University of Basel
Faculty of Psychology

Master's thesis presented to the Department of Psychology of the University of Basel for the degree of Master of Science in Psychology

Smartphone presence and its impact on cognitive impairment

Author: Leonard Stahl

Immatriculation number: 12-260-410

Correspondence email: l.stahl@stud.unibas.ch

Examiner: Prof. Dr. Klaus Opwis

Supervisor: Msc. Sharon Steineman

Personality and developmental psychology, human computer interaction

Submission date: 15.10.2018

Content

Declaration of scientific integrity

The author hereby declares that he has read and fully adhered the Code for Good Practice in Research of the University of Basel.

Leonard Stahl

Abstract

Most people would agree that smartphones make it easier to manage our daily lives. Nevertheless, ringing, vibrating and flashing lights from smartphones attract our attention and make it difficult to focus on a current task. But what is about our cognitive performance when a smartphone is just present without making a sound and no interaction is done? The present research investigates how working memory capacity and informational processing is affected through the mere presence of a smartphone. In a laboratory design support was found that the mere presence of a smartphone impairs participants working memory capacity what in turn decreases the likelihood of a deep and conscious processing of incoming information. The author replicates already existing research findings and includes relations to informational process theory that have not been investigated to this date. The ability of attentional control plays a crucial role when focusing on a current task while ones' smartphone is nearby. The author concludes the practical implication that especially in demanding safety relevant and high priority tasks smartphones should be stand out of reach.

Keywords

Smartphones, interruptions, attentional control, working memory capacity, informational processing

Introduction

Smartphones are probably most people permanent companions in daily life. Beside its life supporting aspects such as its function as a personal organizer, it is documented that mobile phone devices can impair our productivity (e.g. Stothart, Mitchum, & Yehnert, 2015; Kushlev, Proulx, & Dunn, 2016). Regardless whether smartphones are vibrating, ringing, lighting up or if its just in our filed of view, one's attention is vulnerable to swift to the mobile device in inappropriate moments (e.g. Kushlev et al., 2016; Oulasvirta, Rattenbury, Ma, & Raita 2012). However, not much research has been done on how humans are affected in the common situation when a smartphone is present but not in use. Przybylski and Weinstein (2012), Thornton, Faires, Robbins and Rollins (2014) and Ward, Duke, Gneezy, and Bos (2017) come to the conclusion that the mere presence of a cell phone is indicative of attentional and working memory deficits, what impairs the quality of our current tasks. Individuals have limited cognitive resources for all incoming stimuli (Craik & Lockhart 1972). We have to allocate these resources (Engle, 2002) to manage our daily lives and current tasks. Cognitive capacity is composed of the interplay of working memory and attentional resources (e.g. Engle 2002; Halford, Cowan, & Andrews, 2007). Goal of this present investigation is to examine if the mere presence of a smartphone impairs individual cognitive performance with the main focus on working memory capacity and the depth of informational processing. According to the hypotheses the mere presence of a smartphone impairs working memory capacity what in turn leads individuals to unconscious and automatic rule based cognitive processing. In contrast to slow and conscious calculated higher cognitive processes.

Down to this present day only little research has been done relating to the influence of smartphones on our cognitive functions in the everyday situations when smartphones are present but not in use.

Theoretical Background

Attentional Interruptions

There is no question that smartphones have been changing our daily life routines. It is easier than ever before to communicate all over the world at any time. It seems as the new technologies have given us unlimited possibilities. It is about keep in touch with friends, managing our daily life's or just avoiding boredom (Pew Research Center, 2015). A smartphone user uses their digital device on average 85 times (Andrews, Ellis, Shaw, & Piwek, 2015) and achieves a number of 2,617 touches on his phone display per day (dscout, 2016). But the immersion of technology is having impacts on our mind. Resent research show us that the immersion of technology comes along with performance disruptions, stress and forms of inattention and hyperactivity (Stothartet al., 2015; Kushlev et al., 2016; Westermann, Wechsung, & Möller, 2015; Kushlev & Dunn, 2014; Yoon, Lee, Lee, & Lee, 2014; Lee, Chang, Lin, & Cheng, 2014).

Incoming calls and messages produce notifications in the form of alerts, vibrations, pop-ups or blinking LED lights. Smartphone applications generate on average 45 notifications per day. Users click on the notification with 50% probability within the first 30 seconds and in 83% within the first five minutes (Shirazi et al., 2014). These phone related external interruptions carry our attention away from our currently performing tasks. Phone notifications bring up task irrelevant thoughts. Those lasts beyond the notifications themselves. The research from Kushlev et al. (2016) showed, when participants had turned on alerts (sound and/or vibration) reported higher levels of inattention and hyperactivity than when alerts were totally switched off. There are presumptions that individuals may unlearn to be concentrated for a longer period of time without an interruption (causing inattention) because of its broad array of alternative activities who are served within the smartphone device (Kushlev et al., 2016). Stothart et al. (2015) found in their research that a notification from a mobile device, “significantly disrupted performance on an attention-demanding task, even when participants did not directly interact with a mobile device during the task.“

The mere Presence of Smartphones

As presented above, it is documented that the interaction with a smartphone, while engaged in another task, has implications for users' attention and performance (e.g. Kushlev et al., 2016; Stothart et al., 2015). Just a little research is done to examine how the mere presence of cell phones without interaction with it, is distracting our everyday tasks. Przybylski and Weinstein (2012) conducted two experiments to identify the role of a mobile phone within human interactions. The experimenter manipulated the present versus the absence of a mobile phone while the participants had a conversation with a randomly assigned partner about a personal topic. Przybylski and Weinstein found in their research, that the presence of mobile phones in conversations especially in personally meaningful topics, can lead to negative effects in reported closeness, connection and conversation quality with the partner.

Thornton et al. (2014) let participants in two studies do standardized tests to assess inter alia attention, cognitive capacity and mental flexibility. In the first study the experimenter left after the instructions “accidently” a mobile phone or a notebook on the participants' table. In the second study the participants were asked to put their own switched off smartphone on the desktop next to them prior to starting. It was told that the smartphone will be required for one survey later on. The results from both studies showed that the mere presence of a cell phone reduces attentional capacity and performance “[…] when the tasks are more attentionally and cognitively demanding“ (Thornton et al., 2014). This was assessed by tasks for neuropsychological evaluations with differences in difficulty.

Similar effects were shown in a recent research from Ward et al. (2017). Participants completed trials for the measurement of available cognitive capacity containing working memory capacity, fluid intelligence and crystallized intelligence. During the session participants had their own mobile phones outside the room (condition one), in their bag or pocket (condition two) or on silent mode upside down just by side on the desk (condition three). Participants had not to interact with the phone. While the mobile phones were in one of the three positions, participants cognitive performance was tested in two experiments. In experiment 1 Ward et al. (2017) could demonstrate, that the mere presence of one owns mobile phone reduces the availability of limited cognitive capacity recourses. These findings were replicated in experiment 2.

As shown come Przybylski and Weinstein (2012), Thornton et al. (2014) and Ward et al. (2017) to the assumption that the mere presence of a cell phone indicates attentional and cognitive deficits, what impairs the quality of our current tasks. In the next chapters, it will be discussed what components are leading to attentional and cognitive deficits.

Cognitive Capacity

Many researcher (e.g. Engle, 2002; Evans, 2008, Ward et al., 2017) hypothesize that mobile phone related distractions have their roots in our cognitive resources. A user's ability to process information depends on one's limited cognitive system. Individuals are permanently exposed to potentially relevant informational stimuli. But our cognitive system has just a limited available capacity at any given time for the incoming information (Craik & Lockhart 1972). With that limited capacity we have to allocate attention (Engle, 2002) for an organized daily life, a regulated self and to pursuit our goals (Halford et al., 2007). The so called cognitive capacity is composed of the interplay of working memory and attentional resources (e.g. Engle 2002; Halford et al. 2007).

Working memory has to be differentiated from short-term memory stores. We use our short-term memory to temporarily keep a limited number (± 7) of items or chunks in mind (Engle, 2002). But working memory capacity is not all about memory. It is moreover an interplay between memory and executive attention. A greater working memory capacity means that more items can be stored, but this is a consequence of attentional allocation. Individuals with a greater working memory capacity are more likely to maintain attention on relevant information and suppress irrelevant distractors (e.g. Baddeley & Hitch, 1974; Lavie, Hirst, de Fockert, & Viding, 2004). Hence individual differences in working memory capacity are related to the ability of focusing attention on a current task in particular situation (Engle, 2002).

Working Memory and Attentional Allocation

Our cognitive functions are able to flexibly allocate and reallocate attention to several activities in a minimum of time (Liefooghe, Barrouillet, Vandierendonck, & Camos, 2008). There is strong evidence that working memory processes are involved in attentional allocation. In terms of the antisaccade paradigm Roberts, Hager and Heron (1994) found evidence of the involvement of working memory in tasks in which attention-capturing stimuli has to be suppressed. Antisaccade tasks go back on (Guitton, Buchtel & Douglas, 1985) where individuals had to look in the opposite direction of a flashed stimuli and inhibit the reflexive tendency to focus on the stimuli. In a follow-up research Kane, Bleckley, Conway and Engle (2001) obtained a correlation between the error rate in a antisaccade task and individual differences in working memory capacity.

The individual priority of a stimulus which attracts our attention is defined by its physical location (salience) and its importance to achieve personal goals (Fecteau & Munoz, 2006). Thus, the more a personal goal is relevant, the greater is the likelihood it attracts attention even when the stimuli is unrelated to the current task (Shiffrin & Schneider, 1997). This effect is called the cocktail party phenomena and was first examined from Moray (1959). In a follow-up study Conway, Cowan and Bunting (2001) had replicated the findings and proved a link to working memory capacity. Participants in their research were assigned to listen to the words spoken in one ear while ignoring the words spoken in the other ear. At a random moment, the participants name was spoken in the “ignoring ear”. Individuals working memory capacity was responsible if they recognized their name was spoken. Working memory capacity was assessed through the operation span task. Participants with high working memory capacity reported hearing their name in 20% of any cases. While low working memory capacity participants heard their name with a probability of 65%. This experiment shows us that individuals with higher working memory spans are better in suppressing task irrelevant information (Engle 2002). Usually the allocation of attention happens automatically – if it is task relevant or not – and helps individuals achieving their goals without keeping them constantly in mind (Ward 2017).

The impact of switching between tasks on general performance is well documented. Task switches come along with the so-called switch costs: reduced speed, reduced accuracy and higher error rates (e.g. Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995). Switching between tasks is assigned to be a primary function of working memory processes (Barrouillet, Bernardin, & Camos, 2004). Every attentional switch leads to additional demands on working memory capacity (Engle, 2002; Liefooghe et al., 2008). Beside life relevant and long-term-goals (Ward 2017), anxiety over missed notifications (Kushlever al., 2016) or small informational rewards (Oulasvirta et al., 2012) may let individual’s attention switch to one’s smartphone. An automated unconscious checking behavior was observed from Oulasvirta et al. (2012). In this study users did brief mobile phone checks without immediately receiving a notification. This checking habit is characterized through automated brief checks of the standby screen or specific information in an application. According to a more recent study about smartphone use from Andrews et al. (2014) are about 55% of all smartphone uses short checks.

In summary, when individuals are engaged in tasks – and the smartphone is task irrelevant – a nearby located smartphone can impair one’s performance in several ways: a) Even when individuals are successful at controlling their attention on the current task, the mere presence of a phone may reduce their working memory resources (Ward et al. 2017). They are losing working memory resources just in maintaining their attention on the current task and suppressing the want of checking the mobile phone (Engle 2002). Individuals with high working memory spans are more likely to stay with their attention on the current task (Conway, Cowan and Bunting (2001). If this fails, b) our smartphone can automatically attract our attention because of long-term relevant goals (e.g. keeping in contact with someone or reminding the owner of meetings) (Moray 1959; Shiffrin & Schneider 1997; Fecteau & Munoz 2006). Attentional switches are accompanied with a stressed working memory (Engle, 2002; Liefooghe et al., 2008). When individuals focus has switched to one’s smartphone c) it is just a little step to smartphone related thoughts. According to Srivastava (2005) do people associate their phone with their social network. Further the presence of a smartphone may let the individuals’ thoughts drift away towards other people and related events.

Dual-Processing

Many researchers investigated in their work the dual-system theory. In the literature, one will find an enormous number of different names for a higher cognitive process with two different modes of processing (Evans, 2008): e.g. Automatic/ Controlled (Schneider & Schiffrin, 1977), Heuristic/ Systematic (Epstein, 1994), Implicit/ Explicit (Evans & Over, 1996), Intuitive/ Analytic (Hammond, 1996), System 1/ System 2 (Stanovich, 1999). In this paper, the author orientate himself towards the neutral term System1 and System 2 as used from Stanovich (1999) and Evans (2008). All these dual-process theories have in common, that the lower processing level System 1 comes along with unconscious, automatic, fast and with low cognitive effort. We share the unconscious and evolutionary old System 1 with other animals (Schneider & Shiffrin, 1977). Fodor (1985) describes it as responsible for instinctive behaviors that are innately programmed. Because System 1 processes operate unconscious and parallel, just the final product is noticeable and thus conscious (Evans 2003). When I visit my parents' house, I know the women's face in front of me belongs to my mother. That is a typical System 1 process. It operates without a connection to general intelligence, motivation and alertness (Frederick, 2005). The higher processing level System 2 has characterises as conscious, slow and calculated (Schneider & Shiffrin, 1977; Evans, 2008). Whereas System 1 operates without cognitive resources (Evans, 2008), System 2 requires access to the working memory system (Baddeley & Hitch, 1974). There is strong evidence that System 2 reasoning ability correlates with working memory capacity (e.g. Capon, Handley, & Dennis, 2003; Kyllonen & Christal, 1990; Markovits, Doyon, & Simoneau, 2002). Frederick (2005) describes mathematical problems as typical System 2 tasks. Mental calculating $\sqrt{23454}$ to two decimal places demands high cognitive effort, motivation and concentration (Frederick, 2005) and even then, will not every subject be able to solve the problem. For System 2 problems are also amounts of general intelligence required (Evans, 2003).

There is also very strong neuropsychological evidence for dual processes in reasoning (Goel, Buchel, Frith, & Dolan, 2000; Goel & Dolan, 2003). Goel and Dolan (2003) investigated the neurological impact of the belief-bias paradigm (Evans, Bartson, & Pollard, 1983). The belief-bias effect works with syllogisms that creates conflicts between logic reasoning and prior belief. However, Goel and Dolan used fMRI techniques and found differences in neuronal activity dependent on whether logic or belief decisions were made. Correct logical evaluations were processed in the right inferior prefrontal cortex, while incorrect belief-biased responses are activating the ventral medial prefrontal cortex (Goel & Dolan, 2003).

Summary

Individuals have to allocate their limited attentional resources to manage their daily life (Engle, 2002; Halford et al., 2007, Craik & Lockhart 1972). Whenever attention has to be allocated (e.g. driving and eating at the same time) working memory capacity is stressed (Engle, 2002). A stressed working memory system due to a smartphone occurs when the following three factors are present: (1) remaining the attention on the current task, (2) the smartphone reminds us of long-term relevant goals and (3) smartphone related thoughts like our social network (Srivastava, 2005). Thus, attention is divided and available working memory capacity for each task is reduced wich also affects informational processing (e.g. Capon, Handley, & Dennis, 2003; Kyllonen & Christal, 1990; Markovits, Doyon, & Simoneau, 2002). So, we are not able to process incoming information that deep like when all our attention is focused just on one stimuli. Likelihood to System 1 processing are the consequences (Frederick, 2005). To adapt these findings to the present research, the mere presence of a smartphone reallocates our attention and therefore stresses available working memory capacity for the actual task. Hence, when we are working on a high cognitive demanding task our ability to process in System 2 is impaired.

Up to date there are just three (Przybylski & Weinstein, 2012; Thornton et al., 2014; Ward et al., 2017) examinations done to investigate the cognitive consequences when a smartphone is nearby but not in use. The author has set the objective to examine the relationship between the mere presence of a smartphone and individuals' cognitive performance. Working memory capacity plays an important role in cognitive performance and is assessed to examine if there are differences when a smartphone is present vs. absent. Another goal is to figure out if a stressed working memory capacity through a smartphone is sufficient to impair the depth of informational processing.

Hypotheses

Five hypotheses were derived from present research literature and are presented in Table 1. The hypotheses are reflecting an interplay between smartphone presence, working memory capacity, informational processing and attentional control. The model is displayed in Figure 1.

Table 1. Hypotheses one to five.

Hypothesis	
H_1	The mere presence of a smartphone impairs working memory capacity.
H_2	The mere presence of a smartphone lead individuals to System 1 processing.
H_3	Impairments in working memory capacity lead individuals to System 1 processing.
H_4	Higher attentional resources lead to better scores in working memory capacity tasks.
H_5	Higher attentional resources lead individuals to System 2 processing.

Methodology

Design

A between subject experiment design was used. The between-subject factor and thus the independent variable is the position of the smartphone during the cognitive tasks: a) smartphone aside on the table b) Smartphone in a bag out of reach. The score in the cognitive tasks (OSpan working memory task and CRT informational processing task) are dependent variables. While the OSpan task is used as mediator, CRT is the outcome variable. The model with all hypotheses is shown in Figure 1. In the OSpan task, memory span is defined through items individuals remembered (Turner, 1989). Thus, the maximum OSpan score is 16 points. The addition of every correct solved CRT task has a maximum of seven points (one point per correct answer). Attentional capacity is assessed as a covariance by a short version of the attentional capacity scale (ACS) (Derryberry & Reed, 2002; Judah, Grant, Mills, & Lecher, 2013).

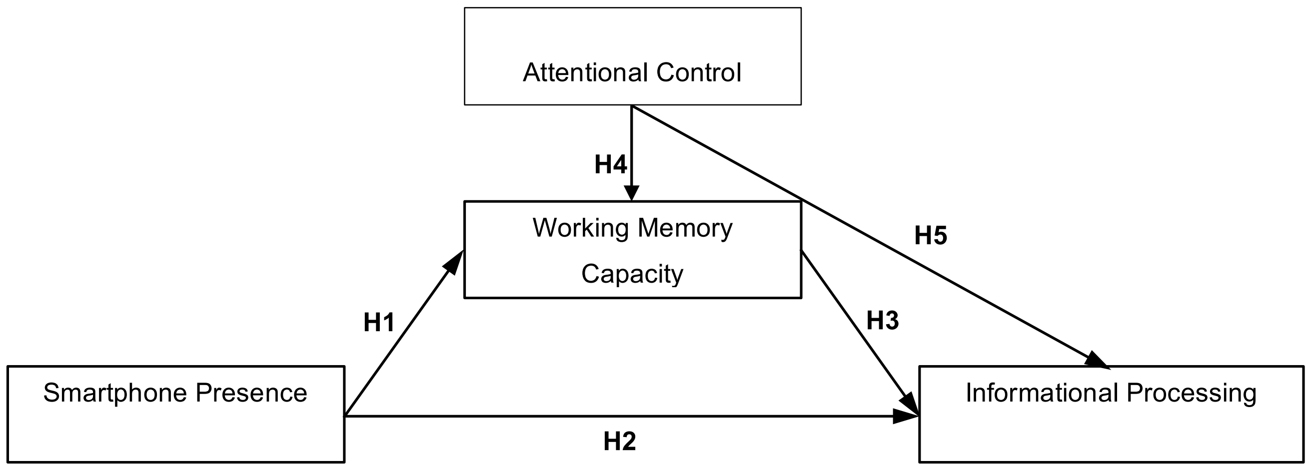


Figure 1. Expected model between Smartphone presence and Informational processing with hypotheses one to five.

Participants

For structural equation modelling with the maximum likelihood method Jackson (2003) recommends the N:q rule. This correspond the ratio of minimum sample size (N) and the number of model parameter that require statistical estimates (q). Jackson (2003) suggest a ratio of 20:1. With five paths data of 100 participants should be analyzed in the present model due to literature.

121 undergraduate psychology students from the University of Basel started the experiment for course credit. Students were recruited from the university’s test subject database via internet. Data collection took place over a span of five weeks. Because the survey is in English participants should understand written English language. Technical issues lead us to exclude data of 15 participants. One participant was excluded right before starting the experiment because of not understanding written English language. 6 participants were excluded because they indicated in the survey control question having

the smartphone during the experiment not where it should be according the experimental group. One outlier (± 3.00 SD) in OSpan and one in CRT preparation time were excluded.

We assumed that the big majority of students possess a smartphone. Avoiding to attract too much attention on smartphones, we did not mention in the experiment invitation the necessity of bringing a smartphone to the laboratory. It was not necessary to exclude any participants because of not possessing a smartphone. In none of the experimental groups were smartphone related indications of visual or acoustic distractions noticeable. Therefore, no exclusions due phone related distractions during the experiment.

In total data of 99 participants was used for the statistical analysis. 70 defined their self's as female and 29 as male. With a mean age of 22 and a range from 19 to 70 the sample size was quite young. The big majority (94) were students (82 psychology, 12 others), the remaining 5 participants were retired, professional or unemployed.

Procedure

Undergraduate students registered in given time slots over five weeks. For a randomized sample, timeslots differ in time and workdays. Data collection took part in a University of Basel's laboratory room. Participants were tested in groups from one to ten individuals on the same time, each on a desktop computer. All participants in each group start the experiment on the same time. The given timeslot groups are randomly assigned to one of the two experimental conditions and one of the two experimenters. Participants are instructed either to place one's smartphone "nearby" or leave it "out of reach" in the room. Avoiding attract too much salience of one's smartphone, instructions were given as follows: Participants in the "nearby" condition are assigned to put their smartphone upside-down right next to them on their desktops. It was explained that in one survey they have to complete questions containing informations about their smartphone. Individuals in the "out of reach" condition are instructed to leave all their personal belongings, particular disruptive artefacts, in their jackets and bags on the wardrobe. That is a common instruction in exams in the University of Basel and should not cause confusion. The experimenter should be aware not to move too much attention towards participant's smartphones. Participants in both conditions are familiarize with the importance to complete the survey as quick and accurate as possible. As additional incentive, we enter the participants with the highest scores in the cognitive tasks into a raffle with the chance of winning one of two CHF 50 coupon for local supermarkets. Participants have to sign an informed consent before they are allowed to start with the computer based testing. After another short instruction, participants are taking the OSpan task and the Cognitive Reflection Task (CRT) in randomized order. Following the last CRT task a question surveyed if and which CRT tasks participants are familiar with. Next the attentional control scale (ACS) is presented. Two questionnaires related to another research (Quanbrough, 2018) were assessed on this point. The Fear of Missing Out and Smartphone Attachment Questionnaire. The author will not go into these two questionnaires in any further detail. Afterwards some explorative questions assess subjective views, like how much participants felt influenced by their phone. At last some demographic information (gender, age and current occupation) are questioned. When finished all surveys participants get as a little thank-you chocolate and the sign needed to get course credit for the participation. Chronological examination sequence is illustrated in Figure 2.

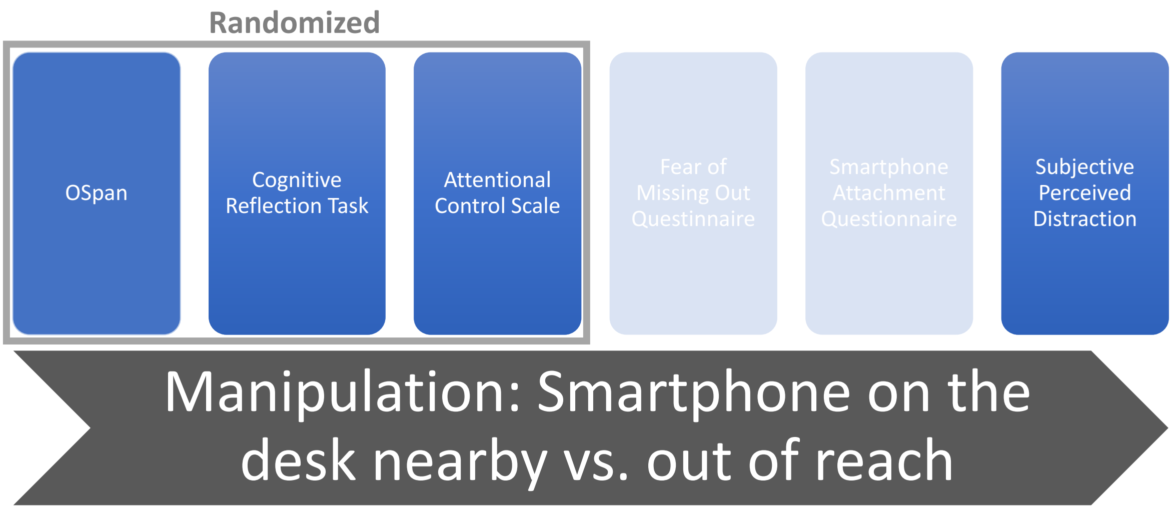


Figure 2. Procedure of the present examination. Participants had to solve for the present research an OSpan, CRT, ACS task and respond questions of their subjective view of distraction through their smartphone. The Fear of Missing Out and Smartphone Attachment Questionnaire data were also collected but were part of another investigation. Participants smartphone was depending on condition nearby or out of reach in the wardrobe.

Measures

The OSpan task is a working memory capacity test. In the current examination an adapted automated version of the Operation Span task (OSpan; Unsworth, Heitz, Schrock, & Engle, 2005; Daneman & Carpenter, 1980) is used (Cronbach's α=.51). In working memory measures subjects typically receive items to memorize while performing other attention demanding tasks (Engle, 2002). Participants have to keep in mind numerical values while judging if given statements are true or false. In the beginning of each set a numerical value is presented for one seconds. Afterwards a simple distracting question has to be answered through keyboard input ("f" for false, "j" for true). For example, first the number 35 is presented, then the statement: "a crocodile is colored blue" appears. Participants have to answer if the statement is true or not. Then the number 18 appears, and so on… There are five trials with remembering and distracting sequences. In the first trial this sequence repeats two times, in the second and third trial three times and in the fourth and fifth trial up to four times before the remembered values have been recalled in the end of each trial. In total 17 numerical values and distraction question were presented. For the global working memory capacity score, just the number of remembered items are taken into account. The questions were just for distraction and were not evaluated.

The original CRT was developed by Frederick (2005) and includes three Items. In this research, the expanded seven item version from Toplak, West and Stanovich (2014) was used (Cronbach's α=.445). CRT is a measure of informational processing postulated by dual process theories (Toplak et al., 2014). Problems in which logic and intuitive belief stands in conflict are used to identify individuals current informational processing stage (Evans, 2003). Items work according to Frederick (2005) as follows: At the first glance the problem seems clear and easy. That is while System 1 is processing and individuals tend do give the first available intuitive (wrong) answer. Just when individuals start to ponder on the problem they will manage to do the step towards System 2 processing and will recognize the solution is not that easy as it seems. An CRT item is like:

"A bat and a ball cost $1.10 in total. The bat costs a dollar more than the ball. How much does the ball cost?"

The correct answer is 5 cents and for the intuitive answer Toplak et al. (2014) expect 10 cents. Thus, the correct answer is just achievable by higher cognition processing. People who gave the intuitive (wrong) answer rated the difficulty easier than subjects who thought deeply about it and respond the correct answer (Frederick, 2005).

Attentional control is an important skill for working memory capacity performance (Baddeley & Hitch, 1974; Lavie et al., 2004) and measured with the attentional control scale (ACS) (Derryberry & Reed, 2002). Originally ACS was developed in a clinical setting to investigate anxiety disorders (Derryberry & Reed, 2002) with a 20-item self-report scale consisting of 9 items measuring attentional focusing and 11 items assessing attentional shifting (Derryberry & Rothbart, 1988). For this study, a short version validated from Judah et al. (2013) with 12 items is used (Cronbach's α=.702). 7 items loading on focusing and 5 items loading on shifting with a high significant correlation of .96 to the original extended version. Participants choose one of four response choices (1 = almost never; 2 = sometimes; 3 = often; 4 = always) while higher scores indicating better attentional control (Ólafsson et al., 2011). To give an example item: "When I am working hard on something, I still get distracted by events around me."

Additionally, participants have to rate on a 5-point Likert scale statements after they finished the cognitive tasks (Cronbach's α=.629). These three statements assessed the subjective perceived distraction: "I believe my smartphone's location influenced my performance", "I believe my smartphone's location had a positive influence on my performance" and "I believe my smartphone's location had a negative influence on my performance".

Results

Preliminary Analysis

With boxplots, univariate outliers ($\pm$ 3.00 SD) were detected in working memory capacity (OSpan), informational processing (CRT) and attentional control (ACS) data. Thus, two participants were excluded for the statistical analysis because they were outlieres.

Shapiro test was used to test the distribution. Neither working memory capacity (OSpan) nor informational processing (CRT) ($p < .001$) or attentional control (ACS) ($p < .001$) were normally distributed tested with Shapiro test. With a Wilcoxon test an experimenter effect for working memory capacity (OSpan; $z=-1.06$, $p=.29$, $n=99$), informational processing (CRT; $z=-0.662$, $p=.508$, $n=94$) and attentional control (ACS; $z=-0.478$, $p=.633$, $n=99$) tasks can be rejected. working memory capacity tasks (OSpan) and informational processing tasks (CRT) were participants presented in random sequence. A Wilcoxon test rejected a sequence effect for the working memory capacity task (OSpan; $z=-0.654$, $p=.512$, $n=99$) and the informational processing task (CRT; $z=-0.549$, $p=.583$, $n=94$).

Because the informational processing tasks one to three were familiar to the majority of the participants, these three questions were excluded for informational processing (CRT) global score calculation. For question four to seven percentiles were built to calculate the global score. Familiar questions are not included in the global score due to avoid corruption of the data. This means when an individual solved 0 unfamiliar and 1 familiar CRT questions right a global score of 0% is assigned. Because the familiar question is not taken into account, a total of 3 (not with 4) questions is used to calculate the percentiles. Additionally, 4 participants who were familiar to more than one CRT task were excluded. Exclusion was made with pairwise deletion principle to unnecessarily avoid reducing the anyway small sample size for the structural equation model (Allison, 2003).

Sample size, means and standard deviations for all variables across both conditions can be seen in Table 2. Consider that the informational processing (CRT) is measured in percentiles whereas the working memory capacity (OSpan) and attentional control (ACS) scores present correct solved points. As we see in Figure 3, there are slight differences in working memory capacity (OSpan; $z=-1.54$, $p=.029$, $n=98$) calculated with Wilcoxon test. In the depth of informational processing (CRT) no significant differences ($p= .125$) were detected. There are also no differences between the attentional control (ACS) scores noticeable. ACS measures the ability to control individuals attention in daily lives and should not differ according to smartphone location. This was also checked with a wilcoxon test. ACS scores do not differ ($p=0.637$) when smartphones are present vs. absent. Table 3 shows Spearman rank-order correlations between smartphone location, working memory capacity, informational processing and attentional control. The only nonsignificant value is between OSpan (working memory capacity) and CRT (informational processing) when participants smartphone is present.

Model Estimation

To test the hypotheses a path analysis model (see Figure 1) was estimated. An advantage of the path analysis compared to regression analysis is that more than one variable can be modelled into complex networks (Steinmetz, 2015). The path analysis was calculated with the R package “lavaan” (Rosseel, 2012). Standard bootstrapping and Satorra-Bentler correction due to non-normality (Kline, 2011) was used.

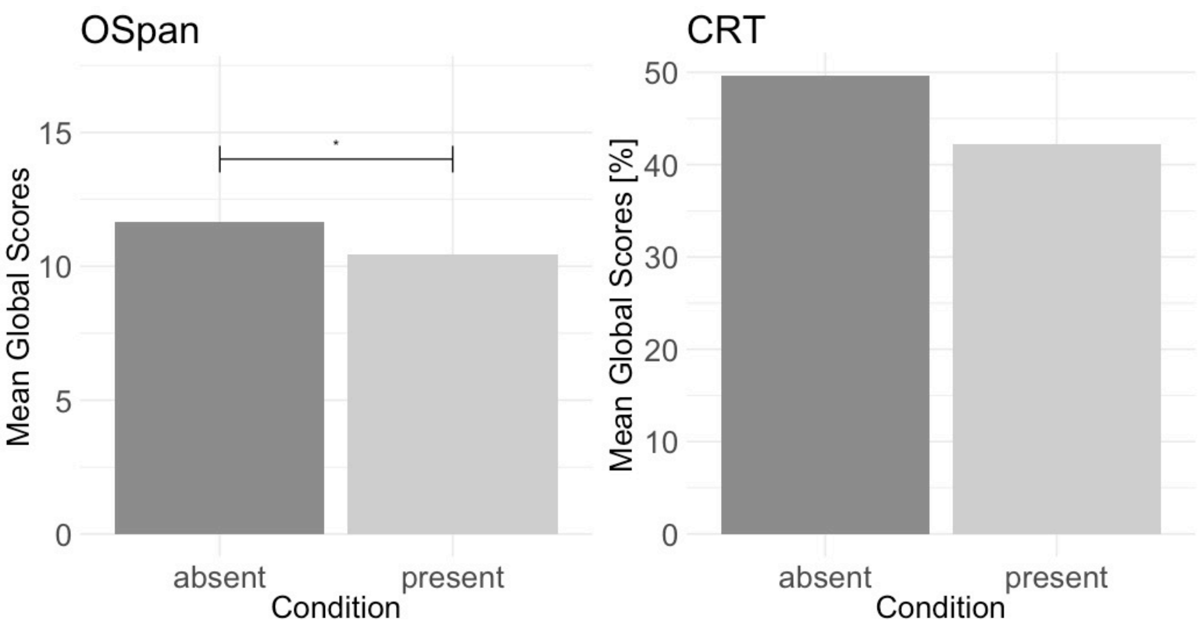
Variables smartphone presence, working memory capacity, informational processing and attentional control were used to estimate the model. The fit indices indicate a good fit for the resulting model

($\chi 2$=.045, df =1, p=.832, comparative fit index [CFI] = 1.000, root mean square of approximation [RMSEA] = .00, 90% CI [.00, .00]).

The modification indices of .045 over all paths lead to the conclusion that it is not necessary to retain paths for a better model fit.

Table 2. Descriptive statistics. Sample size, means and standard deviations by condition (Working memory capacity measured with OSpan task, informational processing measured with CRT, attentional control measured with ACS).

	Smartphone absent		Smartphone present	
Variable	n	M (SD)	n	M (SD)
OSpan	47	11.66 (2.89)	51	10.43 (3)
Percentage CRT	48	49.65 (31.41)	46	42.21 (28.73)
ACS	48	19.42 (3.54)	51	19.27 (2.91)



*p < .05. **p < .01. ***p < .001.

Figure 3. Mean global scores for OSpan and CRT task per condition.

Table 3. Spearman rank-order correlation by condition (Working memory capacity measured with OSpan task, informational processing measured with CRT, attentional control measured with ACS).

	Smartphone present			Smartphone absent	
Variables	ACS	OSpan	Variables	ACS	OSpan
OSpan	.39**		OSpan	.43**	
CRT	.48***	.26	CRT	.36*	.47***

*p < .05. **p < .01. ***p < .001.

Confirmatory Analysis

The five hypotheses were tested based on the estimated model. There was support found for hypothesis 1. Smartphone presence affected significantly Working Memory Capacity (β=-.21, b=-1.20, SE=0.53, p=.023). Hypothesis 2 predicted an impact of smartphone presence on informational processing. This was not supported by the model (β=-.07, b=-3.99, SE=5.83, p=.494). Hypothesis 3 predicted that a low working memory capacity would be associated with to low CRT scores (indication for increased likelihood of System 1 processing). For hypothesis 3 a significant effect was found (β=.28, b=2.87, SE=1.06, p=.007). There was another significant effect found between the covariable attentional control and the dependent variable working memory capacity (β=.39, b=3.57, SE=0.86, p<.001) which supports hypothesis 4. Also, hypothesis 5 is supported. Participants with a higher attentional control have higher scores in CRT task (β=.30, b=2.78, SE=0.53, p=.002) what are indices for an increased likelihood of System 2 processing. The structural equation model with standardized estimates of direct effects is shown in Figure 4.

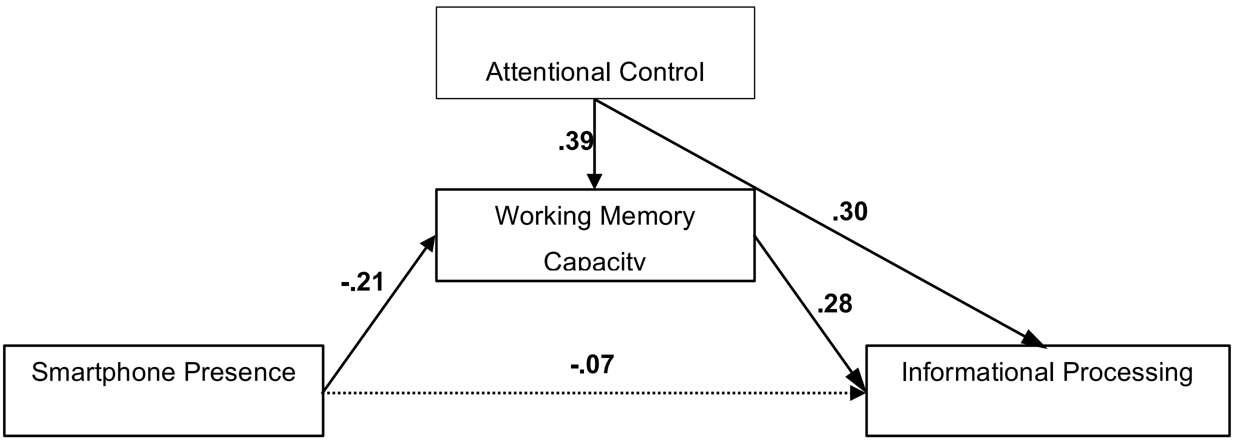
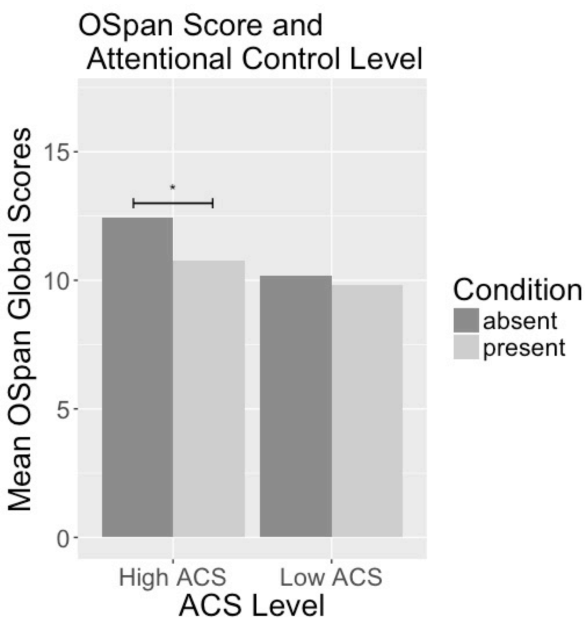


Figure 4: Structural equation model of smartphone presence and informational processing. Standardized estimates of direct effects examined in the confirmatory analysis are included. Solid lines indicate significant pathways, dotted lines indicate nonsignificant pathways.

Exlporatory Analysis

The subjective influence of participants phone on their performance was measured with the questions: “I believe my smartphone's location influenced my performance”, “I believe my smartphone's location had a positive influence on my performance” and “I believe my smartphone's location had a negative influence on my performance”. With Spearman’s rank-order correlation no relation could be found between the three questions and any of the three tested tasks.

In further explorative analyses the author examines if there are differences between participants with high attentional control in contrast to participants with low attentional control. The median ACS score of 20 is used as cut off point with the consequence of two same sized groups. With Spearman rank order correlation significance was found between participants with high attentional control scores and their working memory capacity scores (r=.31, p=.028, n=52) ignoring smartphone presence. Also, significance was found with Wilcoxon test between smartphone presence and participants working memory capacity with high attentional control (z=-2, p=.046, n=94). No correlations were found between participants with low ACS scores and their working memory capacity scores (r=.02, p=.91, n=47). Further there were no differences between smartphone presence and working memory capacity scores from participants with low attentional control (z=-1.6, p=.101, n=94). These explorative findings are presented in Figure 5. An overview of all hypotheses can be seen in Table 4.



*$p < .05$. **$p < .01$. ***$p < .001$.

Figure 5. Differences in participants OSpan Score per condition considering their Attentional Control level.

Table 4. Summary of hypotheses, findings and support.

Confirmatory Analysis			
Hypothesis		Finding	Hypothesis confirmed
H1	The mere presence of a smartphone impairs working memory capacity.	βH1 = -.21	Yes
H2	The mere presence of a smartphone lead individuals to System 1 processing.	βH2 = -.07	No
H3	Impairments in working memory capacity lead individuals to System 1 processing.	βH3 = .28	Yes
H4	Higher attentional resources lead to better scores in working memory capacity tasks.	βH4 = .39	Yes
H5	Higher attentional resources lead individuals to System 2 processing.	βH5 = .30	Yes

Discussion

The aim of this study was to investigate the influence of a present smartphone on cognitive functions as working memory and informational processing. Support was found that the mere presence of a smartphone worsens the working memory performance. This verifies the results from Thornton et al. (2014) and Ward et al. (2017). Individuals working memory capacity was more stressed through the OSpan tasks when participants smartphone was located on the desk. Furthermore, impairments in working memory capacity was significantly related to informational processing. Considering pathway analysis, we can conclude that smartphone presence affect working memory capacity, what in turn increases individuals' likelihood of System 1 processing. The negative impacts are on average around 5% performance reduction in higher cognition tasks.

However, the findings should not tempt observers to jump to the conclusion that the model shows a mediation. To be able to talk about a mediation effects between smartphone presence and informational processing should be found. That has not been the case. What can be said based on the findings is the fact, that the mere presence of a mobile phone stresses our working memory system, what in turn impairs informational processing. This raises the question of why no direct effect found was of smartphone presence on informational processing? The author thinks this is partly due to unfavorable conditions in the CRT data structure. It was necessary to exclude three of the seven CRT items completely and in case of familiarity, even more items per participant. In view of the fact that the items just can be solved right or false, it is hard to find relations to other constructs with four or less dichotomous items in one scale. This assumption also underlines a poor intern consistency with a Cronbach's alpha of 0.45 in present research. Even the original validated CRT version from Toplak et al. (2014) makes a similar alpha of 0.484. Further the data showed a significant relation between OSpan and CRT when participants smartphone was absent, but not when the smartphone was present. One explanation is again the unfavorable CRT data structure. Another but probably unlikely possibility is despite impairments in working memory capacity, informational processing works without restrictions when the own smartphone is present. Due to literature, the second explanation is implausible as many researchers already verify strong evidence for an effect between working memory capacity and informational processing (e.g. Capon et al., 2003; Kyllonen & Christal, 1990; Markovits et al., 2002). Despite the rejected hypothesis 2 (effect between smartphone presence and informational processing) we can not conclude, that the mere presence of our smartphone can impair directly our depth of cognitive processes towards System 1 processing.

Which role plays attentional control? Attentional control and working memory capacity were just correlated when participants attentional control was above median. This means according to the collected data, that differences in individuals attentional control affect working memory capacity just when individuals have high attentional control. In consideration of smartphone presence similar effects are found. Just when participants attentional control is above median their working memory capacity is significantly different when the participants smartphone is present vs. absent. Here questions arise if individuals with low attentional control are less affected of the mere presence of a smartphone? Individuals with low scores in the Attentional Control Scale have difficulties to keep their attention on one specific task (e.g. Judah et al., 2013; Derryberry & Reed, 2002; Derryberry & Rothbart, 1988). Thus, attentional switches occur more often and cause a stressed working memory (Engle, 2002; Liefooghe et al., 2008). When attention is shifting between different stimuli anyway, a present smartphone is just one stimuli among many. It stands to reason for individuals with low attentional control that the mere presence of a smartphone does just have very little or no effects on their anyway stressed working memory capacity.

In contrast to Ward et al. (2017) just one "absent" condition was assessed. While Ward and colleagues had a "Packet/Bag" and an "other Room" condition. Whereas in the "Packet/Bag" group the smartphone was still nearby, but not visible, was the smartphone placed out of the room in the "other Room" condition. In the present research, the smartphone was placed on the wardrobe inside the testing room. In the study of Wart et al. (2017) no significant difference in working memory capacity was found between the "present" on the desk and the "Pocket/Bag" condition. But we found significant effects when the smartphones were located in the wardrobe. This leads to the conclusion that a smartphone does not necessarily have to be out of the room to avoid cognitive performance reduction. It seems to be sufficient when ones' smartphone is out of sight and reach.

Implications, Limitations and Future Research

The present findings are especially important in professions where unfocused work can cause safety risks like in air traffic control. Based on this research the author recommends to place ones' smartphone out of reach and view during safety relevant work or when the outcome of the present task is highly relevant. Future research could examine whether there is a difference in cognitive impairment between one owns smartphone and business mobile phones. It also stands to reason that the mere presence of a mobile phone influence how well students prepare for an exam and thus how they perform during the exam. It would be worth to examine how presence smartphones influence exam scores when its are presence during learning phase. Ward et al. (2017) also point out that consumer choice and advertising effectiveness could be influenced by our smartphones. When working memory capacity is reduced we are more enticed to make heuristic based purchasing decisions characteristic for System 1 processing. This consumer psychology approach is also an interesting field for further examination. In all these mentioned approaches, special focus should be given to the question: Which role plays the ability to control attention when a present smartphone affects our cognitive performance?

Data collection took place in a controlled laboratory setting. It is to be expected that participants are not used to work under such conditions and additionally may encourage social desirability. This could lead to a more focused work than participants would do in a familiar setting (e.g. at home). Although, remaining on a task and suppressing other stimuli (smartphone) stresses working memory (Engle 2002). In a familiar setting working memory is may more tended to be stressed by actual cognitive task switches caused through ones' smartphone. It would be interesting for future research to distinguish different causes of a stressed working memory capacity due to smartphone presence.

As previously mentioned, some of the CRT items were already known by the participants. Thus, three items were excluded from the beginning and some more items were excluded per participant in case of familiarity. Finally, three to four items per participant werer analyzed for the global score of this questionnaire. Further the answer format (dichotomous right or false) led probably to an unfavorable structure in the CRT data which makes it difficult to find relations to other constructs because of its low internal consistency. It should be considered to use a questionnaire with a higher internal consistency and for the participants unfamiliar items to assess depth of informational processing. This could probably be done with the development of a task where participants can rate items on a Likert scale. To counteract the issue of familiarity it would be favorable when the items can be arbitrarily transformed like math problems. Up to date there is no such measurement available. I like to motivate researcher to investigate in this direction.

Conclusion

The mere presence of smartphones can impair ones' cognitive performance. Due to smartphone presence participants likelihood of System 1 processing is not directly increased. Working memory capacity is directly affected by smartphones and has effects on informational processing. A direct effect between smartphone presence and informational processing was not found. There are indications that attentional control plays a crucial role in how strong smartphones impair participants' working memory capacity. Individuals with high scores in attentional control scale show impairments in working memory capacity when ones' smartphone was present. Those findings are relevant in safety relevant tasks or when the outcome of a present task is highly relevant like assessment tests.

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Appendix

Appendix A: Preliminary Study

In a preliminary Study, participants completed an online survey containing the OSpan task and the CRT. The aim of the preliminary study was to ensure that no sequence effect appears between the two cognition tasks. 49 Participants completed the survey. The OSpan task and the CRT were presented and solved in randomized order. 3 participants were excluded for OSpan and CRT calculations because of low self reported seriousness while completing the two tasks. Additionaly in the CRT task 4 participants were excluded because they were familiar to more than three CRT items. The data of the remaining 46 (Ospan) respectively 42 (CRT) participants were analyzed. 20 participants first solved the OSpan and afterwards the CRT, while the two tasks for 29 participants were presented the other way around. Due to not normally distributed data a Wilcoxon test was made over both tasks. 19 participants first solved the OSpan task, 27 participants were the CRT task presented first. There were no sequence effects found in the OSpan task ($z=-0.85$, $p=.394$, $n=46$) with a mean of 11.7 and 11.5. In the analyzed CRT data 17 participants first solved the OSpan taks and 25 had to solve the CRT problems first. Also in the CRT task with a mean of 3.7 and 4 were no sequence effects were assessed ($z=-0.28$, $p=.779$, $n=42$).

Appendix B: Declaration of Consent

Universität Basel

Fakultät für Psychologie

Einverständniserklärung

Sehr geehrte Probandin, sehr geehrter Proband

Vielen Dank für Ihre Teilnahme an dieser Studie.

Das Ziel dieser Studie ist, die kognitive Leistung im Alltag zu untersuchen. Die Dauer des Experiments beträgt ungefähr 20 Minuten.

Die Studienteilnahme ist mit keinerlei gesundheitlichen Risiken verbunden. Die Fragebögen können Fragen persönlicher Natur beinhalten.

Für Ihre Teilnahme erhalten Sie am Ende der Untersuchung, falls benötigt, eine Unterschrift. Zudem werden unter den Teilnehmern mit den besten Ergebnissen in den beiden kognitiven Leistungstests zwei Migros-Gutscheine à CHF 50.- verlost.

Alle in dieser Studie gesammelten Daten werden anonymisiert ausgewertet und ausschliesslich für wissenschaftliche Zwecke verwendet.

Ihre Teilnahme an dieser Studie ist freiwillig. Sie haben jederzeit die Möglichkeit, die Studie ohne Angabe von Gründen abzubrechen. Die Einwilligung zur Verwendung Ihrer Daten können Sie während der Studienteilnahme jederzeit widerrufen. Ein nachträglicher Widerruf nach Beendigung der Studie ist aufgrund der anonymisierten Speicherung Ihrer Daten nicht möglich.

Sollten Sie die Studie abbrechen und Ihre Daten löschen wollen, erstellen Sie bitte einen Code auf dem beiliegenden Blatt und geben ihn dem Versuchsleiter/der Versuchsleiterin ab. Anhand des Codes kann eine Zuordnung zu Ihrem Datensatz gemacht und Ihre Daten somit gelöscht werden.

Ich habe die aufgeführten Bedingungen gelesen und verstanden. Mit meiner Unterschrift bestätige ich mein Einverständnis zur Teilnahme an dieser Studie.

Datum und Unterschrift:

____

Seite 1/1

Appendix C: Deletion Paricipants Data

Universität Basel

Fakultät für Psychologie

Daten löschen

Falls Sie sich während oder am Ende der Studie dazu entschliessen, abzubrechen und Ihre Daten nicht zur Verfügung zu stellen, so verwenden Sie bitte dieses Blatt.

Wir bitten Sie in diesem Fall, einen Code zu erstellen, damit eine Zuordnung zu Ihrem Datensatz gemacht und Ihre Daten gelöscht werden können.

Bitte bilden Sie einen vierstelligen Code aus dem ersten Buchstaben Ihres eigenen Vornamens, dem ersten Buchstaben des Mädchennamens Ihrer Mutter und dem Monatstag (zwei Ziffern) Ihres Geburtstags.

Beispielsweise:

Hannah + **L**imacher + **06**.08.1992 → **HL06**

— — — —

Appendix D: Survey

Instructions per Condition

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

Welcome to the study "Cognitive performance in everyday life"

The following survey is part of a research project from the Center for Cognitive Psychology and Methodology, University of Basel, Switzerland.

You will work through two cognitive tasks followed by some questions. The study will take 15-20 minutes.

As a part of the survey you will be redirected. Please do not close the window until you are requested to do so.

Your data will be treated **anonymously** and **confidentially** and will not be accessible to third parties.

Thank you for making a valuable contribution to research!

For questions please contact:
Leo Stahl or Jasmine Quanbrough

By continuing with the study, you confirm that you agree to the terms and are 18 years old or over.

Press *"Continue"* to start the study.

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

Welcome to the study "Cognitive performance in everyday life"

The following survey is part of a research project from the Center for Cognitive Psychology and Methodology, University of Basel, Switzerland.

As a preparation for a task that will follow later in the study, please place your smartphone upside down in reach on your desk.

You will work through two cognitive tasks followed by some questions. The study will take 15-20 minutes.

As a part of the survey you will be redirected. Please do not close the window until you are requested to do so.

Your data will be treated **anonymously** and **confidentially** and will not be accessible to third parties.

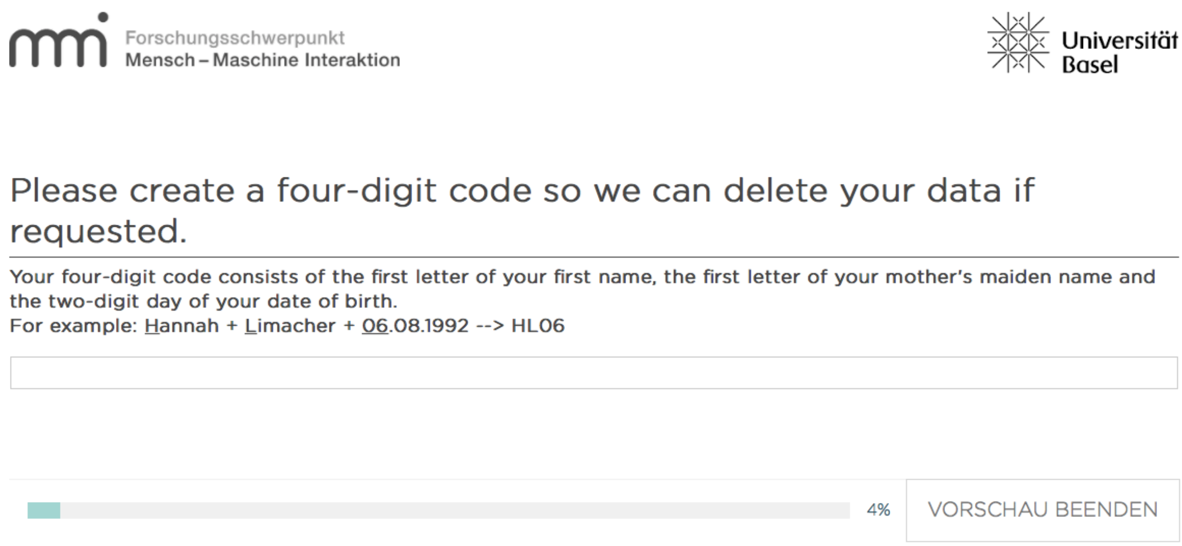
Thank you for making a valuable contribution to research!

For questions please contact:
Leo Stahl or Jasmine Quanbrough

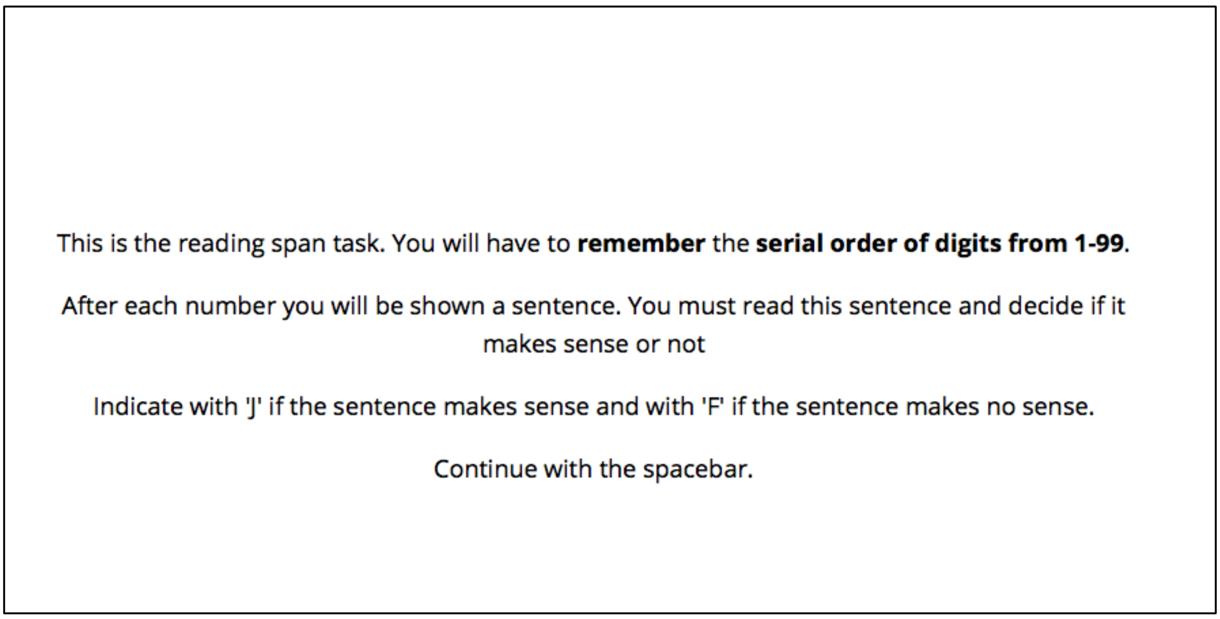
By continuing with the study, you confirm that you agree to the terms and are 18 years old or over.

Press *"Continue"* to start the study.

Participants Code



OSpan Task (example items)



18

A magician performs magic

[F] = makes no sense | [J] = makes sense

35

Horses go to the supermarket

[F] = makes no sense | [J] = makes sense


Enter Number 1
Enter


Enter Number 2
Enter

Cognitive Reflection Task

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

Several problems will now follow which vary in difficulty.
Please try to solve them as **quickly** and **accurately** as possible.

4% CONTINUE

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

A man buys a pig for $60, sells it for $70, buys it back for $80, and sells it finally for $90. How much has he made?
______ dollars

Your answer goes here:

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

If John can drink one barrel of water in 6 days, and Mary can drink one barrel of water in 12 days, how long would it take them to drink one barrel of water together?
______ days

Your answer goes here:

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

Simon decided to invest $8,000 in the stock market one day early in 2008. Six months after he invested, on July 17, the stocks he had purchased were down 50%. Fortunately for Simon, from July 17 to October 17, the stocks he had purchased went up 75%. At this point, Simon has:

- ○ broken even in the stock market
- ○ is ahead of where he began
- ○ has lost money

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?
_____ minutes

Your answer goes here:

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

A bat and a ball cost $1.10 in total. The bat costs a dollar more than the ball. How much does the ball cost?
_____ cents

Your answer goes here:

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

Jerry received both the 15th highest and the 15th lowest mark in the class. How many students are in the class?
_______ students

Your answer goes here:

Forschungsschwerpunkt
Mensch – Maschine Interaktion

Universität Basel

In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?
_____ days

Your answer goes here:

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Were any of the previous questions familiar to you?

Please select all questions you were familiar with.

- ☐ No, none of them
- ☐ Bat and ball
- ☐ Machines and widgets
- ☐ Lily pads on lake
- ☐ John's barrel of water
- ☐ Jerry's mark in the class
- ☐ A man buys a pig
- ☐ Simon's stock market investment

Control Question

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Do you think you know what this study is about?

If you think you have a clue, please tell us your guess. (You can answer in german if you prefer)

- ◯ No, I have no clue.
- ◯ Yes, I think the study is about...

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You have completed the first part of the study and can now start with the second part.

Several subjective questions will follow. Please answer honestly and choose the response option that fits best for you.

Attentional Control Scale

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Below is a collection of statements about your everyday experience. Using the scale provided please indicate how true each statement is of your general experiences. Please answer according to what really reflects your experiences rather than what you think your experiences should be. Please treat each item separately from every other item.

	almost never	sometimes	often	always
It's very hard for me to concentrate on a difficult task when there are noises around.	◯	◯	◯	◯
When I need to concentrate and solve a problem, I have trouble focusing my attention.	◯	◯	◯	◯
When I am working hard on something, I still get distracted by events around me.	◯	◯	◯	◯
When I am reading or studying, I am easily distracted if there are people talking in the same room.	◯	◯	◯	◯
When trying to focus my attention on something, I have difficulty blocking out distracting thoughts.	◯	◯	◯	◯
I have a hard time concentrating when I'm excited about something.	◯	◯	◯	◯

	almost never	sometimes	often	always
I can quickly switch from one task to another.	○	○	○	○
It is difficult for me to co-ordinate my attention between the listening and writing required when taking notes during lectures.	○	○	○	○
I can become interested in a new topic very quickly when I need to.	○	○	○	○
After being interrupted or distracted, I can easily shift my attention back to what I was doing before.	○	○	○	○
When a distracting thought comes to mind, it is easy for me to shift my attention away from it.	○	○	○	○
It is easy for me to alternate between two different tasks.	○	○	○	○

Control Question

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Where is your phone located right now?

○ On the desk nearby.

○ In my pocket (on my body).

○ Out of reach.

○ I don't own a smartphone.

Did you think about your smartphone at any time during the two cognitive tasks in the beginning?

○ No, not at all.

○ Yes, at least once.

○ I don't own a smartphone.

Explorative Questions

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I believe my smartphone's location influenced my performance.

Strongly disagree	Somewhat disagree	Neutral (neither agree nor disagree)	Somewhat agree	Strongly agree
○	○	○	○	○

I believe my smartphone's location had a positive influence on my performance.

Strongly disagree	Somewhat disagree	Neutral (neither agree nor disagree)	Somewhat agree	Strongly agree
○	○	○	○	○

I believe my smartphone's location had a negative influence on my performance.

Strongly disagree	Somewhat disagree	Neutral (neither agree nor disagree)	Somewhat agree	Strongly agree
○	○	○	○	○

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Please answer the following demographic questions:

I identify my gender as...

Female	Male	Trans	Other
○	○	○	○

Age:

Please indicate your age in years as a whole number

Current occupation:

- ☐ studying:
- ☐ working as:
- ☐ unemployed
- ☐ other:

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Do you have any comments about this survey that you would like to share with us?

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It would be very helpful if you could tell us at this point whether you answered all questions seriously, so that we can use your answers for our analysis, or whether you were just clicking through to take a look at the survey.

	not at all seriously						very seriously
How seriously did you answer the questions?	○	○	○	○	○	○	○