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Smartphone Use, Social Support, and Sleep Health

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Abstract. To be determined

Key words: healthcare, smartphone overuse, social support, sleep health, health wearables

1. Introduction

1.1. Practical Motivation

1. Sleep is known as the foundation of health and well-being. (Ramar et al. 2021)

(a) **The significance of sleep deprivation.** Insufficient sleep is increasingly considered a global public health epidemic (Chattu et al. 2019). The Centers for Disease Control and Prevention (CDC) report that approximately one in three adults in the United States fail to reach the recommended amount of sleep.¹

(b) **The worsening trend of sleep deprivation.** Research shows that a human's average sleep duration decreased year by year from 1975 to 2011 and the reduction is particularly significant for middle age

¹<https://www.cdc.gov/sleep/index.html>

group(Hublin et al. 2020). Consequently, other evidence suggests that people with sleep duration of less than six hours increased 31% from 1985 to 2012(Ford et al. 2015).

2. **Highlight the Consequences of Long-Term Sleep Det.** Adequate and high-quality sleep is essential for human physical and mental health(Ramar et al. 2021). Sleep deprivation has multiple impacts on

- (a) Physical Health. Chronic disease, reduced life expectancy...
- (b) Mental Health. Cognitive impairment, memory problems...
- (c) Behaviors. Decrease in productivity, poor decision making..

3. **Smartphone use is one of the most direct and important reasons for sleep deprivation.** Among the various causes of sleep deprivation, smartphone overuse is one of the most common but easily overlooked ones.

(a) **The increasing trend of smartphone overuse.** The time Americans spend on mobile screens significantly increased from 225 minutes in 2019 to 276 minutes in 2023,² which is equal to 14.95 years of one's entire life.

1.2. Research Gap.

1. Evidence Gap:

(a) **On the one hand, smartphone overuse contributes to sleep deprivation.** Several studies suggest that excessive smartphone use is a contributing factor in the worsening of sleep health (Cabr -Riera et al. 2019, Chung et al. 2018, Dewi et al. 2021) (Predominant)

(b) On the other hand, smartphones also plays a significant role in **facilitating interpersonal connection and social interaction/engagement**. For example, smartphones introduce unique and different ways of communicating/staying in touch. (Just a few studies) Build tensions

- i. Reduces the communication barrier of physical distance.
- ii. Improves the flexibility of communication. Frequency of communication is higher
- iii. Supports asynchronous communication
- iv. Improves the richness of communication (Text, image, Hyperlinks, etc.)
- v. Supports the chat of different people

(c) Some studies suggest that **social use** can be particularly problematic compared to non-social use, as it can easily cause overuse (Lopez-Fernandez et al. 2014, Lopez-Fernandez 2017, Rozgonjuk et al. 2019, Zhitomirsky-Geffet and Blau 2016). However, Dissing et al. (2021b) showed that **social interaction** based on smartphones benefits users mental health and sleep, making the impact of smartphone use **contradictory**.

(d) Smartphones support multiple types of tasks, with social and non-social use usually **mixed**(Zhitomirsky-Geffet and Blau 2016). To the best of our knowledge, no study has examined the two types of usage in the context of overall use and their distinctive impacts comprehensively. (don't be too specific)

²<https://www-statista-com.ezproxy.lib.vt.edu/statistics/1045353/mobile-device-daily-usage-time-in-th>

2. **Knowledge Gap:** Although a few studies investigated the impact of social smartphone use on sleep, it is not clear whether communication with **different contacts** has a different impact, considering interpersonal social closeness and relationships vary.

3. **Empirical Gap:**

(a) Prior research largely relies on self-reported data to measure phone use and (or) sleep quality, limiting the conclusions' objectivity and reliability.

(b) The proliferation of mobile technologies has enabled us to obtain objective data on smartphone usage, and the development of wearable technologies has made it possible to monitor individuals' sleep behaviors in real-time.

To sum up, our research questions are summarized as follows:

(a) **Research Question 1** What is the overall impact of smartphone use on sleep quality?

(b) **Research Question 2** Does communication and non-communication smartphone use impact sleep differently?

(c) **Research Question 3** Does communication with different contacts have different impacts on sleep?

1.3. Research Methodology

1. **Data description.** Elaborate how the data is collected
2. Highlight both measurements of DV and IV are **objective**.
3. **Estimation strategy:** Fixed effect model

1.4. Results and Findings

1. **RQ1: the overall impact of smartphone use**

(a) We observe a **U-shaped relationship** between sleep debt and screen time: Moderate smartphone use has a positive impact on sleep, but excessive screen time leads to sleep debt after a certain point, at which point smartphone use becomes problematic.

(b) Unlock frequency consistently **increases** sleep debt

2. **RQ2 : communication vs non-communication smartphone use**

(a) we observe heterogeneous effects from communication and non-communication smartphone use. Specifically, we find that **communication use consistently reduces sleep debt**, suggesting that social support through mobile communication helps reduce sleep debt.

(b) Communication level moderates the impact of overall smartphone use: screen time with a high communication level is associated with lower sleep debt.

3. **RQ3: the moderating impact of social distance.** We observe that the impact of communication-driven screen use is moderated by social distance, which is measured by

- (a) perceived social distance (close contacts reduce sleep debt)
- (b) social relationships (family contacts reduce sleep debt)

1.5. Robustness Checks

1.6. Contributions

1. Our research contributes to multiple research streams in **information systems and healthcare**.

(a) We contribute to the literature on information technology (IT) and the developing streams of work evaluating mobile technologies and their impacts and the broader potential of the **adoption of IT** and its impact on human well-being. (mobile use, technology use)

(b) **Digital Addiction** The study also contributes to information systems (IS) and healthcare on digital addiction. The prevalent strategies for reducing digital addiction primarily focus on reducing screen time, either by incentives or by access limitation (Allcott et al. 2022, McDool et al. 2020), which can be costly and effort-consuming. Our study shows that by slightly switching the purpose of smartphone use, users can effectively reduce the adverse effects of digital overuse. Our findings suggest that smartphone users can strategically leverage healthy social relationships to manage their stress and mental health, thus improving their sleep health. Also, our findings have the potential to broaden the individuals' treatment and management of insomnia.

(c) The study sheds light on the role of social support in mitigating the adverse effects of technology misuse, we advance the contemporary knowledge on reducing the dark side of technology use by providing a nuanced understanding of the underlying mechanisms.

(d) Impact of health IT on population health

2. Contribute to **sleep health literature** We identify a novel approach to mitigate the negative effects of smartphone overuse and promote sleep quality. Our study uncovers the mechanisms of the positive impacts of smartphone use on sleep, showing that strategically using smartphones helps reduce sleep debt (Dissing et al. 2021a,b, 2022).

3. Most research in sleep literature deems smartphone use as a significant factor that contributes to sleep deprivation; this study reveals that smartphones can play a positive role if it is properly used.

4. Improving the caring experience for sleep with little effort (Buysse 2014)

5. Has broad implications for the sleep health of the population

2. Background(Literature)

2.1. Sleep Deprivation

1. Describe **sleep epidemic** (trends). Highlight the significance of sleep deprivation. For example, one-third of Americans do not have enough sleep.

2. Introduce the definition of **sleep debt**, where sleep debt is defined as the amount of sleep one lacks on a particular day.

2.1.1. The Consequences of Sleep Debt/Deprivation

1. Physical Health Consequences

(a) Chronic Diseases \Rightarrow Reduced Life Expectancy

(b) Hormonal Imbalances \Rightarrow Obesity.

2. Mental Health Consequences

(a) Cognitive Impairment. For example, memory Problems.

(b) Mood and Mental Health Disorders

3. Behavioral Consequences

(a) Poor Decision Making

(b) Decreased Productivity

Essentially, one **cannot** completely **makeup** for the sleep they lost. The harm of sleep deprivation is difficult to make up for (Itani et al. 2017, Dudley 2019).

2.2. Smartphone Use and Sleep Health

Elaborate on the literature on the relationship between smartphone use and sleep health(Research gaps).

2.2.1. Effect of Smartphone Use on Sleep The preponderance of studies suggest that mobile use harms sleep quality. However, the current evidence is conflicting and not conclusive.

1. Negative Effects:

(a) Crowding-out effect on sleep time;

(b) Intensive usage can cause users' physiological resources to be consumed, leading to symptoms such as staying up late (Salo et al. 2019)

(c) Increases exposure time to blue light;

(d) Smartphone overuse can make users stressed out (Condliffe 2017)

2. **Positive** Effects: However, understanding the impact of pre-sleep smartphone use on sleep is not so simple.

(a) Social support

(b) Playing smartphones provide psychological comfort and stress relief (Melumad and Pham 2020)

(c) Constant checking is not an addiction; instead, it satisfies users' need to stay up to date (Gerlach and Cenfetelli 2020). Checking smartphones can also reduce FOMO.

(d) Using smartphones for leisure activities increases psychological **detachment from work/study** (Hülshager et al. 2014).

1. Some studies suggest social use is more problematic (Lopez-Fernandez 2017, Lopez-Fernandez et al. 2014, Rozgonjuk et al. 2019, Zhitomirsky-Geffet and Blau 2016)

2. The others suggest that non-social use is more problematic (Elhai et al. 2017, 2018). Furthermore, evidence suggests that smartphone use can benefit sleep under certain conditions (Janin 2024)

2.2.2. Strategies for combating smartphone overuse

1. Incentives
2. Access Limitation (Morris 2017)

Limitations: the above strategies can be costly and effort-consuming (Allcott et al. 2022, McDool et al. 2020).

2.3. Social Support

Social support refers to the perception or assistance one receives from her or his social networks (Taylor 2012, Langford et al. 1997). Evidence suggests that social support benefits both mental and physical health (Taylor 2012)

1. Benefits of Social Support on Health Wellbeing (Thoits 2011)
 - (a) **Emotional Support.** Talking to people helps get past negative emotions.
 - (b) **Companionship.** Social interaction promotes a sense of safety, belonging and security. Decrease the feelings of loneliness, isolation, and anxiety.
 - (c) **Informational Support.** Individuals can receive advice or guidance through their smartphones to help solve problems. Thus, informational support helps individuals relieve stress.
 - (d) **Instrumental Support.** Provide tangible assistance and help. Therefore, instrumental support helps reduce stress.
2. Social support mitigates and prevents distress (Lin and Ye 1999). The social support level of IT managers is negatively correlated with stress level (Weiss 1983).
3. Social support reduces problematic smartphone use (Şimşek et al. 2024)
4. Social support enhances sleep quality (Kent de Grey et al. 2018). Presleep negative emotions are correlated with sleep fragmentation (Vhaduri and Poellabauer 2018) Using smartphones for communication facilitates the **transmission** of social support and contributes to the **development** of supportive relationships (?).

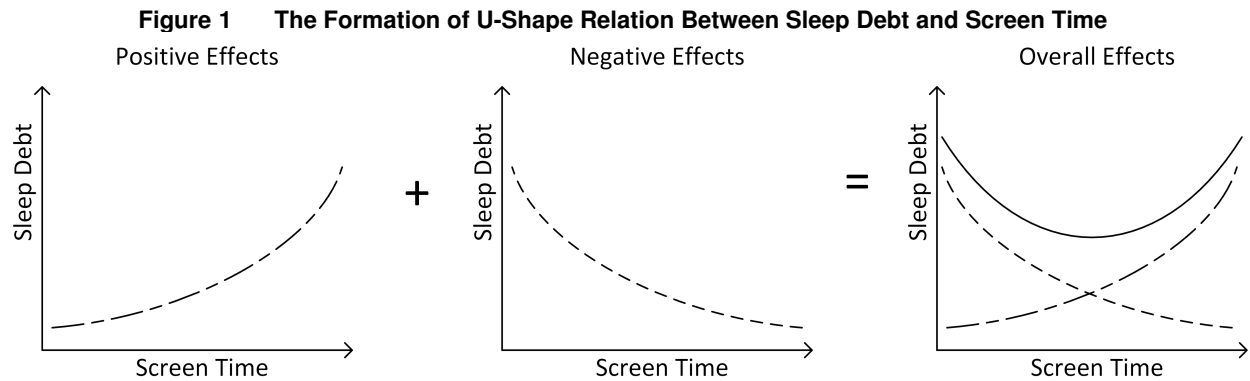
3. Hypothesis Development

3.1. The Impact of Overall Smartphone Use (RQ1)

1. Smartphone usage is one of the most direct and important reasons for sleep deprivation. The measurement of smartphone usage can be measured by:
 - (a) **duration**
 - (b) **frequency** (Marciano and Camerini 2022)

3.1.1. Duration Discuss why and how pre-sleep **duration** of smartphone use impacts sleep debt.

1. “*The dose makes the poison.*” The impact of overall smartphone use on sleep debt may depend on the **amount** of use, and moderate smartphone use could benefit sleep.



2. The benefit effects dominate the overall impact of smartphone use before the turning point; after that, the benefit diminishes, and it is dominated by the harmful effects.

We hypothesize that:

Hypothesis 1a *There exists a U-shaped relationship between sleep debt and the amount of smartphone use before sleep.*

3.1.2. Frequency

1. Unlock frequency causes sleep debt as it increases users' alertness:

(a) **Interrupting the transition to a peaceful state** Frequent unlock actions may cost mental effort, interrupting the relaxation process and increasing alertness, prolonging users' time to fall asleep.

(b) **Cognitive Load.** Frequent unlocking may increase users' cognitive load, making it harder for individuals to transit to a peaceful state (Wilmer et al. 2017, Upshaw et al. 2022). Particularly for **passive** mobile checks.

Therefore, we hypothesize that:

Hypothesis 1b *The pre-sleep unlock frequency of smartphones **increases** sleep debt.*

3.2. The Effects of Social Support in Smartphone Usage (RQ2)

3.2.1. The Impact of Communication-Driven Smartphone Use In addition to the duration and frequency of usage, the **purpose** of smartphone use may also impact sleep debt.

1. The relationship between social support and mobile use:

(a) Individuals are increasingly dependent on digital technologies for receiving social support (Huang et al. 2019). Received social support positively correlates with smartphone usage (Raven et al. 2018)

(b) Smart technologies enhance the social connectedness for senior people at home (Morris et al. 2014).

(c) Information communication technology (ICT) can alleviate social isolation, thus enhancing social support among the elderly (Chen and Schulz 2016).

2. Considering the benefits of social support on sleep, we hypothesize that communication-driven smartphone use benefits sleep by facilitating the provision of social support.

3. Evidence implies that using smartphones may benefit **mental health** if it is used for **social** (Dissing et al. 2021b, 2022).

3.2.2. The Impact of Non-Communication Smartphone Use On the other hand, non-communication use:

1. Smartphone is a derivative of dumb phone. It provides richer and endless stimulating content that increases users' alertness (gaming, short videos, etc.)

2. Increases anxiety and stress due to social media comparison (Yang et al. 2023)

3. Increases cognitive load due to intense activities (productivity, etc.)

4. Prolong overall smartphone use as it provides various sources of **overuse** (Burr et al. 2018):

(a) Rewarding stimulants such as gaming (Trevor Haynes 2018)

(b) Contents based on personalized recommendation. For example, short videos (Gao et al. 2024)

(c) Richer activities: reading, shopping, video watching

(d) Endless content consumption

5. Lacks the benefit of social support.

Considering the distinction between communication and non-communication smartphone use, we hypothesize that:

Hypothesis 2 *An increase in the proportion of communication-driven smartphone use before sleep decreases sleep debt.*

3.3. Moderating Impact of Social Distance (RQ3)

1. **Determinants of Social Support.** Evidence suggests that the social support received by individuals is influenced by a social psychological distance (Fuller et al. 2020).

(a) Closer social distance could

i. Increase **Strength** of social support ↑.

ii. Increase **Diversity** (types) of social support ↑. (Gottlieb and Bergen 2010)

Thus, we hypothesize that:

Hypothesis 3 *Pre-sleep communication with contacts that have closer social distance from the smartphone user **reduces** sleep debt.*

2. We take perceived **social closeness** as the main measurement of social distance and take **social relationships** as an alternative measurement since certain types of social relationships (e.g., family and romantic partners) are usually deemed to have closer social distance.

4. Methodology

4.1. Data

1. **Description of the longitudinal study** To investigate the impact of pre-sleep smartphone usage and sleep debt, we conducted an extensive data mining effort using a longitudinal study that monitored participants' smartphone usage, sleep, and physical activity behaviors from 2015 to 2019.

2. **Description of the Data Set** Discuss the setup of the measurement window and how we extract DVs and IVs.

(a) The Measurements of DV (Sleep Quality)

(b) The Measurements of Overall Use IVs (screen time, unlock frequency). We take **screen time** and **unlock frequency** as measurements of overall smartphone use, as most Human-Smartphone Interactions are through the screen.

(c) The Measurements of Communication IVs (message, social relationships and social distance)

4.2. Model

1. RQ 1 & H1: Estimation of the Impact of Overall Smartphone Use on Sleep Debt

$$\text{Sleep Debt}_{it} = \beta_0 + \beta_1 \cdot \text{ScreenTime}_{it} + \beta_2 \cdot \text{Screen Time}_{it}^2 + \beta_3 \cdot \text{Unlock}_{it} + \gamma \cdot X_{it} + \theta_i + \lambda_t + \varepsilon_{it} \quad (1)$$

ScreenTime_{it} screen time used by an individual *i* on the day *t*; *Unlock_{it}* refers to the number of the screen unlock and lock actions; *Message_{it}* refers to the messages before users fall asleep; *Close_{it}* is a dummy indicating whether messages from **close** contacts; *Relationship_{it}* is a dummy indicating the **relationships** of contacts; *X_{it}* are the control variables such as daily steps, day of a week and break or non-break of a day; θ_i controls for the individual fixed effect (students); λ_t controls for the time-fixed effect (week).

(a)

2. RQ 2 & H2: Estimation of the Impact of Communication-Driven Smartphone Use on Sleep Debt

(a) Estimate the **moderating impact** of communication:

$$\begin{aligned} \text{Sleep Debt}_{it} = & \beta_0 + \beta_1 \cdot \text{Screen Time}_{it} + \beta_2 \cdot \text{Screen Time}_{it}^2 \\ & + \beta_3 \cdot \text{Message Level}_{it} + \beta_4 \cdot \text{Message Level}_{it} \cdot \text{Screen Time}_{it} + \beta_5 \cdot \text{Message Level}_{it} \cdot \text{Screen Time}_{it}^2 \\ & + \beta_6 \cdot \text{Unlock}_{it} + \gamma \cdot X_{it} + \theta_i + \lambda_t + \varepsilon_{it} \end{aligned} \quad (2)$$

(b) Alternative specification for RQ2, estimate *NonCommTime_{it}* and *CommTime_{it}* **separately**:

$$\begin{aligned} \text{Sleep Debt}_{it} = & \beta_0 + \beta_1 \cdot \text{NonComm Time}_{it} + \beta_2 \cdot \text{NonComm Time}_{it}^2 + \\ & \beta_3 \cdot \text{Comm. Time}_{it} + \beta_4 \cdot \text{Comm. Time}_{it}^2 + \beta_5 \cdot \text{Unlock}_{it} \\ & + \gamma \cdot X_{it} + \theta_i + \lambda_t + \varepsilon_{it} \end{aligned} \quad (3)$$

3. RQ 3 & H3: Estimation of the Moderating Impact of Social Relationship and Closeness

$$\begin{aligned} \text{Sleep Debt}_{it} = & \beta_0 + \beta_1 \cdot \text{ScreenTime}_{it} + \beta_2 \cdot \text{Screen Time}_{it}^2 + \beta_3 \cdot \text{Unlock}_{it} \\ & + \beta_4 \cdot \text{Screen Time}_{it} \cdot \text{Close/Relationship}_{it} \\ & + \gamma \cdot X_{it} + \theta_i + \lambda_t + \varepsilon_{it} \end{aligned} \quad (4)$$

5. Results

5.1. Effects of Overall Smartphone Use

5.1.1. Effects of Screen Time U-shaped relationship between screen time and sleep debt.

5.1.2. Effects of Unlock Unlock consistently increases sleep debt.

5.2. Effects of Communication-Driven Smartphone Use

1. Message consistently increases sleep debt.
2. Message level moderates the impact of screen time
3. Communication-driven curve can increase sleep debt due to social overload (Maier et al. 2015)

5.3. Moderating Impact of Social Distance and Relationship

5.3.1. Moderating Impact of Social Distance

5.3.2. Moderating Impact of Social Relationships Our results suggest there is a U-shaped relationship between sleep debt and screen time. Therefore, H1a is partially supported. H1a, H1b, H2, H3 are supported.

6. Robustness Checks

6.1. Endogeneity Issues

6.1.1. Dynamic Panel Model

1. The sleep debt from the previous day can impact the amount of sleep needed: one may need to make up sleep today if the person's sleep is significantly deprived.

2. We extend our main specification to a dynamic panel model (Arellano-Bond Model) by including lagged dependent variables.

3. GMM Specification captures unobserved variables and addresses simultaneity endogeneity:

$$\text{Sleep Debt}_{it} = \beta_0 + \beta_{L1} \cdot \text{Sleep Debt}_{it-1} + \dots \beta_{Ln} \cdot \text{Sleep Debt}_{it-n} + \beta_1 \cdot \text{ScreenTime}_{it} + \beta_2 \cdot \text{Screen Time}_{it}^2 + \beta_3 \cdot \text{Unlock}_{it} + \gamma \cdot \mathbf{X}_{it} + \theta_i + \varepsilon_{it} \quad (5)$$

6.1.2. Busyness To capture the unobserved variable of busyness, we conduct sub-group analyses based on busyness:

1. Weekday Vs. Weekend
2. Break Days Vs. Non-Break Days

6.1.3. Reverse Causality: Lagged First-Difference (LFD) Empirical researchers have suggested using Lagged First-Difference (LFD) to address the problem of reverse causality (Leszczensky 2013, Levanon et al. 2009, Martin et al. 2012)

6.1.4. Alternative Measurement of Social Use We take the number of contacts as an alternative measurement of message Times.

6.1.5. Moderating Impact of Self-Reported Sleep Quality

6.1.6. Moderating Impact of Socioeconomic Status

6.1.7. International Students/WhatsApp Message Time Separately

6.1.8. Outliers Analysis

6.2. Validation for U-Shaped Relationship

6.2.1. Goodness of Fit

6.2.2. Outlier Treatments

6.2.3. Test for U-Shaped Relationship: Spline Regression Spline Regression may work as a robustness check for U-Shape relationship (Kesavan et al. 2014, Huang et al. 2023, Tan and Netessine 2019, Xu et al. 2022, Zou et al. 2023)

$$\frac{d\text{Sleep Debt}}{d\text{Screen Time}} = \begin{cases} a_1 & \text{if Screen Time} < 36 \\ a_2 & \text{if } 36 \leq \text{Screen Time} < 72 \\ a_3 & \text{if } 72 \leq \text{Screen Time} < 108 \\ a_4 & \text{if } 108 \leq \text{Screen Time} < 144 \\ a_5 & \text{if } 144 \leq \text{Screen Time} < 180 \end{cases}$$

6.2.4. Stationary Point Check For a valid U-shaped relationship, the stationary point should be in the range of observations (Haans et al. 2016).

7. Heterogeneous Effect of Smartphone Use

The results of robustness checks support our main findings.

8. Discussion

8.1. Implications

8.2. Limitations and Future Research

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