Think Fast: An Assessment of Cognitive Processing Speed in Relation to Smartphone Proximity

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KEYWORDS. smartphone proximity, smartphone addiction, cognitive processing, cyber psychology.

BRIEF. When habituated to distance from one's smartphone, cognitive processing speed is faster when the smartphone is close to the body and in eyes view

ABSTRACT. Over the past few decades, technology has advanced exponentially. With these advancements has come an increased reliance on smartphones, heavily impacting teenagers specifically. Smartphones have made attention less attainable, and classrooms have significantly experienced their impact. The purpose of this study was to investigate how smartphone proximity affects the cognitive processing of high school students. Students were asked to take two math exams and, for each of the two exams, the location of their smartphone changed. A counterbalancing technique was used in to avoid the practice effect and ensure the results were due to the moving of the smartphone, rather than the students just adjusting to the task. In condition one (called the smartphone face-down condition), students kept their smartphones on their desk, face-down, as they completed the math exam. In condition two (called the smartphone removed condition), students had their smartphones collected from them. The study concluded with a survey, measuring their level of smartphone addiction. The results were unexpected. Results found for students who routinely had their smartphones collected during class performed better when their smartphone was on their desk compared to students who don't routinely have their smartphones collected from them.

INTRODUCTION.

On average, a person spends four hours and ten minutes on their mobile devices daily [1]. In 2020, 54% of teens self-reported being on their smartphones excessively [2]. Kim [3] finds that teens who are addicted to their smartphones are being impacted on an emotional level; addicted participants were more likely to experience depression, anxiety, and ADHD when compared with non-addicted participants. The dopamine rush received from their smartphones leads them to intertwine their digital lives with their concrete or real lives [4]. With smartphone usage increasing, many have developed a "hyperconnected relationship" with their devices [5].

Smartphones have become a pervasive distraction, oftentimes interfering with classroom instruction. McCoy [6] found that college students spend about 20.9% of their class time distracted by their smartphones. Additionally, Kuznekoff and Titsworth [7] found that students who chose to put their smartphone away write 62% more information down during class compared to students who use their smartphones during class time. These findings suggest that much of students' cognitive energy is directed to their smartphones. The distracting nature of smartphones during instruction leads investigators to ask: should educators rely on student access to smartphones and laptops as instructional tools? How will future generations be affected by advancements in technology and to what degree, if at all? How may this impact educators' ability to achieve their educational goals?

Literature Review. Smartphones impact lives in general. However, it is not known the extent they affect intellectual and cognitive functions, such as learning, memory, and reasoning [8]. Smartphones have also affected the microstructural variations in the brain. Wang [9] aimed to assess a relationship between mobile phone dependence (MPD) and changes in brain tissue. Participants were asked to complete the Mobile Phone Addiction Index (MPAI) Scale. In this study, a score of 51 or more classified a participant as MPD. Wang's sample consisted of 34 MPD college students (experimental group) and 34 non-MPD college students (control group). Imaging data were acquired through the use of a 3T Siemens MRI scanner. Researchers found that the MPD group had significantly less gray matter volume and significantly less white matter integrity in comparison to those in the non-MPD group. This study is important to its field because it is the first study to support the idea that overuse of smartphones can alter brain structure [9]. Wang's study demonstrates that his dependence has neurological effects on the brain. Therefore, cognition will be impacted.

May and Elder [10] performed a study looking at the relationship between multitasking and academic performance. They defined multitasking as "dividing attention, switching attention, and maintaining multiple trains of thought" [10]. The study assessed how multitasking impacted one's grade point average (GPA), test performance, memory recall, reading comprehension, note taking, self-regulation, and efficiency [10]. They synthesized data and conducted a meta-analysis from past research and introduced new interpretations of past data. May highlights the "bottleneck theory of attention" which suggests that attention can be allocated to only one task at a time [10]. It was concluded that engaging with technologies while trying to focus on class material can have detrimental effects on learning, which can be attributed to inattention to course material. Moreover, the study revealed that individuals were not good self-assessors of their own level of distraction due to device usage [10]. Additionally, when outside a typical learning environment, May found that smartphones and laptops were particularly intrusive to studying or doing other homework. May's conclusions were helpful to the scientific conversation about technology and its effects on cognition.

Because May's study was a meta-analysis, it is unknown whether it was the mere presence or the use of the smartphone or laptop that caused the inattention. Tanil and Yong [11] specifically examined the correlation between a smartphone's presence and memory. This study utilized 119 undergraduate students who were given a working memory test. Participants learned three types of stimuli: a list of letters, a list of numbers, and a list of words. For a between groups design, those in condition one had their smartphones next to them and those in condition two did not. The aim of this study was to see if smartphone presence had a negative effect on recall accuracy. The results demonstrated that the participants in possession of their smartphones did not perform as well on the working memory test when compared to the group without their smartphones with them.Tanil and Yong's research only evaluated the smartphone's presence versus the lack of the smartphone's presence. Ward et al. [12], in contrast, assessed different levels of the smartphone's presence or accessibility. Ward tested if smartphones could diminish one's intellectual capabilities by simply being present. Ward hypothesized that "the mere presence of one's own smartphone may occupy limited capacity [of] cognitive resources, thereby leaving fewer resources available for other tasks and undercutting cognitive performance" [12]. College students were given two types of standardized tests to measure their fluid intelligence: one assessed a person's ability to sustain focus on a specific task and the other assessed a person's ability to problem-solve. This study isolated one singular variable: the location of the participant's smartphone. Participants were randomly assigned to one of three smartphone location conditions: desk, backpack / pocket, or other room. The purpose of the study was to investigate the impact that smartphone proximity has on cognition. Participants in condition one (desk) did considerably worse than those in condition 3 (other room). As for the participants in condition 2 (bag), their performance was somewhere between the two other groups. The participants who took the exams with their phone on the desk did significantly worse than those who had their phone in a separate location. As for the participants who had their phone in their bag, their scores lied between the other two groups. In this case, it is not the usage of the smartphone, but the *proximity* of the device that affects cognitive performance [12]. While this study has informative data, it is probable that the information requires updating because it was performed in 2017. If experimental research similar to this study were to be conducted in 2023, that could confirm this data.

Past literature has not investigated high school students, leaving a lack of insight into adolescent populations. Teenagers in Generation Z, born in 1997 to 2012, have always lived a world where technological devices are easily accessible and advanced to this level. The purpose of this study is to investigate a potential relationship between adolescent smartphone presence and addiction and impacts on cognition.

Hypotheses. Based on the previous research in this field, I hypothesized that students solve more math problems when their smartphones were collected from them, compared to when their smartphones were face-down on their desk. In other words, I predicted that a close smartphone proximity negatively impacts the number of math problems solved (the variable I used to measure cognitive performance). Additionally, I hypothesized that students with higher smartphone addiction scores solve fewer math problems, suggesting slower cognitive processing speed.

MATERIALS AND METHODS.

Ethics Statement. IRB approval was obtained on September 13, 2023. Students were given consent forms multiple days in advance and any students under the age of 18 were required to have a parent signature, in addition to their own. Each student in the data set had handed in their informed consent form prior to taking part in the study. Students understood that their participation was completely voluntary and that they had the ability to withdraw at any time. Data were collected on three different days in heterogeneous science classes.

Sample. A total of 89 students were recruited for this study, all enrolled in a suburban high school with ages ranging from 14 to 18 years, with a mean age of 16.3 years (SD = 0.84). These students were recruited from two different classes at the same high school. Sample population included 62 female students (67%), 24 male students (27%), and three students (3.4%) who preferred not to disclose their gender identity. Additionally, there were 65 White students (73%), 17 Asian students (19.1%), 11 Hispanic students (12.4%), 5 Black or African American students (5.6%), and 4 Middle Eastern students (4.5%). Moreover, there were 11 tenth grade students (12.4%), 27 eleventh grade students (30.3%), and 51 twelfth grade students (57.3%).

Conditions & Procedure. There were two conditions in this study: the smartphone face-down condition and the smartphone removed condition. In the smartphone face-down condition, students had their smartphones face-down on their desk while taking a math exam. In the smartphone removed condition, students had their smartphones collected from them and completed a similar exam. This study has a within groups design, so all students participated in both conditions. Counterbalancing assignment was allocated randomly. There were 47 students in the first counterbalance order; students completed smartphone face-down condition first, and then the smartphone removed condition. There were 44 students who participated in the second counterbalance order of smartphone removed condition first and then smartphone face-down condition.

During each condition, students were asked to complete a math exam. The math exam, that I created, of simple, two-digit addition was used to operationalize cognitive processing in the context of this study. There was a total of 96 problems on each exam. Students were given 60 seconds to answer questions on each exam and then, after the timer went off, they were asked to stop working. 96 problems were given to ensure that students did not run out of problems to work on during the exam. During data analysis, the number of problems attempted (both the number of correct responses and of incorrect responses) were counted. Participants were not expected to answer all questions within the 60 seconds; questions that were not attempted were not counted in the results as incorrect or correct and, instead, just not acknowledged. Having the exams timed gave both exams consistency as their smartphone traveled around the testing room. All 89 students were assigned a number during data collection so that I could track each student throughout the experiment without breaching any confidentiality rules of experimentation.

Lastly, students completed the Smartphone Addiction Scale [13] and a demographic survey with regards to age, gender, year in school, race, and ethnicity (asked to select all that applied). The Smartphone Addiction Scale (SAS) is a 10-item scale measuring the level of smartphone addiction by assessing traits and patterns in behavior on a self-report basis. The lowest score a student could obtain on the scale was 10 and the highest score a student could obtain was 60. A higher score indicated that the student was more addicted to their smartphone, in comparison to students with lower scores. The SAS includes the items "missing planned work due to smartphone use," "feeling impatient and fretful when I am not holding my smartphone," and eight other similar items [13]. Students answered on a 6-point Likert scale (1 = strongly disagree to 6 = strongly agree). The total length of time for their participation was approximately 10 minutes.

RESULTS.

First, statistics on the number of responses on the exams were conducted (Table 1). Statistical analysis was conducted in SPSS, with a p value of 0.05 set as significance. The mean number of correct responses in the smartphone face-down condition was 12.16 (SD = 5.19). The mean number of correct responses in the smartphone removed condition was 11.80 (SD = 4.61). A dependent t test found a non-significant difference between conditions, $t\,(88) = 0.75$, $p = 0.45$.

Table 1. Cognitive performance, measured with the mean number and SD of correct and incorrect responses on the math exam, between conditions: the smartphone lying face-down on the student's desk and the smartphone removed from the testing room.

Condition	Correct Responses	Incorrect Responses
Smartphone Face-Down	12.16 (SD = 5.19)	0.70 (SD = 0.970)
Smartphone Removed	11.80 (SD = 4.61)	0.79 (SD = 0.971)

The mean number of incorrect responses in the smartphone face down condition was 0.70 (SD = 0.970). The mean number of incorrect responses in the smartphone removed condition was 0.79 (SD = 0.971). A dependent t test found a non-significant result, $t\,(88) = -0.69$, $p = 0.49$.

The mean number of smartphone addiction scores from the SAS was

30.44 (SD = 9.08). A correlation was performed between smartphone addiction scores and the number of correct responses in the smartphone face-down condition, which produced a non-significant, weak, negative correlation, *r* = -.06, *p* = 0.55. Next, a correlation between smartphone addiction scores and the number of correct responses in the smartphone removed condition, which produced a non- significant correlation, *r* = 0.03, *p* = 0.81.

Additional analysis was conducted to see if there was an effect between students who habitually have their smartphones taken and students who do not (Table 2). The data were analyzed as a function of classrooms, a variable referring to the classroom (no smartphone allowed or smartphone allowed) which students were recruited from. The mean number of correct responses in the smartphone allowed classroom during the smartphone face-down condition was 11.17 (SD = 4.997). The mean number of correct responses in the no smartphone allowed classroom during the smartphone face-down condition was 13.54 (SD = 5.199). An independent *t* test found that students who are habitually not permitted to have their smartphones (i.e. no smartphone allowed classroom) had *significantly* more correct responses when in the smartphone face-down condition, *t* (87) = -2.17, *p* = 0.03.

The mean number of correct responses in the smartphone allowed classroom during the smartphone removed condition was 11.25 (SD = 4.926). The mean number of correct responses in the no smartphone allowed classroom during the smartphone removed condition was 12.57 (SD = 4.066). An independent *t* test produced a non-significant result, *t* (87) = -1.335, *p* = 0.185.

Table 2. Cognitive performance, represented by the mean number and SD of correct and incorrect responses on the math exam, as a function of classroom and condition.

Classroom	Condition	Correct Responses	Incorrect Responses
Smartphone Allowed	Smartphone Face-Down	11.17 (SD = 4.997)	0.79 (SD = 1.126)
Smartphone Allowed	Smartphone Removed	11.25 (SD = 4.926)	0.88 (SD = 0.963)
No Smartphone Allowed	Smartphone Face-Down	13.54 (SD = 5.199)	0.57 (SD = 0.689)
No Smartphone Allowed	Smartphone Removed	12.57 (SD = 4.066)	0.65 (SD = 0.978)

The mean number of incorrect responses in the smartphone allowed classroom during the smartphone face-down condition was 0.79 (SD = 1.1256). The mean number of incorrect responses in the no smartphone allowed classroom during the smartphone face-down condition was 0.57 (SD = 0.689). An independent *t* test showed a non-significant result, *t* (87) = 1.059, *p* = 0.292.

The mean number of incorrect responses in the smartphone allowed classroom during the smartphone removed condition was 0.88 (SD = 0.963). The mean number of incorrect responses in the no smartphone allowed classroom during the smartphone removed condition was 0.65 (SD = 0.973). An independent *t* test found non-significant results, *t* (87) = 1.132, *p* = 0.261.

DISCUSSION.

The purpose of this study was to evaluate how cognitive processing is impacted by smartphone proximity for suburban high school students. I hypothesized that when the smartphone was closer to the student, the student's cognitive processing speed would be slower, or they would solve less math problems in comparison to when they had their smartphone removed from them. However, the results of this study do not support the hypothesis, since students did not solve significantly more math problems during the smartphone removed condition, in comparison to the smartphone face-down condition. Further, the analysis of the smartphone addiction scores in context of either condition showed non-significance and, therefore, did not support the hypothesis on smartphone addiction. This tells us that the students' level of smartphone addiction did not significantly impact their performance on the math exam. It can be inferred that their level of dependence on their smartphone did not affect their cognitive processing speed; rather, the cognitive performance is similar across groups.

Surprisingly, during the smartphone face-down condition, students from the classroom where no smartphones are allowed performed better than students from the classroom where smartphones are not permitted. The presence of their smartphones did not negatively affect their cognitive processing, as the hypothesis and previous research had predicted. Students in the prior studies [9, 10, 11, 12] were older, whereas the students in this study are high school students. It is possible that age had an impact on the results. Students in this study are digital natives who have had easy access to modern smartphones for their entire lives; they might not be as impacted by smartphone presence because their brains have become habituated to the distraction that previous studies [9, 10, 11, 12] have found. The participants in previous studies [9, 10, 11, 12] likely obtained their first smartphones later in life during late adolescence, rather than during childhood or early adolescence for the students in this current study.

Additionally, it is possible that the students viewed their smartphone as a sort of safety blanket. Having it with them during the smartphone face-down condition could have comforted them because they knew the exact location of their smartphone and could physically see it. During the smartphone removed condition, students may have experienced anxiety because they were wondering where their smartphone was; their personal possession had been taken, potentially creating an uneasy feeling and, therefore, affected their performance on the task. Still, this does not explain why students in the no smartphone allowed classroom performed significantly better than students in the smartphone allowed classroom *when* there was not a significant difference between conditions, without considering classrooms.

Moreover, a Type I error, or a false positive, must also be considered when trying to explain this unexpected result. The difference in course label could be attributed to this possible error; the no smartphone allowed classroom was an AP Biology class and the smartphone allowed classroom was a college-level genetics class. While both classes are doing advanced level work for high school, there still could be differences between the students in a college level class and the students in an AP course. An AP course could be more demanding because students will take a high stakes, standardized exam from the College Board in May. However, students in the college level class will still be required to take a final exam at the end of the year. Students in the AP course need to score a 3, 4, or 5 on the exam to earn college credit. In contrast, students in the college level course do not need a specific grade to obtain credit. The different demands in these two different courses attracts different types of students and therefore, this is what could have led to an artifact in the results.

Overall, the results of this study demonstrate that cognitive processing in high school students are not affected by the presence of smartphones. Moreover, there was no significant correlation between smartphone addiction and cognitive processing. These results fail to replicate the findings of [9, 10, 11, 12]. Possibilities for this result include the use of high school students rather than college students as well as task differences in measuring the dependent variable.

Limitations. One factor to consider is the difficulty level of the math exam. The questions on the exam consisted of solely two-digit by two-digit addition and were relatively simple. The sample size consisted of high school students enrolled in AP and college level classes, so it can be inferred that they have strong enough mathematical abilities to perform well on the math exams. The lack of significance between the conditions may have been due to the ease of the questions. If the exam had used algebra, geometry, or calculus questions, the exam would have been harder, and then there may have been a difference between conditions. Further, the decision to use only math questions could have had an impact on the results. For instance, one student could be weak in math, causing them to have a harder time while answering questions. It is a possibility that one of the students that did not improve on correctness because they were being tested on a subject that they are not strong in. Lastly, this study only had 89 participants. If there had been a larger sample size, the possibility of a Type I error would diminish, possibly allowing for significant findings.

Implications. The value in this study is that it established a greater understanding of how smartphone proximity impacts our cognitive processing speed, specifically for high school students. The results speak most directly to schools and the educational community. With technology's increased availability in schools, educators are struggling to decide the best course of action. Teachers are now having to choose between collecting smartphones or allowing students to keep them, as there was no significant difference between conditions. This study's results support the second solution. Taking away smartphones creates additional burden on teachers and takes away instruction time. This burden and lost time are unnecessary as the results of this study have found that there is no value in taking smartphones from students. Educators should reevaluate their classroom policies and rules on having smartphones present or out on a student's desk during class. The hysteria over smartphones may be inflated.

Future Direction. Given the mixed findings from prior research [9, 10, 11, 12] and this study, more research is needed to investigate the effects of smartphones on cognition. Future lines of work could examine manner of exam, types of exams, and edits to time constraints. Instead of giving the exams on paper, a researcher could decide to compare how a student performs taking the math exam on paper to taking the math exam on a computer or a smartphone. Moreover, a future researcher could decide to use reading passages or even science questions instead of using math questions. The choice to use math questions could have influenced the results. In addition, instead of setting a time limit, like 60 seconds, a researcher could choose to use a stopwatch and measure how long it takes each student to complete the exams while their phone is different proximity levels. Finally, factors such as screen time could also be examined to see its effect on cognition. Calculating screen time can give more insight to a student's level of dependence on their smartphone. A future researcher may decide to study screen time's correlation to cognitive processing during different levels of smartphone proximity.

CONCLUSION.

In summation, the results contradicted previous studies in the field and failed to support the research hypotheses. Smartphone addiction scores had no significant correlation with how many math problems students could solve. Therefore, the level of addiction does not have a significant effect on cognitive processing speed and the hypothesis is not supported. The second hypothesis was also not supported by the results. The findings suggest that students who habitually have their smartphones collected performed better when their smartphone was on their desk when compared to students who habitually keep their smartphones during class. It is possible the unexpected result could be due to differences in tasks. The math questions created could have been too simple for a significant difference to be found between conditions. Another possibility for this result could be a student's attachment to their device. Having their smartphone closer to them could have comforted them, causing them to perform better. Finally, and most likely, a possible explanation for this unanticipated result could be the age of the participants. This study used high school students that are all digital natives, while the previous research [9, 10, 11, 12] conducted used college students for their participants. It is essential that there be further study on this rarity of a result to confirm the result is not a Type I error. However, if it isn't a Type I error, the results suggest the alarm over the impact of smartphones on cognition is overblown.

ACKNOWLEDGMENTS.

Thank you Dr. Kommor for bringing me into W.C. Mepham's advanced science research program and embracing me as your mentee. I would have never been able to finish the program so quickly without you. Thank you to my other mentor, Dr. Park, who passed onto me so much knowledge and wisdom; thank you for teaching me SPSS and the purposes behind statistical tests, and for training me for LISEF questioning. Both of my mentors helped me become a Regeneron STS Scholar. Finally, thank you to my mom, for always being my biggest supporter. All the acknowledged individuals above helped me create a home for myself in science.

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