Original Article

Effect of smartphone location on pharmacy students' attention and working memory

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ABSTRACT

Smartphone use has become ubiquitous worldwide. Despite smartphone-related convenience, smartphone use has raised concerns regarding addiction among university undergraduates. This study aimed to examine the effect of smartphone location, such as desk, bag, and another room, on attention and working memory, based on electroencephalography parameters, in pharmacy students. We also examined associations among electroencephalography variables (theta, alpha, and beta waves), working memory, correct memory, correct operation, response time, smartphone dependency questionnaire score, grade point average, average daily phone use, Line use, Instagram use, Facebook use, Google use, Yahoo use, and music application use. Partial correlation coefficients were calculated for these variables. Thirty-six students were enrolled in the study. Smartphone location did not affect electroencephalography outcomes and working memory. Partial correlation coefficients between alpha and beta and between theta and alpha values were statistically significant when the smartphone was on the desk ($r = 0.869$, $p < 0.0001$; $r = 0.887$, $p < 0.0001$; respectively); however, the correlation coefficient between alpha and beta values was not statistically significant when the smartphone was in the bag and outside the room. Smartphone location did not affect either electroencephalography or working memory findings. Although smartphone location in the bag and outside the room seemed to influence students' concentration on the task, this effect did not affect working memory.

Keywords: Smartphone, Electroencephalography, Working memory, Smartphone locations

Introduction

Smartphone use has become ubiquitous worldwide. Many research studies have been reported regarding the smartphone [1-5]. According to the Japanese Ministry of Internal Affairs and Communications, 86.8% of households had smartphones and tablets in 2020 [6]. Meanwhile, the smartphone usage rate among high school students in Japan was 95.9% in 2017 [7]. Despite smartphone-related convenience, smartphone use has raised concerns regarding addiction among university undergraduates. Some studies have suggested a positive effect of smartphone use on learning [8, 9]. However, other studies have shown a decrease in academic performance associated with smartphone use [10-12]. Ward *et al*. have suggested that the mere presence of one's smartphone may induce a "brain drain" by occupying cognitive resources associated with attention control [13]. These authors also showed that working memory (WM) capacity may depend on phone location such as desk, pocket/bag, and another room [13]. However, Hartmann *et al*. examined the effect of smartphone location (present on the desk vs. absent from the desk) on short- and long-term (prospective) memory functions and reported inconclusive findings [14]. Although previous studies have examined these effects in independent groups, within-subject effects of smartphone location on WM remain unknown. Recently, Omary *et al*. reported on WM performance over an academic semester in pharmacy students in the United States [15]. The pharmacy students retained a high WM capacity despite increased levels of stress and fatigue. WM is associated with long-term memory [16]; thus, understanding the impact of smartphone location on WM performance in pharmacy students may help anticipate long-term outcomes.

Electroencephalography (EEG), a method of recording electrical potentials generated by neuronal activity using electrodes placed

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on the scalp, is used to examine cognitive processes such as learning, language, and perception. In general, theta waves (4–6 Hz) reflect short-term memory and are linked to WM function [17], alpha waves (7–14 Hz) reflect memory- and attention-demanding cognitive processes [18, 19], and beta waves (beta; 15–23 Hz) reflect the current sensorimotor state, which tends to remain stable [20]. Some research groups have studied the relationships between WM and EEG parameters. Pavlov *et al*. reported that WM performance is accompanied by changes in EEG in a broad frequency range from theta to higher beta bands [21]. In addition, the authors revealed a close relationship between frontal midline theta and central beta activities and the executive components of WM; however, alpha activity was not associated with individual differences [22]. Scharinger *et al*. examined relationships among WM and EEG parameters using simple and complex tasks [23]. Overall, WM and EEG parameters appear to be closely related, suggesting that an investigation into the impact of smartphone location on WM and EEG parameters in pharmacy students is valuable. This study aimed to examine the effect of smartphone location on WM, based on the EEG parameters. In contrast to previous studies by Ward *et al*. [13] and Hartmann *et al*., [14] this study used a within-subject design.

Smartphones are associated with "multitasking" during learning. Cain *et al*. reported that junior high school students with longer multitasking time have lower academic performance in math and language and poorer working memory than their counterparts [10]. Uncapher *et al*. showed that university students with a high frequency of multitasking had a higher risk of ADHD, lower working memory, and lower long-term memory retention than their counterparts [11]. Given this evidence, relationships among EEG parameters, WM, and smartphone application use may be relevant to student performance. The present study findings may help improve educational outcomes at pharmacy schools by informing smartphone use policies in the classroom as well as during independent study at home.

Materials and Methods

This study involved freshmen and sophomore pharmacy students. The primary outcomes were EEG findings during a WM task, with the smartphones placed at different locations. The secondary outcomes were correlations among EEG parameters (theta [microV], alpha [microV], beta [microV]), WM (span score), correct memory (%), correct operation (%), response time (ms), smartphone dependency questionnaire scores, average grade point average (GPA), average daily phone use (min/day), Line use (min/day), Instagram use (min/day), Facebook use (min/day), Google use (min/day), Yahoo use (min/day), and music application use (min/day). Partial correlation coefficients were calculated for these variables.

The participants underwent practice rounds using a span tester several days before the EEG measurement. EEG examinations were performed using Alphatec V™ and MinD Sensor V for Windows (Brain Function Research Center, Tokyo, Japan), which is a simple EEG measurement system. The system measured voltage differences between the sensor on the forehead and the electrode on the ear. Each participant was assigned a testing slot, and an investigator performed the EEG and span tester measurements. The EEG measuring time was 8 min; the first 1 min was a waiting phase without the task, followed by 6 min of task completion and data collection, and then 1 min of the end phase without any task. An outline of the process is shown in **(Figures 1 and 2)**.

Figure 1. Image showing the setup for electroencephalography (EEG) measurement. A participant takes a seat over the board and an investigator collects EEG data

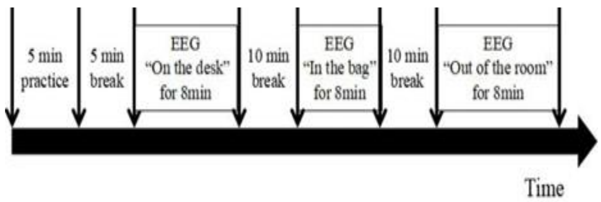

Figure 2. Time schedule of EEG measurements per participant

A computerized version of the operation span test (OSPAN) for the Japanese population was applied in the study to measure WM. Kobayashi *et al*. observed positive correlations between the OSPAN scores and other WM scores (reading span test; $r_{partial} = 0.28$, $p < 0.05$) [24].

An outline of the OSPAN procedure is presented in **(Figure 3)**. A formula is presented on the screen. If the combination of the equation and the answer is correct, the left button of the mouse is pressed. If the combination is incorrect, the right button is pressed. The formula is an addition/subtraction of three arithmetic operations. The screen changes to the next screen when the button is pressed, or the time limit expires. The reaction time and type of key pressed are recorded automatically. One of the following letters is presented on the screen: "F," "H,"

"J," "K," "L," "N," "P," "Q," "R," "S," "T," and "Y." The calculation and memory screens are presented repeatedly for a set number of times per trial. Twelve letters and a checkbox are presented. Participants click on the checkboxes in the order in which the letters appear in each trial. A number appears to the right of the letter as they click, indicating the order of the letters. If they wish to proceed without selecting a letter, they can click the "Skip" button. If they click the "Redo" button, the task can be redone. The "OK" button is clicked to confirm the answer and to proceed to the next trial. The type and order of the checked letters are recorded automatically.

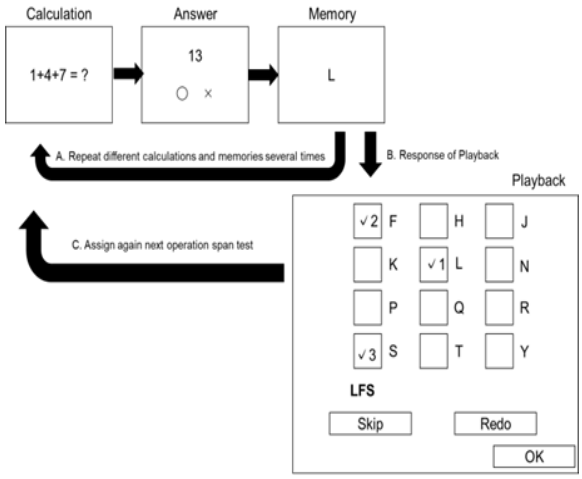

Figure 3. Outline of the operation span test

The participants were requested to record their daily use of smartphones and that of applications such as Line, Instagram, Facebook, Music, Google, and Yahoo. Android and iPhone smartphone users were instructed to install Action Dash and Screen Time, respectively, to evaluate these habits for 2 weeks during the EEG tests. Smartphone dependency questionnaire scores were obtained using the Wakayama Smartphone-Dependence Scale (WSDS) [25]. This scale was developed for the Japanese population. The WSDS consists of three dimensions; "immersion in internet communication," "using a smartphone for extended periods and neglecting social obligations and other tasks," and "using a smartphone while doing something else and neglecting etiquette." The reliability coefficient (Cronbach's alpha) values of all subscales and total WSDS scores ranged from 0.79 to 0.83 and 0.88, respectively.

This study was approved by the Ohu University ethics committee (Approval No. 331). The investigators visited freshmen and sophomore classes to provide a letter explaining the purpose of the study. Students willing to participate in the study provided written informed consent. All protocols adhered to the relevant guidelines and regulations. The work described was performed following The Code of Ethics of the World Medical Association (Declaration of Helsinki) [26].

Statistical analysis

The number of participants required for the study was calculated using G*Power software, given a partial eta squared of 0.06 with 80% power in a one-way within-subject analysis of variance (one group, alpha of 0.05, non-sphericity correction of 1). This study required 28 participants.

A univariate type III repeated-measures ANOVA assuming sphericity and Friedman rank-sum test were performed to compare three-paired data that followed parametric and non-parametric distributions, respectively. The Mann–Whitney U test was performed to compare the participants' demographic characteristics. All statistical analyses were performed using EZR, which is a graphical user interface for the programming language R [27].

Results and Discussion

The participants' characteristics are presented in **(Table 1)**. Thirty-six students were enrolled in the study. There were significant sex differences in GPA; however, there were only nine male participants, which might have introduced selection bias. Therefore, adjusted analyses such as ANCOVA, with GPA as a covariate, were not performed in the study. The other variables were not statistically different. Dependence test scores for female and male students were 21.8+/-10.3 points and 23.8+/- 10.4 points, respectively. A full dependence test score was 84 points, suggesting the participants did not present with smartphone dependence. Smartphone use durations among female and male students were 315+/-170 min/day and 424+/-244 min/day, respectively, amounting to a total of 5 to 7 hours/day. Total application use durations for female and male students were 96.2 min/day and 113.5 min /day, respectively, suggesting the participants engage with applications other than those examined in this study.

Table 1. Participant demographic and digital media use characteristics

	Female	Male	Total	Freshman vs. Sophomore; *p*	Female vs. Male; *p*
Participants	27	9	36		
Freshman	12	6	18	1.000	<0.01*
Sophomore	15	3	18		
GPA; mean (SD)	3.21 (0.61)	2.72 (0.61)	-		
Freshman	3.37 (0.46)	2.55 (0.56)	-	0.899	0.031*
Sophomore	3.09 (0.70)	3.07 (0.65)	-		
Dependence Test Score (full score 84); mean (SD)	21.8 (10.3)	23.8 (10.4)	-		

Freshman	25.0 (13.5)	26.0 (7.80)	-	0.075	0.625
Sophomore	19.3 (6.27)	19.3 (15.3)	-		
Smartphone Use (min/day); mean (SD)	315 (170)	424 (244)	-		
Freshman	262 (143)	443 (221)	-	0.568	0.305
Sophomore	355 (181)	385 (336)	-		
Line Use (min/day); mean (SD)	17.3 (14.6)	65.6 (161)	-		
Freshman	25.2 (18.5)	89.3 (198)	-	0.276	0.584
Sophomore	11.3 (7.10)	18.1 (18.4)	-		
Instagram Use (min/day); mean (SD)	14.0 (18.7)	4.68 (11.9)	-		
Freshman	18.6 (17.3)	7.03 (14.4)	-	0.066	0.068
Sophomore	10.7 (19.6)	0.00 (0.00)	-		
Facebook Use (min/day); mean (SD)	0.00 (0.00)	0.33 (1.00)	-		
Freshman	0.00 (0.00)	0.50 (1.22)	-	0.331	0.102
Sophomore	0.00 (0.00)	0.00 (0.00)	-		
Google Use (min/day); mean (SD)	39.2 (36.8)	24.7 (48.1)	-		
Freshman	24.5 (22.1)	28.5 (58.1)	-	0.101	0.082
Sophomore	50.0 (42.1)	17.0 (26.1)	-		
Yahoo Use (min/day); mean (SD)	5.51 (15.3)	3.56 (8.95)	-		
Freshman	0.47 (1.09)	4.50 (11.0)	-	0.255	0.844
Sophomore	9.20 (19.5)	1.67 (2.89)	-		
Music Application Use (min/day); mean (SD)	20.2 (48.4)	14.6 (21.3)	-		
Freshman	32.8 (66.2)	7.33 (12.8)	-	0.614	0.893
Sophomore	10.9 (28.9)	29.0 (30.6)	-		

GPA, grade point average; SD, standard deviation.
*$p < 0.05$ (Mann–Whitney U test)

(Table 2) presents the primary outcomes. As the data for alpha waves and theta waves were parametric and those for beta waves were non-parametric, univariate type III repeated-measures ANOVA assuming sphericity was utilized for alpha waves and theta waves and the Friedman rank-sum test was used for beta waves. Smartphone location did not affect any outcomes. As data for span scores and response time were non-parametric, univariate type III repeated-measures ANOVA assuming sphericity was used. Smartphone location affected span scores (p = 0.025); however, post-hoc Bonferroni analysis revealed no significant differences in outcomes among smartphone locations (on the desk vs. in the bag, p = 0.052; in the bag vs. outside the room, p = 0.930; on the desk vs. outside the room, p = 0.275).

Table 2. EEG and span score findings during a working memory task obtained with smartphones placed at different locations

	On the Desk	In the Bag	Outside the Room	*p*
Alpha (μV): (n = 36)				
Median	5.71	5.76	5.68	NA
Mean (SD)	5.86 (1.89)	6.03 (1.51)	6.03 (1.76)	0.788**
Beta (μV): (n = 36)				
Median	3.30	3.19	3.25	0.423*
Mean (SD)	3.80 (1.90)	3.72 (2.00)	3.71 (1.80)	NA
Theta (μV): (n = 36)				
Median	10.1	11.5	10.1	NA
Mean (SD)	9.82 (3.96)	10.5 (3.43)	10.7 (4.11)	0.241**
Span score				
Median	5.0	5.5	5.3	0.025*
Mean (SD)	4.90 (1.07)	5.31 (0.98)	5.15 (0.95)	NA
Response time (ms)				
Median	2,801	2,685	2,713	0.062*
Mean (SD)	2,810 (330)	2,789 (400)	2,728 (348)	NA

* Friedman rank-sum test.
**Univariate Type III Repeated-Measures ANOVA Assuming Sphericity
SD: Standard deviation
NA: Not applicable

(Table 3) presents the secondary outcomes and corresponding partial correlation coefficients. When smartphones were placed on the desk, significant correlations were as follows: alpha waves vs. beta waves and theta waves vs. alpha waves. When smartphones were in a bag and outside the room, theta waves vs. alpha waves remained significantly correlated, but alpha waves vs. beta waves did not. In contrast, the other parameters did not correlate with any parameters on the desk, in a bag, and outside the room.

Table 3. Partial correlations among EEG variables, working memory (span score), correct memory, correct operation, response time, smartphone dependency questionnaire scores, average grade point, average daily phone use, Line Use, Instagram use, Facebook use, Google use, Yahoo use, and Music application use

Partial Correlation	r	p
On the Desk		
Alpha vs. Beta	0.869	< 0.0001
Theta vs. Alpha	0.887	< 0.0001
In the Bag		
Theta vs. Alpha	0.860	< 0.0001
Outside the Room		
Theta vs. Alpha	0.860	< 0.0001

In this study, we investigated the effect of smartphone location on WM, based on the EEG parameters. Smartphone locations did not affect EEG (theta, alpha, and beta) and WM parameters. Smartphones located in the bag and outside the room influenced students' concentration on the task, but this effect did not seem to affect WM. Thus, this study partially supported the findings of Hartmann *et al*., who showed no evidence of cognitive costs due to smartphone presence in a short-term memory task [9].

Herein, we observed partial correlations among the EEG parameters examined under different smartphone location conditions. When a smartphone was placed on a desk, partial correlations between alpha and beta and between theta and alpha values were observed; however, correlations with beta disappeared when the smartphone was placed in a bag or outside the room. The theta band has been linked to WM [28, 29] and alpha-band oscillations have been related to WM function and short-term memory retention [30]. In contrast, a previous study reported that the beta band may signal the tendency of the sensorimotor system to maintain the status quo [20]. Herein, the participants' brain functions presented with the evidence of short-term memory, attention, and the sensorimotor system maintenance (theta waves vs. alpha waves vs. beta waves) when a smartphone was located on the desk. When a smartphone was located in a bag or outside the room, the participants' brain functions were not maintained on the task and the sensorimotor state was altered. We speculate that the farther the location of the smartphone, the more difficult it was for the students to concentrate and perform tasks demanding short-term memory such as simple calculations. As smartphone-dependency questionnaire scores did not correlate with any parameters, it remains unclear whether smartphone addiction interferes with task performance.

Nishida *et al*. proposed that adolescent female students spend a significant amount of time on online activities, including chatting, social networking, and browsing, which increases the risk of depression. Meanwhile, adolescent male students spend more hours playing games than female students, but their smartphone use is not associated with depression [31]. In the current study, smartphone use durations for female and male students were 315+/-170 min/day and 424+/- 244 min/day, respectively, amounting to a total of approximately 5 to 7 hours/day. The mean total application use durations for female and male students were 96.2 min/day and 113.5 min /day (sum total of the average time spent using the applications of interest), suggesting the participants used primarily applications other than those of interest in this study; these applications were likely Twitter, for social networking, and YouTube, for entertainment, alongside dedicated game applications. Burleigh *et al*. reported that individuals with a gaming disorder have increased delta and theta activity and reduced beta activity [32]. Overall, this evidence suggests that extended use of social networking sites and game playing may have reduced beta wave activity when the smartphone was located away from the individuals. Nonetheless, smartphone locations may affect students' brain function.

In this study, smartphone application use was not associated with GPA. Sakurai *et al*. reported that Line was the most frequently used application among adults aged 18–39 years in Japan, followed by Twitter [33]. As Line usage was relatively low in this study, the associated "multitasking" did not affect learning outcomes.

This study had some limitations. First, the measurement time was short (6 min). Smartphone location may not affect short-term memory performance, suggesting that studying with a smartphone in hand may not be detrimental. However, further studies are required to elucidate the effect of smartphone location on long-term performance. Second, in this study, we used a simple EEG measurement system; therefore, the observed values may be imprecise, making it difficult to detect any significant differences. Further studies are required to validate these findings. Finally, all measurements were performed in the same order of smartphone placement conditions—desk, bag, and outside the room. The participants may have become habituated to this design; future studies should change the order of conditions. Further studies should also involve tasks such as quizzes after a long lecture, given each smartphone location, to elucidate these relationships.

Conclusion

Previous studies using independent groups reported that the WM capacity may be affected by smartphone location such as desk, pocket/bag, and another room. This study examined these associations using a within-subject study design. In this study, we investigated the effect of smartphone location on WM measured with EEG parameters (theta, alpha, and beta). The amount of time spent on application use, smartphone dependency questionnaire scores, and GPA were examined. In conclusion, this study did not show any association between smartphone locations, EEG parameters, and WM. Smartphones located in the bag and outside the room seemed to decrease students' concentration on the task (loss of association between alpha vs. beta waves) but this effect did not affect WM. These findings may help design classroom and independent study smartphone use recommendations.

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