Correlation Analysis of Learning Environment Factors and Concentration: An Integrated Study of Physiological, Cognitive, and Subjective Responses

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ABSTRACT

This study investigates how physical environmental factors in school study spaces-illuminance, noise level, and spatial openness-affect students' concentration and cognitive performance. Grounded in environmental psychology, the research adopts a multi-layered approach consisting of three components: a subjective perception survey, physiological measurement using Electroencephalography (EEG), and cognitive performance tests (Stroop and word memorization tasks). A survey of 60 middle and high school students revealed that quietness and moderate lighting were the most influential factors affecting perceived concentration. Subsequently, four experimental scenarios were developed based on actual illuminance, noise, and openness conditions observed in school study rooms. Six participants completed EEG-based concentration measurements and cognitive tasks under these controlled environments. The results showed that the baseline condition produced generally stable concentration levels, while the noise-enriched environment yielded high EEG concentration and memory performance. The low-light condition enhanced speed-based task performance, whereas the enclosed condition showed relatively lower concentration across measures. These findings demonstrate that optimal learning environments vary depending on task characteristics and the learner's cognitive state. The study provides empirical evidence that supports strategic environmental design and adjustment for enhancing learning efficiency.

KEYWORDS

Correlation Analysis, Environmental Psychology, Learning Environment Factors, Concentration, Electroencephalography (EEG)

INTRODUCTION

This study originated from the question, *"Do environmental differences between study spaces on a school campus have a measurable impact on students' concentration?"* Students exhibit diverse preferences regarding where they study: some favor quiet spaces such as personal rooms or reading rooms, while others report that the moderate background noise of classrooms or cafés enhances their focus. The research team noted that such differences may not simply reflect individual preference, but rather the influence of physical environmental factors such as illuminance, noise, and spatial openness—on cognitive engagement and concentration. This led to the central research question: *"Do the physical conditions of a learning space exert a measurable effect on students' concentration?"*

Y High School in Yongin provides a variety of learning environments, including classrooms, self-study rooms, and dormitory study spaces, from which students freely select during evening self-study hours. However, students' subjective experiences differ markedly: some report difficulty concentrating in the dormitory study room, while others feel more immersed in classroom environments. Determining whether these differences stem from psychological factors or from physical characteristics of the spaces is essential for understanding how learning environments can be scientifically designed and how students can be supported in selecting spaces that enhance their learning performance.

To address these questions, this study analyzed the effects of environmental factors on concentration using three complementary approaches: subjective perception, physiological responses measured through EEG, and cognitive performance measured through the Stroop test and short-term memory tasks. Students' subjective evaluations and spatial preferences were first collected, and EEG and cognitive performance were then measured across several real study spaces on campus. Through this data, the study objectively evaluated how environmental variations influence concentration and examined the relationships among physiological, cognitive, and subjective responses in order to identify the environmental conditions that best support student focus. These findings can help students better understand which study spaces suit their personal learning patterns and may also inform future improvements to on-campus learning environments.

A key methodological foundation of this study was the work of **Oh (2024),** whose research provided detailed procedures for EEG preprocessing, environmental variable configuration, and experimental scenario design. Oh's study examined how variations in indoor illuminance and noise affect EEG patterns and task performance, using frequency-band analysis to quantify psychological states such as attention and immersion. This framework served as a core model for constructing the present study's experimental design. In particular, the principles used in Oh's work—environmental control of illuminance, noise, and openness; EEG interpretation standards; and cognitive task design—were adapted to compare four distinct real-world study spaces on campus.

The study was conducted in several self-study rooms and classrooms at Y High School in Yongin, with participating students drawn from the school's population. Because the experiment was performed in actual learning spaces regularly used by students, the resulting data reflects real environmental conditions, providing empirical evidence that is often difficult to obtain in laboratory settings. This study offers practical insights to help students select learning environments that enhance their concentration and provides foundational data that may guide future improvements to the school's study spaces.

CONCEPTUAL AND THEORETICAL REVIEW

Basic Concepts of Environmental Psychology and Learning Spaces

Environmental psychology is a field that examines how human cognition, emotion, and behavior are influenced by physical environmental conditions, and it is closely connected to research in architecture, education, and indoor environmental studies. A learning space is not merely a physical location but a complex environmental stimulus in which perception, physiological responses, and cognitive performance interact (Anderson, 2010). Environmental psychology posits that specific physical conditions can alter a learner's attention, arousal, concentration, and stress responses, thereby ultimately affecting learning performance (Mayer, 2009).

This mechanism is well illustrated by the Yerkes–Dodson law, which explains that both very low and very high levels of stimulation hinder concentration, whereas an optimal level of environmental stimulation leads to the best learning outcomes. Thus, the fact that students report different levels of concentration in various spaces—such as self-study rooms, classrooms, or dormitory study areas—aligns with environmental psychology's view that environmental stimuli shape a learner's emotional stability, arousal level, and attentional resources.

Illuminance (Lighting)

The illuminance of a learning space is a key physical factor that directly affects visual information processing, arousal, and cognitive performance. Environmental psychology suggests that insufficient lighting increases visual strain and fatigue, while excessively bright lighting can lead to over-stimulation, thereby reducing concentration.

Noise

Noise is traditionally regarded as a distractor in learning environments; however, environmental psychology highlights that the type and intensity of noise can sometimes enhance attention and cognitive performance. This perspective is supported by the Yerkes–Dodson law (Yerkes & Dodson, 1908). Furthermore, steady and continuous white noise has been shown to enhance memory and attentional performance through the mechanism of stochastic resonance, which facilitates the detection of weak signals (Söderlund et al., 2007).

Openness & Enclosure

Openness and enclosure influence psychological stability, stress responses, and attentional control through the spatial form and visual structure of an environment. Open spaces provide a wide field of view and a sense of psychological release but may increase the risk of attentional distraction when there is substantial peripheral movement. In contrast, more enclosed spaces reduce external stimuli and may temporarily support focused work; however, excessive enclosure can induce stress, anxiety, and heightened physiological arousal.

Theoretical Review of EEG Indicators and Cognitive Responses

Basic Concept of Brainwaves

Brainwaves, commonly analyzed via Electroencephalography (EEG), represent the very small electrical currents generated by neural activity in the brain. These signals arise when groups of neurons fire simultaneously, and they are recorded through electrodes placed on the scalp. Brainwaves appear as oscillatory signals, and each frequency band is closely associated with specific cognitive and emotional states.

Brainwave Frequency Bands

The frequency bands of brainwaves provide important information about a participant's mental state. In general, an increase in beta waves is associated with heightened concentration and cognitive engagement, whereas increases in alpha or theta waves indicate drowsiness, reduced vigilance, or attentional disengagement. For this reason, the beta, alpha, and theta bands are the most important in educational and learning research. Accordingly, the present study focuses on changes in these three frequency bands to analyze variations in students' concentration levels.

Figure 1. Characteristics of Brainwave Frequency Bands and Their Associated Cognitive States

Brainwave	Frequency (Hz)	Associated State
Beta	12–30 Hz	Thinking, anxiety, or tense mental state
Alpha	8–12 Hz	Relaxed and calm state, stable mental state; increases when eyes are closed
Theta	4–8 Hz	Emotionally stable state, drowsy or light sleep state
Delta	0.5–4 Hz	Deep sleep, meditation, unconscious state
Gamma	Above 30 Hz	Highly tense state, deep concentration or focused attention

Concentration Index Derived from EEG

In this study, concentration was quantified using an index calculated from the three major EEG frequency bands discussed above. This metric has also been widely applied in previous research examining engagement and attention, including Hitt (1997) and Biercewicz et al. (2020), and is therefore appropriate for the present experimental context.

$$\textbf{Focus Index} = \beta / (\alpha + \theta)$$

This index represents the relative dominance of the concentration-related beta (β) band over the distraction- or relaxation-related alpha (α) and theta (θ) bands. Because increases in alpha and theta reduce the index (reflecting decreased concentration), whereas increases in beta elevate the index (reflecting heightened focus), this metric is well suited for analyzing participants' concentration levels during the experiment.

Research Process

This study adopted a multi-layered approach by combining a psychological perception survey, cognitive performance tests, and EEG-based concentration measurements. The goal was to analyze how environmental factors influence learners' subjective experiences, physiological responses, and cognitive performance.

In Phase 1, a perception survey on learning environments was administered to students ranging from first-year middle school to third-year high school, including current students at H High School in Yongin. This step aimed to identify students' perceived spatial experiences and environmental preferences.

In Phase 2, experimental scenarios were designed based on actual study rooms within the school. EEG measurements and cognitive task assessments were conducted to quantitatively verify the objective effects of environmental conditions on concentration.

RESEARCH METHOD 1: LEARNING ENVIRONMENT PERCEPTION SURVEY (ANALYSIS OF SUBJECTIVE PERCEPTIONS)

Overview of the Survey

As a preliminary step for the environmental-psychological analysis, this survey aimed to measure learners' subjective perceptions and preferences regarding how learning environments influence their concentration. The survey was conducted over a three-day period from August 9 to 11, 2025, and included a total of 60 participants ranging from first-year middle school to third-year high school students, including current students at H High School in Yongin. The questionnaire consisted of 15 items, and respondents were asked to answer freely based on their own experiences and perceptions.

The survey was composed of two major sections: (1) study-room usage patterns, and (2) preferred environmental conditions.

The first section, 'Study-Room Usage Patterns', was administered only to students currently attending H High School. Respondents selected up to two learning spaces they most frequently use and indicated up to three primary reasons for their choices, including quietness, comfortable temperature or air quality, bright and pleasant lighting, desk/chair comfort, presence of familiar peers, and proximity to daily living spaces. Participants also rated their perceived level of concentration in the chosen spaces using a five-point Likert scale ('strongly agree' to 'strongly disagree'). In addition, they selected factors that most hinder their concentration-such as noise (conversation, door sounds), uncomfortable desks/chairs, thermal discomfort, stale air, lighting issues (too bright or too dim), or lack of facilities (insufficient outlets, unstable Wi-Fi). The section further asked students to identify the structural type of study space they use (e.g., partitioned individual desk, open desk, shared table, window- or wall-facing seat) and to evaluate how each structure affects their concentration using a five-point scale ('very helpful' to 'very distracting').

The second section, 'Preferred Environmental Conditions', examined students' subjective perceptions of the optimal environmental variables for concentration, including temperature, lighting, noise level, and spatial density. Temperature preferences were categorized into four ranges: below 18 °C, 18~23 °C, 24~29 °C, and above 30 °C.

Noise conditions were classified as: below 30 dB (library), 30~40 dB (quiet classroom), 40~50 dB (white noise/café), and above 50 dB (conversation/TV). Lighting preferences were surveyed in terms of both brightness (bright, slightly bright, slightly dim, dim) and color temperature (daylight, warm white, cool white).

Results of the Survey

Analysis of Students' Preferred Learning Environment Factors

Figure 2. Analysis of Factors Influencing Students' Preferred Learning Environments

Reason for Preference	Frequency	Percentage (%)
Quiet environment that supports concentration	16	39.0
Proximity to living spaces	11	26.8
Bright lighting	6	14.6
Comfortable temperature or air quality	6	14.6
Comfortable desk and chair	6	14.6
Sufficient seating availability	4	9.8
Other (e.g., open hours, studying with friends)	4	9.8

The results show that the factor students valued most when choosing a study space was a **quiet environment**, indicating that the ability to control noise is a more decisive criterion than convenience or proximity. Although physical comfort elements such as lighting, ventilation, and furniture were also important, they ranked lower in priority compared to noise control.

Analysis of Factors That Hinder Learning

Figure 3. Analysis of Environmental Factors That Disrupt Learning

Disruptive Factors	Frequency	Percentage (%)
Noise (e.g., conversations)	15	30.6
Uncomfortable desk or chair	8	16.3
Insufficient facilities (e.g., Wi-Fi, power outlets)	6	12.2
Disturbance caused by people moving around	5	10.2
Too cold	4	8.2
Poor air quality	3	6.1
Too hot	2	4.1
Lighting that is excessively bright	2	5.1
Other (e.g., drowsiness, smartphone use)	4	8.2

Respondents identified a wide range of environmental factors that disrupted their concentration during study, but sensitivity to noise emerged as the most prominent. The most frequently selected factor-chosen by multiple respondents-was noise, including conversation or door sounds. This indicates that the control and management of noise play a substantial role in students' subjective perception of concentration. These survey results provide a baseline for how students subjectively evaluate their learning environments and serve as an important reference point for interpreting changes in objective concentration indicators under different physical environmental conditions.

Analysis of Spatial Openness in Learning Environments

The enclosed study environment showed an average increase in concentration that was approximately three times higher than that of the open environment (+0.875). This indicates that visual shielding and the provision of personal space positively contribute to maintaining learners' concentration. In contrast, open environments exhibited a relatively smaller increase in concentration, likely due to visual distractions or interactions with others. These differences suggest the importance of structural enclosure in the design of learning spaces and quantitatively demonstrate how environmental adjustments can influence learning efficiency.

Figure 4. Analysis of Spatial Openness in Learning Environments

Category Type	Detailed Items	Total Concentration Score	Total Number of Responses	Average Change in Concentration
Enclosed Environment	Partitioned desk/ Wall-facing seat	70	80	0.875
Open Environment	Open desk / Shared table / Window seat	35	120	0.292

Respondents identified a variety of environmental factors that hindered their concentration, but **noise** emerged as the most dominant. Sounds such as conversation or doors opening and closing were reported as immediate distractions, accounting for approximately 30% of all disturbance factors. This finding indicates that maintaining quietness is a critical task in learning environments and suggests that improvements in physical layout or operational management could meaningfully enhance concentration. Moreover, these responses provide insight into the criteria students prioritize when evaluating their environment and serve as an important reference point for linking subjective assessments with subsequent analyses of objective concentration changes.

Analysis of Key Environmental Variables (Brightness, Light Color Temperature, Noise Conditions)

This section summarizes which conditions-brightness, light color, and noise level-students perceive as the most conducive to concentration.

Preferred Brightness (Illuminance)

Figure 5. Students' Preferred Brightness Levels (Illuminance)

Brightness Level	Frequency	Percentage (%)
Slightly bright (typical classroom fluorescent lighting)	20	50.0
Slightly dim (lights off, desk lamp at maximum)	14	35.0
Bright (overhead lighting + desk lamp at maximum	5	12.5
Dim (lights off, desk lamp at minimum)	1	.2.5

Half of the students selected **"slightly bright"** as the most conducive brightness level for concentration. This aligns with the understanding that moderate illuminance-neither too bright nor too dim—reduces visual fatigue and provides a stable visual environment suitable for focused study.

Preferred Noise Conditions

Figure 6. Students' Preferred Noise Levels

Disruptive Factors	Frequency	Percentage (%)
Library level (≤ 30 dB)	19	47.5
Quiet classroom (30–40 dB)	15	37.5
White-noise / café level (40–50 dB)	5	12.5
Conversation / TV level (≥ 50 dB)	1	2.5

Approximately 50% of students preferred very low noise levels equivalent to a library. When including the 30~40 dB range, 85% of all respondents favored a quiet environment, indicating that students expect a lower noise level than what is typically measured in real classrooms or study rooms.

Synthesizing the survey results, respondents most frequently identified noise such as conversations and door sounds—as the primary factor disrupting concentration. Students also showed a strong preference for quiet environments, particularly noise levels below 30 dB (library) or between 30–40 dB (quiet classroom). Regarding lighting, students favored moderately bright or slightly dim conditions, avoiding overly intense desk-lamp lighting. The most preferred color temperature was cool white, indicating a general preference for balanced, non-extreme lighting conditions. In addition, enclosed individual desks with partitions were overwhelmingly selected as the most effective for concentration, reflecting students' desire to minimize visual intrusion and social distractions.

Based on these subjective preferences, the experimental control variables for the EEG-based physiological measurements were set to illuminance, noise level, and spatial openness. To objectively verify the strong preference for enclosed environments, a fully shielded booth-like setting was created using panel structures for the openness-control scenario. These subjective findings serve as foundational data for interpreting EEG results under different environmental manipulations and for examining the relationship between perceived cognitive focus and physiological indicators of comfort and attention.

RESEARCH METHOD: QUANTITATIVE EEG-COGNITIVE TEST EXPERIMENT (PHYSIOLOGICAL·COGNITIVE EXPERIMENT)

Overview of the Experimental Design: Environmental Condition Settings

This experiment was designed to measure changes in concentration by manipulating three environmental variables-illuminance, noise level, and spatial openness-based on the physical conditions of actual study rooms within the school. Four experimental scenarios were constructed by systematically controlling these variables. First, the illuminance and noise levels of multiple study rooms were measured, and their overall averages were used to create Scenario 1, which represented the 'typical learning environment'. The adjustments to illuminance, noise, and openness were not intended to replicate specific study rooms, but rather to analyze the effects of environmental factors on concentration in isolation. The experiment was conducted in Room C308 of the H High School academic building over a two-day period, from November 2 to November 3, 2025.

Description of the Four Experimental Scenarios

Typical Learning Environment (Scenario 1)

This baseline condition reflected the average illuminance (≈374 lux) and noise level (40 dB) measured across four school study spaces: C201, D501, C202 classroom, and the dormitory study room. Lighting and sound were not intentionally adjusted, creating the most typical study environment found on campus.

Increased Noise Environment – Studying in a Café (Scenario 2)

In this condition, continuous café white noise was played at a level of about 70–80 dB to simulate a noisy environment. The purpose was to examine how stronger auditory stimulation affects students' concentration and cognitive performance

Reduced Illuminance Environment – Studying with Only a Desk Lamp (Scenario 3)

All room lights were turned off, leaving only individual desk lamps (about 500 lux on the work surface) for illumination. This condition analyzed how reduced ambient light and a single concentrated light source influenced EEG activity and reaction time

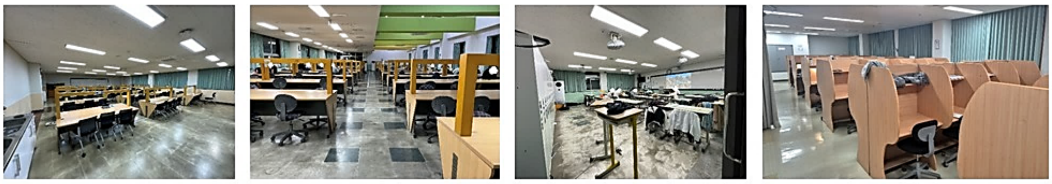
Reduced Openness Environment – Studying in a Cubicle or Reading Room (Scenario 4)

In this condition, a box-shaped partition was installed to replicate a fully enclosed reading-room space. A desk lamp providing about 300 lux was used inside the box, and this setup was designed to evaluate how limited visual exposure and spatial enclosure influence concentration

Figure 7. Comparative Study Environments at H High School: Baseline, Noise, Low-Light, and Enclosed Conditions

A study room and some classrooms for students at H High School in Yongin, Gyeonggi Province

Category		Scenario 1 (Baseline)	Scenario 2 (noise)	Scenario 3 (Low Light)	Scenario 4 (Enclosed)
Features	Lighting(lux)	432	498	193	220
	Noise(dB)	42	49	31	36
	Sense of enclosure	X(open)	X(open)	X(open)	O(enclosed)
	Desk arrangement	6-person shared desk	12-person shared desk	Individual desks	Cubicle-style desks
	Description	A baseline study environment with average illuminance and noise levels	A high-noise environment with shared seating and added café-like ambient noise	A low-light environment with overhead lights turned off and only a desk lamp used	An enclosed environment with partitioned, visually shielded cubicle-style desks



Scenario 1 (Baseline) Scenario 2 (noise) Scenario 3 (Low Light) Scenario 4 (Enclosed)

EEG-Based Concentration Measurement and Cognitive Performance Testing (Objective Analysis)

This experiment measured concentration changes under four environmental scenarios derived from real school study spaces. After establishing baseline condition based on average illuminance and noise levels, the three environmental variables-illuminance, noise, and spatial openness-were systematically manipulated. Six first-year students from H High School participated. During each scenario, EEG data and cognitive performance were recorded simultaneously.

Implementation of Tests & Environmental Setup for Each Scenario

- **Stroop Test**: assessed selective attention and inhibition control.
- **Word Memorization Test**: measured short-term memory and learning performance.

Environmental values from C201, D501, C202, and the dormitory study room were pre-measured, and these averages were used to construct the baseline condition. Each scenario selectively controlled one variable while holding the others constant.

Measurements and Equipment

- **Physiological data**: EEG was recorded using the wireless dry-electrode device *MeasureWiz*
- **Concentration metric**: The *Focus Index* was calculated using the formula

$$\mathbf{FI = \beta / (\alpha + \theta)}$$

representing the dominance of beta activity (focus) over alpha and theta activity (relaxation/drowsiness). This index has also been employed in previous research examining cognitive engagement, including Hitt (1997) and Biercewicz et al. (2020).

Figure 8. Summary of Measurement Tools and Procedures

Category		Hardware & Software Used	Measurement Method
EEG Device	Biosignall Measurement	Wireless dry-type MeasureWiz wearable biosignal measurement and analysis system	Measurement of participant's brainwaves (EEG)
	EEG Data Collection & Analysis	MeasureWiz Application	
Illumination Measurement		APP Light Meter LM-3000	• Using smartphone light sensor. • Measure the bottom-left, center, and top-right areas of the space, then calculate the average value.
Noise Measurement		APP Noise Meter	• Using smartphone noise meter. • Measure the bottom-left, center, and top-right areas of the space, then calculate the average value.
Desk Arrangement Measurement		Field observation	• Check whether the desk is cubicle-type (1-person) or long shared desk. For accurate analysis, photos were taken showing desk structure and shape from the wall to the edge of the desk.

Cognitive Performance Measurement and Analysis Method

Cognitive performance was assessed using two tasks: the Stroop Test and the Word Memorization Test.

Stroop Test

Participants selected the button corresponding to the color of the text, not the written word, for 1 minute. Mismatched color–word combinations were presented (e.g., the word “red” shown in blue), requiring fast, selective attention and interference control. Four colors (green, red, blue, yellow) were used, and each correct response increased the score by one point. The next item appeared immediately after each selection. In this experiment, four colors-green, red, blue, and yellow-were used, and each new item appeared immediately after the participant selected the color during the 1-minute task. The results of this test were used to assess participants' selective attention and their ability to control cognitive interference.

Word Memorization Test

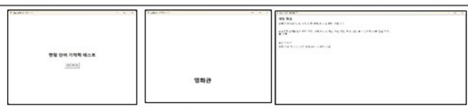
This task assessed short-term memory and learning efficiency by requiring participants to recall and reproduce randomly presented words after a brief viewing period. Fifteen Korean words (e.g., library, car, book) were displayed on the screen, each appearing for 2 seconds at a random location before disappearing. After all 15 words had been shown, participants were given 1 minute to type and submit as many words as they could remember. To prevent learning effects from repeated exposure, a different randomized set of words was used in each scenario. The results of this test were used to evaluate participants' selective attention and cognitive interference control.

Participants took part in the experiment while wearing the EEG measurement device. After an adaptation phase, they repeated cycles of testing and rest for each scenario. The order of Scenarios 1, 2, 3, and 4 was randomly assigned to all participants to minimize practice effects, prevent performance improvement caused by repetition, and eliminate order effects that might occur if specific conditions consistently appeared first or last. This ensured that any observed differences in concentration were solely attributable to environmental factors.

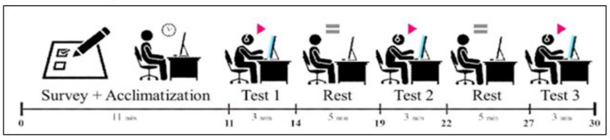
Analysis Method

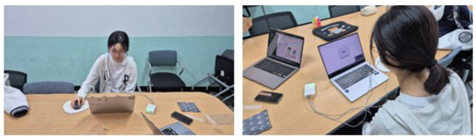
EEG data were preprocessed through noise removal and frequency separation, and changes in the Focus Index ($\beta / (\alpha + \theta)$) were compared across conditions. Stroop reaction time and accuracy, along with word recall scores, were analyzed to identify correlations between environmental factors, physiological responses, and cognitive performance. Grounded in environmental psychology, the analysis aimed to determine how variations in learning environments produce measurable differences in concentration and cognitive functioning. Raw EEG data were preprocessed to remove artifacts caused by eye blinks, muscle movements, and electromagnetic interference. A 0.5–30 Hz bandpass filter and a notch filter were applied, and blink artifacts were automatically detected and masked. These steps ensured reliable analysis of concentration-related EEG indicators under different environmental conditions.

Figure 9. Summary of Experimental Design and Cognitive Assessment Methods

	Stroop Test	Word Memorization Test
Test Description	A program to measure response speed by choosing the actual color of a word regardless of its meaning.	Words are shown one by one on screen; users must later recall and input them.
Evaluation Content	Evaluates selective attention and cognitive control.	Evaluates short-term memory and learning efficiency.
Reference Image		

Experiment Procedure	① Adaptation (7 minutes): Allow physical adjustment to lighting and noise changes. ② Scenario 1 - Stroop Test (1 minute) ③ Scenario 1 - Word Memorization Test (1 minute) ④ Break (3 minutes): Rest period to prevent fatigue between scenarios ⑤ Repeatthe same procedure for Scenarios 2, 3, and 4. Note: The order of 1, 2, 3, 4 is randomized per participant to avoid bias.	Experiment Date	2025.11.2.~3
		Experiment Location	Room 308, Building C (Faculty Building)
		Participants	5 male students, 1 female student(Total: 6)





	No.		Environmental Setup Content
Scenario Setup	1	Baseline	General learning space with average dormitory lighting and noise
	2	Increased Noise	Added ambient café noise to create a louder environment
	3	Reduced Lighting	All lights off; only desk lamp used for a dim environment
	4	Decreased Privacy	Enclosed cubicle using partitions to simulate a library-style setup

Preprocessing Experimental EEG Data

In this study, standard EEG preprocessing procedures were applied to address the susceptibility of raw EEG signals to artifacts such as eye blinks, muscle movements, and electromagnetic interference. A 0.5–30 Hz bandpass filter was first applied to remove low-frequency noise (below 0.5 Hz) caused by movement or electrode contact, as well as high-frequency components (above 30 Hz) associated with electromyographic (EMG) activity. A notch filter was additionally used to eliminate electromagnetic interference originating from indoor lighting and power sources.

High-frequency components generated by muscle tension were attenuated through filtering, and large-amplitude blink artifacts were removed by automatically detecting blink intervals and masking the corresponding frames. These preprocessing steps ensured the reliability of the EEG-based concentration indicators used to analyze the effects of environmental conditions.

Experimental Results

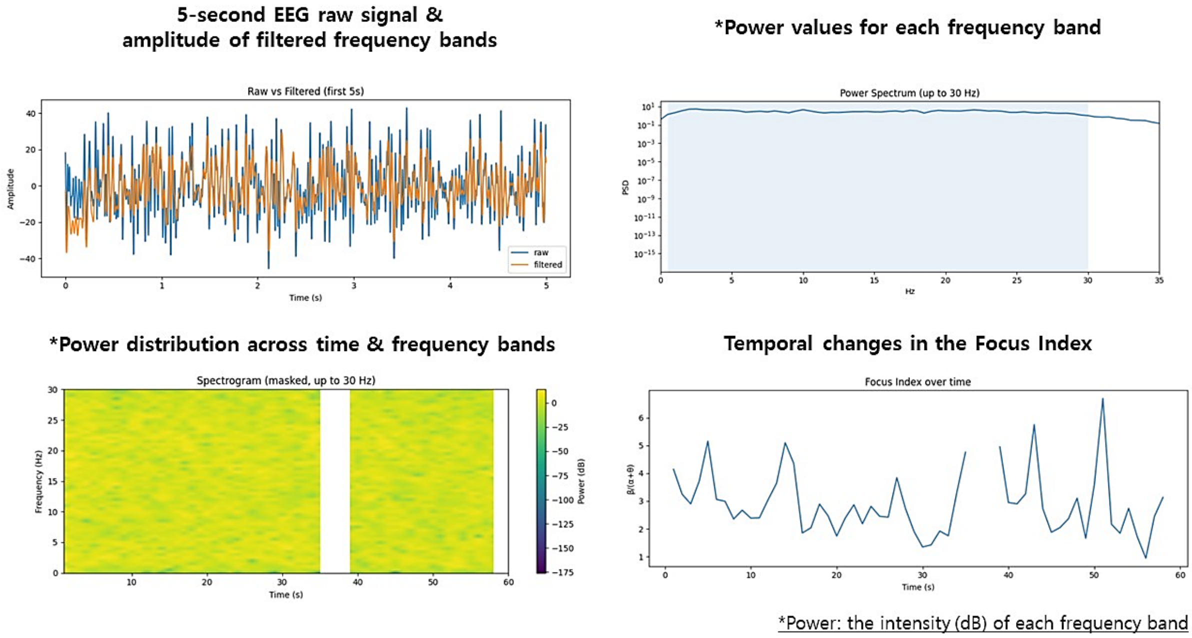
After computing the Focus Index ($\beta/(\alpha+\theta)$) from the EEG signals, the average values for each participant were calculated for the Stroop and word-memorization intervals under each environmental condition. The individual mean concentration values for the four scenarios are as follows:

Figure 10. EEG-Based Concentration Levels Under Different Learning Conditions

Participant	Scenario 1 (Baseline)	Scenario 2 (Noise)	Scenario 3 (Low Light)	Scenario 4 (Enclosed)
A	2.488	1.968	1.589	1.347
B	0.792	0.921	0.776	0.832
C	2.798	1.564	1.846	1.639
D	0.741	0.764	0.765	0.821
E	3.151	2.735	2.307	2.595
F	0.775	0.846	0.955	0.955
Mean	**1.7909**	**1.4663**	**1.3730**	**1.3648**

Overall, EEG-based concentration results showed the following pattern: **Baseline > Noise > Enclosed > Low-Light** conditions. However, considerable variability was observed across participants, indicating notable individual differences in how environmental conditions influenced concentration.

Figure 11. Stroop Test Results for Participant F in the Baseline Environment



In the Stroop Test, four out of six participants achieved their highest scores in the low-light (lighting) environment. The noise condition also showed positive effects for some participants. However, the enclosed environment was generally not the most favorable for most participants. Although the Stroop results did not perfectly align with the EEG outcomes, individuals tended to score higher in environments where their EEG-based concentration levels were also elevated. The average Stroop scores across conditions were as follows: Lighting (71.83) > Noise (71.16) > Baseline (69.66) > Enclosed (68.83).

Figure 12. Stroop Test Performance Across Four Environmental Conditions

Participant	Scenario 1 (Baseline)	Scenario 2 (Noise)	Scenario 3 (Low Light)	Scenario 4 (Enclosed)
A	70	73	76	68
B	69	73	74	69
C	75	76	72	74
D	63	70	70	64
E	66	67	70	68
F	75	68	69	70
Mean	69.67	71.17	71.83	68.83

Word Memorization Test Results

A notable pattern in the word memorization test was that many participants showed improved performance in the lighting or noise environments. Some students also achieved higher scores in the enclosed environment, whereas none showed their best performance in the baseline condition. The average scores across conditions were as follows: Noise (10.0) > Lighting (9.33) > Enclosed (9.16) > Baseline (8.66).

Figure 13. Comparison of Word Memory Test Scores Under Four Study Environments

Participant	Scenario 1 (Baseline)	Scenario 2 (Noise)	Scenario 3 (Low Light)	Scenario 4 (Enclosed)
A	7	7	6	6
B	6	7	9	8
C	9	8	7	8
D	10	12	9	10
E	8	12	12	10
F	12	14	13	13
Mean	8.66	10.00	9.33	9.16

Correlation Analysis Between EEG Concentration and Cognitive Test Performance

To determine whether the cognitive tests conducted during the experiment were meaningfully related to EEG-based concentration levels, a correlation analysis was performed. The results showed that there was no strong correlation between EEG indices and the outcomes of the Stroop or word memorization tests. This finding contrasts with the initial hypothesis and suggests that the cognitive test scores and physiological concentration indicators did not move together in a consistent pattern. Several factors may explain this discrepancy, which are discussed in the following section.

Figure 14. Correlation Between EEG Measures and Cognitive Performance Tests

Variable Pair	r	Interpretation
EEG ↔ Stroop Test	-0.16	Weak negative correlation
EEG ↔ Word Memorization Test	+0.25	Weak positive correlation

EEG, the Stroop Test, and the Word Memorization Test measure different constructs.

EEG evaluates physiological arousal and attentional focus, whereas the Stroop and memorization tests assess cognitive performance. In particular, the Focus Index used in this study reflects the moment-to-moment fluctuations in arousal and concentration during the 1-minute task. This makes it inherently different from the Stroop and memory tests, which yield a single aggregated performance score, and therefore direct comparison is limited.

The Stroop Test and the Word Memorization Test assess different cognitive functions.

The Stroop Test measures inhibitory control, attentional shifting, and executive function. In contrast, the word memorization test evaluates working memory, encoding ability, and chunking strategies. Thus, higher physiological concentration does not automatically translate into better performance unless the relevant cognitive functions are simultaneously engaged.

The Yerkes–Dodson law may explain the weakened correlations.

The Yerkes–Dodson law states that too little arousal reduces concentration, while excessive arousal causes overload, and optimal performance occurs at a moderate level. This implies that EEG-based arousal does not increase linearly with performance scores, which may weaken the correlation. A more detailed discussion of this phenomenon is provided in a later section.

The small sample size is methodological limitation.

Correlation coefficients are easily distorted by outliers when the sample is small. As a result, estimating a stable relationship between EEG data and task performance was statistically limited. Even a few atypical scores could shift the correlation substantially, making causal interpretation premature.

Previous studies also report on weak correlations between EEG and cognitive performance.

For the reasons noted above, similar findings exist in earlier research. Jensen and Rohwer's 1965 study was the first to argue that arousal and performance do not exhibit a linear relationship but rather follow a Yerkes–Dodson–type curve.

Figure 15. Comparative Summary of Cognitive and EEG Outcomes Across Learning Environments

Learning Environment	EEG	Stroop	Memory	Overall Interpretation
Scenario 1 (Baseline)	High	Moderate	Moderate	A generally stable environment
Scenario 2 (Noise)	Very high	High	Highest	Noise had a positive effect on cognitive performance
Scenario 3 (Low Light)	Moderate	Highest	Low	Optimal for speed-based tasks
Scenario 4 (Enclosed)	Lowest	Low	Moderate	Overall least efficient condition

Overall, when integrating the experimental results, it became evident that each environment favored different types of learning performance. In the baseline environment, EEG concentration, Stroop scores, and memory performance all showed moderate levels, indicating a stable condition suitable for sustained study over long periods.

In contrast, the noise environment produced notably high EEG concentration and memory performance. This suggests that it may support long-term learning and memorization tasks, a result that can also be interpreted in connection with the effects of white noise, which will be discussed later.

In the low-light environment, the Stroop test yielded the highest performance, while EEG concentration remained at a moderate level. This pattern indicates an advantage for speed-based tasks such as problem-solving or rapid decision-making. The localized use of a desk lamp likely boosted short bursts of attentional focus. However, this benefit may not extend to longer study sessions, a point supported by prior research on lighting conditions, which will also be addressed later.

Finally, the enclosed environment showed low or moderate performance across EEG, Stroop, and memory outcomes. This suggests that the closed setting may have imposed cognitive load or discomfort on participants. At the same time, the enclosed space in the experiment—created using temporary cardboard partitions—differs meaningfully from typical study carrels found in actual school study rooms. Therefore, caution is needed when directly generalizing these results to the school's existing study environment.

RESULTS AND DISCUSSION

Based on the results, the cognitive functions and task types that benefit relatively from each environmental condition can be summarized as follows.

Baseline Environment (300 lx, 30 dB, Open Setting)

This condition showed the highest EEG-based concentration level, making it suitable for maintaining stable arousal without excessive stimulation. Although it did not produce outstanding performance in any specific task, both Stroop and memory scores remained at average levels. Thus, this environment can be interpreted as appropriate for tasks requiring persistence and stability, such as long-duration studying, reading, and conceptual organization.

Noise Environment (300 lx, Café Noise 80 dB, Open Setting)

EEG, Stroop, and memory performance were all relatively high, with the highest mean score observed in the word memorization task. Considering the Yerkes–Dodson law and findings from white-noise studies, an appropriate level of continuous noise may support encoding and sustained attention in repetitive memorization, habituated tasks, or relatively automated problem-solving. However, for learners sensitive to noise, such stimulation may become a distracting factor, making selective and individualized use necessary.

Lighting Environment (Dark Surroundings with 500 lx Task Light, 30 dB, Open Setting)

The Stroop score was the highest among the four conditions, and memory performance was the second highest. Illuminating only the task surface while keeping the surroundings dark concentrated visual attention on the task area and reduced distracting stimuli. This effect was advantageous for Stroop tasks, where inhibitory control and processing speed are essential. Given that high illuminance can increase arousal but also induce visual fatigue, the lighting environment may be effective for speed-based tasks or situations requiring short-term focus but may pose a risk of increased fatigue during long-term memorization or extended study sessions.

Enclosed Environment (Partitioned Space, 300 lx, 30 dB)

EEG, Stroop, and memory performance were all low or near average, with the lowest Stroop score among all conditions. The enclosed box-type environment used in this study may have induced excessive confinement and discomfort, potentially triggering stress and diverting cognitive resources toward non-task-related factors. However, since the partition structure used in this experiment differs from typical study cubicles, there are limitations in directly comparing it to real study-room environments.

CONCLUSION

This study aimed to examine how variations in illuminance, noise level, and spatial openness within everyday learning environments influence students' actual concentration and cognitive performance. The research was motivated by the idea that students' preferences for different study spaces are not merely matters of taste but may reflect underlying physiological and cognitive responses to specific physical conditions. To investigate this, the study integrated analyses of students' subjective environmental perceptions, EEG-based concentration levels, and performance on the Stroop test and word-memory task.

Rather than identifying a single "best" study space, the study sought to demonstrate that the physical elements of lighting, noise, and spatial openness affect arousal and cognitive functions (such as inhibition, working memory, encoding, and processing speed) in different ways. The findings suggest that tasks requiring inhibition and selective attention—such as the Stroop test—may benefit from lighting that concentrates illumination on the task surface while minimizing peripheral visual stimuli. In contrast, tasks that rely on encoding and short-term memory, such as repetitive memorization, can be supported by an appropriate level of continuous background noise. Excessively enclosed environments, however, were likely to hinder overall cognitive performance.

At the same time, it should be acknowledged that partial spatial separation can enhance performance, as noted in prior work, and that the current findings are exploratory rather than causal due to limitations in sample size and experimental control. Nevertheless, by jointly examining EEG patterns and cognitive task performance, this study provides quantitative insight into the relationship between learning environments and cognitive functioning. These results offer a basis for designing learning environments and selecting environmental conditions according to the type of task required. They also indicate that students can benefit from choosing study spaces matched to their learning goals and task characteristics, and that schools may need to configure their learning spaces more functionally by adjusting lighting, noise levels, and openness. By integrating subjective perception, physiological response, and cognitive performance, this study contributes a multidimensional understanding of how learning environments shape concentration and engagement. Future research that includes a wider range of environmental variables and participant groups is expected to provide more concrete and practical evidence for personalized learning-space design.

DECLARATION OF AI

In this study, AI tools were used as auxiliary resources throughout the research process. First, during the literature review stage, NotebookLM was used to organize and summarize prior studies in environmental psychology. This tool helped identify recurring key concepts and research trends and supported the development of the study's theoretical framework. Next, during the survey analysis stage, AI was used to numerically compare and organize similar questionnaire items (e.g., noise-related variables). In addition, pie-chart–based survey results were converted into bar charts or tables to improve visualization and analytical clarity. During the EEG data collection stage, OpenAI ChatGPT version 5.1 was used to design the algorithms for the Stroop test and the word-memory test programs. It was particularly utilized in the code debugging process to resolve an issue in which only color values, rather than both color and word stimuli, were randomized in the Stroop test. In the EEG analysis stage, ChatGPT 5.1 was used to study the principles and applications of Python signal-processing functions, including scipy.signal.butter(), scipy.signal.filtfilt(), scipy.signal.welch(), and scipy.signal.spectrogram(), while developing a Python-based EEG analysis tool. ChatGPT was also used to cross-validate mean values and correlation coefficients calculated in Excel to ensure numerical accuracy. Finally, ChatGPT was used to review and refine the overall grammar of the manuscript.

REFERENCES

Ryu, J. (2013). *Study of Appropriate Lighting Environment in the Student''s Study Room*, (Master's thesis). Chungnam National University, Daejeon, Korea.

Lee, S., & Choi, J. (2025). An Empirical Approach to Improving Indoor Environmental Comfort in Senior Welfare Centers - Through POE Analysis - *Proceedings of the Architectural Institute of Korea Conference, 45(1), 459–462.*

Oh, D. (2024). *Analysis of Human-Building Interaction to construct Occupant-customized Indoor Space - Focusing on Concentration and Stability-* (Master's thesis). Seoul National University of Science and Technology, Seoul, Korea.

Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology*, 18, 459–482.

Söderlund, G. B. W., Sikström, S., Loftesnes, J. M., & Sonuga-Barke, E. J. S. (2007). Listen to the noise: Noise is beneficial for cognitive performance in ADHD. *Journal of Child Psychology and Psychiatry*, 48(8), 840–847.

Anderson, J. R. (2010). *Cognitive psychology and its implications* (7th ed.). Worth Publishers.

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge University Press.

Oxford English Dictionary. (n.d.). Focus. In OED Online. https://www.oed.com/

Oxford English Dictionary. (n.d.). Cognition. In OED Online. https://www.oed.com/