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RESEARCH ARTICLE

The Effect of Smartphone Environments on the Encoding of Life Science Terminology: A sLORETA Study

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ABSTRACT

The purpose of this study was to analyze the effect of smartphone environments on life science terminology learning, focusing on EEG activation changes. To this end, the task performance environment was divided into three conditions: a smartphone-free environment, a smartphone-present environment, and a smartphone-notification environment. Twenty-five second-grade high school students participated in the study. EEG data were collected during life science terminology encoding tasks in each environment, and sLORETA analysis analyzed EEG activation differences. The results were as follows: First, students achieved significantly higher scores when performing rote encoding tasks in a smartphone-free environment than in a smartphone-present environment. Second, no significant EEG activation differences were found during meaningful encoding tasks across the three smartphone environments. Third, during rote encoding tasks in a smartphone-present environment, the beta band activation in the right hippocampal gyrus of the limbic lobe was significantly greater than in a smartphone-free environment. Additionally, when performing rote encoding tasks in a smartphone-notification environment, the beta band activation was significantly greater in several regions of the right frontal lobe(the superior frontal gyrus, the middle frontal gyrus, the medial frontal gyrus, and the inferior frontal gyrus), and the insula of the right sub-lobar than in a smartphone-free environment. These results suggest that the physical presence and notifications of smartphones increase cognitive load, affecting attention and memory processes critical for learning life science terminology. Furthermore, these findings emphasize the importance of managing smartphones in creating an efficient learning environment.

Key words : Smartphone, life science terminology encoding, EEG activation, sLORETA, cognitive function

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Introduction

As of 2023, approximately 93.4% of South Koreans own smartphones, which shows that smartphones have become essential in daily life (Korea Communications Commission, 2023).

Notably, 99.6% of teenagers were found to own smartphones (Korea Communications Commission, 2023). Teenagers use smartphones for various purposes such as learning, communication, and leisure activities (Choi & Chung, 2023). Additionally, 95.5% of teenagers identified smartphones as the most necessary medium in their daily lives (Korea Communications Commission, 2023). This shows that smartphones are not just devices for teenagers—the digital generation—but are also perceived as an important medium connecting their lives and society (Sung & Jin, 2012).

While adolescents utilize smartphones in various areas, excessive use can lead to numerous adverse effects, with smartphone overdependence being a prominent issue. According to a 2022 report by the Ministry of Science and ICT, 40.1% of adolescents were categorized as being at risk of smartphone overdependence (Ministry of Science and ICT, 2022). Adolescents are reported to be more likely than adults to experience mental health issues caused by smartphone overdependence due to their higher impulsivity and weaker self-regulation abilities (Park, 2023).

Adolescence is a critical period characterized by significant physical, emotional, and social changes, during which individuals transition into adulthood (Moon et al., 2019). Habits formed during this period are likely to persist into adulthood (Moon et al., 2019). Furthermore, research highlights the negative impact of smartphone overdependence on adolescents. Moon et al. (2019) reported that smartphone over-reliance negatively affects adolescents' physical, emotional, and social aspects as well as their academic achievement levels. Similarly, Lee and Oh (2022) reported that smartphone overdependence impairs attention, increases impulsivity, and negatively influences academic adjustment and achievement. Kim (2018) also observed that high school students' reliance on smartphones contributes to cognitive failures and academic stress. Additionally, Ward et al. (2017) revealed that the mere physical presence of a smartphone can increase cognitive load, divert attention, and negatively impact learning and memory. Conversely, some studies present conflicting findings regarding the impact of smartphone use on cognitive functions. On the other hand, Al-Amri et al. (2023) found that repeated use of smartphones can improve sensory-motor coordination and shorten reaction times in middle school students. This study shows that smartphone use does not always have a negative impact on learners.

The studies reviewed above reported that excessive smartphone use affects students in terminology of cognitive or emotional aspects. However, since there are both positive and negative views on its impact, it is necessary to understand the relationship between smartphones and students' academic achievement levels and cognitive functions more objectively.

Meanwhile, previous studies primarily analyzed the correlation between smartphone exposure and academic achievement, through methods commonly utilized in cognitive psychology research, such as surveys and behavioral observations. However, these methods indirectly infer cognitive changes based on behavioral changes, which limits their ability to explain the neural activity that influences cognitive thinking (Jeong & Kim, 2022). Since human behavior and cognitive changes are driven by changes in brain neural activation, it is more valid to analyze and identify changes in brain activation that occur during the performance of specific cognitive tasks (Jeong & Kim, 2022). This neuroscientific approach can provide a more direct and objective understanding of human cognitive processes (Jeong & Kim, 2022).

Therefore, the purpose of this study was to examined the effects of the smartphone environments on the encoding of life science terminology in high school students from the perspective of EEG activation changes. In addition, based on the analysis results, it was intended to provide evidence-based data to help students devise a plan to manage smartphones for the purpose of creating an effective learning environment.

Materials and Methods

Participants

This study involved 25 second-year high school students. All participants were mentally and physically healthy, and they had obtained consent from both themselves and their parents to participate in the study. All of the study participants were male students, with an average age of 16.96 (SD=0.64) years.

Before the EEG measurement, the purpose of the study, the procedure, and precautions during EEG measurement were thoroughly explained. Sufficient practice opportunities were provided to help participants familiarize themselves with the EEG measurement tasks. EEG measurement was conducted while students performed the life science terminology encoding task, and the task performance level was evaluated through a response paper written by recalling the terminology encoded by the students. Since artificial noise was generated in the EEG measurement process and used as analysis data, EEG data of 19 people were used for analysis after excluding 6 EEG data judged to be inappropriate. EEG data were collected through research conducted after IRB approval by the Bioethics Committee of D University. In addition, the data collected in accordance with the IRB regulations were managed by assigning an unidentifiable code number arranged in letters and numbers to protect personal information.

Procedure

The purpose of this study is to analyze the impact of smartphones on students' life science terminology encoding tasks in terminology of changes in electroencephalography(EEG) activation. To achieve this objective, the study was conducted in the order of EEG measurement task development and modification, EEG pre-training, EEG measurement, sLORETA analysis, and deriving implications & conclusions.

EEG Measurements Tasks

The EEG measurement task was developed by dividing it into the criteria task and life science terminology encoding task. First, the criteria task is designed to measure baseline EEG data for identifying changes in EEG activation. According to preceding studies of EEG, individual EEG activation differences may occur depending on individual cognitive abilities and environmental experiences, so it is necessary to set a reference point to correct individual differences in EEG activation to compare differences in EEG activation accurately (López et al., 2023; Popov et al., 2023). EEG data collected with opened eyes and a stable state has been verified as reliable for standardizing individual differences and accurately comparing changes in EEG activation during task performance (López et al., 2023; Popov et al., 2023). Accordingly, the criteria task consists of activity where participants open their eyes and focus on a '+' mark, which is cognitively neutral, while maintaining a stable state. An example of the criteria task is shown in Fig. 1.

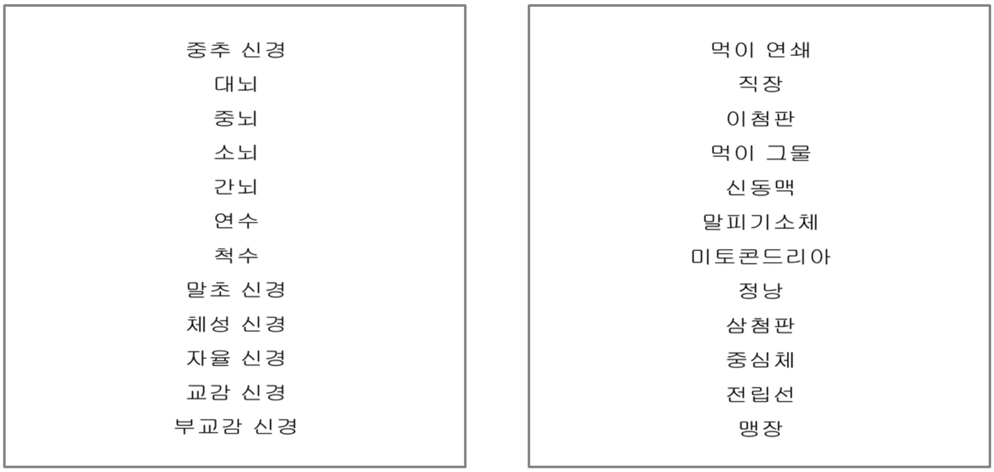
화면에 제시되는
+ 표시를
편안한 자세로
바라보고 있으시면 됩니다.

<Guidance for the start of the criteria task activity>

<The criteria task>

Fig. 1. Example of the criteria task

The life science terminology encoding task is divided into meaningful encoding tasks and rote encoding tasks, with examples of each shown in Fig. 2.



중추 신경
대뇌
중뇌
소뇌
간뇌
연수
척수
말초 신경
체성 신경
자율 신경
교감 신경
부교감 신경

<The meaningful encoding task>

먹이 연쇄
직장
이첨판
먹이 그물
신동맥
말피기소체
미토콘드리아
정낭
삼첨판
중심체
전립선
맹장

<The rote encoding task>

Fig. 2. Example of the meaningful encoding task and rote encoding task

The meaningful encoding task involved encoding 12 items of life science terminology with high semantic relevance, such as 'cerebrum,' 'peripheral nerve,' and 'sympathetic nerve,' all of which belong to the nervous system. In contrast, the rote encoding task involved encoding 12 items of life science terminology with low semantic relevance, representing distinct domains of life science, such as 'food web' (ecology), 'centriole' (genetics), and 'Malpighian corpuscle' (physiology), which reflect various domains of biologys.

To develop these encoding tasks, the researcher first extracted 96 items of life science terminology from the curriculum of Life Science I in the 2015 Revised National Curriculum and created eight meaningful encoding tasks. A panel of experts, including specialists in life science education, EEG research, and field practitioners, rigorously reviewed and validated these tasks to ensure their accuracy and relevance. Based on their evaluation, six tasks were selected for EEG measurement, while the remaining two were designated as practice tasks. The six rote encoding tasks were created by randomly selecting terminology items from the meaningful encoding tasks and reorganizing them to minimize semantic relevance while maintaining consistency in structure. These tasks were also subjected to expert review and validation.

Participants performed two meaningful encoding tasks and two rote encoding tasks under each of three conditions: a smartphone-free environment, a smartphone-present environment, and a smartphone- notification environment. Initially, the experimental design intended to present the three environmental conditions and task types in the same order for all participants. However, prior research highlighted concerns that presenting similar task patterns in the same sequence might influence task performance (Jeong & Kim, 2022). To address these concerns and ensure unbiased results, the sequence of tasks and environmental conditions was systematically randomized for each participant.

The tasks followed a structured sequence. First, baseline EEG was recorded in a relaxed state, with participants' eyes closed and then with eyes open. Next, participants completed meaningful encoding and rote encoding tasks in the smartphone-free environment, followed by the smartphone-present environment, and finally in the smartphone-notification environment. After completing each task, participants recalled the encoded terminology items and recorded their responses on an answer sheet. These responses were later used to evaluate task performance. To mitigate cognitive and physical fatigue, participants were provided a 30-second rest period following each task.

EEG measurement was conducted in a quiet science laboratory for approximately 20 minutes and 30 seconds. First, baseline EEG was measured once for 60 seconds with eyes closed and once for 60 seconds with eyes open. Subsequently, participants performed the meaningful encoding task and the rote encoding task in a smartphone-free environment, a smartphone-present environment, and a smartphone-notification environment. Each meaningful encoding task and rote encoding task lasted 30 seconds. After each task, participants had a 30-second recall period, followed by a 30-second rest period. Each task in each environment was repeated twice.

EEG Measurements and Analysis

In this study, the equipment used for EEG measurement was the E-series EEG system developed by Compumedics in Australia (Compumedics, 2002). EEG data collection was carried out using the Profusion EEG software developed by the same company (Compumedics, 2002). The EEG measurements were conducted in a quiet high school science laboratory to minimize external interference. EEG measurement was conducted in a quiet high school science room to minimize external interference. The measurement system was configured with a sampling frequency of 512 Hz, a high-pass filter of 1 Hz, a low-pass filter of 70 Hz, and a notch filter of 60 Hz. Thirty electrodes were attached to the scalps of the study participants using Compumedics' 32-channel Quik-Cap, in which multiple electrodes were arranged according to the provisions of the 10-10 International Electrode Placement Standard (Compumedics, 2002). (Compumedics, 2002).

Additionally, two reference electrodes were attached to the outer ears, and two reference electrodes were placed below the eyes, above the cheeks, to detect artificial noise such as eye blinking. The reference electrodes on the outer ears were used to correct hemispheric deviation values of the brain, while those below the eyes were utilized to detect artificial noise, including eye blinks.

Current Source Density (CSD) analysis was performed in this study to identify EEG activation, using the standardized Low Resolution Brain Electromagnetic Tomography (sLORETA) analysis method. sLORETA divides the brain into 6,239 voxels (5x5x5 mm) based on the standardized MNI (Montreal Neurological Institute) coordinate system and calculates current density values for each voxel (Kwon, 2024). Since this study analyzed time-series EEG data, only log transformation was applied to the average voxel data for each task, without additional smoothing, allowing estimation in a linear function form. Comparisons between tasks were made using paired t-tests. When performing the paired t-test, the probability threshold values for the maximum activated t-values were calculated by randomly comparing current density voxel data from each condition 5,000 times. This nonparametric analysis (Statistical NonParametric Mapping; SnPM) method minimizes errors caused by repeated measurements (Kwon, 2024). The frequency bands analyzed in this study were theta waves (3.0–7.9 Hz), alpha waves (8.0–12.9 Hz), beta waves (13.0–29.9 Hz), and gamma waves (30.0–50.0 Hz).

For comparative analysis of changes in EEG activation that occurred when performing meaningful encoding tasks or rote encoding tasks in the environment under a smartphone-free environment, a smartphone-present environment, and a smartphone-notification environment, respectively, sLORETA analysis was performed. This allowed us to explore the impact of the three conditions on the cognitive processes performed to solve life science term encoding tasks from a neuroscience perspective.

Results

Life Science Terminology Learning Performance Analysis

The scores of the meaningful encoding and rote encoding tasks performed by the study participants in the smartphone-free environment, smartphone-present environment, and smartphone-notification environment are presented in Fig. 3.

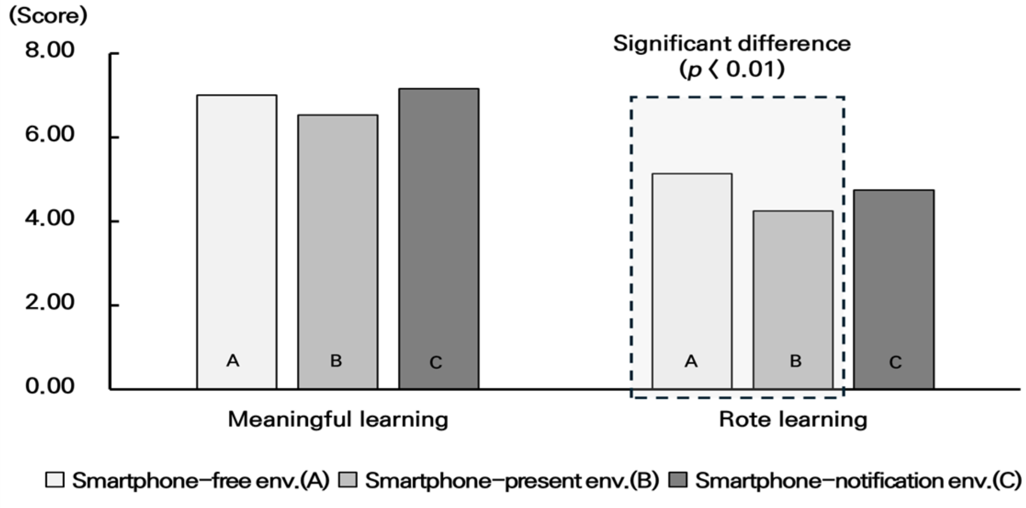


Fig. 3. EEG task behavioral result

For the meaningful encoding task, the study participants scored 7.00 points in the smartphone-free environment, 6.53 points in the smartphone-present environment, and 7.16 points in the smartphone-notification environment. However, the difference in scores recorded under the three environmental conditions was not found to be statistically significant. On the other hand, for the rote encoding task, the study participants scored 5.13 points in the smartphone-free environment, 4.24 points in the smartphone-present environment, and 4.74 points in the smartphone-notification environment. Only the difference in scores between the smartphone-free environment and the smartphone-present environment among the three conditions was statistically significant ($p < 0.01^{**}$).

EEG Activation in Meaningful Encoding Task across Smartphone Environments

Comparison between Smartphone-free and Smartphone-present Environments

No statistically significant difference was observed in EEG current density activation during the performance of the meaningful encoding task between the smartphone-free environment and the smartphone-present environment (Table 1).

Table 1. Current density differences during meaningful encoding in smartphone-Free vs. Smartphone-Present Environments

Division	Log of F ratio of spectral densities			ExtremeP
	0.01	0.05	0.10	
One-Tailed (A>B)	4.261	3.777	3.486	0.56720
One-Tailed (A<B)	-4.302	-3.744	-3.512	0.09360
Two-Tailed (A<>B)	4.459	3.989	3.753	0.17960

Comparison between Smartphone-free and Smartphone-notification Environments

No statistically significant difference was found in EEG current density activation during the performance of the meaningful encoding task between the smartphone-free environment and the smartphone- notification environment (Table 2).

Table 2. Current density differences during meaningful encoding in smartphone-free vs. smartphone-notification environments

Division	Log of F ratio of spectral densities			ExtremeP
	0.01	0.05	0.10	
One-Tailed (A>B)	3.937	3.443	3.184	0.80500
One-Tailed (A<B)	-3.947	-3.444	-3.187	0.05340
Two-Tailed (A<>B)	4.136	3.688	3.442	0.10480

Comparison between Smartphone-present and Smartphone-notification Environments

There was no statistically significant difference in EEG current density activation during the performance of the meaningful encoding task between the smartphone-present environment and the smartphone-notification environment (Table 3).

Table 3. Current density differences during meaningful encoding in smartphone-present vs. smartphone-notification environments

Division	Log of F ratio of spectral densities			ExtremeP
	0.01	0.05	0.10	
One-Tailed (A>B)	4.018	3.535	3.286	0.80600
One-Tailed (A<B)	-4.045	-3.549	-3.292	0.35060
Two-Tailed (A<>B)	4.313	3.741	3.545	0.64660

EEG Activation in Rote Encoding Task across Smartphone Environments

Comparison between Smartphone-free and Smartphone-present Environments

There was a statistically significant result in the EEG current density activation observed during the performance of the rote encoding task in different learning environments with different smartphone presence (Table 4).

Table 4. Current density differences during rote encoding in smartphone-free vs. smartphone- present environments (current density, one-tailed t-test, p=0.03780)

Division	Log of F ratio of spectral densities			ExtremeP
	0.01	0.05	0.10	
One-Tailed (A>B)	4.300	3.716	3.441	0.64560
One-Tailed (A<B)	-4.276	-3.700	-3.438	0.03780
Two-Tailed (A<>B)	4.536	3.947	3.706	0.07600

Table 5 and Fig. 4 show that beta wave activation in the right parahippocampal gyrus (BA 30) was greater during rote encoding in the smartphone-present environment compared to the smartphone-free environment.

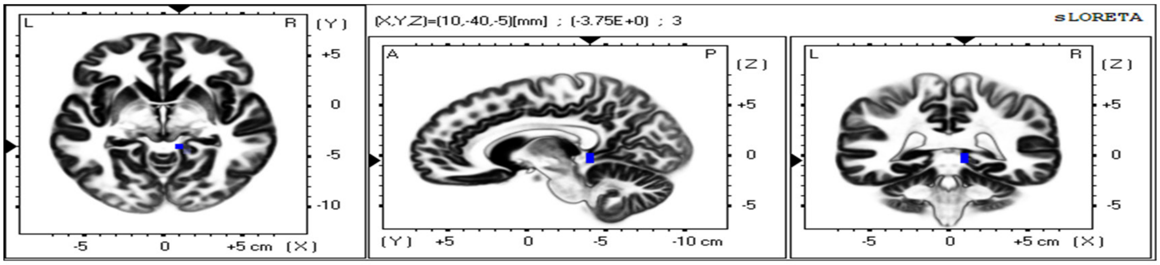


Fig. 4. Brain regions with current density differences during rote encoding in smartphone-free and smartphone-present environments (Beta band, blue voxel: negative activation)

Table 5. Brain activation region differences between smartphone-free vs. smartphone-present environments (beta band, *p*<.05)

Lobe	Region	BA	Cerebral Hemisphere	MNI Coordinate value			Voxel value
				X	Y	Z	
Limbic Lobe	Parahippocampal Gyrus	30	Right	10	-40	-5	-3.7549

Comparison between Smartphone-free and Smartphone-notification Environments

The difference in EEG current density when performing the rote encoding task in the smartphone-free environment and the smartphone-notification environment was statistically significant (Table 6).

Table 6. Current density differences during rote encoding in smartphone-free vs. smartphone-notification environments (current density, two-tailed t-test, p=0.02180)

Division	Log of F ratio of spectral densities			ExtremeP
	0.01	0.05	0.10	
One-Tailed (A>B)	4.030	3.423	3.128	0.81560
One-Tailed (A<B)	-4.011	-3.477	-3.183	0.01040
Two-Tailed (A<>B)	4.298	3.712	3.448	0.02180

According to Table 7 and Fig. 5, beta wave activation during the rote encoding task was significantly higher in the smartphone-notification environment compared to the smartphone-free environment. Increased activation was observed in the right medial frontal gyrus (BA 6, 9, 8), middle frontal gyrus (BA 10, 11, 46), superior frontal gyrus (BA 9, 10), inferior frontal gyrus (BA 10, 46, 47), and insula (BA 10).

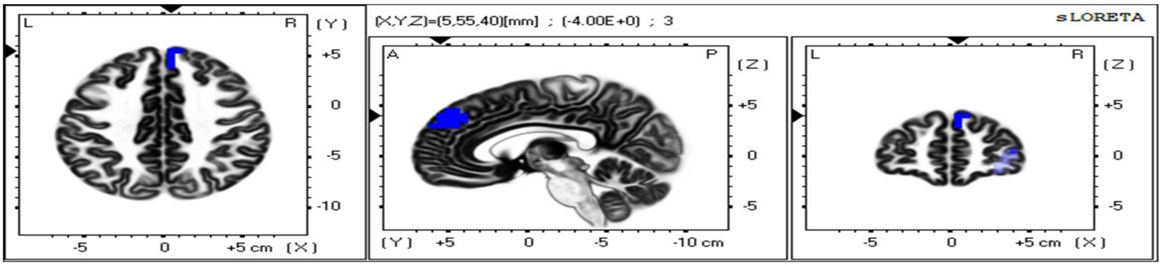


Fig. 5. Brain regions with current density differences during rote encoding in smartphone- present and smartphone-notification environments*(Beta band, blue voxel: negative activation)*

Table 7. Brain activation region differences between smartphone-free vs. smartphone-notification environments(Beta band, p<.05)

Lobe	Region	BA	Cerebral Hemisphere	MNI Coordinate value			Voxel value
				X	Y	Z	
Frontal Lobe	Medial Frontal Gyrus	9	Right	5	55	40	-4.0031
	Medial Frontal Gyrus	6	Right	5	45	40	-3.7561
	Medial Frontal Gyrus	8	Right	5	50	45	-3.7047
	Middle Frontal Gyrus	46	Right	45	35	20	-3.7892
	Middle Frontal Gyrus	10	Right	40	40	15	-3.6039
	Middle Frontal Gyrus	11	Right	30	40	-5	-3.5071
	Superior Frontal Gyrus	9	Right	5	55	35	-3.9487
	Superior Frontal Gyrus	10	Right	5	60	30	-3.5075
	Inferior Frontal Gyrus	46	Right	40	35	15	-3.6655
	Inferior Frontal Gyrus	47	Right	25	30	-5	-3.5018
	Inferior Frontal Gyrus	10	Right	40	50	5	-3.4894
Sub-lobar	Insula	13	Right	30	25	5	-3.4778

Comparison between Smartphone-present and Smartphone-notification Environments

EEG current density differences between the smartphone-notification and smartphone-free environments during rote encoding were not statistically significant (Table 8).

Table 8. Current density differences during rote encoding in smartphone-present vs. smartphone-notification environments

Division	Log of F ratio of spectral densities			ExtremeP
	0.01	0.05	0.10	
One-Tailed (A>B)	3.992	3.404	3.096	0.64300
One-Tailed (A<B)	-3.973	-3.390	-3.111	0.83780
Two-Tailed (A<>B)	4.196	3.654	3.396	0.96460

Discussions

The primary objective of this study was to compare EEG activation patterns observed when high school students performed life science terminology encoding tasks under three conditions: a smartphone-free environment, a smartphone-present environment, and a smartphone-notification environment. The key findings and discussions based on the study results are summarized as follows.

First, no statistically significant differences were found in task performance scores for meaningful encoding tasks across the three conditions. Meaningful learning involves high-level cognitive processes, such as integrative encoding, where newly learned information is incorporated into existing cognitive structures (Zhou & Wu, 2024). This process relies on internal thinking and self-directed information processing, which reduces the cognitive burden on working memory (Brady & Störmer, 2022; Zhou & Wu, 2024). The findings suggest that meaningful learning, driven by internal cognitive mechanisms, is relatively unaffected by external factors like the physical presence of smartphones or their notifications. This result highlights the robust nature of meaningful learning, which is resilient to environmental distractions.

In contrast, the performance scores for rote encoding tasks were significantly higher in the smartphone-free environment compared to the smartphone-present environment ($p < 0.01$). Rote learning, characterized by repetitive memorization of external cues, requires lower levels of cognitive processing (Sweller et al., 1998). Learners process external information as discrete units, repeating and storing it in memory without integrating it into existing cognitive structures. Consequently, rote encoding tasks impose a greater cognitive load on attention and working memory, making them more vulnerable to external distractions (Sweller et al., 1998). The significant decline in task performance in the smartphone-present environment indicates that the physical presence of smartphones disrupts attention and depletes cognitive resources required for working memory.

Second, EEG analysis revealed no significant differences in brain activation patterns during meaningful encoding tasks across the three conditions. This underscores the inherent demand for internal cognitive resources in meaningful learning, which depends on advanced, self-directed processes such as the integration of new and existing knowledge. Unlike rote encoding, meaningful learning is relatively resistant to external environmental distractions due to its reliance on deeper cognitive engagement.

Third, significant beta band activation was observed in the right parahippocampal gyrus (Brodmann area 30) within the limbic lobe during rote encoding tasks in the smartphone-present environment compared to the smartphone-free environment. The parahippocampal gyrus plays a critical role in integrating visual stimuli and spatial context, systematically organizing this information, and transferring it into long-term memory (Sulpizio et al., 2013). The increased beta band activation suggests that the physical presence of a smartphone imposed additional cognitive demands, requiring learners to allocate greater effort for visual information processing and memory integration. Even without direct visual attention to the smartphone, the brain appeared to treat its physical presence as contextual information, incorporating it into memory formation.

In the smartphone-notification environment, significantly higher beta band activation was observed in the right frontal lobe, including the medial frontal gyrus, middle frontal gyrus, superior frontal gyrus, and inferior frontal gyrus, as well as the insula in the sub-lobar region. In the medial frontal gyrus (Brodmann areas 6, 8, and 9), this increased activation reflects heightened cognitive effort for maintaining working memory, processing linguistic information repetitively, and selectively focusing on critical details (Desmond et al., 1998; Hanakawa et al., 2002; Voytek & Knight, 2010). Similarly, beta band activation in the middle frontal gyrus (Brodmann areas 10, 11, and 46) indicates increased effort to manage attention, switch between internal and external focus, and implement goal-directed learning strategies (Japee et al., 2015; Miller & Cohen, 2001). The superior and inferior frontal gyri exhibited activation patterns associated with organizing semantic relationships, prioritizing information, and structuring it sequentially for encoding (Liakakis et al., 2011; Rajkowska & Goldman-Rakic, 1995).

Additionally, beta band activation in the insula (Brodmann area 13) was significantly higher in the smartphone-notification environment. The insula is linked to self-awareness, emotional regulation, and metacognitive functions, suggesting that learners exerted greater effort to monitor their cognitive states and manage stress effectively during task performance (Denny et al., 2012).

In conclusion, the physical presence of smartphones increases cognitive burdens during rote encoding tasks by disrupting attention and overloading working memory. Smartphone notifications further amplify cognitive load, causing heightened activation in multiple brain regions. These results indicate that smartphones, especially their notifications, serve as major external stimuli that distract attention, consume cognitive resources, and reduce learning efficiency. Minimizing smartphone-related distractions in educational environments is essential for fostering more effective learning conditions.

Conclusions and Implications

In this study, we compared EEG activation patterns observed during meaningful encoding tasks or rote encoding tasks performed in three conditions: smartphone-free environment, smartphone-present environment, and smartphone-notification environment. We further analyzed the impact of smartphones on learning life science terms. The findings and conclusions of the study are as follows.

First, in the case of the meaningful encoding task, no significant differences in task performance scores were observed across conditions, regardless of the physical presence of a smartphone or the presence of notifications. This suggests that learners may be relatively less affected by the cognitive load induced by external stimuli, such as the physical presence of smartphones or notifications, during the meaningful encoding task. Moreover, meaningful learning emphasizes high-level internal cognitive processes, focusing on systematically integrating newly learned information into the cognitive structures that compose existing knowledge. Additionally, the EEG activation patterns observed during meaningful encoding tasks across different conditions revealed no significant differences, further demonstrating that meaningful learning is less affected by external stimuli and supports internal thinking and integrative information processing as a type of learning.

Second, task performance scores for rote encoding tasks in a smartphone-free environment were significantly higher than in a smartphone-present environment. This suggests that the physical presence of smartphones acts as a factor that distracts attention and increases cognitive load when performing rote encoding tasks involving the simple repetition and encoding of external visual text information. Notably, during rote encoding tasks in a smartphone-present environment compared to a smartphone-free environment, beta band activation was relatively higher in the right Parahippocampal Gyrus. This finding indicates that the physical presence of a smartphone likely required additional cognitive resources to integrate visual information and spatial context into long-term memory. Even when smartphones were not visually perceived, the brain appeared to recognize their physical presence as contextual information within the learning environment, attempting to include them in memory formation and information integration processes.

In the smartphone-notification environment, higher beta band activation was observed in the medial frontal gyrus, middle frontal gyrus, superior frontal gyrus, and inferior frontal gyrus in the right frontal lobe, as well as in the insula in the right limbic lobe, compared to the smartphone-free environment. This finding suggests that external stimuli, such as smartphone notification sounds, disrupted learners' attention and consumed cognitive resources. The increased beta band activation in the frontal lobe and insula further indicates that learners required additional cognitive effort to suppress external stimuli and maintain their learning goals. These results provide empirical evidence that the physical presence of smartphones and notifications disrupt attention and increase cognitive resource consumption during learning.

Third, significant EEG activation differences observed when performing rote encoding tasks across the three conditions were found only in the beta band. This reflects the characteristic of the beta band, where activation increases with higher levels of cognitive load and focus (Schmidt et al., 2019). In particular, the beta band activation observed in the right frontal lobe in the smartphone-notification environment compared to the smartphone-free environment supports previous findings that activation in this region is associated with contextual monitoring, successful memory encoding, and visual working memory operations (Gourtney et al., 1997; Henson et al., 1999).

Based on these conclusions, the educational implications and recommendations are as follows:

Firstly, in rote encoding processes that involve simple repetition, sustained attention to key information and maintenance of working memory are critical. However, the physical presence of smartphones and environmental factors like notifications can lead to attentional distraction and cognitive load. Therefore, excluding smartphones from the learning environment can reduce unnecessary stimuli and help learners focus solely on essential information, thereby enhancing their learning efficiency.

Secondly, the influence of smartphones can vary depending on the type of learning task. Thus, it is necessary to flexibly implement smartphone usage restriction policies based on the nature of the task. For instance, restricting smartphone usage during repetitive memorization tasks can prevent distraction, whereas allowing smartphone access during tasks requiring high-level understanding and analysis may facilitate access to diverse information resources and support learning effectively.

Thirdly, future research should examine the impact of various external stimuli beyond smartphones on learners' attention and cognitive resource utilization. By doing so, researchers can develop optimal learning strategies tailored to diverse learning environments and task types, ultimately maximizing learning efficiency. Such research could provide evidence-based strategies to design learning environments that support learners' attention and improve academic achievement.

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