Reexamining the “Brain Drain” Effect: Does Ward et al. (2017) Replicate?

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Funding Sources: This research was supported by a Discovery Grant awarded to J. P. Minda by the Natural Sciences and Engineering Research Council (NSERC Grant No. R3507A19) of Canada.

Conflict of Interest: None declared.

Acknowledgements: The authors would like to thank NSERC for providing the funding for this research. Thanks also to Sophie Wharamby and Lauren Martyn for helping with data collection and organization.

Ethical Considerations & Disclosure: Study was conducted in accordance with ethics protocols approved by Western University’s Non-Medical Research Ethics Board (#110296).

Abstract

The present study was a pre-registered direct replication of Ward et al.'s (2017) second experiment (OSF pre-registration found at: <https://osf.io/5fq4r>). This replication assigned both smartphone location (on desk, in pocket/bag, or outside of the testing room) and smartphone power (on, or off) for a total of six conditions. Participants completed an automated operation span (OSpan) task, a cue-dependent go/no-go task, and the smartphone attachment and dependency inventory. It was hypothesized that performance on an attention-demanding task (i.e., the OSpan task) would be worse for those in closer proximity to their smartphone (on desk) and that those with greater smartphone attachment and dependency would have a larger “brain drain” effect. Using the same tasks and conditions as in Ward et al.'s (2017) second experiment, the present study found that the “brain drain” effect did not replicate: there was no difference between smartphone location conditions on performance on either the o-span task or the go/no-go task. These findings demonstrate that the mere presence of one's smartphone may not be enough to affect cognitive performance. Understanding these effects is crucial in a time where smartphones are a basic necessity.

Keywords: smartphone presence, attention, response inhibition, smartphone dependency

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Increased Smartphone Prevalence

Smartphones provide an easy and effective method of communicating with the world right at our fingertips. They have become a staple in most people’s everyday life: in North America, smartphone ownership has gone from 77% in 2016 to 81% in 2019 (Pew Research Center, 2019). Not only are more North Americans owning a smartphone, but also, roughly one in five report using their smartphones primarily for their internet use (Pew Research Center, 2019). The World Health Organization (2015) reported that the “behavioural addictions” associated with internet and smartphone use has occurred comorbid with some psychopathology (e.g., hyperactivity disorder and major depression) and health conditions (e.g., substance use disorders and insomnia). Therefore, there has been an increase in research investigating the possible effects of smartphone use on cognition. An overview of smartphone research, including the “brain drain” effect (Ward et al., 2017), is presented. The present study’s main goal was to investigate if the “brain drain” effect found in Ward et al.’s (2017) second experiment replicated.

Smartphone Research

A focus on cognition. Smartphone availability is a relatively recent phenomenon, and research into its effects on cognition have been even more recent. Researchers looked first at the effects of smartphones on attention. Previous research has found attentional costs of smartphone usage during driver performance (Caird et al., 2014). However, the rising prevalence of smartphones has prompted research about how they can impact other cognitive abilities (Stothart et al., 2015; Thornton et al., 2014; Ward et al., 2017; Wilmer & Chein, 2016). This research includes investigating how smartphone use (Stothart et al., 2015; Wilmer & Chein, 2016) and smartphone presence (Thornton et al., 2014; Ward et al., 2017) can impact cognition. Smartphone use has been linked with depletion in cognitive function during day-to-day self-regulation (Wilmer & Chein, 2016). It was found that heavier mobile device users tended to have lower impulse control and a weaker tendency to delay gratification (Wilmer & Chein, 2016).

Stothart et al. (2015) addressed the impact of smartphone notification on cognitive resources. They found that receiving notifications affected performance on an attention-demanding task. Participants were randomly assigned to one of three conditions: call notification, text notification, or no notification. Those in the notification conditions received a notification during the second block of the main task (Stothart et al., 2015). They showed that, even with no direct contact with a smartphone, participants performed worse under the notification conditions when compared to the no notification condition on a sustained-attention to response task (i.e., a go/no-go task). Additionally, Clayton et al. (2015) found that separation from one’s phone led to psychological and physiological anxiety: participants who were unable to answer their ringing phone (which was within viewing distance) during a wordsearch puzzle reported feeling increased anxiousness and unpleasantness, and showed higher physiological measures for anxiety (e.g., heart rate and blood pressure).

Thornton et al. (2014) found that smartphones can affect performance on difficult tasks. In study one, participants were tested in pairs (i.e., each sitting on their own desk and facing away from each other) and told that they would complete several tasks that required attention and concentration to complete successfully. For each pair of participants, one would have the experimenter’s smartphone (experimental) and the other would have a similar-sized notebook (control) placed on the edge of the table. In study two, participants were tested in a group setting

(i.e., a classroom with around 20 students) and were randomly assigned to either place their cell phone on their desk (experimental) or nothing about their cell phones (control). For both study one and two, participants completed two digit cancellation tasks (i.e., measured attention, cognitive capacity, and executive functioning), two trail making tasks (i.e., required attentional processes, mental flexibility, and motor function), and two brief questionnaires (i.e., measuring attentional difficulties and cell phone use and possession). Each task had two versions to each task in order to compare performance on an easier and a difficult version of each task. The digit cancellation task was either the normal/easier (i.e., cross out the target number; 90s) or additive/difficult (i.e., cross out the target number and any adjacent numbers that add up to the target; 180s) version. The trail making task required participants to draw a line connecting either numbers sequentially (i.e. easy; e.g. 1-2-3-4-) or alternating numbers and letters sequentially (i.e., difficult; e.g., 1-A-2-B-3-C-4-D-) for 15s. Results in both studies demonstrated a detriment associated with smartphone presence on the harder, resource-intensive versions of the tasks and no effect on the simpler versions of the same tasks (Thornton et al., 2014). Contrastingly, Hartanto and Yang (2016) found that smartphone separation (i.e., participants who were away from their smartphones) led to significantly worse performance on a measure of task switching (i.e., a color-shape switching task) compared to participants who had their smartphones with them during the study.

The “brain drain” effect. Recently, a study by Ward et al.(2017) found that the mere presence of a participant’s smartphone decreased performance on a cognitive task (i.e., a “brain drain” effect). In both experiments, Ward et al.manipulated participant’s smartphone location. Each participant’s smartphone was placed in one of three locations: (1) on the participant’s desk, (2) in their pocket/bag, or (3) outside the testing room.

Experiment 1 investigated the effect of people’s smartphone on their available cognitive capacity. Participants were randomly assigned to their smartphone location condition and kept their smartphone on silent (i.e., no vibrations if any notifications were received during the study). Those in the “on desk” location conditions were instructed to keep their devices facing down in a specific location. Participants completed two tasks that measured available cognitive capacity: the Automated Operation Span (OSpan) task (Unsworth et al., 2005) and a 10-item subset of Raven’s Standard Progressive Matrices (RSPM) test (Raven et al., 1998). They also completed a third task: the Ending-Digit Drop-Off task.

The OSpan task measured working memory capacity by forcing participants to keep track of task relevant information while engaging in another task. Participants were first presented with the math component of the task: a simple math question (e.g., “ $(7/7) + 6 = ?$ ”) and then indicated whether the correct answer matched a number that was displayed on the next screen (e.g., “7” is “TRUE”). Following the math component, participants were presented with a letter (i.e., the letter component). The math-then-letter component trials were then repeated in blocks. The blocks ranged from a letter string length of three to seven letters, which were randomly displayed. After each block, participants were then asked to recall the letters that were presented between the math questions in order of appearance. Following the recall, participants were given feedback on both math and letter recall performance: they were told how many letters they got in the right order and what percentage of math problems they answered correctly. Only data from those who performed at 85% math accuracy or higher was used (i.e., to ensure that participants were not ignoring the math component).

The RSPM test was a measure of nonverbal functional fluid intelligence. Participants were given an incomplete pattern matrix and selected an element that would best complete the given pattern. Only 10 items from the original five 12-item series (A-E, ordered according to difficulty; 60 items total) were used. Item series from sets D and E were chosen to measure analytic reasoning (i.e., D2, D4, D6, D8, D10, D12, E1, E2, E4, and E6). The Ending-Digit Drop-Off task measured the tendency to disregard the ending digits of a product's price, which was thought to be more evident in participants whose smartphones were closer to them. Participants estimated how many items (i.e., with either a .99 or .00 price ending) they could buy with a given budget. Overestimating the purchasing power for a .99-item compared to a matched .00-item was considered evidence of a "drop-off" effect. After the three tasks, participants in experiment 1 completed a survey measuring their typical smartphone use and some general demographic questions. Results demonstrated that increased participants in closer proximity to their smartphone had decreased working memory capacity (i.e., OSpan task performance) and fluid intelligence (i.e., RSPM test performance), but showed no effect on the Ending-Digit-Drop-Off task (Ward et al., 2017).

Experiment 2 investigated the effect of smartphone presence on cognitive capacity and sustained attention. There were two independent variables: smartphone location (as in experiment 1) and smartphone power. For smartphone power, a participant's smartphone was either: (1) powered ON or (2) powered OFF in their respective location. For all conditions, participants kept their smartphones on silent (i.e., no vibrations if any notifications were received during the study). Also, participants in the "on desk" location conditions were instructed to keep their devices facing up. Participants completed two counterbalanced tasks: OSpan task (Unsworth et al., 2005), which was identical to experiment 1; and the Cue-Dependent Go/No-Go task (Bezdjian et al., 2009). The Cue-Dependent Go/No-Go task was a behavioural measure of sustained attention. Participants responded to go targets as fast as possible (i.e., a green rectangle) and withhold a response to no-go targets (i.e., a blue rectangle). Targets were first presented as outlines of rectangles and were either vertical or horizontal. The orientation of the initial target was a cue component, which showed the probability that a given target would be either a go (i.e., 80% vertical and 20% horizontal) or no-go target (i.e., 80% horizontal and 20% vertical). Once both tasks were completed, participants completed an exploratory survey that measured typical smartphone use and included the Smartphone Attachment and Dependency Inventory (Ward et al., 2017). Results in experiment 2 showed that closer proximity to one's smartphone (i.e., the "on desk" location) was associated with decreased cognitive capacity (i.e., OSpan task performance), but not associated with sustained attention (i.e., Cue-Dependent Go/No-Go task performance). There was no effect of smartphone power on either task. This effect was moderated by smartphone attachment and dependency, where higher smartphone attachment and dependency scores showed a greater "brain drain" effect. Therefore, as in experiment 1, those closer to their smartphone showed impaired OSpan performance and this brain drain effect was amplified when participants were more reliant on their smartphone (Ward et al., 2017).

Similar findings were seen in Tanil and Yong (2020), where participants either left their smartphone with the experimenter (i.e., away from the participant) or the participant's smartphone was left with the participant. Then, they completed a computerized working memory task span task. Participants recalled either words with increasing length (i.e., pen, refrigerator), letters, or digits (i.e., "1" to "9"). Each stimuli type was used in a separate 25-trial test, where

participants were shown the stimuli in sequence, starting at a minimum length and increasing by one for each correct recall (i.e., in the same order as shown) for a total possible score of 25. Participants who had their smartphone with them showed significantly lower performance. In contrast, Hartmann et al. (2020) found no overall effect of smartphone placement when a participant's smartphones were either present (i.e., on their desk) or absent (i.e., away from their desk, across the testing room) during a short-term memory and prospective memory task. A moderating effect of smartphone dependency was found for prospective memory, where those with less dependency showed better performance in the absent condition. Overall, there is contracting evidence for a "brain drain" effect of smartphone presence.

The Present Study

The purpose of the present study was to carry out a direct replication of Ward et al.'s (2017) second experiment. Ward et al. found a "brain drain" effect, where closer proximity to one's smartphone impaired working memory capacity (i.e., OSpan performance). This effect was moderated by people's smartphone reliance (i.e., smartphone attachment and dependency score), where higher smartphone reliance resulted in a larger brain drain effect. The evidence provided by experiment 2 in Ward et al. compliments previous findings (e.g., Thornton et al., 2014; Wilmer & Chein, 2016) that the mere presence of one's smartphone is enough to affect cognition. Additionally, an influx of smartphone research has also led to policy changes. For example, the Ontario government banned cell phones and smartphones in high schools based on the idea that these devices could distract students from their academic work (Jones, 2019). Such policy changes should be based on accurate and reproducible data. Therefore, a direct replication of Ward et al.'s (2017) findings will determine whether the brain drain effect is a stable and reproducible effect.

The present study investigated how the mere presence of one's smartphone affects cognition. Based on findings from Ward and colleagues, three main hypotheses were made: a (1) location effect, (2) power effect, and (3) moderation effect. The location effect hypothesis predicted that those who were closest in proximity to their smartphone (i.e., those with their smartphones on their desk) would show lower performance on the OSpan task (Unsworth et al., 2005) but not on the Cue-Dependent Go/No-Go task (Bezdjian et al., 2009). Secondly, the power effect hypothesis predicted that smartphone power (i.e., either ON or OFF) would not affect performance on both cognitive tasks. Lastly, the moderation effect hypothesis predicted that smartphone attachment and dependency would moderate the location effect: those who reported higher smartphone attachment and dependency would have lower OSpan task performance. Replicating Ward et al.'s (2017) findings will not only help to support their original results, but will also help guide future studies regarding the influence of smartphones on cognition. Understanding these effects are crucial in a time where smartphones are a basic necessity.

Method

The present study was pre-registered as a direct replication of Ward et al.'s (2017) second experiment on Open Science Framework (OSF; <https://osf.io/5fq4r>). The study's design, hypotheses, and analysis plan followed this OSF registration.

Participants

A total of 453 students were recruited from Western University's undergraduate research pool. Of the total sample size, 44 participants were excluded due to either testing error (11; e.g., incomplete task data), or experimenter or external confounds (33; e.g., interruption during testing, distracting noise during testing). Only data from participants who scored at 85%

accuracy or above (i.e., including 85% accuracy) on the math component of the testing session of the OSpan (Unsworth et al., 2005) were used for the final analysis. This is the exclusion criteria from the original task, which helped control for participants who did not follow the math component of the task. For the Cue-Dependent Go/No-Go task (Bezdjian et al., 2009), only data from participants who scored higher than chance performance (i.e., responded to at least 50% of “Go” trials and withheld response to at least 50% of “No-Go” trials) were used for the final analysis. Additionally, any participants who had a reaction time (RT) that was higher than two standard deviations from the mean RT were not included in the final analysis. This helped control for any participants who did not follow the task instructions. Therefore, 26 participants were removed during the data cleaning phase, which removed participants who met an exclusion criteria (OSpan math criteria: 20; Go/No-Go response criteria, horizontal/no-go cue: 6; Go/No-Go response criteria, vertical/go cue: 6), were identified as having outlier data (OSpan: 0; Go/No-Go Error Analysis: 0; Go/No-Go Accuracy Analysis: 0), and had incomplete or missing data (OSpan: 3; Go/No-Go Error Analysis: 0; Go/No-Go Accuracy Analysis: 3). Overall, 70 participants were removed from the analysis, where a participant may have been removed due to multiple criteria.

Therefore, a total of 383 students (198 females and 185 males) were used in the present study’s analyses. The ages ranged from 17-38 years old ($M = 18.87$, $SD = 1.43$). Each participant received a course credit for completing the study. Most participants reported being in their first year of their program (68.67%; second year = 17.23%; third year = 7.31%; fourth year = 4.18%; did not specify = 2.61%) and in the Social Science faculty (33.94%; followed by Science, 23.24% and Medicine & Dentistry, 18.28%; see Table 1 for more details). Inclusion criteria for the present study was as follows: all participants were able to consent as university students (i.e., 17 years old or older) and had normal or corrected-to-normal vision (i.e., glasses and contacts were considered corrected and were therefore, acceptable). Participants were also required to have English as their first language or be fluent in English as a second language. The present study was approved through the WREM Ethics Board at Western University.

Table 1. Demographic measures as descriptive statistics or frequency counts by smartphone power, location, and overall.

Measure	Powered ON			Powered OFF			Overall (383)
	On Desk (70)	Pocket/Bag (67)	Outside (59)	On Desk (58)	Pocket/Bag (65)	Outside (64)	
Age							
<i>M</i>	18.80	18.66	19.10	18.66	19.08	18.95	18.87
<i>SD</i>	0.91	0.88	2.67	1.05	1.33	1.05	1.43
Min.	18	18	18	17	18	18	17
Max.	21	21	38	22	23	22	38
Gender*							
Male	32	32	30	34	32	25	185
Female	38	35	29	24	33	39	198
First Language							
Other	15	12	9	7	10	11	64
English	55	55	50	51	55	53	319
Year of Study							
First Year	46	48	41	42	44	42	263
Second Year	15	10	10	7	10	14	66
Third Year	2	5	3	6	5	7	28
Fourth Year	4	1	3	1	6	1	16
No Selection	3	3	2	2	0	0	10
Faculty							
Arts & Humanities	2	2	0	2	2	1	9
Engineering	1	0	0	0	0	0	1
Health Sciences	10	8	14	6	10	10	58
Information & Media Studies	3	2	1	1	3	3	13
Medicine & Dentistry	14	8	10	14	12	12	70
Music	0	1	2	1	1	0	5
Science	18	17	13	12	11	18	89
Social Science	19	28	18	20	26	19	130
No Selection	3	1	1	2	0	1	8

Note. Top shows descriptive statistics for responses to continuous measures. Bottom shows frequency counts for responses to nominal measures. Sample size is shown for each group in parentheses.

* Gender options included “Other” and “Prefer not to say”, but were not chosen by any participants.

Materials

The Automated Operation Span (OSpan) Task. The OSpan task (Unsworth et al., 2005) required participants to retain letter strings in memory while solving some simple math problems. This task is a behavioural measure of the attentional control component of working memory. As in Ward et al. (2017), the OSpan task was administered using a computer screen. The present study used a web version of the OSpan task

(<https://www.millisecond.com/download/library/ospan/>), which used the Inquisit 5 software. It was composed of four sessions: three practice sessions (i.e., letter training, math training, and task training) and one testing session.

Letter training. The first practice session trained participants on the letter component of the task. For each trial, a randomly generated letter was presented (i.e., one letter at a time) on a screen for 800ms. A block consisted of a set of 2-3 letters in total. Participants were instructed to remember each letter in their presented order. After the letters were presented, participants recalled the letter string in the correct order by selecting the letters from a 4x3 matrix that displayed all the possible letters (i.e., F, H, J, K, L, N, P, Q, R, S, T, and Y). They were given the

option to clear their selection during the recall stage. Also, they had the option to select a “BLANK” box to mark a spot for a missing letter that they did not remember in order to recall the remaining letters in the correct order. Once they completed the recall stage, they indicated they were finished on the screen. Once they indicated they were done, feedback was given regarding the number of letters they correctly recalled (e.g., “You recalled ___ out of ___ letters correctly.”). Participants had no time limit for this practice session. In total, participants completed three letter training blocks. The purpose of the letter training was to allow participants to become familiarized with the letter recall component of the task.

Math training. The second practice session trained participants on the math component of the task. For each trial, participants were presented with a simple math question (e.g., “ $(7/7) + 6 = ?$ ”). The participant then clicked the left mouse button, which indicated that they solved the problem. Following this, they were asked to indicate whether a displayed answer (e.g., “7”) was correct by selecting either “TRUE” or “FALSE” on the screen. Following their selection, participants were given feedback on their performance: the number of correct trials out of the total they had currently completed (e.g., “You were correct on ___ of ___ math trials.”) and the percent accuracy (e.g., “That is, ___ percent correct.”). Participants were instructed to solve the math problems correctly and as quickly as they could. In total, participants completed 15 math training trials. The purpose of the math training was not only to allow participants to familiarize themselves with the math component of the task, but also to obtain an average math solving time for each participant. The average time it took each participant to indicate they had solved a math problem plus 2.5 SD was used as the maximum time limit to solve math problems in the math component of the task training and testing session.

Task training. The third and final practice session trained participants on the full task: a combination of the letter and math components. For each trial, participants were first presented with a simple math question and, once they indicated they had solved the problem, they indicated whether the following screen depicted the correct answer (i.e., by selecting either “TRUE” or “FALSE”). Then, a randomly generated letter was presented (for 800 ms). Each combination of the math and letter component made up one trial. Each block was made up of three to seven trials in total. After each block, participants recalled the letter string in the order that they were presented. This recall stage was presented and gave the same options as in the letter training. Feedback for the task training was different than the previous letter and math components: participants were then given feedback on their math and letter accuracy. Participants were told how many letters they recalled correctly (e.g., “You recalled ___ out of ___ letters correctly.”), how many math errors they made (e.g., “You made ___ math error(s) on this set of trials.”), and what percentage of math problems they answered correctly so far (e.g., “___%”; in the top right of the screen). It should be noted that participants had a time restriction to indicate they had solved the math problem, which was determined during the math training. Participants were told that if they took longer than their average time from their math training to indicate they solved the math problem, they would skip to the next letter and have that math problem marked as a math error. Similar to the math training, participants were asked to answer the math questions as fast as possible without sacrificing math or letter accuracy. Participants were told to try to maintain a minimum 85% math accuracy to ensure that participants were not ignoring the math problems to try to remember the letters. The task training consisted of three blocks. The purpose of the task training was to prepare participants for the testing session.

Testing session. The testing session was the main task. Participants completed 75 blocks identical to the task training blocks (i.e., 75 math problems and 75 letter sets) without any breaks between blocks. The letter sets ranged from three to seven letters in length, which was randomized for each participant. Feedback identical to the task training was given after each block. Once the blocks were completed (i.e., the main task was finished), the following data were presented on the screen: subject number, OSpan absolute score, OSpan total number correct, math total errors, math speed errors, and math accuracy errors. These data were recorded by the experimenter.

The Cue-Dependent Go/No-Go Task. The Cue-Dependent Go/No-Go Task (Bezdjian et al., 2009) measured reaction time (RT) and response accuracy: this task is a behavioural measure of sustained attention. The task was administered on a computer screen using Psychopy (version 1.85.4) and was designed to match the task described in Ward et al. (2017). For each trial, participants were first shown a fixation cross (800ms), followed by a blank screen (500ms), and then an outline of either a vertical or horizontal rectangle (displayed for 100ms, 200ms, 300ms, 400ms, or 500ms; randomized between trials). Then, the rectangle would become filled with either the colour green (i.e., a “go target”) or blue (i.e., a “no-go target”). Once the rectangle was filled in, for the “go target”, participants were instructed to respond with a key press (i.e., “/” on a standard English QWERTY keyboard) as fast as possible. For the “no-go targets”, participants were instructed to withhold any response (1,000ms). Each trial ended after either a key press or the 1,000ms had elapsed after the target was presented. After 700ms, the next trial began. The cue component of the task determined the probability that the rectangle would be either a “go” or “no-go” target. Vertical targets were more likely to become “go” targets (i.e., 80% “go” and 20% “no-go”), while horizontal targets were more likely to become “no-go” targets (i.e., 80% “no-go” and 20% “go”). Participants were not explicitly made aware of the cue component. Each participant completed a total of 250 trials (50% “go” trials, 50% “no-go” trials) without a break between trials. The data recorded from the task was the following: omission errors (i.e., when a participant fails to respond to a “go” target), commission errors (i.e., when a participant responds to a “no-go” target), and a RT measure.

The Demographic Questionnaire. The demographic items (i.e., four items in total) in the present study asked participants to report their age (i.e., in years), gender (i.e. male, female, other, or prefer not to say), program (e.g., psychology, engineering), and year of study (e.g., first, fourth). Participants reported their program in an open-ended question and grouped into faculties manually. The purpose of these items was to give a brief description of the sample. The demographic questionnaire is shown in Appendix A.

The Smartphone Use Questionnaire. The smartphone use questionnaire was created for the present study and consisted of modified items from Ward et al.'s (2017) exploratory survey measures (i.e., found in the “‘BRAIN DRAIN’ WEB APPENDIX”). Some items were forced-choice and some were on a 7-point likert scale ranging from 1 (“Never”) to 7 (“Always”). There were 10 items in total and there were three types of items, which measured: (1) smartphone use frequency (three items; e.g., “On average, how many text messages do you send per day?”); (2) smartphone use without external stimulation (two items; e.g., “If I am waiting to meet a friend, I pass the time by using my smartphone.”), or during other activities (two items; e.g., “I use my smartphone while driving.”); (3) exploratory items, measuring smartphone subjective value (one item; e.g., “How much money would it take for you to give up your phone for a full day?”), smartphone notification type (one item; e.g., “Do you receive notifications (a

sound or vibration) on your phone? Please indicate all that apply.”), and phantom vibrations (one item; e.g., “Have you ever thought you heard your phone ring or thought you felt it vibrate, only to find out you were wrong?”). The purpose of the smartphone use questionnaire was to measure participants' typical smartphone use. The smartphone use questionnaire is shown in Appendix B.

The Smartphone Attachment and Dependency Inventory. The smartphone attachment and dependency inventory (Ward et al., 2017) consisted of 13 items, where participants indicated whether they agreed or disagreed with statements regarding their attachment and dependency to their smartphone. A 7-point likert scale (ranging from 1, “Strongly Disagree”, to 7, “Strongly Agree”) was used. Items measured participants' smartphone dependency (e.g., “I feel like I could not live without my cell phone.”) and emotional attachment (e.g., “I feel lonely when my cell phone does not ring or vibrate for several hours.”). The purpose of the smartphone attachment and dependency inventory was to measure each participant's reliance on their smartphone. The smartphone attachment and dependency inventory is shown in Appendix C.

Procedure

Participants were randomly assigned to one of six possible conditions. These conditions were based on the two independent variables: smartphone location and smartphone power. For smartphone location, a participant's smartphone was either: (1) on the participant's desk (on desk), (2) in their pocket/bag (pocket/bag), or (3) outside the testing room (outside). For smartphone power, a participant's smartphone was either: (1) powered ON, or (2) powered OFF, in their respective location. Therefore, each participant was in one of six conditions: desk-on ($n = 70$), pocket/bag-on ($n = 67$), outside-on ($n = 59$), desk-off ($n = 58$), pocket/bag-off ($n = 65$), and outside-off ($n = 64$). For all conditions, participants were instructed to keep their smartphones on silent (i.e., no vibrations if any notifications were received during the study). Also, as per Ward et al. (2017), participants in the “on desk” location conditions were instructed to keep their devices facing up.

Once a participant was randomly assigned to their condition, all participants then completed two counter-balanced cognitive tasks: the OSpan task (Unsworth et al., 2005) and the Cue-Dependent Go/No-Go task (Bezdjian et al., 2009). The OSpan task took approximately 20 minutes to complete and the Cue-Dependent Go/No-Go task took approximately 15 minutes to complete. After completing both tasks, all participants completed the survey measures (approximately 5 minutes to complete): demographic questionnaire, the smartphone use questionnaire, and the smartphone attachment and dependency inventory (Ward et al., 2017). The entire study took approximately 60 minutes to complete.

Results

The present study was pre-registered as a direct replication of Ward et al.'s (2017) second experiment on OSF (<https://osf.io/5fq4r>) along with a data analysis plan.

Scoring

The OSpan Task. As in Ward et al. (2017), cognitive capacity was measured by the OSpan (Unsworth et al., 2005): a behavioural measure of the attentional control component of working memory. Performance, measured with the OSpan absolute score, was shown by how many trials a participant correctly recalled all the letters in a given block (75 blocks in total). For example, a participant who recalled three letters (in a block with three letters), five letters (in a block with five letters), and two letters (in a block with six letters) would have an OSpan absolute score of eight for those blocks (i.e., $3 + 5 + 0 = 8$). Since the OSpan absolute score only increased when a participant recalled all letters in a trial correctly, a score of zero was possible.

A participant who did recall some letters correctly in any trial, but either incorrectly recalled or missed one or more letters as well would receive a score of zero. Therefore, the OSpan absolute score showed performance where higher scores represented better performance.

The Cue-Dependent Go/No-Go Task. As in Ward et al. (2017), sustained attention was measured with the Cue-Dependent Go/No-Go task (Bezdjian et al., 2009). Performance was measured with mean omission errors and RT. It should be noted that mean errors can be divided into total error, commission error, and omission error. Commission errors occurred when a participant responded to a target stimulus. Omission errors occurred when a participant failed to respond to a non-target stimulus. Total errors were the sum of commission and omission errors. The present study focused on mean omission errors. Therefore, for each participant, higher mean omission errors represented lower performance. Additionally, higher mean RT also showed lower performance (i.e. indicative of greater interference).

The Smartphone Attachment and Dependency Inventory. Participant's level of smartphone attachment and dependency (i.e., smartphone reliance) was measured with the smartphone attachment and dependency inventory (Ward et al., 2017). The 13-item inventory was scored by calculating a sum total for each item with a range of 13 to 91. Higher scores indicated a higher level of reliance with three levels.

Analyses

The OSpan task. The OSpan absolute score was used. A 3(Smartphone location: desk, pocket/bag, or outside) x 2(Smartphone power: ON or OFF) between-subjects analysis of variance (ANOVA) was conducted. Descriptive statistics are shown in Table 2). All analyses assumptions (i.e., independent random sampling, normality, and homogeneity of variance) were met. There was no significant main effect of smartphone location on OSpan performance, $F(2, 377) = 0.10, p = .91, \eta^2_G = .001$. There was no significant main effect of smartphone power on OSpan performance, $F(1, 377) = 0.21, p = .65, \eta^2_G = .001$. There was also no significant interaction between smartphone location and power on OSpan performance, $F(2, 377) = 1.19, p = .31, \eta^2_G = .006$ (Figure 1). Since there were no significant main or interaction effects, no post-hoc tests were completed.

Figure 1. Comparing Operation Span Performance between Smartphone Location and Power Conditions: Visual Depiction of ANOVA Test.

Note. Plots depict the average performance on the Operation Span (OSpan) Task (i.e., OSpan absolute score; y-axis) for participants across smartphone location (i.e., on desk, left bars; pocket/bag, middle bars; or outside, right bars) and smartphone power (i.e., on, light blue bars; or off, dark blue bars). Black dots and multi-coloured dots represent the mean and individual data points for each condition, respectively. Error bars represent standard error. OSpan absolute score was calculated by summing the total letters recalled for each trial where all letters were recalled correctly; therefore a score of 0 was possible for any participant who either incorrectly recalled or missed one or more letters in every trial.

The Cue-Dependent Go/No-Go Task. An error (i.e., omission errors) and accuracy (i.e., RT) analysis was completed using the average omission errors and RT for each participant. For the error analysis, a 3 (Smartphone location: desk, pocket/bag, or outside) x 2 (Smartphone power: ON or OFF) x 2 (Cue type: Go or No-Go) mixed factorial design with the between-subjects factors of smartphone location and power, and a within-subjects factor of pre-target cue type was completed. Descriptive statistics are shown in Table 2). Since the homogeneity assumption was not met for the mixed ANOVA, a White-corrected F-test was completed for the between-subject effects. There was no significant main effect of smartphone location, $F(2, 377) = 0.67, p = .51, \eta^2_G = .002$, and smartphone power, $F(1, 377) = 0.15, p = .70, \eta^2_G = .001$. There was a significant main effect of cue type, $F(1, 377) = 23.22, p < .001, \eta^2_G = .02$) for average omission errors. Additionally, there was no significant interaction between smartphone location and power, $F(2, 377) = 1.01, p = .37, \eta^2_G = .003$, smartphone

power and cue type, $F(1, 377) = 0.26, p = .61, \eta^2_G < .001$, and between all three factors (i.e., smartphone location, power, and cue type), $F(2, 377) = 0.32, p = .72, \eta^2_G < .001$. There was a significant interaction between smartphone location and cue type, $F(2, 377) = 3.19, p = .04, \eta^2_G = .005$, however, post-hoc simple main effects for cue type across smartphone location did not show any significant main effects for the “go”, $F(2, 380) = 1.42, p = .49, \eta^2_G = .008$, and “no-go”, $F(2, 380) = 0.60, p = .55, \eta^2_G = .003$, cue type (see Figure 2).

Figure 2. Comparing Cue-Dependent Go/No-Go Omission Errors between Smartphone Location and Power Conditions by Cue Type: Visual Depiction of ANOVA Test.

Note. Plots depict the average performance on the Cue-Dependent Go/No-Go Task (i.e., omission errors: responding to a “no-go” target; y-axis) for participants across smartphone location (i.e., on desk, left bars; pocket/bag, middle bars; or outside, right bars) and smartphone power (i.e., on, light blue bars; or off, dark blue bars) by cue type: “go” (A) or “no-go”(B). Black dots and multi-coloured dots represent the mean and individual data points for each condition, respectively. Error bars represent standard error.

For the accuracy analysis, a 3 (Smartphone location: desk, pocket/bag, or outside) x 2 (Smartphone power: ON or OFF) between-subjects ANOVA was conducted. Descriptive statistics are shown in Table 2). All analyses assumptions (i.e., independent random sampling, normality, and homogeneity of variance) were met. There was no significant main effect of smartphone location on average RT, $F(2, 377) = 1.49, p = .77, \eta^2_G = .001$. There was no

significant main effect of smartphone power on average RT, $F(1, 377) = .002, p = .95, \eta^2_G < .001$. There was also no significant interaction between smartphone location and power on average RT, $F(2, 377) = 0.04, p = .96, \eta^2_G < .001$. Since there were no significant main or interaction effects, no post-hoc tests were completed for the accuracy analyses (see Figure 3).

Figure 3. Comparing Cue-Dependent Go/No-Go Average Reaction Time between Smartphone Location and Power Conditions: Visual Depiction Of ANOVA Test.

Note. Plots depict the average performance on the Cue-Dependent Go/No-Go Task (i.e., average reaction time in seconds; y-axis) for participants across smartphone location (i.e., on desk, left bars; pocket/bag, middle bars; or outside, right bars) and smartphone power (i.e., on, light blue bars; or off, dark blue bars). Black dots and multi-coloured dots represent the mean and individual data points for each condition, respectively. Error bars represent standard error.

Table 2. Descriptive statistics for the operation span and cue-dependent go/no-go task by smartphone power, location, and overall.

Measure	Powered ON			Powered OFF			Overall
	On Desk	Pocket/Bag	Outside	On Desk	Pocket/Bag	Outside	
OSpan Absolute Score							
<i>M</i>	41.46	42.76	39.05	40.76	41.25	43.63	41.54
<i>SD</i>	16.22	15.44	18.25	18.93	17.33	15.68	16.90
Min.	6	6	4	0	3	0	0
Max.	75	75	75	75	75	75	75
OSpan Math Score (%)							
<i>M</i>	95.03	95.74	94.89	94.99	95.65	95.46	95.3
<i>SD</i>	3.42	3.06	3.22	3.46	3.17	3.32	3.27
Min.	86.67	88	85.33	86.67	86.67	85.33	85.33
Max.	100	100	100	100	100	100	100
Cue-Dependent Go/No-Go: Omission Errors for “Go” Trials							
<i>M</i>	0.70	0.36	0.51	0.97	0.57	0.31	0.56
<i>SD</i>	2.16	0.85	1.06	3.09	2.93	0.73	2.03
Min.	0	0	0	0	0	0	0
Max.	14	4	5	20	23	4	23
Cue-Dependent Go/No-Go: Omission Errors for “No-Go” Trials							
<i>M</i>	0.11	0.09	0.25	0.12	0.22	0.14	0.15
<i>SD</i>	0.36	0.29	0.68	0.50	0.93	0.39	0.56
Min.	0	0	0	0	0	0	0
Max.	2	1	3	3	7	2	7
Cue-Dependent Go/No-Go: Average Reaction Time							
<i>M</i>	1.66	1.66	1.66	1.67	1.66	1.66	1.66
<i>SD</i>	0.05	0.06	0.04	0.09	0.06	0.06	0.06
Min.	1.58	1.56	1.56	1.57	1.56	1.56	1.56
Max.	1.88	1.8	1.77	2.21	1.84	1.87	2.21

N = 383

The Smartphone Attachment and Dependency Inventory. As in Ward et al. (2017), responses to the smartphone attachment and dependency inventory were assessed with a factor analysis. A principal axis factor analysis with a Varimax rotation was completed to assess which factors, if any, fit our data and to compare to the two main factors found by Ward et al. (i.e., smartphone dependence and emotional attachment). The results of the factor analysis were also used to form subscale scores for each factor found in the final solution. Factorability of the data was confirmed using: (1) Bartlett’s test for correlation adequacy, $\chi^2(78) = 1943.16$, $p < .001$, which confirmed that correlations between the items were sufficiently large; and (2) the Kaiser-Meyer-Olkin measure for sampling adequacy (MSA), which confirmed that both the

overall MSA ($MSA_{overall} = 0.88$) and each item's MSA ($MSA_{1-13} = 0.79 - 0.94$) were above the required criteria (0.60 and 0.77, respectively; (Kaiser, 1974)).

A four-factor solution was chosen for the best fit for the data based on a parallel analysis scree plot, the Kaiser's criterion (i.e., eigen values greater than one), and by comparing the structure for the two-, three-, and four-factor solutions. After an initial four-factor solution was completed using all 13 items in the smartphone attachment and dependency inventory, however, one item (i.e., 4) was split-loaded between factor 1 and 3 and was excluded from further analyses (Costello & Osborne, 2005). This final solution achieved simple structure and was used for subsequent analyses. The final solution showed a good fit (Root Mean Square of the Residual = .03).

The final solution's factors explained 52.97% of the variance and suggested the following three factors: dependence, emotional attachment, accessibility, and distractibility (see Table 3). Dependence was related to the degree of dependence on one's smartphone, it consisted of 3 items (i.e., 1, 2, and 3) and explained 16.68% of the variance (e.g., "I would have trouble getting through a normal day without my smartphone.", "I feel like I could not live without my smartphone."). Emotional attachment was related to one's smartphone use for emotional support, it consisted of 4 items (i.e., 8, 9, 10, and 11) and explained 15.48% of the variance (e.g., "I feel lonely when my smartphone does not ring or vibrate for several hours.", "Using my smartphone makes me feel happy."). Accessibility was related to the ability to access the utility of one's phone (e.g., powered on, internet access), it consisted of 3 items (i.e., 5, 6, and 7) and explained 11.84% of the variance (e.g., "It drives me crazy when my smartphone runs out of battery.", "I feel impatient when the Internet connection speed on my smartphone is slow."). Distractibility was related to one's smartphone retaining one's attention, it consisted of two items and explained 8.97% of the variance (e.g., "I find it tough to focus whenever my smartphone is nearby.", "I become less attentive to my surroundings when I'm using my smartphone."). All three factors had moderate reliability, measured with Cronbach's alpha ($\alpha_{Dep.} = 0.83$, $\alpha_{EA} = 0.76$, $\alpha_{Access} = 0.72$, $\alpha_{Dist} = 0.63$; Kline, 1999). No increases were seen in Cronbach's alpha by eliminating more items for any of the factors. A composite sum-score was created for each factor, where higher scores indicated higher dependency (possible range = 3–21; $M = 12.63$, $SD = 4.73$), emotional attachment (possible range = 4–28; $M = 16.73$, $SD = 4.91$), accessibility (possible range = 3–21; $M = 9.98$, $SD = 2.70$), and distractibility (possible range = 2–14; $M = 6.25$, $SD = 1.03$), respectively. Descriptive statistics for the four factors are shown in Table 4.

Table 3. Summary of exploratory factor analysis of the 13 items in the Smartphone Attachment and Dependency Inventory from Ward et al. (2017).

		Rotated Factor Loadings			
		1(*)	2(*)	3(*)	4
Item	Description				
Factor 1: Dependency					
1	I would have trouble getting through a normal day without my smartphone.	.72(.85)	.21	.24	.12
2	It would be painful for me to give up my smartphone for a day.	.82(.81)	.28	.19	.05
3	I feel like I could not live without my smartphone.	.61(.79)	.18	.24	.17
Factor 2: Emotional Attachment					
8	I feel lonely when my smartphone does not ring or vibrate for several hours.	.18	.44(.73)	.32	.19
9	Using my smartphone relieves me of my stress.	.24	.58(.71)	.20	.09
10	I feel excited when I have a new message or notification.	.10	.73(.70)	.21	.13
11	Using my smartphone makes me feel happy.	.30	.67(.68)	.09	.11
Factor 3: Accessibility					
5	It drives me crazy when my smartphone runs out of battery.	.37(.66)	.20	.56	.14
6	I am upset and annoyed when I find I do not have reception on my smartphone.	.26(.64)	.21	.68	.19
7	I feel impatient when the Internet connection speed on my smartphone is slow.	.15(.52)	.25	.48(.43)	.21
Factor 4: Distractibility					
12	I find it tough to focus whenever my smartphone is nearby.	.15	.18(.64)	.09	.67
13	I become less attentive to my surroundings when I'm using my smartphone.	.06	.08	.24(.90)	.63
Eigen Values		2.00	1.89	1.42	1.08
Percent of Variance Explained (*)		16.68(31.02)	15.48(21.65)	11.84	8.97
α(*)		.83(.89)	.76(.79)	.72	.63

Note: Items have been sorted based on rotated (varimax) factor loading. Strongly loaded items for present study ($>.40$) are shown in bold font. Item four was removed due to split-loading between factors 1 (.58) and 2 (.41): "I am upset and annoyed when I find I do not have reception on my smartphone.". This loading was .75 in Ward et al. (2017).

* Values given in Ward et al. (2017). Only two strong factors (smartphone dependency and emotional attachment) were included with respective strong loadings.

$N = 383$

Table 4. Descriptive statistics for the smartphone attachment and dependency inventory for subscales and across all items by smartphone power, location, and overall.

Measure	Powered ON			Powered OFF			Overall
	On Desk	Pocket/Bag	Outside	On Desk	Pocket/Bag	Outside	
Dependency							
<i>M</i>	11.73	12.51	12.42	13.31	12.2	13.77	12.63
<i>SD</i>	5.57	4.61	5.07	4.39	4.38	3.98	4.73
Min.	3	3	3	3	3	5	3
Max.	21	21	21	21	20	21	21
Emotional Attachment							
<i>M</i>	16.8	16.3	16.39	16.55	16.43	17.88	16.73
<i>SD</i>	5.05	5.32	5.07	4.58	4.73	4.63	4.91
Min.	4	4	4	5	4	6	4
Max.	28	28	27	26	26	28	28
Accessibility							
<i>M</i>	14.67	15.01	14.98	15.31	14.6	15.55	9.98
<i>SD</i>	4.01	3.43	3.84	3.95	3.68	3.32	2.70
Min.	3	6	3	6	4	8	2
Max.	21	21	21	21	21	21	14
Distractibility							
<i>M</i>	10.1	10.36	9.66	10.07	9.75	9.88	6.25
<i>SD</i>	2.84	2.49	2.78	2.89	2.43	2.82	1.03
Min.	2	2	4	2	3	2	1.50
Max.	14	14	14	14	14	14	7
All items							
<i>M</i>	57.67	58.94	58.08	59.86	57.32	62.23	58.99
<i>SD</i>	15.32	13.58	14.60	13.15	12.39	12.46	13.66
Min.	19	27	22	25	19	32	19
Max.	89	87	86	87	79	87	89

N = 383

The present study's findings partially supported Ward et al.'s (2017) findings and provided the groundwork for the moderator analysis. To examine if smartphone dependency, emotional attachment, accessibility, or distractibility were moderators of the relationship between the experimental manipulation and OSpan performance, a pre-registered analysis using a univariate generalized linear model was used. As in Ward et al. (2017), OSpan performance was the criterion, smartphone location (i.e., desk, pocket/bag, and outside) was the independent variable, and the following were used as possible predictors, each in a separate analyses: the mean-centered dependency, emotional attachment, accessibility, and distractibility composite

score. Additionally, all independent variable x moderator interaction terms were included as predictors in the model (Baron & Kenny, 1986). Therefore, each regression model had the following predictors for the criterion (i.e., OSpan absolute score): (1) moderator, (2) smartphone location comparisons (i.e., desk vs. pocket/bag, desk vs. outside, and outside vs. pocket/bag), and (3) all interaction between (1) and (2). Outliers were removed if participants fell outside of both the Leverage and Cook's criteria, for dependency ($N = 376$), emotional attachment ($N = 379$), accessibility ($N = 377$), and distractibility ($N = 375$). For all models, the assumptions of multicollinearity, linearity, normality, and homogeneity were met.

Smartphone Dependency. The overall model predicting OSpan performance using smartphone location and dependency score failed to account for the data and was not significant, $F(5, 370) = 0.31, p = .91, R^2 = .004$. Dependency, $p = .30$, smartphone location, $p > .62$, and the dependency x smartphone location interactions, $p > .36$, were not significant predictors of OSpan absolute score (see Table 5 for more details). A visual inspection of the model did not show any trends (Figure 4A).

Smartphone Emotional Attachment. The overall model predicting OSpan performance using smartphone location and emotional attachment score failed to account for the data and was not significant, $F(5, 373) = 1.05, p = .39, R^2 = .01$. Emotional attachment approached a significant predictor of OSpan performance, $p = .05$. Smartphone location, $p > .70$, and emotional attachment x smartphone location interactions, $p > .18$, were not significant predictors of OSpan absolute score (see Table 5 for more details). A visual inspection of the data showed a trend in the desk condition, where participants who reported lower smartphone emotional attachment showed higher OSpan performance. This trend was weaker in the outside condition and not seen in the pocket/bag condition (Figure 4B). This trend was investigated using an exploratory simple slopes analysis using emotional attachment score as a predictor of OSpan performance for each smartphone location condition. Emotional attachment score was a marginally significant predictor of OSpan performance, $b = -0.63, t(125) = -1.94, p = .06$, in the desk condition. However, this trend was not seen in the pocket/bag, $b = -0.31, t(129) = -1.07, p = .29$, or outside, $b = -0.02, t(119) = -0.07, p = .94$, conditions.

Smartphone Accessibility. The overall model predicting OSpan performance using smartphone location and accessibility score failed to account for the data and was not significant, $F(5, 371) = 0.27, p = .93, R^2 = .004$. Accessibility, $p = .42$, smartphone location, $p > .63$, and moderator x smartphone location interactions, $p > .29$, were not significant predictors of OSpan absolute score (see Table 5 for more details). A visual inspection of the model did not show any trends (Figure 4C).

Smartphone Distractibility. The overall model predicting OSpan performance using smartphone location and distractibility score failed to account for the data and was not significant, $F(5, 369) = 0.23, p = .95, R^2 = .003$. Distractibility, $p = .59$, smartphone location, $p > .57$, and moderator x smartphone location interactions, $p > .67$, were not significant predictors of OSpan absolute score (see Table 5 for more details). A visual inspection of the model did not show any trends (Figure 4D).

Table 5. Summary of moderation analyses of OSpan performance.

		Smartphone Location Comparisons			Interactions		
		(i) Desk vs. Pocket/Bag	(ii) Desk vs. Outside	(iii) Outside vs. Pocket/Bag	M x (i)	M x (ii)	M x (iii)
(A) Dependency							
<i>b</i>	0.31	0.75	1.06	-0.31	-0.40	-0.23	-0.17
<i>t</i> (370)	1.04	0.36	0.50	-0.15	-0.91	-0.51	-0.36
<i>p</i>	.30	.72	.62	.88	.36	.61	.72
(B) Emotional Attachment							
<i>b</i>	-0.63	0.80	0.27	0.53	0.32	0.61	-0.29
<i>t</i> (373)	-1.99	0.38	0.13	0.25	0.74	1.34	-0.66
<i>p</i>	.05	.70	.90	.80	.46	.18	.51
(C) Accessibility							
<i>b</i>	-0.32	1.00	0.52	0.48	0.62	0.29	0.33
<i>t</i> (371)	-0.81	0.48	0.24	0.23	1.06	0.48	0.54
<i>p</i>	.42	.63	.81	.82	.29	.63	.59
(D) Distractibility							
<i>b</i>	0.31	1.19	0.83	0.36	0.14	-0.21	0.36
<i>t</i> (369)	0.54	0.57	0.39	0.17	0.17	-0.26	0.42
<i>p</i>	.59	.57	.70	.87	.87	.79	.67

Note. Moderation analyses showed no significant predictors of Operation Span (OSpan) performance (i.e., absolute score) for each moderator (M); smartphone location comparisons, desk vs. pocket/bag (i), desk vs. outside (ii), and outside vs. pocket/bag (iii); and interactions.

Figure 4. Moderation Analyses of Operation Span Performance for Each Subscale in the Smartphone Attachment and Dependency Inventory Grouped by Smartphone Location: Visual Depiction of Moderation Models.

Note. Plots depict the average performance on the Operation Span (OSpan) Task (i.e., OSpan absolute score; y-axis) vs. the mean-centered score (x-axis) for Dependency (A), Emotional Attachment (B), Accessibility (C), and Distractibility (D) across the smartphone location conditions (i.e., on desk, light blue; pocket/bag, purple; or outside, dark blue). Shaded region depicts the 95% confidence interval. Individual data points are shown for each condition, respectively.

The Smartphone Use Questionnaire. Smartphone use frequency was measured with respect to average daily text messages sent, social media based messages sent, and social media posts. Most participants reported sending more than 15 text messages (60.31%), more than 15 social media based messages (64.23%), and only zero to five social media based posts (80.94%) per day. Average smartphone use without external stimulation ($M = 6.25$, $SD = 1.03$) was higher than use during other activities ($M = 2.73$, $SD = 1.22$). Smartphone subjective value showed that most people reported willingness to go without their phone for a day for only \$0-\$20 (36.55%). With respect to smartphone notification type, out of all the notifications participants reported receiving (1,256 total), Snapchat (23.33%) was the application they most receive a sound or vibration notification on their phone (followed by Email, 22.05%; Instagram, 19.27%; and, Facebook, 18.23%, respectively). Finally, most participants (86.42%) reported they had felt a phantom vibration (i.e., perceiving they received a notification on their phone, when in fact there was no notification) in the past (see Table 6 for more details).

Table 6. Smartphone use questionnaire responses as descriptive statistics and frequency counts by smartphone power, location, and overall.

Measure	Powered ON			Powered OFF			Overall
	On Desk	Pocket/Bag	Outside	On Desk	Pocket/Bag	Outside	
Smartphone use in the absence of other stimulation							
<i>M</i>	6.12	6.28	6.21	6.19	6.32	6.36	6.25
<i>SD</i>	1.14	1.06	1.04	1.04	0.92	0.97	1.03
Min.	1.50	2	2.50	4	3.50	3.50	1.50
Max.	7	7	7	7	7	7	7
Smartphone use during other actions							
<i>M</i>	2.71	2.93	2.51	2.84	2.78	2.58	2.73
<i>SD</i>	1.24	1.38	1.06	1.18	1.24	1.16	1.22
Min.	1	1	1	1	1	1	1
Max.	6	7	6.50	6	7	7	7
Average text messages per day							
0-5	18	11	10	10	10	9	68
6-10	5	11	9	6	6	8	45
11-15	8	3	5	5	10	8	39
>15	39	42	35	37	39	39	231
Average social media based messages per day							
0-5	12	7	9	10	12	12	62
6-10	12	6	9	4	7	3	41
11-15	5	8	5	5	7	4	34
>15	41	46	36	39	39	45	246
Average social media based posts per day							
0-5	60	58	45	44	52	51	310
6-10	5	3	1	6	8	6	29
11-15	2	1	5	5	1	3	17
>15	3	5	8	3	4	4	27
Smartphone subjective value							
\$0-\$20	32	24	25	12	23	24	140
\$21-\$40	13	13	12	22	21	12	93
\$41-\$60	8	11	11	12	16	9	67
>\$60	17	19	11	12	5	19	83
Type of notification(s) *							
Email	47	45	47	46	39	53	277
Facebook	42	41	38	36	36	36	229
Twitter	13	22	14	14	11	22	96
Instagram	44	46	39	33	37	43	242
LinkedIn	5	2	4	5	1	7	24
Snapchat	53	51	47	43	49	50	293
Other	23	16	10	11	17	18	95
Phantom vibrations							
Experienced	62	54	52	53	54	56	331
Not Experienced	8	13	7	5	11	8	52

Note. Top shows descriptive statistics for responses to continuous measures. Bottom shows frequency counts for responses to nominal measures.

* Multiple selections were allowed across notification types.

N = 383

Discussion

Smartphones provide an easy and effective method of communicating with the world right at our fingertips. The rising prevalence of smartphones (Pew Research Center, 2019) has prompted research including possible behavioural addictions (WHO, 2015) and how these might affect cognitive abilities. Although there are many benefits to using a smartphone in terms of

communication, the present study investigated how smartphones affect performance on cognitively demanding tasks. This was done by reexamining the “brain drain” effect (i.e., those who were in closer proximity to their smartphone performed worse on a cognitively demanding task, which is moderated by smartphone reliance) found by Ward et al.'s (2017) second experiment.

The three main hypotheses (i.e., location effect, power effect, and moderation effect) from Ward et al. (2017) were evaluated in the present study. There were no significant main or interaction effects of smartphone location on performance on OSpan absolute score. There was a significant main effect of cue type and an interaction effect of cue type and smartphone location on omission errors in the Cue-Dependent Go/No-Go task (Bezdjian et al., 2009). However, this effect was explored with tests of simple main effects and found no significant effect of smartphone location for either cue type. Overall, the present study did replicate Ward et al.'s null effect on the Cue-Dependent Go/No-Go task performance. More notably, however, the present study's findings failed to replicate Ward et al.'s main effect concerning performance on the OSpan task (Unsworth et al., 2005). Therefore, the “brain drain” effect was not replicated in the present study. The smartphone power effect hypothesis was supported: there was no significant difference between power conditions (i.e., powered ON vs. OFF) on performance for both tasks. This was a replication of Ward et al.'s findings. Findings from a principal components analysis on the smartphone attachment and dependency inventory (Ward et al., 2017) partially supported the two-factor findings from Ward et al. (i.e. smartphone dependence and emotional attachment), but also added a third factor: smartphone distractibility. Finally, the moderation effect did not replicate: smartphone dependency, emotional attachment, and distractibility were not significant moderators of OSpan performance. In contrast with Ward and colleagues, emotional attachment showed a trend for those in the desk condition, where higher emotional attachment predicted lower OSpan performance. It should be noted that this analysis was completed as a pre-registered analysis and was exploratory in nature. Overall, the present study demonstrated that the “brain drain” effect may not be a replicable effect of smartphone presence on cognition. Possible reasons for this are given.

A stark difference in performance was observed between the present study's OSpan performance and in Ward and colleague's second experiment. This was one of the critical results in Ward et al, because they described the OSpan as a difficult working memory task intended to be sensitive to a decrease in cognitive capacity. They argued that this difficulty difference was the reason why they found an effect on OSpan performance but not on the Cue-Dependent Go/No-Go (Bezdjian et al., 2009) performance, and indeed this was the locus of the “brain drain” effect. However, participants in our study did not find the OSpan as challenging and the presence of their own smartphone on the desk did not seem to interfere with their performance on the task. Not only was mean-difference in OSpan performance for the present study was much smaller ($M_{\text{desk-outside}} = 0.29$, $M_{\text{desk-pocket/bag}} = 0.88$, $M_{\text{pocket/bag-outside}} = 0.59$) than for Ward et al. ($M_{\text{desk-outside}} = 4.67$, $M_{\text{desk-pocket/bag}} = 2.30$, $M_{\text{pocket/bag-outside}} = 2.37$), but also, the average performance between the present study ($M_{\text{desk}} = 41.14$, $M_{\text{pocket/bag}} = 42.02$, $M_{\text{outside}} = 41.43$) and Ward et al. (approximate values: $M_{\text{desk}} \approx 28.50$, $M_{\text{pocket/bag}} \approx 30.80$, $M_{\text{outside}} \approx 33.10$) implies that participants in the present study did not find the OSpan task as challenging as in Ward and colleague's study. This difference was also seen when compared to Ward et al.'s first experiment, where average OSpan performance was lower than a score of 34. These differences may explain why participants in our experiment did not experience a “brain drain” in their performance: the task did not diminish

participant's available cognitive capacity. In fact, the present study showed participants with perfect performance on both the math and letter recall components and, consequently, there was a possible ceiling effect. This defeated the purpose of the OSpan as a more difficult cognitive task. Therefore, to determine the underlying mechanisms behind smartphones' impact on cognition, future work should use reliable and normed cognitive tasks. The Cambridge Brain Sciences (CBS; Hampshire et al., 2012) test battery, for example, evaluates a broad range of cognitive abilities such as selective attention, response inhibition, reasoning, and working memory. These short cognitive tests have been used across different populations (Wild et al., 2018) to test people across three main components (i.e., short-term memory, reasoning, and verbal ability) with varying difficulty levels. Therefore, using this test battery could examine how smartphone presence affects an overview of cognitive aspects and could explain why the present study did not replicate the "brain drain" effect.

Limitations and Implications of the Present Study

Another limitation to consider in the present study was the measure for smartphone reliance. In order to directly compare the present study to Ward et al.'s second experiment, the smartphone attachment and dependency inventory (Ward et al., 2017) was used to measure participant's smartphone attachment and dependency (i.e., reliance). However, current research typically uses additional measures to measure things such as nomophobia (i.e., the fear of being without one's phone or the internet; Yildirim & Correia, 2015) and smartphone involvement (Walsh et al., 2010). Although the use of the smartphone attachment and dependency inventory (Ward et al., 2017) allowed the present study to directly compare findings to Ward et al.'s second experiment, measuring smartphone reliance based on only one scale limited the present study. Therefore, future research should expand on other measures of smartphone reliance.

Conclusion

The present study reexamined the "brain drain" effect found in Ward et al.'s (2017) second experiment. The "brain drain" effect found that those who were in closer proximity with their smartphones (i.e., those with their smartphones on their desk during the task) performed worse on a cognitively demanding task (i.e., the OSpan). In order to investigate this effect, the materials, methods, and analyses were completed based on the original study (all of which was pre-registered through OSF; Ruiz Pardo et al., 2018). Although some findings were replicated (e.g., the non-significant effect of smartphone power, the partial support for the same factors in the smartphone attachment and dependency inventory), the main "brain drain" effect was not replicated in the present study. This is an important finding because it presents an interesting new question in the field: what effect can smartphone presence, if any, have on cognition? It is possible that the mere presence of one's smartphone is not the cause of a cognitive deficit. Some possible reasons include individual differences (e.g. gender, age, personality differences) or simply the task used to investigate the effect. The continued increase in global smartphone ubiquity (Pew Research Center, 2019) makes this gap in the field relevant to every-day life. Finding and understanding these possible impacts remains critical to deciphering how smartphones may impact cognition and provide scientific evidence for means to help thwart these effects.

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Appendices

Appendix A. Demographic questionnaire.

GENERAL DEMOGRAPHICS

1. What is your gender?
 - a. Male
 - b. Female
 - c. Other (please specify) _____
 - d. Prefer not to say
2. Age (in years): _____
3. Program: _____
4. Year of Study: _____
5. Is your first language English?
 - a. Yes
 - b. No

Appendix B. Smartphone Use Questionnaire.

SMARTPHONE USE FREQUENCY

1. On average, how many **text messages** do you send **per day**?
 - a. 0-5
 - b. 6-10
 - c. 11-15
 - d. >15
2. On average, how many **social media based messages** do you send **per day** from your smartphone? (iMessage, Facebook Messenger, WhatsApp, WeChat, direct messages within social media platforms, etc.)
 - a. 0-5
 - b. 6-10
 - c. 11-15
 - d. >15
3. On average, how many **social media posts** (e.g., written post, picture, article, etc.) do you send **per day** from your smartphone? (Facebook, Twitter, Instagram, etc.)
 - a. 0-5
 - b. 6-10
 - c. 11-15
 - d. >15

SMARTPHONE USE WITH EXTERNAL STIMULATION OR DURING OTHER ACTIVITIES

For the following questions, please indicate how often the following statements apply to you.

Never		Neutral			Always	
1	2	3	4	5	6	7

Tendency to turn to one's smartphone in the absence of external stimulation:

1. I look at my smartphone before I roll out of bed in the morning.
2. If I am waiting to meet a friend, I pass the time by using my smartphone.

Tendency to turn to one's smartphone in the midst of other activities:

3. I use my smartphone while driving.
4. If my smartphone rings or vibrates in the middle of personal business, I look at it.

EXPLORATORY ITEMS

Smartphone subjective value:

1. How much money would it take for you to give up your phone for a full day?
 - a. \$0-\$20
 - b. \$21-\$40
 - c. \$41-\$60
 - d. >\$60

Types of smartphone notifications:

2. Do you receive notifications (a sound or vibration) on your phone? Please indicate all that apply.

- ☐ Email ☐ Twitter ☐ LinkedIn ☐ Other (please specify) _____
- ☐ Facebook ☐ Instagram ☐ Snapchat

Phantom vibration experiences:

3. Have you ever thought you heard your phone ring or thought you felt it vibrate, only to find out you were wrong?
 - a. Yes
 - b. No

Appendix C. Smartphone Attachment and Dependency Inventory.
Source: Ward et al. (2017)

For the following questions, please indicate how much you agree or disagree to the following statements.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
1	2	3	4	5	6	7

1. I would have trouble getting through a normal day without my smartphone.
2. It would be painful for me to give up my smartphone for a day.
3. I feel like I could not live without my smartphone.
4. If I forgot to bring my smartphone with me, I would feel anxious.
5. It drives me crazy when my smartphone runs out of battery.
6. I am upset and annoyed when I find I do not have reception on my smartphone.
7. I feel impatient when the Internet connection speed on my smartphone is slow.
8. I feel lonely when my smartphone does not ring or vibrate for several hours.
9. Using my smartphone relieves me of my stress.
10. I feel excited when I have a new message or notification.
11. Using my smartphone makes me feel happy.
12. I find it tough to focus whenever my smartphone is nearby.
13. I become less attentive to my surroundings when I'm using my smartphone.

Source citation:

Ward, A. F., Duke, K., Gneezy, A., & Bos, M. W. (2017). Brain drain: The mere presence of one's own smartphone reduces available cognitive capacity. *Journal of the Association for Consumer Research*, 2, 140–154.
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