning. Another study with children showed a greater increase in cortisol just after using DVD screens versus playing with wooden blocks [77].

It is worth noting that the closer-to-face use of smartphones compared to other traditional media such as television [78], which is usually placed at a greater distance from the face, can lead to greater exposure to shortwave light [79] and thus cause greater sleep disturbance compared to other types of screens. In fact, a study by Figueiro et al. [80] found that the light emitted by 70-inch LED-backlit LCD televisions located 1.8 to 2.7 metres from the subjects did not alter melatonin production in adults.

Regarding radiofrequency electromagnetic fields (RF-EMFs) emitted by smartphones, a review of the literature by Selmaoui and Touitou [81] states that no conclusive evidence has been found that this type of radiation alters melatonin or cortisol secretion. Instead, according to these authors, there are indications that melatonin may be a protective agent against the negative effects of RF-EMFs, such as oxidative stress and DNA damage, as well as having neuroprotective properties.

3. Increased Arousal

According to another line of research, increased arousal (especially cognitive and somatic arousal) before sleep may negatively influence sleep quality.

A study by Kheirinejad et al. [82] used the OURA wearable [83] to measure different components of sleep and the AWARE instrument [84] to assess smartphone usage by automatically collecting usage data. They concluded that the cognitive activation required during bedtime to perform different smartphone uses, such as conversing with other people or consuming images, text, video and audio, have a negative impact on sleep quality, but without a significant difference between them. On the other hand, Ong et al. [85] proposed a model in which two types of cognitive arousal, primary and secondary, contribute to the maintenance of insomnia. Secondary (metacognitive) cognitive arousal would encompass biases towards sleep-related thoughts and behaviours, rigidity in behavioural or sleep-related beliefs, and absorption in sleep problem solving. Primary cognitive arousal would consist of expectations about sleep, beliefs about the daytime consequences of sleep deprivation and, what concerns us in this section, increased mental activity at bedtime.

One of the main uses of smartphones is social media and communication applications, which sometimes require high cognitive functioning, which is not suitable for sleep induction or good sleep quality [86]. Specifically, of the 3 h and 40 min of smartphone time per day of Spanish adults, 1 h and 20 min are spent on social networks and another 40 min on instant messaging applications [16], which combined account for more than 50% of the total time spent on smartphones. It has been shown how increased arousal before sleep is a mediating variable between the negative effect of binge-watching TV series via smartphones [87] or the use of social networks [88] on sleep quality.

However, although correlational studies point to increased arousal as a possible cause of reduced sleep quality [89][90][91], an experimental study blocking the effect of blue light from smartphones conducted by Combertaldi et al. [92] found no such relationship. They did not observe empirical evidence of increased arousal from the use of social networks such as WhatsApp or Snapchat, nor a reduction in sleep quality. The authors hypothesise that the negative effect of smartphone use on sleep quality is due to the use of smartphones at bedtime (which usually exceeds 30 min) and its corresponding displacement of sleep time.

4. Bedtime Procrastination and Sleep Displacement

Self-regulation, according to Gillebaart [93], can be defined as the cognitive ability to monitor, plan and guide a person's behaviour to facilitate goal attainment and inhibit disruptive emotions and behaviour. Proper self-regulation requires adequate functioning in the brain's reward system and top-down control of the prefrontal cortex [94]. As Zhang and Wu [95] point out, it has been shown that addictive behaviours can alter brain circuits related to self-regulation such as prefrontal cortex functioning and top-down control [96][97][98][99][100]. A deficit in inhibitory control, a feature closely related to self-regulation, is present in individuals with a PSU [101]. Additionally, Rebetez et al. [102] suggested the depletion of self-regulatory resources and the failure of self-regulation as a source of procrastination. Thus, when talking about self-regulation and sleep, we must talk about bedtime procrastination, a relatively recent concept [103] that is defined as the action by which people deliberately delay going to bed without external interference, even though negative outcomes are anticipated.

A qualitative study by Nauts et al. [104] found three reasons why people procrastinate sleep: deliberate bedtime procrastination, unconscious bedtime procrastination and planned delay. The first refers to consciously delaying sleep time to perform tasks that could be done at another time or to have a moment to oneself after a long day of work. Unconscious bedtime procrastination occurs when, for example, people lose perception of time while absorbed in a task. Finally, strategic procrastination is when people make a conscious decision to delay sleep in order to avoid negative emotions related to rumination, long sleep latency or as a remedy for insomnia (accumulating "sleep pressure"). However, some authors argue that the belief held by these subjects that sleep delay benefits them (even if it does not) means that strategic delay is not considered bedtime procrastination per se [104][105][106].

Kroese and De Ridder [106] indicate how people with low self-regulation show higher bedtime procrastination as well as insufficient sleep. Another study by Ma et al. [107] involving 1550 university students found that bedtime procrastination is a strong predictor of prevalence and severity of poor sleep quality. Authors have proposed that smartphone use may be one of the causes of the so-called displacement theory. This theory is based on the idea that unstructured leisure use of electronic devices, such as smartphones, can displace other activities, such as sleep. Thus, smartphone use may delay sleep time (causing bedtime procrastination) and possibly reduce the amount of sleep, or even create an association between being in bed and being active [108][109][110]. In this regard, a study conducted in China involving 2741 university students found that a total of 57.5% of their sample used a smartphone in bed [111]. At the same time, a Danish study [112] found that 12% of participants used their smartphone for 3–5 h late at night. There is no consensus regarding gender differences in bedtime procrastination, as some studies find significant differences [113], while others do not [114].

In addition, procrastination using the smartphone can induce negative self-evaluations such as self-defeating thoughts [115]. Consequently, these self-evaluations may in turn cause stress [116], guilt [117] or feelings of self-condemnation [118], which manifest as sleep problems [115]. The same can be inferred to be true for bedtime procrastination, as it is a form of procrastination and has been directly linked to depression [119]. The opposite relationship has also been observed, where rumination and other forms of negative affect may increase bedtime procrastination and thus affect sleep quality [120]. Moreover, some studies suggest that smartphone use may be a form of experiential avoidance of negative emotions [121]. This could be explained by the bidirectional relationship between PSU, increased depressive or anxious symptoms, and vice versa [122][123]. In addition, it has also been shown that the ability of smartphones to impair sleep quality and sleep drift can increase symptoms of depression and stress [124]. Simultaneously, PSU itself may increase depression and anxiety, and thus impair sleep [61]. This impact could form a vicious cycle in which negative emotions (including depressive and anxious symptoms towards sleep quality or bedtime procrastination) lead to maintaining or increasing their smartphone use and fuel negative affectivity.

Recently, different authors have conducted different studies based on mediational analyses observing how the impact of smartphone use (problematic or not) in sleep quality is mediated by bedtime procrastination, in addition to other variables such as self-regulation [95], psychological detachment [125] or fear of missing out (or FoMO) [126]. A similar phenomenon has been observed in the impact of problematic internet use and poorer sleep quality, mediated by bedtime procrastination [127].

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