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Acute smartphone use impairs vigilance and inhibition capacities

Thomas Jacquet, Romuald Lepers, Benjamin Pageaux, Bénédicte Poulin-Charronnat

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32 ABSTRACT

33 Smartphones are now in very widespread use, and concerns have arisen about potential
34 detrimental effects, even with acute use. These adverse consequences are often linked to the
35 emergence of mental fatigue. While the cognitive implications of fatigue are well-
36 documented, knowledge about the specific influence of acute smartphone use on cognitive
37 performance remains scarce. The aim of this study was therefore to investigate the impact of
38 acute smartphone use on cognitive performance. It included two experiments: one designed to
39 assess the impact of smartphone use on vigilance, and the other focusing on evaluating
40 inhibition capacities. In Experiment 1, two groups of 40 participants completed a
41 Psychomotor Vigilance Task (PVT) before and after using a smartphone for 45 min
42 (experimental group), or before and after watching a documentary (control group). In
43 Experiment 2, two groups of 40 participants were subjected to a similar experimental design
44 but had to perform a Go/NoGo task instead of a PVT. Mental fatigue and drowsiness were
45 evaluated with visual analog scales before and after smartphone use and watching a
46 documentary. Results suggested that both watching a documentary and using a smartphone
47 for 45 min increased subjective mental fatigue and drowsiness. Watching the documentary did
48 not impair cognitive performance. Reaction times on the PVT and number of errors on NoGo
49 trials in the Go/NoGo task were higher among the participants in the smartphone condition.
50 These results indicate reduced vigilance and impaired inhibition capacities only after
51 smartphone use. We conclude that acute smartphone use induces mental fatigue and decreases
52 cognitive performance. Further research is needed to understand the mechanisms underlying
53 this decline in cognitive performance.

54 KEYWORDS:

55 Cognitive fatigue, Mental fatigue, Cognitive performance, Drowsiness, Vigilance, Inhibition,
56 Smartphone

57 **Introduction**

58 The smartphone is playing a growing role in society as a key everyday tool for
59 communication and information sharing. While only 35% of Americans said they owned a
60 smartphone in 2011, that number had increased to about 85% in 2021¹. According to a survey,
61 users spend more than 20 hours per week texting, emailing, and using social media,
62 demonstrating a high level of reliance on smartphones for social interaction and
63 communication². However, even if the smartphone is a valuable tool that improves our daily
64 lives by facilitating communication, task management and our access to entertainment,
65 negative side effects have also been reported.

66 When used regularly over a period of several months, the smartphone can negatively affect
67 sleep quality³ and mood⁴. Furthermore, a positive correlation between smartphone addiction,
68 depression and anxiety levels has been found in adolescents³. This both reduces life happiness
69 and increases the likelihood of future health risks⁵. Intensive smartphone use could also
70 exacerbate musculoskeletal disorders due to the high level of muscle activity solicited in the
71 upper body parts, i.e., neck extensors, upper trapezius, and erector spinae⁶. Moreover,
72 extended periods of smartphone use are related to lower physical fitness, including decreased
73 flexibility and strength⁷.

74 Chronic smartphone use can also impair cognitive performance. Intensive smartphone users
75 have poorer numerical processing capacities⁸ than nonusers and poorer inhibitory control⁹
76 than “normal” users. Moreover, three months of smartphone use has been found to lead to a
77 decline in performance on an arithmetic task in nonsmartphone users⁸.

78 Although the impacts of chronic smartphone use (e.g., repeated sessions) on cognitive and
79 physical performances are receiving increasing attention, studies of the effects of acute use
80 (e.g., a single session) remain rare. In 2017, Greco et al.¹⁰ found evidence that acute
81 smartphone use for 30 min can bring about a decrease in physical and technical performances
82 among young football players. A decline in performance has also been observed in other
83 sports with, for example, an impairment of visuomotor abilities in volleyball players¹¹,
84 decision-making in boxers¹², or an increase in the time taken to cover 50m by swimmers¹³.
85 However, to the best of our knowledge, only a few studies have investigated the effect of
86 acute smartphone use on cognitive performance^{12,14,15}. In these studies, all conducted by the
87 same group of researchers, the acute use of a smartphone increased reaction times and/or
88 errors during a subsequent Stroop task. It is important to note that the authors of studies that
89 have examined the effects of acute smartphone use have also specified the activity to be

90 performed during this period of use. Participants have had to either play games¹⁰ or use social
91 networks^{11–15}. While this approach makes it possible to control the experimental conditions
92 better, it should be noted that it may also be less ecological than free and unrestricted
93 smartphone use. Furthermore, these studies all had low sample sizes ($N \leq 20$) and replications
94 with a larger sample size are therefore needed in order to confirm or challenge the observed
95 results. All these studies found a significant increase in the subjective feelings of mental
96 fatigue after acute smartphone use. For this reason, the authors attributed the adverse effects
97 of smartphone use on subsequent performance to the induction of mental fatigue.

98 Mental fatigue is a common phenomenon that is defined as a psychobiological state caused by
99 prolonged periods of demanding cognitive activity. Mental fatigue is characterized by an
100 increase in subjective feelings of “tiredness” and “lack of energy”¹⁶, associated with a
101 decrease in cognitive performance or an increase in the effort required to maintain
102 performance¹⁷. It is usually induced by means of controlled laboratory tasks, such as the
103 Stroop task, performed for 30 min or more¹⁸. The effects of mental fatigue on both cognitive
104 and physical performances are well documented. Mental fatigue impairs sport-related
105 decision-making¹⁹, technical skills²⁰, motor control²¹, and endurance²² performances. All the
106 adverse effects lead to a decrease in sporting performances, in particular in the case of
107 soccer²³, table tennis²⁴, cricket²⁵, golf or swimming²⁶ performances.

108 Cognitive performances are also impaired by mental fatigue. For instance, Smith et al.²⁷
109 demonstrated that mental fatigue induced by a 45-min AX-CPT or Stroop task resulted in a
110 decreased vigilance, characterized by sustained alertness over time and evidenced by an
111 approximate 4% increase in reaction times during a subsequent psychomotor vigilance task
112 (PVT). In addition to vigilance, attention, which requires a selective focus on specific stimuli
113 or tasks, may also be impaired as a result of mental fatigue²⁸. Furthermore, mental fatigue has
114 been found to negatively impact executive functions, including mental flexibility²⁹,
115 planning²⁹, decision-making³⁰, emotional regulation³¹, and inhibition capacities^{32,33}. Inhibition
116 capacities have often been evaluated using Go/NoGo tasks, and studies have shown that
117 performance declines over time during prolonged Go/NoGo tasks³². Moreover, Guo et al.³³
118 demonstrated that performing a mentally fatiguing task, such as a 90-min driving task, can
119 decrease performance on a subsequent Go/NoGo task, as indicated by the observed increased
120 reaction times and omissions.

121 As described above, it is now well established that mental fatigue negatively impacts both
122 physical and cognitive performances. A number of recent studies have found evidence that
123 acute smartphone use might also negatively affect physical performance, while also bringing

124 about an increase in feelings of mental fatigue^{10,13,15}. In this context, the present study aims to
125 investigate the effects of acute smartphone use (i.e., 45 min) on cognitive performance, and in
126 particular on vigilance, attention, and inhibition capacities. We hypothesized that acute use of
127 a smartphone would induce a feeling of mental fatigue associated with an impairment of
128 vigilance, attention, and inhibition.

129 **Experiment 1**

130 **Methods**

131 **Participants**

132 Eighty healthy young adults (73 females, 7 males, $M_{\text{age}} = 20.0$, $SD = 2.2$ years), recruited
133 from the Université de Bourgogne, participated in Experiment 1 and were randomly divided
134 into two groups (i.e., smartphone use or documentary watching). Participants were instructed
135 to get at least six hours of sleep, to refrain from consuming alcohol, and to avoid vigorous
136 physical activity the day before each visit. They were also required not to consume caffeine or
137 nicotine and to avoid using their smartphones for at least three hours before testing.
138 Participants were asked to disclose any medication or acute illnesses, injuries, or infections.
139 These instructions were checked at the beginning of the laboratory visit with a questionnaire.
140 All participants complied with these instructions. Before the experiment, each participant read
141 the information notes and gave their written informed consent. The experiment was conducted
142 in accordance with the most recent version of the Declaration of Helsinki (1964) and was
143 approved by the local Ethics Committee of the Université Bourgogne Franche-Comté
144 (CERUBFC-2021-05-12-010).

145 **Experimental procedure**

146 Experiments started between 8:00 a.m. and 11:00 a.m. for all participants and lasted about
147 1.5 h. Each session took place in a small and quiet room without windows. It started with a
148 short period of familiarization (10 trials) with a PVT, which consisted in responding as fast as
149 possible to the appearance of a visual stimulus (see 2.1.3.3). The participants then completed
150 a questionnaire to evaluate their sleep duration and quality, motivation to perform the
151 experiment, mental fatigue, and drowsiness levels. They then performed the PVT (pretest),
152 followed by either 45 min of smartphone use or a control task (i.e., watching a documentary).
153 Subsequently, after indicating their levels of mental fatigue, drowsiness, boredom, and the
154 perceived workload of using the smartphone or watching the documentary (control task),
155 participants performed the PVT again (posttest). Finally, participants reported the specific
156 activities they were engaged in on their smartphones during the 45-min use period.

157 **Experimental tasks**

158 **Smartphone use.** Participants were asked to use their smartphones for 45 min in a way that
159 was as normal as possible in their daily lives. They were free to use their smartphone as they

160 wanted, except for watching videos longer than 3 min and making phone calls. The same
161 room was used for all tasks. The participants were comfortably seated on a chair.

162 **Control task.** The control task consisted in watching an emotionally neutral documentary on a
163 smartphone. To help prevent the participants from experiencing boredom while watching the
164 documentary, three different documentaries were proposed: “Legacy” by Y. Arthus-Bertrand,
165 “Schumacher” by H.-B. Kammertöns and “Bill Gates” by S. Malterre. Watching movies was
166 recently found to act as a good control intervention to study mental fatigue³⁴. The viewing
167 duration was the same as period of smartphone use (i.e., 45 min).

168 **Psychomotor Vigilance Task.** The PVT is a simple visual reaction time test developed to
169 evaluate vigilance³⁵. Experiment Builder software (SR Research) was used to monitor
170 stimulus presentation. Participants were asked to focus their attention on a red rectangular box
171 in the middle of a black screen. They were instructed to press a button as quickly as possible
172 when a green circle appeared in the center of a red rectangle. This stimulus was displayed for
173 100 ms, and the reaction time was shown on the screen for 1 s after the button press. If the
174 participant took 500 ms or more to respond, the message "Miss" was displayed on the screen.
175 The stimuli were presented with a random interstimulus interval of between 2 and 10 s. The
176 task consisted of 50 trials and lasted approximately 5 min 20 s. Reaction times faster than 100
177 ms and those more than two standard deviations above or below the mean were excluded from
178 the analysis.

179 **Psychological measures**

180 **Sleep.** The Saint Mary's Hospital Sleep questionnaire was administered to assess the
181 participants' sleep quality and duration the night before each experimental session. This
182 questionnaire comprises 14 items that delve into various aspects of sleep quality, including
183 depth, nighttime awakenings, satisfaction, morning alertness, difficulty falling asleep, and
184 early awakenings.

185 **Motivation.** Motivation is defined as “the attribute that moves us to do or not to do
186 something”³⁶. Motivation to complete the experiment was measured using a motivation scale
187 developed by Matthews et al.³⁷. The questionnaire consisted of seven questions related to
188 intrinsic motivation (e.g., "I want to do my best") and seven related to extrinsic motivation
189 (e.g., "I only did this task for an external reward"). Participants could choose among five
190 possible responses to each question (0 = not at all, 1 = a little bit, 2 = somewhat, 3 = very
191 much, 4 = extremely). The scores for each motivation type ranged from 0 to 28.

192 **Subjective workload.** The National Aeronautics and Space Administration Task Load Index
193 (NASA-TLX) was used to evaluate subjective workload³⁸. The NASA-TLX consists of six
194 subscales: mental demand (how much mental and perceptual activity was required?), physical
195 demand (how much physical activity was required?), temporal demand (how much time
196 pressure did you feel due to the rate or pace at which the task occurred?), performance (how
197 much successful do you think you were in accomplishing the goals of the task set by the
198 experimenter?), effort (how hard did you have to work to achieve your level of
199 performance?), and frustration (how irritating or annoying did you find the task?). Participants
200 rated each item on a scale divided into 20 equal intervals anchored by a bipolar descriptor
201 (e.g., high/low). The scores were multiplied by 5, resulting in a final score of between 0 and
202 100 for each subscale.

203 **Mental fatigue level.** A visual analog scale (VAS) was used to measure feelings of mental
204 fatigue before and after smartphone use and before and after documentary watching. The
205 VAS consisted of a 100-mm line with bipolar end anchors (0 mm = "Not tired at all"; 100 mm
206 = "Extremely tired"). Participants were asked the question: "How mentally fatigued do you
207 feel right now?" and were told to place a mark on the line to indicate their current level of
208 fatigue. The VAS score was determined by measuring the distance between the first anchor (0
209 mm: "Not tired at all") and the mark placed by the participant.

210 **Drowsiness level.** A VAS was used to measure feelings of drowsiness before and after
211 smartphone use and before and after documentary watching. This VAS consisted of a 100-
212 mm line with bipolar end anchors (0 mm = "Not drowsy at all"; 100 mm = "Extremely
213 drowsy"). Participants were asked the question: "How drowsy do you feel right now?" and
214 were told to place a mark on the line to indicate their current level of drowsiness. The VAS
215 score was determined by measuring the distance between the first anchor (0 mm: "Not drowsy
216 at all") and the mark placed by the participant.

217 **Boredom.** Feelings of boredom after smartphone use and documentary watching were
218 evaluated by using a VAS with bipolar end anchors (0 mm = "Not bored at all"; 100 mm =
219 "Extremely bored"). Participants were asked the question: "How bored do you feel right
220 now?" and were instructed to place a mark on the line to indicate their current level of
221 boredom. The VAS score was determined by measuring the distance between the first anchor
222 (0 mm: "Not bored at all") and the mark placed by the participant.

223 **Activities performed on smartphone.** Participants reported on a questionnaire the specific
224 activities they were engaged in on their smartphone during the 45-min use period.
225 Subsequently, we categorized these activities into four different groups: "Social network,"

226 "Internet search," "Productivity" (which included activities such as email, diary management,
227 and writing), and "Games".

228 **Statistics**

229 The data are presented as means \pm standard errors of the mean. When sphericity was violated,
230 the degrees of freedom were adjusted using the Greenhouse-Geisser method (the corrected
231 degree of freedom and p -values are reported). Only significant results are reported unless the
232 absence of significance is relevant to the hypotheses tested.

233 T tests were used to evaluate differences in sleep duration, motivation, boredom, and NASA-
234 TLX scores participants in the control versus smartphone groups.

235 Effects on the mental fatigue VAS, drowsiness VAS, and performances during the PVT
236 (reaction times, anticipation, omissions, and global errors [omissions + anticipations]) were
237 evaluated using a two-way mixed-model repeated-measures 2×2 ANOVA with group
238 (Control, Smartphone) as between-subject factor, and time (Pre, Post) as within-subject factor.
239 All analyses were performed using JASP (Version 0.17.1.0) [Windows software]. Significant
240 interactions were further analyzed by means of contrast tests with Bonferroni correction, and
241 adjusted p -values were reported. Partial eta squared was calculated for each repeated-
242 measures ANOVA. Thresholds for small, moderate, and large effects were set at 0.01, 0.07,
243 and 0.14, respectively³⁹. Cohen's d was calculated for each t test. Thresholds for small,
244 moderate, and large effects were set at 0.2, 0.5, and 0.8, respectively³⁹.

245

246 **Results**

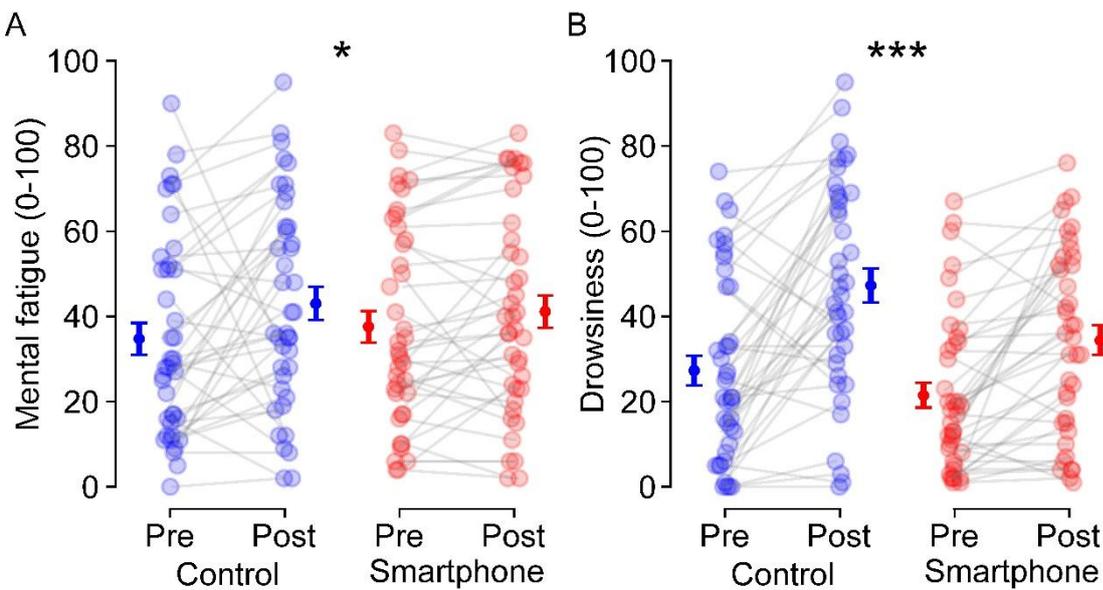
247 **Psychological measures**

248 **Sleep duration.** No difference in sleep duration was observed, $t(78) = -0.604$, $p = .547$, $d = -$
249 $.135$, between participants in the smartphone condition and those in the documentary
250 condition (505 min \pm 88 vs. 495 min \pm 62, respectively).

251 **Motivation.** There was no difference in intrinsic, $t(78) = -0.801$, $p = .426$, $d = -.179$ (17.5 \pm
252 0.5 vs. 18.0 \pm 0.5), or in extrinsic motivation, $t(78) = -1.340$, $p = .184$, $d = -.300$ (17.7 \pm 0.4
253 vs. 18.6 \pm 0.5) to perform the session between the two experimental conditions.

254 **Mental fatigue.** Mental fatigue increased following both smartphone use and documentary
255 watching [time effect: $F(1, 78) = 9.809$, $p = .011$, $\eta_p^2 = .080$; from 36.2 \pm 2.6 to 42.1 \pm 2.7].
256 However, neither a group effect, $F(1, 78) = 0.009$, $p = .924$, $\eta_p^2 < .001$, nor a group \times time
257 interaction, $F(1, 78) = 1.087$, $p = .300$, $\eta_p^2 = .014$, were observed (Fig 1. a).

258 **Drowsiness.** Drowsiness increased following both smartphone use and documentary watching
 259 [time effect: $F(1, 78) = 50.505, p < .001, \eta_p^2 = .393$; from 24.4 ± 2.3 to 40.8 ± 2.7], and the
 260 participants in the control group were more drowsy than those in the smartphone group [group
 261 effect: $F(1, 78) = 50.505, p < .001, \eta_p^2 = .393$; Control: 37.3 ± 3.2 , Smartphone: 28.0 ± 2.9].
 262 However, no a group \times time interaction was observed, $F(1, 78) = 2.352, p = .129, \eta_p^2 = .029$
 263 (Fig 1. b).



264
 265 **Figure 1**
 266 *Effects of smartphone use on subjective mental fatigue (A) and drowsiness (B) evaluated*
 267 *using a visual analog scale. Individual ($N = 40$) data are represented with empty markers and*
 268 *means \pm SEM as filled markers. * and *** indicate main effects of time significant at $p < .05$*
 269 *and $p < .001$, respectively.*

270
 271 **Boredom.** Analyses performed on boredom did not reveal any differences, $t(78) = -0.960, p =$
 272 $.340, d = -.214$, between participants' feeling of boredom after smartphone use and
 273 documentary watching (38.1 ± 3.0 vs. 33.7 ± 3.1 , respectively).

274 **Perceived workload.** Analyses performed on the NASA-TLX revealed that smartphone use
 275 was perceived as less temporally demanding than documentary watching, $t(78) = 3.151, p =$
 276 $.002, d = .705$. In addition, participants perceived their performance as being higher for
 277 smartphone use than for documentary watching, $t(78) = -3.066, p = .003, d = -.686$ (Table 1).

278 **Table 1**

279 *The perceived workload for the Control and Smartphone groups (Experiment 1)*

Mental	Physical	Temporal	Frustration	Performance	Effort
--------	----------	----------	-------------	-------------	--------

	demand	demand	demand			
Control	20.4 (± 1.9)	10.1 (± 1.6)	45.6 ** (± 4.1)	21.0 (± 3.2)	82.4 ** (± 2.3)	17.0 (± 1.8)
Smartphone	16.0 (± 2.4)	7.1 (± 1.3)	27.5 (± 4.0)	20.3 (± 4.1)	91.8 (± 2.5)	13.8 (± 2.5)

280 *Note.* **: Significant main effect of group ($p < .01$). Data are presented as means (\pm SEM).

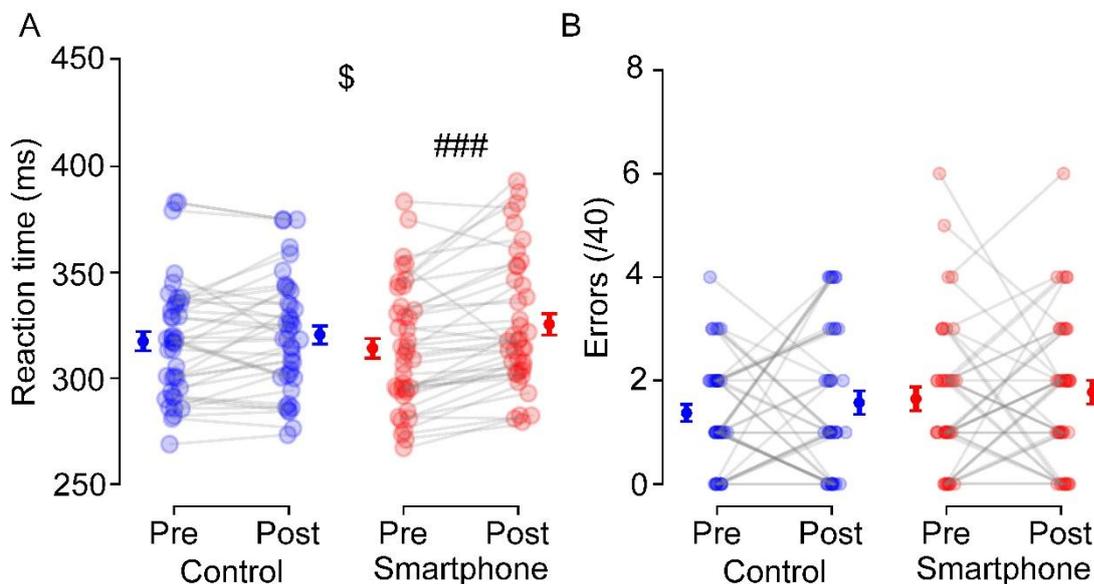
281

282 **Activities performed on smartphone.** Participants reported spending 32.9 min (± 1.9) on social
 283 network, 5.7 min (± 1.5) on Internet search, 1.6 min (± 0.6) on productivity applications, and
 284 4.6 min (± 1.8) on games.

285 **Behavioral performances for vigilance**

286 The analyses run on reaction times revealed a significant group \times time interaction, $F(1, 78) =$
 287 6.190, $p = .015$, $\eta_p^2 = .076$, indicating a significant increase in reaction times after smartphone
 288 use, $t(39) = -4.646$, $p < .001$, $d = -.735$ (314.1 ms \pm 4.6 to 325.5 ms \pm 5.0), but not after
 289 documentary watching, $t(39) = -1.400$, $p = .169$, $d = -.221$ (317.37 ms \pm 4.3 to 320.5 ms \pm 4.3,
 290 Fig 2. a). However, there were no significant effects (all $ps > .17$, $\eta_p^2 < .03$) on omissions,
 291 anticipations, or global errors (missed targets + anticipations, Fig 2. b).

292



293

294 **Figure 2**

295 *Effects of smartphone use on reaction time (A) and global errors (B) during the psychomotor*
 296 *vigilance task. Individual (N = 40) data are represented with empty markers and means \pm*

297 *SEM as filled markers. \$: significant group × time interaction. ###: difference between pre*
298 *and post within the same group ($p < .001$).*

299

300 **Experiment 2**

301 **Material and methods**

302 **Participants**

303 Eighty healthy young adults (73 females, 7 males, $M_{\text{age}} = 19.5$, $SD = 2.8$ years), recruited
304 from the Université de Bourgogne and different from those who performed Experiment 1,
305 participated in Experiment 2. They were randomly divided into two groups (i.e., smartphone
306 use and documentary watching). All information regarding inclusion-exclusion criteria, pre-
307 laboratory visits, and ethics is identical to Experiment 1

308 **Experimental procedure**

309 The experimental procedure was similar to that used in Experiment 1, except that the PVT
310 was replaced by a Go/NoGo task, which evaluates inhibition capacities (see Section 2.1.2).

311 The session began with a brief habituation (30 trials) to the Go/NoGo task (see 2.1.3.3).
312 Participants completed a questionnaire to evaluate their sleep duration and quality,
313 motivation, levels of mental fatigue, and drowsiness. Next, they performed the Go/NoGo task
314 (pretest), followed either by a 45-min period of smartphone use or a control task of the same
315 duration (watching a documentary). Participants reported their levels of mental fatigue,
316 drowsiness, boredom, and the subjective workload induced by either smartphone use or the
317 control task. Then, participants performed the Go/NoGo task again (posttest). Finally,
318 participants reported the specific activities they were engaged in on their smartphone during
319 the 45-min use period.

320 **Experimental tasks**

321 Smartphone use and control task. These tasks were the same as in Experiment 1 (see Section
322 2.1.3).

323 **Go/NoGo task.** The Go/NoGo task is a cognitive task currently used to evaluate inhibition
324 capacities. Experiment Builder software (SR Research) was used to monitor stimulus
325 presentation. A white fixation cross was displayed continuously at the center of a black
326 screen. The stimulus was either a white triangle (Go stimulus) or a white circle (NoGo
327 stimulus) and was presented on the left or right side of the fixation cross. The stimuli were
328 displayed for 100 ms, with an interstimulus interval of 2500 ms. The task consisted of 150

329 trials and lasted approximately 6 min 30. There were 120 (80%) Go stimuli and 30 (20%)
 330 NoGo stimuli. When a Go stimulus was displayed, the participants had to respond by pressing
 331 the space bar with their right index finger, whereas they were told not to react to NoGo
 332 Stimuli. The left or right positions were used equally often and in random order. Participants
 333 were instructed to respond as quickly and as accurately as possible. Reaction times faster than
 334 100 ms or two or more standard deviations above or below the mean were excluded from the
 335 analysis. Errors on the Go and NoGo trials were analyzed separately.

336 **Psychological measures**

337 The psychological measures were the same as in Experiment 1 (see Section 2.1.4).

338 **Statistics**

339 The statistical analyses performed to assess differences in psychological measures were the
 340 same as in Experiment 1. To analyze the Go/NoGo performance (reaction times for Go trials,
 341 errors for Go trials, and errors for NoGo trials), we used two-way mixed-model repeated-
 342 measures 2×2 ANOVAs with group (Control, Smartphone) as a between-subject factor, and
 343 time (Pre, Post) as a within-subject factor were used.

344

345 **Results**

346 **Psychological measures**

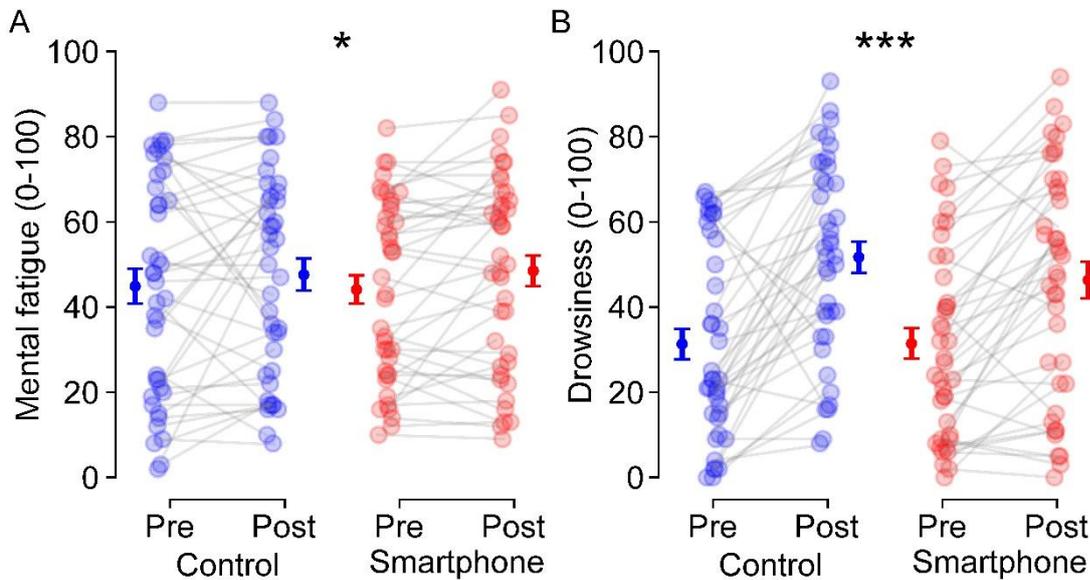
347 **Sleep duration.** No difference in sleep duration, $t(78) = 0.441$, $p = .661$, $d = -0.099$, was
 348 observed between participants in the smartphone condition and those in the documentary
 349 condition (484 min \pm 9.4 vs. 490 min \pm 9.8, respectively).

350 **Motivation.** There were no differences in either intrinsic, $t(78) = 0.881$, $p = .381$, $d = -0.197$
 351 (18.1 \pm 0.5 vs. 17.5 \pm 0.4) or in extrinsic motivation, $t(78) = -0.557$, $p = .579$, $d = -0.125$ to
 352 perform as a function, smartphone vs documentary (18.2 \pm 0.4 vs. 18.5 \pm 0.4, respectively).

353 **Mental fatigue.** Mental fatigue increased following both smartphone use and documentary
 354 watching [time effect: $F(1, 78) = 3.978$, $p < .050$, $\eta_p^2 = .049$; from 44.5 \pm 2.6 to 48.1 \pm 2.6].
 355 However, neither a group effect, $F(1, 78) < 0.001$, $p = .988$, $\eta_p^2 < .001$, nor a group \times time
 356 interaction, $F(1, 78) = 0.199$, $p = .657$, $\eta_p^2 = .002$, were observed (Fig 3. a).

357 **Drowsiness.** Drowsiness increased following both smartphone use and documentary watching
 358 [time effect: $F(1, 78) = 60.665$, $p < .001$, $\eta_p^2 = .438$; from 31.4 \pm 2.5 to 49.0 \pm 2.8]. However,
 359 neither a group effect, $F(1, 78) = 0.296$, $p = .588$, $\eta_p^2 = .004$, nor a group \times time interaction,
 360 $F(1, 78) = 1.457$, $p = .231$, $\eta_p^2 = .018$, were observed (Fig 3. b).

361
362



363
364

Figure 3

365 *Effects of smartphone use on subjective mental fatigue (A) and drowsiness (B) evaluated*
366 *using a visual analog scale. Individual (N = 40) data are represented with empty markers and*
367 *means ± SEM as filled markers. * and *** indicate main effects of time significant at p < .05*
368 *and p < .001, respectively.*

369

370 **Boredom.** Analyses performed on boredom did not reveal any differences, $t(78) = -0.691, p =$
371 $.492, d = -0.154$, in the results after smartphone use and documentary watching (39.3 ± 3.6 vs.
372 36.1 ± 3.0 , respectively).

373 **Subjective workload.** Analyses performed on the NASA-TLX revealed that smartphone use
374 was perceived as less temporally demanding than documentary watching, $t(78) = 2.430, p =$
375 $.002, d = .543$. In addition, participants perceived their performance as being higher for
376 smartphone use than for documentary watching, $t(78) = -3.125, p = .003, d = -.699$ (Table 2).

377 **Table 2**

378 *The perceived workload for the Control and Smartphone use groups (Experiment 2)*

	Mental demand	Physical demand	Temporal demand	Frustration	Performance	Effort
Control	28.5 (± 3.3)	12.4 (± 2.4)	46.6 ** (± 3.5)	25.1 (± 3.8)	81.1 ** (± 2.4)	24.4 (± 3.5)
Smartphone	21.0	10.0	34.3	18.0	91.6	19.3

(± 3.0) (± 1.7) (± 3.7) (± 3.1) (± 1.9) (± 3.1)

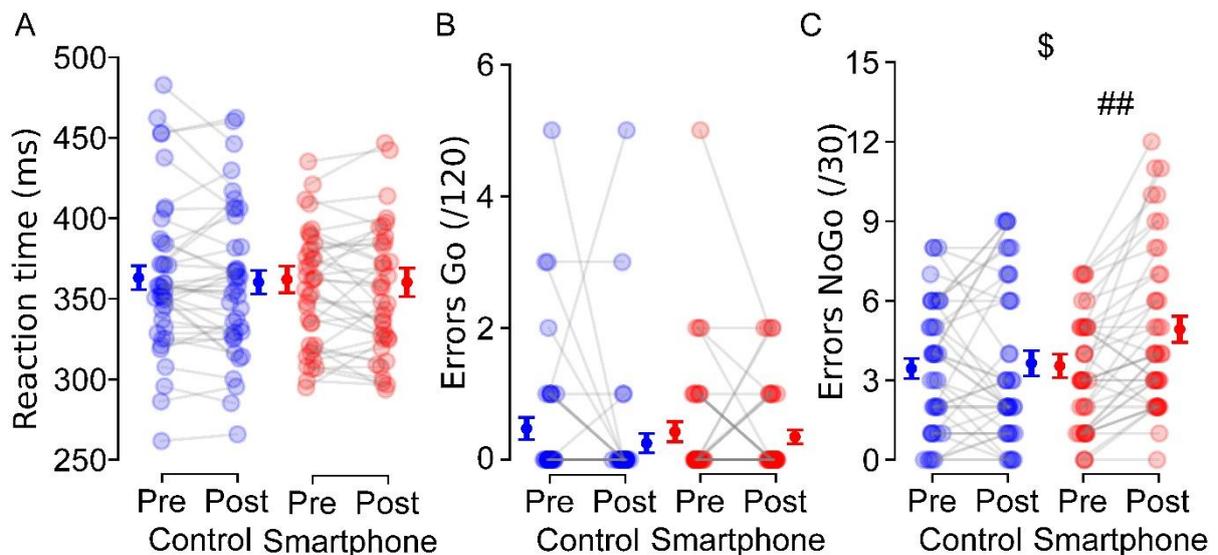
379 Note. **: main effect of group ($p < .01$). Data are presented as means (\pm SEM).

380 **Activities performed on smartphone.** Participants reported spending 32.2 min (± 1.9) on social
 381 network, 6.7 min (± 1.6) on Internet search, 1.5 min (± 0.6) on productivity applications, and
 382 4.6 min (± 1.5) on games.

383 **Behavioral performances for inhibition capacities**

384 For reaction times, neither a significant time effect, $F(1, 78) = 1.098, p = .298, \eta_p^2 = .014$, nor
 385 a group \times time interaction, $F(1, 78) = 0.048, p = .828, \eta_p^2 = .001$, were observed (Fig 4. a).
 386 While there were no significant effects on errors for Go trials (all $ps > .20, \eta_p^2 < .021$, Fig 4.
 387 b), the analyses on NoGo trials revealed a group \times time interaction, $F(1, 78) = 5.231, p =$
 388 $.025, \eta_p^2 = .063$, thus indicating an increase in errors after smartphone use, $t(78) = -3.075, p =$
 389 $.008, d = -.486 (3.55 \pm 0.44$ vs. $4.92 \pm 0.49)$ but not after documentary watching, $t(78) = -$
 390 $0.312, p = 1.000, d = -.049 (3.45 \pm 0.38$ vs. 3.65 ± 0.48 , Fig 4. c).

391



392

393 **Figure 4**

394 *Effects of smartphone use on reaction times (A), errors for Go trials (B), and NoGo trials (C)*
 395 *during the Go/NoGo task. Individual (N = 40) data are represented with empty markers and*
 396 *means \pm SEM as filled markers. \$: significant group \times time interaction. ##: difference*
 397 *between pre and post within the same group ($p < .01$).*

398

399 **Discussion**

400 The present study aimed to examine the impact of acute smartphone use on vigilance,
401 attention, and inhibition capacities. Participants reported an increase in subjective mental
402 fatigue, as assessed by a VAS, following smartphone use. However, it is noteworthy that a
403 similar increase in mental fatigue was also observed in a control group whose participants
404 watched a documentary. After 45 min of smartphone use, the results indicated a decline in
405 vigilance, as evidenced by increased reaction times during the PVT. Interestingly, reaction
406 times and the number of omissions remained constant during the Go/NoGo task, suggesting
407 that attention abilities were preserved. However, an increase in errors during the NoGo trials
408 indicated impaired inhibition capacities. This study highlights the negative impact of acute
409 smartphone use on vigilance and inhibition capacities. While feelings of mental fatigue
410 increased in both groups, performance declined only after acute smartphone use. This
411 objectively indicates that mental fatigue occurred only after acute smartphone use. As the
412 increased feeling of mental fatigue occurred in both conditions, even when there were no
413 detrimental effects on cognitive performance, future studies should attempt to identify the
414 electrophysiological markers of the presence of mental fatigue after acute smartphone use.

415 **Evaluation of mental fatigue**

416 In line with other recent studies, our research has shown that using smartphones can increase
417 feelings of mental fatigue^{10,13}. However, we observed a similar increase in feelings of mental
418 fatigue in the control group. In addition, we observed that both smartphone use and
419 documentary watching led to increased drowsiness. Drowsiness is the intermediate state
420 between awareness and sleep⁴⁰. Since all participants reported having more than six hours of
421 sleep the night before the experiment and the experimental tasks were relatively short (45
422 min), it is unlikely that drowsiness was related to sleep deprivation. One possible explanation
423 for the drowsiness experienced by the participants relates to the experimental conditions
424 themselves. The study was conducted in a windowless room with a relatively low lighting
425 level and this may have contributed to the onset of drowsiness. Although mental fatigue and
426 drowsiness are two distinct and dissociable phenomena⁴¹, they can manifest themselves in
427 similar ways, such as feeling tired and experiencing reduced alertness. Even if subjective
428 measurements like VAS have been widely adopted for assessing mental fatigue²⁷, it is
429 necessary to back them up with objective measures, such as behavioral performances, or
430 physiological measurements such as electroencephalography and/or heart rate variability, in
431 order to confirm the link between acute smartphone use and mental fatigue.

432 Effects of acute smartphone use on cognitive performances

433 The effects of smartphone use have mainly been studied in the context of chronic use,
434 and many different effects have been reported. In addition to the appearance of sleep or
435 emotional disorders, chronic smartphone use can lead to impaired cognitive performance. The
436 present study aimed to evaluate the effects of acute smartphone use on attentional and
437 inhibition capacities. We observed (i) an increase in reaction times during the PVT
438 unaccompanied by any changes in error rate after acute smartphone use, thus indicating
439 impaired vigilance, and (ii) an increase in NoGo errors in the Go/NoGo task showing an
440 impairment in inhibition capacities. Such differences were not observed in the control group.

441 One previous study found an increase in reaction times and errors during a Stroop task
442 after 30 and 45 min of acute smartphone use¹⁵. In contrast, another study reported an increase
443 in reaction times without any increase in errors¹². An increase in reaction times suggests
444 slower processing and delayed responses during the Stroop task. The authors attributed the
445 performance impairment, which was also observed for physical tasks, to the presence of
446 mental fatigue as evaluated with a VAS. The performance deterioration might have been due
447 to a decrease in attentional resources and difficulties in inhibiting the automatic response
448 when reading the word. The increased reaction times might have been attributable to reduced
449 attentional resources, especially in selective attention, and difficulties in inhibiting the
450 automatic reading response⁴². Moreover, the increased errors during the Stroop task suggest a
451 reduced ability to inhibit automatic responses and overcome interference. In the present study,
452 the increase in errors on the NoGo trials during the Go/NoGo task confirms the impairment of
453 inhibition capacities after acute smartphone use. The maintenance of reaction times and errors
454 for Go trials indicates that participants continued to try to perform the task correctly but found
455 it more difficult to inhibit a motor response when presented with an irrelevant stimulus.

456 At the same time, the increase in reaction times during the PVT after 45 min of
457 smartphone use, without this having any effect on errors, testified to impaired vigilance. This
458 impairment has already been observed in the presence of mental fatigue. Smith et al.²⁷ not
459 only found an increase in reaction times overtime during a prolonged PVT (i.e., 45 min) but
460 also an increase in reaction times, unaccompanied by an effect on errors, during a PVT after a
461 mentally fatiguing task of 45 min (e.g., Stroop task).

462 **Potential role of the anterior cingulate cortex in performance**
463 **impairment**

464 Studies on mental fatigue revealed changes in cortical activity, in particular modulations of
465 activity in the prefrontal cortex. Among the structures concerned, there is a decrease in the
466 activity of the anterior cingulate cortex (ACC), a brain region involved in attentional control
467 and conflict resolution^{43,44}. It has been found that a decrease in ACC activity was linked to an
468 increase in reaction times during a PVT⁴⁵. The observed detrimental impact of acute
469 smartphone use on reaction times during the PVT may have been due to a reduction in ACC
470 activity, potentially associated with the presence of mental fatigue. Although this hypothesis
471 could not be validated in the present study, some neuroimaging studies have shown a decrease
472 in ACC activity in intensive smartphone users^{46,47}. Based on the similarity between the effects
473 usually observed and those observed with acute smartphone use, and also considering the
474 imaging data, there is reason to hypothesize that the use of smartphones can affect the activity
475 of the ACC and lead to impaired performance. The ACC is also highly activated during
476 response inhibition⁴³. Lesions or damage to the ACC can lead to deficits in inhibitory control
477 and difficulties in suppressing inappropriate responses⁴⁸. However, further neuroimaging
478 studies (functional magnetic resonance imaging or near-infrared spectroscopy) are needed in
479 order to confirm that smartphone use leads to a decrease in ACC activity that may be
480 responsible for the impairment of attentional and inhibition capacities.

481 **Neuronal substrates of performance impairment: exploring the**
482 **involvement of the prefrontal cortex**

483 The prefrontal cortex, including the ACC, is considered to be a key brain area involved in the
484 phenomenon of mental fatigue⁴⁹. Many different studies have reported an association between
485 prefrontal activation and fatigue following prolonged, demanding physical or mental exertion.
486 A recent study also revealed that the induction of mental fatigue due to prolonged cognitive
487 work is associated with an increase in glutamate accumulation in the lateral prefrontal
488 cortex⁵⁰. Regarding the diminished activation of the dorsolateral prefrontal cortex (DLPFC),
489 Lim et al.⁴⁵ found that, in addition to a decrease in ACC activity, mental fatigue might induce
490 a reduction in the activity of the middle frontal gyrus, a part of the DLPFC. Consequently, it
491 has been hypothesized that a functional adaptation takes place due to the costs associated with
492 the effort made. The fatigue-induced decline in motor performance is regulated by means of
493 the crucial role played by inhibitory projections from the DLPFC to the motor cortex. It is
494 worth mentioning that the application of transcranial direct current stimulation (tDCS) to the

495 left DLPFC has been shown to mitigate the adverse impacts of mental fatigue on athletic
496 performance⁵¹. Moreover, emerging research suggests that intensive smartphone users exhibit
497 reduced DLPFC activity^{9,52}, associated with an impairment in inhibition processing⁹. To the
498 best of our knowledge, no study has as yet investigated the changes in brain activity related to
499 acute smartphone use. However, based on the literature, a decrease in DLPFC activity after
500 acute smartphone use would potentially be a way of accounting for the impairment in the
501 ability to inhibit a motor response during nonrelevant trials in a Go/NoGo task and the
502 increase in errors during NoGo trials. Regarding the accumulation of glutamate in the lateral
503 prefrontal cortex, Wiehler et al.⁵⁰ reported a higher glutamate concentration in this brain area
504 following daylong cognitive work. This glutamate accumulation has been correlated with
505 attention deficit in hyperactivity disorder⁵³ and impulsivity in healthy adults⁵⁴, and is likely
506 linked to the deterioration in vigilance and inhibition capacity observed in our study.

507 **Limitations and outlooks**

508 While behavioral performance declined only after acute smartphone use, the feeling of fatigue
509 increased both with acute smartphone use and when watching a documentary. Furthermore,
510 drowsiness increased in both groups. We cannot exclude the possibility that the increased
511 drowsiness following acute smartphone use and watching a documentary could be a
512 confounding factor in the rating of mental fatigue. Our findings suggest that using only
513 subjective evaluations of tiredness and lack of energy may not be the best way of monitoring
514 the progression of mental fatigue. It would therefore be worst investigating the effects of
515 mental fatigue on cognitive and physical performance, not just by assessing subjective fatigue
516 indicators (i.e., feelings of mental fatigue) but also by examining objective manifestations of
517 fatigue. These objective manifestations of fatigue could be captured through changes in
518 performance or neurophysiological variables. Additionally, future studies should consider
519 monitoring the educational and socioeconomic levels of the population under investigation to
520 better characterize the observed effects. Understanding how these factors may interact with
521 smartphone use and other cognitive tasks can provide a more comprehensive picture of the
522 impact of mental fatigue. Moreover, while we evaluated sleep, we did not evaluate for the
523 presence of emotional disorders or other mental health disorders in our participants, which
524 can also considerably affect cognitive performance⁵⁵. In future investigations, it might be of
525 value to consider controlling for these parameters. Furthermore, we did not control for
526 participants' typical average duration of smartphone use. It is perfectly conceivable that

527 individuals accustomed to prolonged smartphone use may respond differently to acute
528 smartphone use.

529 **Conclusion**

530 The findings of this study demonstrate that acute smartphone use (i.e., 45 min) induces an
531 increase in the sensation of mental fatigue and drowsiness. However, the increase in the
532 feeling of mental fatigue and drowsiness was comparable in magnitude after viewing a
533 documentary (i.e., control group). Behavioral results indicated a decline in vigilance and
534 inhibition capacities after acute smartphone use only. Further studies are needed to (i) confirm
535 the presence of mental fatigue after acute smartphone use based on the use of objective
536 measures (e.g., electroencephalography, heart rate variability) and (ii) determine the
537 neurophysiological mechanisms underlying the negative effects of smartphone use on
538 attention and inhibition processes. Finally, individuals may need to be more aware of the
539 impact of smartphone use on their cognitive abilities and take appropriate measures to
540 mitigate any negative effects.

541

542 Data availability

543 The datasets generated and analyzed during the current study are available from the
544 corresponding author upon reasonable request.

545

546 Authors' contributions

547 TJ, RL, BP, and BPC designed the experiment; TJ collected the data; TJ analyzed the data; TJ
548 developed figures; TJ wrote the first draft of the manuscript; RL, BP, and BPC provided
549 feedback on the manuscript; all co-authors read and approved the submitted version.

550

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554

555 Competing interests

556 The authors declare that the research was conducted in the absence of any commercial or
557 financial relationship that could be construed as a potential conflict of interest.

558

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