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Smartphones and attention, curse or blessing? - A review on the effects of smartphone usage on attention, inhibition, and working memory

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ABSTRACT

The smartphone has become ubiquity in everyday life. Today, it is no longer the question of what these devices are capable of, but rather on related effects of using it. During recent years, studies increasingly focused on smartphone-related effects on cognitive functions, however, existing findings are limited. Therefore, the present manuscript aims to provide an overview of previous findings but also to highlight existing gaps in the field of smartphone-related effects on attention, inhibition, and working memory. We provide a hypothetical model assuming a differentiation between immediate and long-term effects of smartphone use on respective cognitive functions. It also describes the relations between attention, working memory, and inhibition, which have been extensively studied in the past. The model further suggests a quantification of smartphone usage based on different quantitative parameters, such as usage time, usage frequency, used applications, and received notifications. In addition, individual attributes and situational factors are highlighted as directly influencing attention, inhibition, and working memory, but also moderating smartphone-related effects on respective cognitive functions. Until now, there are many unresolved questions regarding the effects of smartphone usage on specific cognitive functions. However, until these are clarified, and despite a growing literature on adverse effects, it should be kept in mind that a general smartphone use may also have beneficial effects on certain processes of attention, inhibition, and working memory.

1. Introduction

During recent years, the smartphone has become a device that puts the world at our fingertips. We trade stocks while waiting at the airport, we look for restaurants or sights while navigating through any city, and we can connect with our loved ones from nearly everywhere of the world. A decade ago, this was inconceivable, today it seems indispensable. In Germany, 81% over the age of 14 years own a smartphone (https://t1p.de/statista18). In the UK the numbers are higher for younger people between the age of 16 and 24 years, since 90% in this age group own a smartphone, while solely 50% between the age of 55 and 64 years own one (https://t1p.de/Ofcom). This amount is likely to increase within the next years. For example, in the United States, the number of smartphone users is estimated to increase up to 285.3 million people until 2023 (https://t1p.de/Statista19). Previous tracking-studies on smartphone usage report broadly differing percentiles, ranging from an average time of $M = 59.23$ min per day (Böhmer et al., 2011) to $M = 305.00$ min per day ($SD = 183.00$ min) (Andrews et al., 2015). Here, social network applications are discussed as the most frequently used applications, especially in younger people (Andone et al., 2016; Montag et al., 2015a,b).

Due to methodological differences between previously conducted smartphone studies, it is impossible to conclude a precise and realistic average usage behavior, so far. Furthermore, previous studies report that humans experience time distortions on using their phones which leads to biased information in questionnaires (Lin et al., 2015; Montag et al., 2015a,b). Despite these problems, Table 1 aims to provide an overview of exemplary studies on smartphone usage by focusing on the most frequently described parameters of usage time, frequency, and applications.

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Table 1
Overview of exemplary studies on smartphone usage.

Study	Participants	Time/day	Frequency/day	Applications	Quantification
Andone et al. (2016)	N = 30,677 (*M* = 24.3 years, 14,523 female)	166.78 min (females), 154.26 min (males), 193.64 (14–17 years old), 117.95 min (51+ years old)		Younger group: entertainment and social interactions; Older group: getting information and classic phone	App
Andrews et al. (2015)	N = 29 (*M* = 22.52 years, 17 female)	5.05 ± 2.73 h	84.68 ± 55.23		App
Aljomaa et al. (2016)	N = 416 (204 female)	<2 h: 37; 2–4 h: 110; >4 h: 269			Questionnaire
Böhmer et al. (2011)	N = 4125	59.23 min		Most used libraries: inherent apps of the operating system (Google Services Framework, default Updater, Motorola Updater); Most used game applications: Angry Birds, Wordfeud FREE5, and Solitaire.	App
Dingler & Pielot (2015)	N = 42	Attentive to messages: 12.1 h			Questionnaire
Elhai et al. (2018)	N = 296 (*M* = 20.0 ± 3.02 years, 169 female)		43.32 ± 7.82		Questionnaire
Elhai et al. (2018)	N = 298 (*M* = 19.45 ± 2.17 years, 229 female)		48.25 ± 7.63		Questionnaire
Falaki et al. (2010)	N = 255	0.50–8.33 h	10–200	Communication: 46.5%; Browsing: 11%; Productivity: 10.5%; Media: 7%; Games: 6%, Maps: 3%; System: 3%; Others: 13%	App
Hussain et al. (2017)	N = 640 (*M* = 24.89 ± 8.54 years, range 13–69 years)	190.6 ± 138.6 min		Social networking applications: 49.9%, messaging applications: 35.2%, music applications: 19.1%	Questionnaire
Jacobsen & Forste (2011)	N = 1026 (*M* = 18.54 ± 1.24 years, 667 female)	Approx. 45 min talking or texting		11-20 text messages/day	Self-reported
Kuss et al. (2018)	N = 512 (*M* = 25.5, range 13–68 years, 107 female)	<30 min: 10; 30 min-1 h: 34; 1–2 h: 134; 3–5 h: 219; 5–10 h: 92; >10 h: 22		Calls/day: 0–1: 262, 2–5: 214, 5–10: 27, >10: 8; Texts/day: 0–5: 50, 5–10: 64, 10–20: 82; 20–30: 79, 30–40: 39, >40: 198	Self-reported
Lee et al. (2014b)	N = 95 (*M* = 20.6 ± 1.7 years, 28 female)	Risk group: 4.22 ± 1.52 h; Non-risk group: 3.46 ± 1.29 h	Communication apps: non-risk: 112.5, risk: 126.3; Web app: non-risk: 22.3, risk: 38.5	Communication apps: non-risk: 87.1min, risk: 98.8min; Web app: non-risk: 41.1min, risk: 67.1min	App
Long et al. (2016)	N = 1062 (*M* = 20.65 ± 1.54 years)	≤2 h: 267; 2–4 h: 383; ≥4 h: 412		Social networking services: 79.66%; Internet surfing: 52.29%; Video watching: 31.45%	Questionnaire
Montag et al. (2015a,b)	N = 2418 (*M* = 24.64 ± 10.44 years, 950 female)	161.95 ± 83.36 min		Whatsapp usage: 32.11 ± 35.36 min; Whatsapp usage (female): 40.08 ± 36.88 min; Whatsapp usage (male): 26.94 ± 33.34 min	App
Pearson & Hussain (2017)	N = 256 (*M* = 29.2 ± 9.4 years, 181 female)	3.63 ± 2.83 h		Social networking sites: 87%; instant messaging apps: 52%; News apps: 51%	Questionnaire
Richardson et al. (2018)	N = 244 (*M* = 29.8 ± 11.9 years, 149 females)	179.6 ± 109.1 min.			Self-reported

Along with the relatively high usage times, previous studies highlight smartphone-related negative affections on domains such as sleeping (Lanaj et al., 2014), stress (Lee et al., 2014a), and academic performance (Samaha and Hawi, 2016). In contrast, others identify beneficial effects of smartphone usage (Bakker, Kazantzis, Rickwood, & Rickard, 2016; Donker et al., 2013; Klimova and Valis, 2018).

Based on the stated effects as well as its ubiquitous character in daily life, it can be assumed that smartphone usage has the potential to negatively affect cognitive functions. Although there is consistent evidence for this assumption, findings are limited as those are mostly based on media-multitasking studies, where smartphones are simultaneously used to other devices (Wilmer et al., 2017, for a review). Therefore, it should be of outmost importance to provide a better understanding regarding to what extent smartphone applications themselves affect specific cognitive functions. Since smartphone usage highly differ, it begs the assumption that depending on the used application (e.g., telecommunication, navigation, multimedia, etc.), various cognitive functions are relevant. Especially regarding attentional processes, it can be assumed that smartphone-related effects depend on the individual usage behavior and more importantly vary between respective domains (e.g., selective attention, divided attention). Evidence for these assumptions come from related fields, such as video gaming. Next to findings on gaming-related modifications of selective attention (Bavelier, Achtman, Mani, & Föcker, 2012; Green and Bavelier, 2003), studies show improvements in cognitive functions after sessions of video gaming, also in non-gamer (Bleakley et al., 2015).

Based on its relevance, the present manuscript focuses on specific attentional domains in the context of smartphone usage. We reviewed previous studies regarding the effects of smartphone usage on attentional processes as well as related functions of inhibition and working memory in healthy people with no problematic/pathological use of smartphone applications. During the chapters of "Smartphones and Respective Attentional Domains" as well as "Smartphones, Inhibition, and Working Memory" we illustrate respective findings from previous studies in two models which are summarized in a hypothetical model, subsequently. The hypothetical model contains further aspects such as individual attributes and should be subject of interest for numerous future studies.

1.1. Smartphones and Respective Attentional Domains

The Pew Research Center states that every second American smartphone user feels distracted by their smartphones, at least once a week (https://t1p.de/Pewresearch). Converging evidence shows that participants immediately focus their attention towards their smartphone when receiving a notification, even when the device is set to vibration or silent (Chang and Tang, 2015; Pielot et al., 2014; Sahami Shirazi et al., 2014). Studies indicate significant distractions of smartphone notifications, even when participants did not reply (Stothart et al., 2015) as well as larger effects when hearing tones related to smartphones, compared to other tones (Shelton, Elliott, Eaves, & Exner, 2009). Furthermore, the same involuntary attentional system has been reported to be active in hearing one's own name and hearing one's own phone ringing (Roye et al., 2007). Others show that the sole presence of a smartphone without receiving any notification or interaction distracts participants and decreases primary task performance (Ward et al., 2017). However, the effect could not be shown with the presence of a notepad instead of a smartphone (Ito and Kawahara, 2017). This phenomenon is explained by early findings on controlled versus automatic processing, which show impaired performance in cognitive tasks in the mere presence of personally relevant stimuli (Bargh, 1982; Geller & Shaver, 1976).

Evidence from more applied studies highlight a smartphone-related delay in reaction times and inattentional blindness during walking and driving (Caird et al., 2008). For example, drivers show increased errors in detection of traffic lights when making a conversation on the cell phone but not when simply holding the phone or listening to audiobooks while driving, which contrasts with reported findings on effects of its mere presence (Strayer and Johnston, 2001). Additional eye-tracking data indicate a reduced attention to foveal information when simultaneously talking on a cell phone, compared to solely driving (Strayer and Drews, 2007). In situations of walking while interacting with a smartphone, participants show a deteriorate awareness of roadside surroundings as well as decreased auditory attention. However, this effect is more prominent when reading news or weblogs compared to texting or playing simple games (Haga et al., 2016). So far, the stated findings share one common aspect, they all consider immediate smartphone-related effects in situations of selective attention (e.g., performing a cognitive task while a smartphone is ringing or placed next to the laptop), divided attention (e.g., talking on a smartphone while driving), or vigilant attention (e.g., sustain attention to a monotonous task while being aware of a missed notification or call) (see also Fig. 1 for an explanation of specific attentional domains).

Here, smartphone-related inattentiveness can be triggered either endogenously (top-down) via the conscious direction of attention (Connor, Egeth, & Yantis, 2004; Corbetta & Shulman, 2002; Itti & Koch, 2001) or exogenously (bottom-up) due to stimulus salience such as ringtones or vibrations (Katsuki and Constantinidis, 2014).

In past, numerous studies with different backgrounds investigated immediate effects of smartphone usage on attentional domains. However, findings of long-term effects are rather rare and somehow contrary. On the one hand, studies show no relation or a unique negative relation of general smartphone use (time/frequency) and inattention (Marty--Dugas et al., 2018). On the other hand, participants report higher levels of inattention and hyperactivity when enabling notifications and keeping the phone permanently within reach, compared to conditions in which they are asked to minimize phone interruptions (Kushlev et al., 2016). However, neurophysiological studies report reduced early transcranial magnetic stimulation evoked potentials in the right prefrontal cortex of heavy smartphone users to be associated with self-reported attentional problems, compared to non-users (Hadar et al., 2017). Furthermore, findings indicate significant differences in a numerical processing task, between the two groups with a significantly lower accuracy rate in heavy users. No significant results were found in working memory as well as in inhibition performance. A group of non-users show a significant deterioration in numerical processing, but not in working memory after a 3-month exposure to smartphones (Hadar et al., 2017). It can be summarized that previous studies on long-term effects of a general smartphone use on attentional processes are quite rare. Based on the stated findings, it can be solely assumed that general smartphone usage affects humans' attention. However, a conclusion on specific attentional domains is currently not possible (see also Fig. 2).

1.2. Smartphones, inhibition, and working memory

Resisting the urge to focus attention on one's own smartphone requires inhibitory processes, which describes the ability that enables us to overcome automatic and experienced behavior by controlling one's attention, behavior, thoughts, and emotions (Diamond, 2013; Friedman et al., 2008; Jurado and Rosselli, 2007). Inhibitory control as a trait variable is usually quantified by questionnaires (DeYoung, 2010), whereas behavioral inhibitory control as a state variable is most often assessed with paradigms such as the stop-signal task, go/no-go task, or Stroop task, in which participants have to inhibit a prepotent response tendency (Bari and Robbins, 2013).

In the context of smartphone usage, previous studies indicate that the inability to inhibit the tendency to check for messages can have a negative impact on the productivity at work or university, motivation, and self-efficiency (Calderwood et al., 2014; Duke and Montag, 2017). However, people with low inhibitory control seem more likely to respond to messages immediately, compared to others (Berger et al., 2018). This may be one reason why individuals with low trait inhibitory control more often show an addictive smartphone use behavior, or use in situations where it is prohibited or dangerous (Billieux, 2012; Jiang and Zhao, 2016, 2017). Consistent with these results, it has been shown that the ability of effortful control could be a protective factor regarding the development of a problematic smartphone usage (Liu et al., 2019). Especially habitual and automatic behavior seem to be relevant factors in a self-regulation failure of smartphone use (i.e., texting while driving or walking) (Bayer et al., 2016; Moore and Brown, 2019; Panek et al., 2015; Soror et al., 2015; van Deursen et al., 2015). In contrast, it has been shown that the presence of a smartphone as well as additional notifications have a negative effect on experienced vigilance and distraction but not on the performance in a stop-signal task (Johannes et al., 2018). Despite the missing effects on a behavioral level, electrophysiological studies identified a lager amplitude in the N2 event-related potentials during inhibitory control in excessive smartphone users compared to normal users, which might be an indicator for altered neural processing of inhibitory control (Chen et al., 2016). A similar finding is reported for excessive social network sites users, with an especially high neural effect when participants were confronted with images associated with social-network sites (Gao et al., 2019). These cues might trigger

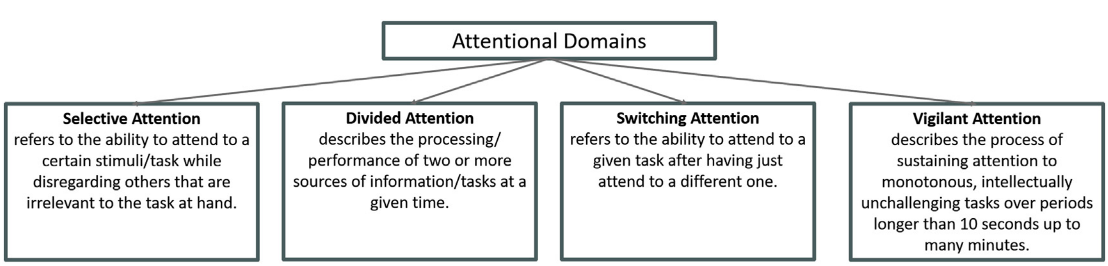

Fig. 1. Attentional domains relevant in the context of smartphone usage.

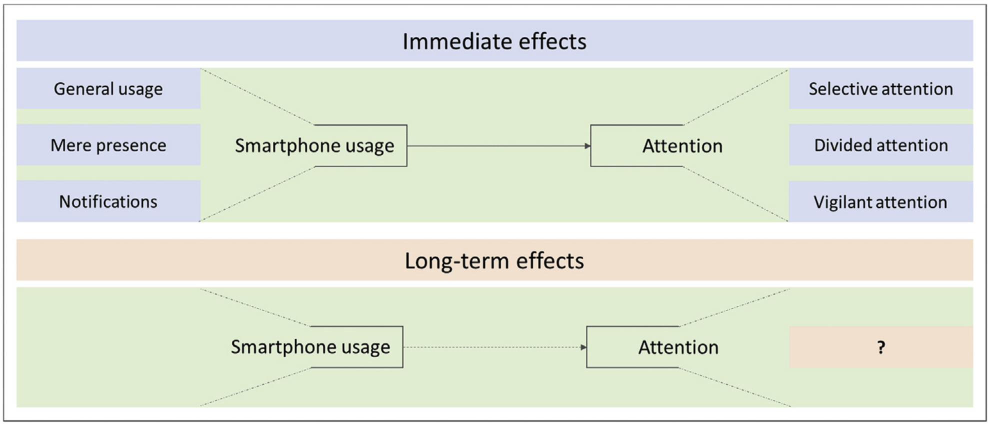

Fig. 2. Smartphone Usage and Attentional Domains. Summarizing previous findings on smartphone-related effects on attentional processes. On the one hand, ample evidence indicates immediate effects of smartphone usage on different attentional demands. On the other hand, findings of long-term effects are rather rare.

impulsive behavior and the failure of inhibitory control in a certain situation. In addition, it can be assumed – based on dual-process models (Bechara, 2005; Schiebener and Brand, 2017) – that decreased inhibitory control in smartphone phone use may be the result of strong bottom-up (e.g., habits) and reduced top-down processes (e.g., self-regulation) (Soror et al., 2015).

Working memory has been traditionally described as a core component of higher cognitive functions with limited capacity to temporarily store information by actively controlling and regulating cognitive processes, but distinct from attentional processes (Baddeley, 2000; Baddeley & Hitch, 1974; Ericsson & Kintsch, 1995). Today, a common idea is that the underlying structures serve the central executive to integrate information and immediate attention to relevant current tasks (Awh & Jonides, 2001; Gazzaley & Nobre, 2012). However, findings on smartphone-related effects on working memory are quite rare but describe somehow adverse effects. In addition to the aforementioned findings indicated by Hadar et al. (2017), there is evidence that the mere presence of one's own smartphone reduces performance in a working memory task (Ward et al., 2017). Participants show similar results, even if the device was completely switched off. However, they performed significantly better when their phone was in an adjacent room than in conditions where their phone was kept in their bag or put on the desk (on silent mode and face down). Furthermore, it has been shown that reproducing a list of ten words is negatively affected after a short break, where participants interact with their smartphones (Kalafatakis, Bekiaridis-Moschou, Gkioka, & Tsolaki, 2017). This discrepancy was even more prominent in the elderly and individuals with mild cognitive impairments. In addition to the stated effects of smartphone usage or its mere presence, previous studies show that being separated form once smartphone negatively affects mental shifting, inhibitory control, and working memory, which is mediated by anxiety (Hartanto and Yang, 2016). Especially those individuals with a high symptom severity of what the authors called "smartphone addiction" performed worst in the inhibitory control task. However, symptom severity had no effect on findings of mental shifting.

In reviewing the effects of smartphone usage on inhibition and working memory, it can be summarized that people with low inhibitory control are more likely to respond immediately to messages. No effects of the presence of a smartphone as well as additional notifications on inhibitory performance, have been found. In contrast, neurophysiological studies on inhibitory control report differences between excessive smartphone users compared to normal users, but long-term effects of a general smartphone usage on inhibitory control are somehow missing. In working memory, studies report a decreased performance in the presence of a smartphone, even if it is completely switched off. However, findings on long-term effects are also rare and discussed controversially (see also Fig. 3).

2. Hypothetical model of immediate and long-term effects of smartphone usage on attentional domains, inhibition, and working memory

In the following we summarize the two models described in the chapters before as well as add further aspects, such as situational factors or individual attributes, within a hypothetical model. The hypothetical model is based on previous findings on smartphone usage, but also from related fields, such as gaming or media-multitasking (see Fig. 4). Since we discussed single relations between smartphone usage and the respective cognitive functions of attention, inhibition, and working memory, in the previous chapters, the following paragraph sheds light on the overall model, which aims to provide a recommendation on specific aspects that should be further addressed in future studies.

The model suggests a differentiation between immediate and long-term effects of smartphone usage. Evidence for immediate effects come

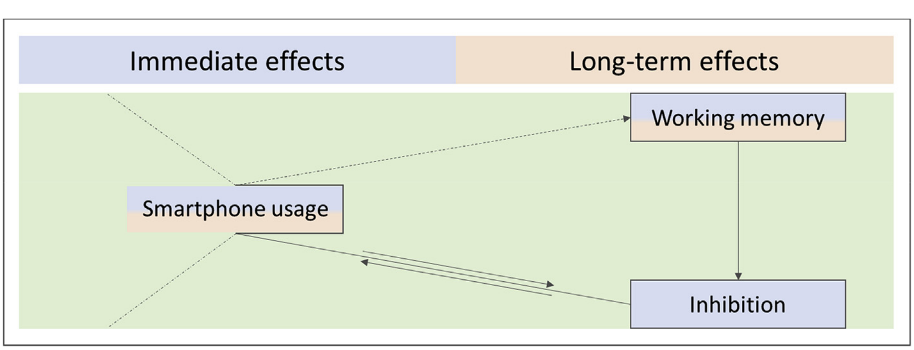

Fig. 3. Smartphone Usage, Woking memory, and Inhibition. The effects of smartphone usage on working memory based solely on rare literature, which states somehow adverse effects. Findings on inhibition show that low inhibitory control leads to increasing responds to messages. While behavioral findings identified no effects of smartphone usage on inhibitory control, neurophysiological studies report differences between excessive smartphone users compared to normal users. However, there are no previous findings regarding long-term effects of smartphone usage on inhibitory control.

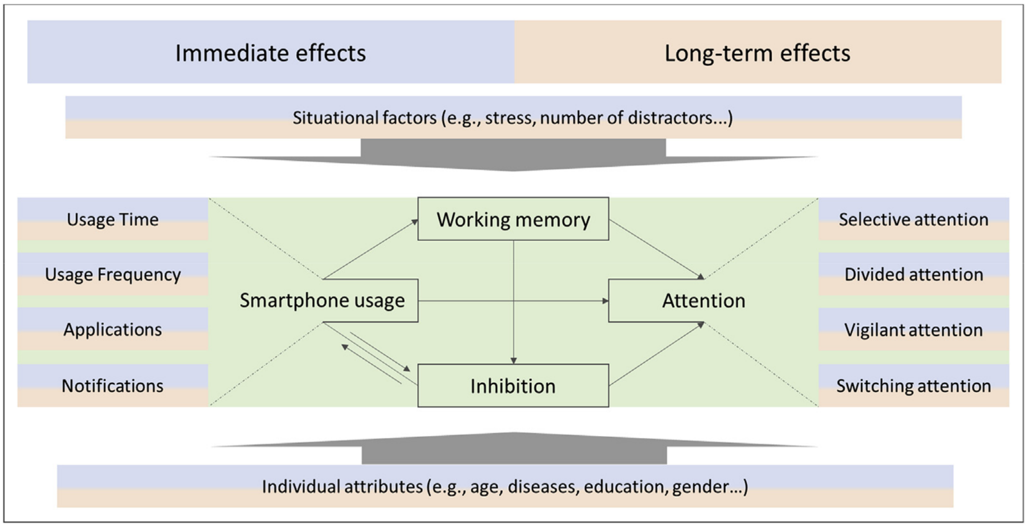

Fig. 4. Hypothetical model of immediate and long-term effects of general smartphone usage on attentional domains of selective attention, divided attention, vigilant attention, and switching attention. Furthermore, the model implements related cognitive functions of working memory and inhibition, as well as additionally influencing factors.

from various smartphone studies (Caird et al., 2008; Chang and Tang, 2015; Pielot et al., 2014; Sahami Shirazi et al., 2014; Stothart et al., 2015; Strayer and Drews, 2007; Ward et al., 2017). For example, within a recent study, Montag et al. (2019) illustrate the interruption potential, by showing an average of 49.05 smartphone screen unlocks every day. Since smartphone interactions are usually combined with the execution of another task (e.g., texting while standing in the train, or posting comments while sitting in a bar with friends), occurring interferences can be explained by dual-task theories (Pashler, 1994, for a review). For example, "Capacity Sharing Theories" postulate a possible distribution of processing capacity to existing demands. Based on the assumption that the human attention system has a limited processing capacity, any perturbations occurring are attributed to this aspect (Kahneman, 1973; Navon & Gopher, 1979). Furthermore, Navon & Gopher, 1979 describe the characteristics of a task, underlying environmental factors, and the person itself as influencing the successful execution. In contrast, "Bottleneck Theories" assume that it is impossible to process two or more tasks simultaneously. Here, it is supposed that a bottleneck occurs when two tasks simultaneously require a single mechanism (Pashler, 1994; Pashler and Johnston, 1989). Therefore, these models implicate structural limitations rather than strategic decisions. In addition, "Cross talk models" assume that the amount of interferences depends on the similarity of simultaneously performed tasks (Navon & Miller, 1987). For example, Navon & Miller, 1987 show that situations in which the distractor of one task is similar to the target category of a second task lead to higher interferences compared to situations with clear differences in the content. Based on "cross talk models", it can be assumed that smartphone-related effects also depend on the applications used. Here, it has been generally shown that factors such as the amount of cognitive resources required for the respective tasks, involved modalities, spatial presentations, as well as required neural mechanisms, need to be considered (Herath et al., 2001).

While various theories provide explanations for interferences occurring in interacting with the smartphone, explanations for the effects of the mere presence of the device seems less obvious.

In accordance with the findings of larger effects on smartphone related tones compared to neutral tones (Shelton, Elliott, Eaves, & Exner, 2009) as well as differences in leaving a notepad or a smartphone next to participants laptop (Ito and Kawahara, 2017), it can be assumed that communication applications, such as WhatsApp, Telegram, Instagram, etc., but also email programs, might be responsible for the occurring phenomenon of distraction without physical interaction. Here the concept of fear of missing out might provide an explanation. It describes a pervasive apprehension of missing something worthwhile and is frequently discussed in specific studies on internet communication (e.g., Wegmann, Oberst, Stodt, & Brand, 2017). Furthermore, processes such as craving and cue-reactivity, might additionally explain smartphone related effects without any interaction (Brand et al., 2019).

The assumption of long-term effects of smartphone usage on cognitive functions based on findings from related fields (e.g., media multitasking, video gaming) (Bavelier, Achtman, Mani, & Föcker, 2012; Green and Bavelier, 2003; Hubert-Wallander et al., 2011), and the knowledge that brain structures can be altered with prolonged exposure to novel environments (Blakemore & Van Sluyters, 1975), as well as experience and training (Draganski et al., 2004). For example, the "google effect" postulates that people put less effort into storing information in the brain as it is nowadays easily available online. Participants who expect to have future access to information, show decreased recall rates but instead were able to report where to get the information (Sparrow, Liu, & Wegner, 2011). Therefore, we assume that generally using the smartphone, might have the potential to train functions such as switching attention, as it is permanently required by using the device.

Based on previous smartphone studies, summarized in Table 1, we included the most frequently reported parameters of usage time, usage frequency, used applications but also the number of received notifications, within the present model. It is important to note that we assume usage behavior to be best predicted by taking into account these parameters and their interaction terms. Although the present review focuses on associated functions of working memory and inhibition, the relation between those and attentional processes will be not described in detail. Rather, reference is made to the relevant previous literature which commonly highlights a relation between attention and working memory (e.g., Gazzaley & Nobre, 2012) as well as inhibition (e.g., Lijffijt et al., 2009).

In addition, the model states effects of situational factors as well as individual attributes, which can affect both, the respective relations in form of a moderated connection as well as the respective cognitive functions, directly. The relevance of taking these factors into account is shown by numerous previous studies out of various fields of interest, which justifies the inclusion within the model (Reuter et al., 2019). For example, in aging, previous studies show a significant decline in cognitive functions of the elderly compared to youngers, but more importantly an inverted u-shaped course over the lifespan (Reuter et al., 2019). While previous studies frequently demonstrate the relevance of considering the effects of situational factors and individual attributes on cognitive functions, findings on the effects of smartphone usage on specific attentional domains, inhibition, and working memory are somehow rare. For this reason, the present hypothetical model should encourage future studies to test the stated assumptions. Certain aspects should be taken into account, which are described in the following chapter.

3. Recommendations for future studies

In order to address outstanding questions regarding smartphone-related effects on attention, inhibition, working memory, but also other cognitive functions, the following paragraph focusses on aspects that should be considered in future studies. Here, we discuss the four topics of neurophysiological measures, tracking apps, ambulatory assessments, as well as individual attributes/situational factors.

3.1. Neurophysiological measures

To our best knowledge, there are no studies so far that have considered neurophysiological correlates of immediate or long-term effects of smartphone usage on attentional domains. However, conducting combined studies of tracking peoples' smartphone usage as well as investigating their performance in tasks of specific attentional domains and respective brain areas involved (e.g., by using functional Magnetic Resonance Imaging), might provide best insight regarding long-term effects. Evidence for this approach comes from different areas, such as Psychoneuroinformatics (Montag et al., 2016). In order to get a better understanding on immediate effects of smartphone usage on attentional domains, we suggest using mobile measures such as electroencephalography (EEG) and eye-tracking. Since these methods have been improved in recent years, it is possible to use both measures in real-life situations, such as real-world driving (Protzak and Gramann, 2018) or walking (Pizzamiglio, Naeem, Abdalla, & Turner, 2017). Current developments of these technologies, such as ear-EEG (Mikkelsen, Kappel, Mandic, & Kidmose, 2015), will provide increased independency as well as reduced biases for future smartphone studies. To provide a better understanding of the underlying mechanisms of respective situations, these studies should aim to synchronize neurophysiological measures and tracking apps.

3.2. Tracking apps

The smartphone literature is dominated by correlational and self-report data. However, significant correlations between self-reported data of smartphone use and actual use are missing (Andrews et al., 2015). This highlights the relevance of using tracking apps to quantify smartphone usage behavior in future studies (see also as aforementioned, Lin et al., 2015; Montag et al., 2015a,b). However, existing apps differ between the focus of tracking. While most specify between different applications, some focus solely on the time as well as frequency of usage, by recording screen on/off times (Andrews et al., 2015). In addition to application specific parameters such as frequency, duration, and type of application, some apps record parameters of network traffic, energy drain etc. (Falaki et al., 2010). Nevertheless, most tracking apps are limited to screen interactions and the sole popping up of news, notifications etc. as well as talking on the phone while the screen is turned off is not been measured. Although, tracking apps act in the background and participants are not permanently aware that they are being observed, some might assume that the fact that people know that they are participating in a study influences the behavior (Montag et al., 2016). However, previous findings indicate differences only in the first two days, which should be therefore rejected from further analyses (Lee et al., 2014a).

3.3. Ambulatory assessments

In leading psychological journals such as Perspectives on Psychological Science (Baumeister et al., 2007), as well as from the American Psychological Association (Azar, 2000) it is required that laboratory experiments should be supplemented by real-world data whenever possible in order to provide externally and ecologically valid findings (Baumeister et al., 2007). Same ideas have been postulated in other fields, such as personality psychology (Montag and Elhai, 2019). Although the idea is strongly overlapping with those of tracking apps, ambulatory assessments additionally includes the usage of paradigms, questionnaires, and other measures (hormone analyzes, heart rate, etc.) in everyday contexts. Furthermore, ambulatory assessments address aspects such as individual attributes and situational factors, which are stated in the following topic. Together with Montag et al. (2019) who introduced a new tracking app that allows to investigate smartphone usage behavior as well as to apply different questionnaires at any time and context, we recommend combining tracking of smartphone usage with applied measures of attentional domains, working memory, and inhibition, to investigate the respective paradigms in situations of everyday life.

3.4. Individual attributes/situational factors

The relevance of considering individual attributes as well as situational factors is highlighted in numerous studies from various fields of research and also pointed out in the present hypothetical model. Previous studies on attention most frequently discuss aspects such as the process of aging, gender, stress, diseases, as well as the type and number of stimuli/tasks (Duchek et al., 2009; Merritt et al., 2007). These factors should be additionally addressed in future studies on smartphone usage and cognitive functions by implementing respective questionnaires in tracking apps (Montag et al., 2019).

4. Conclusion

In accordance with (Wilmer et al. (2017)), it can be postulated that "it is crucial to understand how smartphone technology affects us so that we can take the steps necessary to mitigate the potential negative consequences" (p. 12). However, findings regarding smartphone-related effects on attentional domains, inhibition, and working memory are rather limited. Therefore, assumed relations of the hypothetical model should be further tested as well as stated recommendations considered, in future studies. Especially, with regard to the effects of smartphone usage on different attentional domains, there are still many unresolved questions. However, until these are clarified, it should be kept in mind that a general smartphone usage may also have beneficial effects on certain processes of attention, and therefore may not only be curse but also blessing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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