**Investigating the Impact of Smartphone Addiction on Cognitive Control: Insights from Behavioural and Electrophysiological Evidence in the Navon Task**

**Abstract**

The pervasive use of smartphones has raised concerns about potential addiction and its impact on cognitive functions. This study intends to investigate how smartphone addiction affects cognitive performance through Navon oddball task. A pilot study with six university students explored the initial effects, confirming the effect of smartphone addiction. While EEG data analysis was not conducted, hypotheses based on prior research suggest that smartphone may disrupt early cognitive processes for those with higher susceptibility to smartphone addiction, as reflected in N2 and P2 components. These findings may underscore the importance of understanding the impact of smartphone addiction on cognitive control and facilitates potential interventions to mitigate distractions associated with smartphone use.

1. **Introduction**
   1. **Background**

In the digital era, smartphones have emerged as the most widely used devices. According to the Pew Research Center, 94% of adults in advanced economies own a smartphone or a similar device (Taylor & Silver, 2019). However, the wide spread of smartphone has increased the concerns about its addiction potential. Although neither the DSM-5 nor the ICD-11’s draft has mentioned smartphone addiction, screening studies have identified three key criteria of smartphone addiction: (1) six symptoms of smartphone addiction (Impulse Control Failure, Withdrawal Symptoms, Excessive Use Duration, Quitting Difficulty, Time Consumption, Usage Despite Consequences), (2) four functional impairment (Usage-Induced Problems, Hazardous Use, Social/Work Disruption, Distress/Time Consumption) and (3) the exclusion criteria to rule out manic episodes and Obsessive Compulsive Disorder (OCD) (Choi et al., 2015; Jin Jeong et al., 2020; Kwon et al., 2013; Lin et al., 2016; Rozgonjuk et al., 2023).

Based on these criteria, studies about smartphone addiction have expanded in recent years, which connected it to various critical aspects of life, including social interactions (Przybylski & Weinstein, 2013), academic performance (Lepp et al., 2014; Rosen et al., 2018), and mental wellbeing (Twenge, 2019). High levels of social media engagement in smartphone have also been associated with an increased risk of severe anxiety (Vannucci et al., 2017), behavioral and attention issues (Rosen et al., 2014), and heightened suicide-related outcomes (Rosen et al., 2014).

* 1. **Cognition and Smartphone Addiction**

In cognitive studies, a common element about the impact of smartphones addiction is its effect on users’ executive functions, where emerging evidence suggests a correlation between increased smartphone usage and diminished performance in tasks that measure cognitive control (Liebherr et al., 2020; Wilmer et al., 2017). For instance, heavy smartphone users displayed reduced ability to sustain attention during mathematical tasks (Hadar et al., 2017). Individuals engaged in high levels of social media in smartphones also presented an inability to ignore the irrelevant stimuli and tend to show increased attentional impulsivity (Ophir et al., 2009; Sanbonmatsu et al., 2013). Despite the concerns about smartphones' negative effects, a few behavioral studies have indicated potential cognitive benefits associated with their presence. For example, research by Liu et al. (2023) observed that participants exhibited faster reaction times in various trials with the presence of smartphone, although this was also associated with a higher rate of incorrect responses. On the other hand, these results may be attributed to participants’ attention shifting from the task to the smartphone, leading to hurried responses that decrease reaction time but increase errors.

To further explore the relationship between smartphone usage and cognitive control, it would be beneficial to utilize neurophysiological tools such as electroencephalogram (EEG), as it can monitor fluctuations in attention when a participant’s attention lapse during the task. This capability is crucial for assessing the impact of smartphones on cognitive tasks in real-time, offering a more comprehensive understanding of how smartphone addition level and the presence of smartphone interplay to affect cognitive control.

* 1. **Present Study**

Consequently, the current study aims to investigate the impacts of smartphone on behavioral and neural indicators of cognitive control involved in stimulus categorization. We will utilize the Navon Task, a local/global hierarchical letter three-stimulus oddball paradigm, which could be used to assess event-related potentials (ERPs) and behavioral performance (Katayama & Polich, 1998; Polich, 2007). The Navon task requires participants to shift their attention and update their working memory to accurately respond to target letters, while also being alert to rare distractor letters that appear at different levels of visual focus (Navon, 1977; Theeuwes, 1994). The target letter demands a significant recruitment of cognitive control resources, crucial for conflict monitoring (Duchaine et al., 2007). Although cognitive control paradigms such as the Stroop or Eriksen Flanker tasks also measure conflict monitoring, Navon task specifically enhances engagement with early attentional orienting mechanisms (Álvarez-San Millán et al., 2022; Hübner & Töbel, 2019).

Participants need to navigate the complexity of frequent, rare, and non-target trials while disregarding inconsistent visual information that demand local or global attention. This setup allows us to simultaneously examine the effects of smartphone on cognitive control. Better cognitive control is indicated by a smaller RT oddball effect and a larger ERP oddball effect (Zabelina & Ganis, 2018).

This study will examine three key ERPs—P200 (P2), N200 (N2), and P300 (P3)—which are widely recognized as neural indicators of cortical activity linked to cognitive control processes (Crowley & Colrain, 2004; Folstein & Van Petten, 2008; Polich, 2007). The N2 component is typically observed as the second negative peak occurring at 200–350ms and appears near frontocentral and central electrode sites. It is associated with various cognitive functions including strategy adjustment, feedback processing, immediate control of actions, detection of new stimuli, and the orientation of visual attention (Folstein & Van Petten, 2008). Though N2 has several subcomponents, our research centered on a frontocentral N2 component that is involved in inhibiting responses, resolving response conflict, and monitoring errors (Eimer et al., 2009). The P2 component manifests at 150–250 ms in the frontal areas, which is implicated in early sensory processing and attentional categorization (Crowley & Colrain, 2004). If smartphone captures attention during Navon task, there will be an amplified P2 response in trials featuring the absence of attention. The P3 component is the third positive peak around 250–500 ms near the frontoparietal scalp regions. This component is linked to later stages of cognitive processing, which is associated with frontal lobe activation for attention-driven stimuli processing, especially during the processing of task-irrelevant stimuli (Zabelina & Ganis, 2018). Unlike P2 and N2, which are likely influenced by oddball stimuli, P3 is thought to reflect deeper cognitive processes that should remain unaffected by external distractions (Bocquillon et al., 2014).

1. **Research Questions**

Given the mixed results of previous studies regarding the influence of smartphone addiction levels on task performance, this investigation will incorporate EEG technology and Navon task to answer the following research questions:

1. How does smartphone affect the reaction times and error rates of the Navon task?
2. What neural changes are observed when participants have smartphone during Navon tasks?
3. Does the level of smartphone addiction modify the impact of smartphone on Navon task?

By addressing these questions, the study intends to provide a deeper understanding of the mechanisms by which smartphone can influence cognitive processes and to establish a clearer link between addiction levels and cognitive interference.

1. **Method** 
   1. **Participants**

Originally, 84 participants from 18 to 28 are expected to join this experiment. This sample size was selected based on the power analysis, which is computed by using the MorePower program (Campbell & Thompson, 2012) ensuring 90% of power to detect significant interactions with a medium size effect (0.06 partial eta2) at the 5% significance level.

Currently, a pilot study has been done by inviting the classmates. The 6 university students (5 female) participated. Participants were daily smartphone users and had no history of brain damage, concussions or any psychiatric disorders.

* 1. **Materials** 
     1. **Questionnaire**

The Smartphone Addiction Proneness Scale (SAPS) is a 24-item self-administered questionnaire designed to evaluate individual susceptibility to smartphone addiction (Dong-il, 2012). It breaks down into four categories: 1) Impact on Functioning (example item: “Excessive smartphone use has led to a decline in my academic grades.”), 2) Dependence on Virtual Environments (example item: “Without my smartphone, I feel cut off from the world.”), 3) Compulsion to Use (example item: “Not being allowed to use my smartphone would be unbearable.”), and 4) Inability to Reduce Use (example item: “I have tried to decrease my smartphone use but have not succeeded.”). Responses are scored on a 4-point Likert scale from 1 (strongly disagree) to 4 (strongly agree).

* + 1. **Navon Paradigms**

In this experiment, a Local-Global Navon letter task was employed to assess the oddball effect (Navon, 1977). This task replicates the design used in prior studies, ensuring participants recognize both local and global characters at similar speeds and with the same accuracy (Zabelina & Ganis, 2018).

In this task, participants are instructed to determine if the target letter is presented (either at the global or local level). The experiment consisted of two sessions. In the first session, a smartphone was placed below the computer screen, while in the second session, the smartphone was switched out for a mobile battery. Each session included one practice block and four experimental blocks, with each block containing 40 trials (Fig 1a). On each block, target letters were displayed on the screen at global attentional level on 80% of trials, referred to as frequent trials. During the same task block, target letters of the local level of attention were displayed on 10% of trials, referred to as rare trials. The final 10% of trials did not include a target letter, referred to as non-target trials (Fig 1b).​

 The study follows a counterbalanced design, meaning that half of the participants start with the smartphone condition and the other half with the battery condition.

1. 一張含有 文字, 螢幕擷取畫面, 字型, 圖表 的圖片

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**Figure 1 a)** The structure of an individual trial in the oddball task. Inter-trial interval (ITI) refers to the time between the end of one trial and the beginning of the next. **b)** In this scenario, participants were asked to identify whether the letter E appeared in the display, either on a global (80%) or at a local level (10%). In the remaining 10% of trials, the target letter was absent.

* 1. **EEG Data Collection**

We will use 128-conductor EGI EEG device. The presentation of stimuli was managed using PsychoPy v2023.2.3, with the EGI PyNetstation v1.0.1 module facilitating the connection between PsychoPy and EGI Netstation. During recording, the sampling rate was 1 kHz. The impedance of each electrode was kept below 50 kΩ during the experiment and all electrodes were arranged according to the 10–20 system. To precisely co-register EEG segments with individual characters during the experiment, we marked the EEG data with triggers. The raw EEG data was exported to metafile format (.mff) files on the macOS system.

* 1. **Experimental Design**

In the pilot study, participants who met the eligibility criteria volunteered to participate in the study. They were positioned 67 cm from the center of the computer screen and received instructions for the Navon oddball task. Participants were guided to respond quickly and accurately on all trials. EEG data were recorded continuously throughout the experiment to monitor and analyze brain activity responses to the task. To reduce EEG artifacts, participants were asked to minimize blinking, facial movements, and bodily movements throughout the task. After completing the task, participants filled out questionnaires via Qualtrics. The entire session lasted approximately 20 minutes. In the end, participants should complete the SAPS questionnaire.

* 1. **Behavioral Data Analysis**

The reaction times (RTs) and correct rates were analyzed using repeated measures ANOVA to investigate the effects of trial frequency and phone condition on cognitive performance, which were performed using the *stats* package in R (Tabachnick & Fidell, 2007). More specifically, the ANOVA model included the main effects of trial frequency (frequent vs. rare) and phone condition (phone-present vs. phone-absent), as well as their interaction.

Statistical significance was evaluated using F-tests, with p-values reported to determine the presence of significant effects. An alpha level of 0.05 was used to assess statistical significance.

* 1. **EEG Data Analysis**

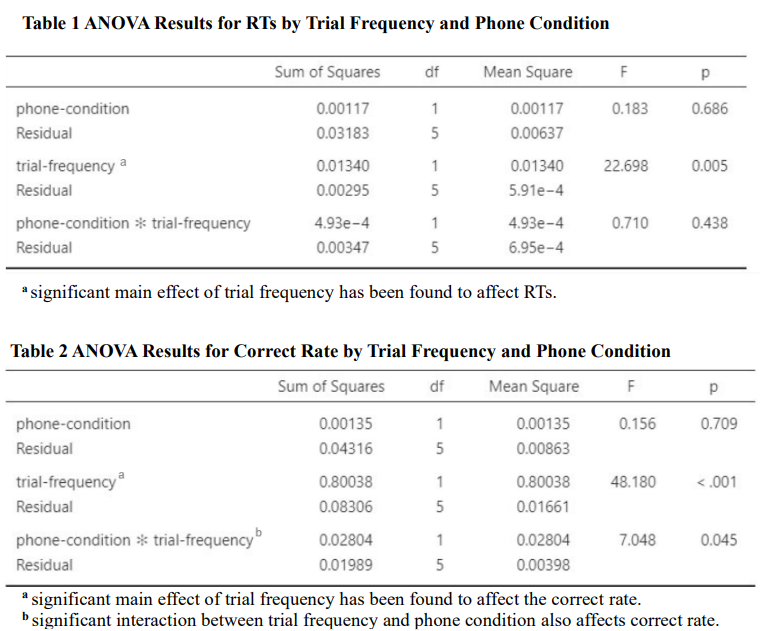
EEG data were preprocessed in MATLAB (2023a) using the EEGLAB toolbox (Delorme & Makeig, 2004). Continuous EEG data were down-sampled off-line to 512 Hz and high pass Basic FIR filtered at .1 Hz. ERPs were averaged off-line for a 1000 ms total epoch segment (200ms prestimulus and 800ms post-stimulus). Artifact detection was performed to assess trials contaminated with eye blinks, horizontal eye movement, muscle activity, or other signal noise. Participants with greater than 25% overall artifact rejections were reprocessed using independent component analysis (ICA) and bad components were inspected using ICLabel.

After getting ERPs, ANOVA will be employed to assess the grand averaged mean amplitudes of the P2, N2, and P3 components, focusing on different experimental conditions. Specifically, ERP amplitudes will be compared between frequent and rare trials to capture the oddball effect, which reflects how infrequent stimuli modulate attentional processes. Additionally, comparisons between phone-present and phone-absent conditions will also be conducted to examine the impact of smartphone on cognitive control. The potential interactions between trial frequency and phone condition will be examined to see if the cognitive effects of stimulus frequency are modulated by the presence of a smartphone.

Furthermore, linear models will be utilized to investigate whether the SAPS scores can predict variations in ERP responses, which targets overall ERPs, overall oddball ERPs, and the differences in oddball ERPs across phone conditions. This is intended to determine if higher SAPS scores are associated with ERP responses in different phone availability contexts.

1. **Expected Outcome** 
   1. **Behavior Results**

According to the previous behavioral study in oddball effect, it is anticipated that the interaction between phone presence, trial frequency, and SAPS scores will significantly influence both RTs and accuracy (Duchaine et al., 2007; Liu et al., 2023). Specifically, it is hypothesized that RTs will be longer in rare trials when a phone is present, particularly for participants with higher SAPS scores, reflecting increased cognitive load. In terms of accuracy, it is predicted that under conditions of rare trials with phone presence and higher SAPS scores, the accuracy rates will decrease, supporting the hypothesis that external distractions compound to impair performance.

The results of pilot study partially align with these hypotheses. The repeated measures ANOVA identified a significant main effect of trial frequency on both reaction times (F(1,5) = 22.68, *p* < 0.005) and correct rates (F(1,5) = 48.10, *p* < 0.001), demonstrating longer reaction times (Table 1) and lower accuracy (Table 2) in rare trials compared to frequent ones, which highlighted the oddball effect. Conversely, the phone condition did not significantly affect reaction times (F(1,5) = 0.183, *p* = 0.686), but it did influence correct rates when interacting with trial frequency (F(1,5) = 7.048, *p* = 0.045) (Table 2). This interaction suggested that the presence of a smartphone could differentially affect performance, particularly reducing accuracy in rare trials.

* 1. **EEG Results**

Unfortunately, due to the lack of equipment and time, this study is unable to report the results from EEG data, but the expected results could be estimated from the previous studies (Barry et al., 2000; Stothart et al., 2015). Based on the EEG study of oddball effect, the current study hypothesizes that the N2 components will exhibit significant oddball effects (Fig 2), which is similar for P2 components. These effects may be influenced by the presence of a smartphone, suggesting that the ERP oddball effect might be diminished when the phone is present, especially in individuals with higher SAPS scores. This would indicate poorer cognitive control under these conditions. Conversely, the P3 component, which represents later cognitive processes, is hypothesized to be less susceptible to the effects of phone presence. We predict a significant oddball effect for the P3 component as well (Fig 3); however, we expect this effect to be reduced only in cases of lower SAPS scores, suggesting that the influence of smartphone addiction is less pronounced on later cognitive processes compared to earlier ones. This will be further explored through linear regression once collecting data.

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自動產生的描述一張含有 兒童藝術, 圖畫, 鮮豔, 藝術 的圖片

自動產生的描述一張含有 文字, 螢幕擷取畫面, 設計 的圖片

自動產生的描述Figure 2 The Example Figure for Hypothesized Results of N2 component**

**a. Bar Graph results of N2 Amplitude**

**c. N2 Results under Smartphone Condition**

**b. N2 Results under Control Condition**

**a)** N2 ERP amplitudes for rare (white bars) and frequent (gray bars) trials under different conditions.

**b)** N2 amplitudes in frequent and rare trialsunder control condition show significant differences.

**c)** N2 amplitudes in frequent and rare trialsunder smartphone condition may not have difference.

**一張含有 鮮豔, 圓形, 圖形, 兒童藝術 的圖片

自動產生的描述一張含有 圖表, 行, 繪圖, 文字 的圖片

自動產生的描述Figure 3 The Example Figure for Hypothesized Results of P3 component**

1. Displays aggregated ERP waveforms for frequent trials (black lines) and rare trials (red lines).
2. Shows scalp distribution maps for the P3 at 450ms latencies.

**b.**

**a.**

1. **Discussion**

This study addresses the impact of smartphone on cognitive performance during Navon oddball task. As pilot study and previous study indicate (Barry et al., 2000; Liu et al., 2023), smartphone presence may exacerbates distraction, particularly affecting individuals with higher susceptibility to smartphone addiction. This suggests that smartphone addiction may affect cognitive control, exacerbating challenges in environments requiring sustained mental focus and task accuracy.

The alterations in N2, P2, and P3 components suggest that initial cognitive control processes are the primary interference points under distraction. This insight underscores the specific vulnerabilities in individuals with smartphone addiction, demonstrating how external stimuli like smartphones can divert cognitive resources from tasks. Given the relationship between smartphone addiction and cognitive disruptions, future research could delve deeper into the neurophysiological impacts of this addiction. Such studies should explore intervention strategies aimed at alleviating smartphone distractions in those with high addiction susceptibility. Additionally, comparing the effects across different populations, especially between adolescence and other age groups, may reveal broader implications for the management of attention-related disorders. By further studying the smartphone addiction, these investigations could lead to targeted interventions, and improve outcomes for those with this increasingly prevalent disorder.

**Reference**

Álvarez-San Millán, A., Iglesias, J., Gutkin, A., & Olivares, E. I. (2022). Progressive attenuation of visual global precedence across healthy aging and Alzheimer’s disease. *Frontiers in Aging Neuroscience*, *14*, 893818.

Barry, R. J., Kirkaikul, S., & Hodder, D. (2000). EEG alpha activity and the ERP to target stimuli in an auditory oddball paradigm. *International journal of psychophysiology*, *39*(1), 39-50.

Bocquillon, P., Bourriez, J.-L., Palmero-Soler, E., Molaee-Ardekani, B., Derambure, P., & Dujardin, K. (2014). The spatiotemporal dynamics of early attention processes: a high-resolution electroencephalographic study of N2 subcomponent sources. *Neuroscience*, *271*, 9-22.

Choi, S.-W., Kim, D.-J., Choi, J.-S., Ahn, H., Choi, E.-J., Song, W.-Y., Kim, S., & Youn, H. (2015). Comparison of risk and protective factors associated with smartphone addiction and Internet addiction. *Journal of behavioral addictions*, *4*(4), 308-314.

Crowley, K. E., & Colrain, I. M. (2004). A review of the evidence for P2 being an independent component process: age, sleep and modality. *Clinical neurophysiology*, *115*(4), 732-744.

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods*, *134*(1), 9-21.

Dong-il, K. (2012). Development of smartphone addiction proneness scale for adults: Self-report. *Korea Journal of Counseling*, *13*(2), 629-644.

Duchaine, B., Yovel, G., & Nakayama, K. (2007). No global processing deficit in the Navon task in 14 developmental prosopagnosics. *Social cognitive and affective neuroscience*, *2*(2), 104-113.

Eimer, M., Kiss, M., Press, C., & Sauter, D. (2009). The roles of feature-specific task set and bottom-up salience in attentional capture: an ERP study. *Journal of Experimental Psychology: Human perception and performance*, *35*(5), 1316.

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology*, *45*(1), 152-170.

Hadar, A., Hadas, I., Lazarovits, A., Alyagon, U., Eliraz, D., & Zangen, A. (2017). Answering the missed call: Initial exploration of cognitive and electrophysiological changes associated with smartphone use and abuse. *PloS one*, *12*(7), e0180094.

Hübner, R., & Töbel, L. (2019). Conflict resolution in the Eriksen flanker task: Similarities and differences to the Simon task. *PloS one*, *14*(3), e0214203.

Jin Jeong, Y., Suh, B., & Gweon, G. (2020). Is smartphone addiction different from Internet addiction? comparison of addiction-risk factors among adolescents. *Behaviour & Information Technology*, *39*(5), 578-593.

Katayama, J. i., & Polich, J. (1998). Stimulus context determines P3a and P3b. *Psychophysiology*, *35*(1), 23-33.

Kwon, M., Lee, J.-Y., Won, W.-Y., Park, J.-W., Min, J.-A., Hahn, C., Gu, X., Choi, J.-H., & Kim, D.-J. (2013). Development and validation of a smartphone addiction scale (SAS). *PloS one*, *8*(2), e56936.

Lepp, A., Barkley, J. E., & Karpinski, A. C. (2014). The relationship between cell phone use, academic performance, anxiety, and satisfaction with life in college students. *Computers in Human Behavior*, *31*, 343-350.

Liebherr, M., Schubert, P., Antons, S., Montag, C., & Brand, M. (2020). Smartphones and attention, curse or blessing?-A review on the effects of smartphone usage on attention, inhibition, and working memory. *Computers in Human Behavior Reports*, *1*, 100005.

Lin, Y.-H., Chiang, C.-L., Lin, P.-H., Chang, L.-R., Ko, C.-H., Lee, Y.-H., & Lin, S.-H. (2016). Proposed diagnostic criteria for smartphone addiction. *PloS one*, *11*(11), e0163010.

Liu, W., Kawashima, T., & Shinohara, K. (2023). Effects of cell phone presence on the control of visual attention during the Navon task. *BMC psychology*, *11*(1), 334.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive psychology*, *9*(3), 353-383.

Ophir, E., Nass, C., & Wagner, A. D. (2009). From the cover: Cognitive control in media multitaskers. *Proceedings of the national academy of sciences of the United States of America*, *106*(37), 15583.

Polich, J. (2007). Updating P300: an integrative theory of P3a and P3b. *Clinical neurophysiology*, *118*(10), 2128-2148.

Przybylski, A. K., & Weinstein, N. (2013). Can you connect with me now? How the presence of mobile communication technology influences face-to-face conversation quality. *Journal of Social and Personal Relationships*, *30*(3), 237-246.

Rosen, L. D., Carrier, L. M., Pedroza, J. A., Elias, S., O’Brien, K. M., Lozano, J., Kim, K., Cheever, N. A., Bentley, J., & Ruiz, A. (2018). The role of executive functioning and technological anxiety (FOMO) in college course performance as mediated by technology usage and multitasking habits. *Psicologia Educativa*, *24*(1), 14.

Rosen, L. D., Lim, A. F., Felt, J., Carrier, L. M., Cheever, N. A., Lara-Ruiz, J. M., Mendoza, J. S., & Rokkum, J. (2014). Media and technology use predicts ill-being among children, preteens and teenagers independent of the negative health impacts of exercise and eating habits. *Computers in Human Behavior*, *35*, 364-375.

Rozgonjuk, D., Blinka, L., Löchner, N., Faltýnková, A., Husarova, D., & Montag, C. (2023). Differences between problematic internet and smartphone use and their psychological risk factors in boys and girls: a network analysis. *Child and adolescent psychiatry and mental health*, *17*(1), 69.

Sanbonmatsu, D. M., Strayer, D. L., Medeiros-Ward, N., & Watson, J. M. (2013). Who multi-tasks and why? Multi-tasking ability, perceived multi-tasking ability, impulsivity, and sensation seeking. *PloS one*, *8*(1), e54402.

Stothart, C., Mitchum, A., & Yehnert, C. (2015). The attentional cost of receiving a cell phone notification. *Journal of Experimental Psychology: Human perception and performance*, *41*(4), 893.

Tabachnick, B. G., & Fidell, L. S. (2007). *Experimental designs using ANOVA* (Vol. 724). Thomson/Brooks/Cole Belmont, CA.

Taylor, K., & Silver, L. (2019). Smartphone ownership is growing rapidly around the world, but not always equally.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human perception and performance*, *20*(4), 799.

Twenge, J. M. (2019). More time on technology, less happiness? Associations between digital-media use and psychological well-being. *Current Directions in Psychological Science*, *28*(4), 372-379.

Vannucci, A., Flannery, K. M., & Ohannessian, C. M. (2017). Social media use and anxiety in emerging adults. *Journal of affective disorders*, *207*, 163-166.

Wilmer, H. H., Sherman, L. E., & Chein, J. M. (2017). Smartphones and cognition: A review of research exploring the links between mobile technology habits and cognitive functioning. *Frontiers in psychology*, *8*, 251723.

Zabelina, D. L., & Ganis, G. (2018). Creativity and cognitive control: Behavioral and ERP evidence that divergent thinking, but not real-life creative achievement, relates to better cognitive control. *Neuropsychologia*, *118*, 20-28.