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RESEARCH ARTICLE

# EEG Activation Differences in Information Memory Activities with Single and Dual Coding Material: A Focus on sLORETA Analysis

Jin-su Jeong[1], Yong-Seong Kim[2]*
[1]Daegu University,
[2]The Research Institute for Special Education & Rehabilitation Science, Daegu University

Corresponding Author: Yong-Seong Kim, dr-kys@naver.com

## ABSTRACT

The purpose of this study was to analyze the changes in brain activation during the process of remembering information through text tasks, which are single-code data that only present textual information, and illustration tasks, which are dual-code data that present both textual and picture information. To this end, we developed a criteria task and memory task In memory tasks, participants in the study performed activities to recognize and remember specific information through text and illustration tasks. EEG data were collected from 26 second-year high school students in A city, Gyeongsangbuk-do, and sLORETA analysis was performed based on the collected EEG data. The results of the study are as follows. First, when comparing the differences in brain activation between the criteria task and the text task or illustration task, it was found that brain activation increased in all frequency band during the text task and illustration task. Second, when comparing the differences in brain activation between the text task and the illustration task, only significant results were found in the theta band. During the memory of text task information than illustration task, theta showed relatively greater activation in the middle frontal gyrus and the inferior frontal gyrus. These results suggest that dual-code data, which presents pictures and texts simultaneously, can help facilitate cognitive thinking performance, such as planning and execution for task resolution, secondary integration of information received from other brain areas, selection of appropriate information, selective memory retention and forgetting, and goal-directed attention. This provides neurophysiological evidence for the validity of cognitive psychological explanations of visual presentation strategies that apply dual-coding theory, and suggests the possibility of various follow-up studies.

**Key words:** Dual coding material, visual material presentation style, EEG, sLORETA, cognitive thinking

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## Introduction

Teaching and learning activities conducted in schools mainly aim to synthesize and convey scientific knowledge contained in textbooks (Kim, 2022). Textbooks serve as a guide for teachers to design and conduct lessons, and provide students with learning materials (Noh et al., 2017).

Science textbooks consist of narrative text and visual materials such as illustrations (Jung & Lim, 2018; Kim, 2022). Teachers and students obtain information from science textbooks through textual information and visual materials. Visual materials include visualized data, graphs, illustrations, and graphics that combine text and image information (Jung & Lim, 2018; Kim, 2022). In other words, students acquire information through narrative text or illustrations that combine text and image information when they learn using textbooks. In other words, students are learning using single-coded materials that provide only text information and dual-coded materials that provide both text and image information.

The influence of single-coded and double-coded data on learning has been dealt with as a major topic in numerous studies. Through these various studies, various views on the influence of single-coded and double-coded data on people's information processing and recognition process have been presented. Most scholars have argued that presenting materials that utilize two representational formats, such as dual-code materials, has a positive effect on learning effectiveness, learning motivation, attention, and cognitive load (Cuevas & Dawson, 2018; Kim & Do, 2007; Ryu & Jung, 2013). They announced that the cognitive load generated in the process of recognizing and accepting information is reduced when linguistic representations through text information are combined with spatial representations such as picture information or when near-field picture data and text information are dealing with the same content. (Cuevas & Dawson, 2018; Kim & Do, 2007; Ryu & Jung, 2013) However, there were also scholars who argued that dual-code materials have a negative effect on learning and cognitive load (Ginns, 2005; Park, Choi, & Jung, 2012; Schnotz & Bannert, 2003). Park et al. (2012) found that students' learning outcomes were higher when text materials were provided than when dual-code materials were provided in memory areas. Additionally, Ginns (2005) and Schnotz & Bannert (2003) argued that when people perceive and recall information in situations where text and picture information are presented simultaneously, their attention is divided between the process of understanding the meaning of text and picture information, so dual-code materials may not always be an effective way to learn.

The aforementioned studies have investigated the effects of single-code and dual-code materials on learning and cognitive load using behavioral observation and written assessments based on cognitive psychology research methods. These research methods indirectly infer cognitive thinking based on neural activation in the brain by quantifying changes in overt behavior. While this approach provides valuable information about the quantitative changes in overt behavior, it has limitations in providing objective information about the factors that cause overt behavior changes (Jung & Kim, 2022). To understand the brain-level changes that cause changes in human overt behavior, brain imaging techniques have been introduced to the field of research on human learning and cognition (Jung & Kim, 2022). Brain imaging techniques include EEG, fMRI, and MEG (Jung & Kim, 2022). EEG has several advantages, including the ability to select measurement locations with portable measurement devices, relatively low measurement costs, and easy device operation (Jung & Kim, 2022). In addition, although EEG is limited to measuring brain activity at the scalp, it has the advantage of being able to explore brain neural activity in the spatiotemporal dimension (Jung & Kim, 2022). Furthermore, EEG activity can show task-specific activation in different frequency band, providing practical information about the characteristics of cognitive thinking when performing specific tasks (Jung & Kim, 2022).

The relative power spectrum analysis method is commonly used in EEG analysis (Jung & Kim, 2022). This method calculates the ratio of EEG power values in a specific frequency band to the EEG power values in the entire frequency band, and can show the EEG activation patterns that occur during specific cognitive tasks (Jung & Kim, 2022). However, the relative power spectrum analysis method only represents EEG activation patterns at the level of cerebral cortex, such as the frontal, parietal, temporal, and occipital lobes, and has the limitation that it cannot determine which specific brain regions are responsible for the neural activation that occurs during specific cognitive tasks (Jung & Kim, 2022). In other words, there is a limitation that the source of the EEG signal cannot be tracked (Jung & Kim, 2022). To overcome these problems, the sLORETA analysis method was developed (Jung & Kim, 2022). The sLORETA analysis method converts the two-dimensional EEG activation images presented by detecting EEG activation changes on the scalp into three-dimensional spatial images, and has the advantage of being able to track the source of EEG signals in reverse and detect the source of EEG signals that occur during specific cognitive tasks at the level of subcortical regions of the brain (Jung & Kim, 2022). Therefore, it is possible to provide information about the brain regions that cause changes in EEG activation during specific cognitive tasks through the sLORETA analysis method.

As discussed above, the effects of single-code data that only provide text information and dual-code data that provide both text and picture information on cognitive load have been argued differently by researchers. In addition, the explanations based on cognitive psychology research related to this are made in terms of theoretical concepts, so there are limitations in explaining the patterns of thinking based on brain-level neural activation that actually cause cognitive load (Kim & Jeong, 2021). However, by identifying EEG activation changes using the sLORETA analysis method, it is possible to explore the patterns of cognitive information processing procedures performed to solve problems from the perspective of brain neural changes (Kim & Jeong, 2021). Based on the need for such research, the purpose of this study was to investigate the effects of text tasks, which are single-code data that only provide text information, and picture tasks, which are dual-code data that provide both text and picture information, on human information recognition and memory at the level of brain activation. Furthermore, we aimed to examine the validity of cognitive psychology-based explanations for exploring the relationship between single and dual codes and human cognitive thinking based on the results of the study.

# Materials and Methods

## Participants

The study was conducted among second-year high schools located in A city, Gyeongsangbuk-do, and 26 students (13 males and 13 females) who submitted consent forms to participate in the study participated. All of them were students without any emotional, cognitive, or physical abnormalities. Before participating in the study, participants were given time to listen to a description of all the things they would experience during the EEG measurement process from the researcher, and to exchange opinions with the researcher on questions and suggestions related to the measurement. This study was conducted after obtaining approval from the Institutional Review Board (IRB), and the research procedures and collected data were managed in accordance with the regulations of the Research Ethics Committee. EEG analysis utilized EEG measurement data from 24 students, excluding data from two students whose data were found to be erroneous in terms of research participation behavior and the inclusion of artifacts such as muscle artifacts.

## Procedure

This study was conducted in the following order: a literature review and analysis of previous studies on learning material presentation types and cognitive load, development of EEG measurement tasks, pilot testing and modification of EEG measurement tasks, EEG measurement pre-training, EEG measurement, sLORETA analysis, and conclusion and suggestions. The EEG measurement task was developed by dividing it into a criteria task and a memory task through single and double-coded materials. The memory task is a task that involves finding, recognizing, and remembering information that fits the focus question from materials presented on the screen. A pilot test was conducted with 26 high school sophomores who did not participate in EEG measurement to check the validity of the developed EEG measurement task. The content and presentation order of the final EEG measurement task were reviewed and modified based on the results of the pilot test at a science education expert seminar attended by two science education experts and one in-service teacher. Participants in the study were provided with an opportunity to undergo EEG measurement pre-training, which included education and practice on EEG measurement procedures, activities to be performed during EEG measurement, precautions during EEG measurement, and how to request assistance during EEG measurement before and after wearing the cap-type electrodes. After pre-training, EEG was measured for participants while they performed information recognition and memory activities through single and double-coded materials. Based on the collected EEG data, sLORETA analysis was conducted to analyze the EEG activation differences during information memory through single and double-coded materials.

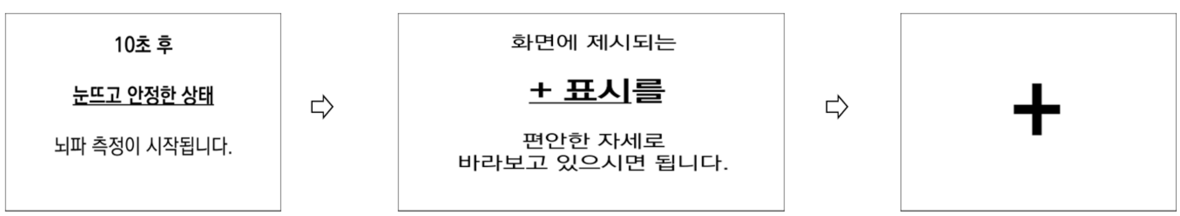
## EEG Measurements and Analysis

The EEG measuring device used in this study was the E-series EEG System device from an Australian company (Compumedics, 2002). The software used to collect EEG data was Profusion EEG software developed by the same company (Compumedics, 2002). Electrodes for EEG measurement were attached using a 32-channel Compumedics Neuroscan Quik-Cap. The Quik-Cap is a cap-type electrode in which electrodes are placed according to the 10-20 international electrode placement system (Jasper, 1958) and is worn on the head. The electrodes attached for EEG measurement totaled 34, including 30 active electrodes and 4 reference electrodes. The thirty active electrodes were attached to collect EEG data generated during the task, with 12 electrodes located in the frontal lobe, 9 in the parietal lobe, 6 in the temporal lobe, and 3 in the occipital lobe. Two of the four reference electrodes were attached to detect artificial miscellaneous band caused by blinking behavior, and the remaining two were attached to correct cerebral hemispherical deviations. Cap-type electrodes were worn while checking the electrode attachment state to ensure that the impedance, the resistance value between each electrode and the scalp, fell below 10 ㎐. The values set in the EEG measurement device were Sampling rate 512 ㎐, High pass filter 1 Hz, Low pass filter 70 ㎐, and Notch filter 60 ㏀.

To develop an EEG measurement task, six topics were selected from life science contents that high school sophomores did not learn in school. These topics included structural differences between C3 plant leaves and C4 plant leaves, phyllotaxis, ribosome structural differences, blood vessel-specific structural differences, pituitary anterior hormonal action mechanism, and structural differences between dicotyledonous and monocotyledonous plant roots. A pilot test was conducted to identify the difficulty of the task and select task material that matched the research topic, considering the view that the level of visual data content affects students' cognitive load when recognizing information through visual data. Based on the pilot test results, four subjects were finally selected as task materials: structural differences between C3 plant leaves and C4 plant leaves, phyllotaxis, structural differences by blood vessel, and pituitary anterior hormonal action mechanism.

The EEG measurement was conducted in a quiet laboratory environment, and the EEG measurement was conducted in the following order: EEG preparation (total 3,000 seconds, wearing cap-type electrodes 1,800 seconds, EEG measurement pre-training, 1,200 seconds) → eyes closed and stable state (60 seconds) → rest (30 seconds) → eyes open and stable state (60 seconds) → rest (30 seconds) → criteria task (60 seconds) → rest (30 seconds) → task performance [total 960 seconds, first textual information memory task (30 seconds) → memory check and rest (90 seconds) → first illustration information memory task (30 seconds) → memory check and rest (90 seconds) → second textual information memory task (30 seconds) → memory check and rest (90 seconds) → second illustration information memory task (30 seconds) → memory check and rest (90 seconds) → third illustration information memory task (30 seconds) → memory check and rest (90 seconds) → third textual information memory task (30 seconds) → memory check and rest (90 seconds) → fourth illustration information memory task (30 seconds) → memory check and rest (90 seconds) → fourth textual information memory task (30 seconds) → memory check and rest (90 seconds)]. It took a total of 20 minutes and 30 seconds for one participant to complete the EEG measurement. In accordance with the view that the presentation of tasks with the same content in the same order may affect the level of task performance of the participants (Jeong & Kim, 2022), the tasks were presented randomly to each participant.

The example and procedure of the reference task are shown in Fig. 1.




<Task Start Guide> <Task performance activity guide> <Performing a task>

**Fig. 1.** Criteria task example and progress order

The reference task aims to measure the background brain band that serve as a reference point for EEG activity occurring when information is recognized and recalled through single and dual coding materials. This task involves focusing on the '+' mark (Jeong & Kim, 2022), a visual marker that does not carry specific cognitive thinking aspects such as visual attention.

An example of a text task that recognizes and remembers information appropriate to the focal question through a single-code data that only provides textual information is shown in Fig. 2.

뇌하수체 전엽 호르몬

질문 : 뇌하수체 전엽 호르몬의 생성과 분비 과정은 무엇인가?

뇌하수체 전엽 호르몬의 생성과 분비는 시상하부의 신경분비세포에서 호르몬이 분비되는 것부터 시작된다. 분비된 시상하부 호르몬이 문맥을 통해 뇌하수체 전엽 내분비세포에 신호를 전달한다. 전달된 신호에 따라 뇌하수체 전엽 내분비세포에서 뇌하수체 전엽 호르몬이 생성된다. 생성된 뇌하수체 전엽 호르몬은 혈액으로 방출된다.

**Fig. 2.** Text task example

As shown in Fig. 2, in the text task, the focus question and the scientific concept related to the focus question are presented in a paragraph format on the screen. This task consists of memorizing the textual information presented on the screen within a given time and then recording the memorized information on a provided sheet to check the level of task performance.

The example of the illustration task, which involves recognizing and memorizing the information appropriate to the focus question through dual-coded materials that provide both pictures and textual information, are shown in Fig. 3.

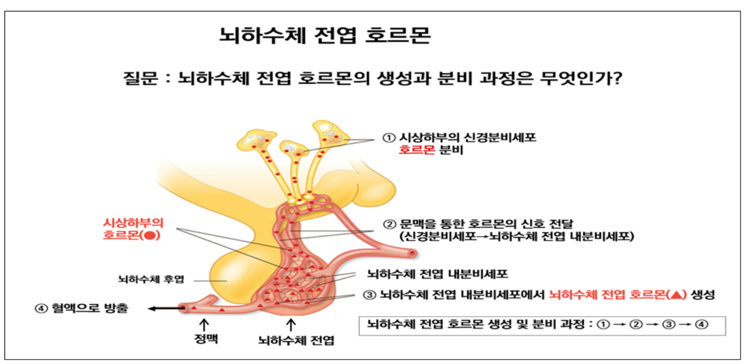



**Fig. 3.** Illustration task example

As evident from Fig. 3, in the illustration task, focal questions such as 'What is the process of generation and secretion of the anterior pituitary hormone?' were presented along with an illustration of the secretion process of the anterior pituitary hormone and brief textual information on the process of its generation and secretion, inserted at necessary locations within the illustration. In this task, participants memorized the visual and textual information presented on the screen within the given time. Subsequently, they recalled the information related to the question displayed on the screen for a few seconds and recorded the recalled information on the provided paper.

The sLORETA analysis was conducted to examine the differences in brain activity during the remembrance and recall of information through text and illustration tasks, focusing on the cortical subareas and the Brodmann areas known for functional division within the cerebral cortex. The sLORETA analysis was conducted using data from a 20-second segment judged to have minimal artifacts caused by muscle movements such as blinking eyes and eye movements. The entire brain area was divided into 6239 3D voxels with a size of 5mm×5mm×5mm, and the current density value was calculated for each voxel (Kwon, 2022). The process involved randomly comparing voxel data on brain current density for each task type when remembering and recalling information through text and picture assignments, performed 5,000 times in a statistical nonparametric mapping method. The subcortical region and the Brodmann region, considered to have meaningful activity for each task type, were estimated as current density values for each voxel calculated by the corresponding sample t-test method. The analysis results are presented in tables and figures.

The EEG frequency band used for sLORETA analysis included theta band in the 4.0-7.9 ㎐ band, alpha band in the 8.0-12.9 ㎐ band, beta band in the 13.0-29.9 ㎐ band, and gamma band in the 30.0-50.0 ㎐ band.

## Results

The results of the sLORETA analysis conducted to investigate the differences in EEG activation between text task information retention and the performance of the criteria task are shown in Table 1. The analysis showed that compared to the criteria task, there were statistically significant differences in current density activation in all frequency band of the EEG during the performance of the textual information retention task (two-tailed A<>B, P=0.0002).

**Table 1.** Analysis result of differences in brain activation areas according to task types

| Division | Log of F ratio of spectral densities | | | ExtremeP |
|---|---|---|---|---|
| | 0.01 | 0.05 | 0.10 | |
| One-Tailed (A>B) | 0.546 | 0.449 | 0.386 | 0.0002 |
| One-Tailed (A<B) | -0.553 | -0.453 | -0.394 | 0.0716 |
| Two-Tailed (A<>B) | 0.588 | 0.494 | 0.451 | 0.0002 |

As shown in Table 2 and Fig. 4, theta band activation was greater in four regions - the frontal lobe, temporal lobe, limbic lobe, and sublobar region - when performing a text memory task than when performing a criteria task. When examining this in more detail, in the frontal lobe, greater theta band activity was observed in the medial frontal gyrus, rectal gyrus, orbital gyrus, subcallosal gyrus, inferior frontal gyrus, middle frontal gyrus, superior frontal gyrus, and extra-nuclear regions, in the superior temporal gyrus of the temporal lobe, and in the anterior cingulate, uncus, and parahippocampal gyrus of the limbic lobe. In the sublobar region, greater theta band activity was observed in the insula and extra-nuclear regions when text tasks were used to memorize information.

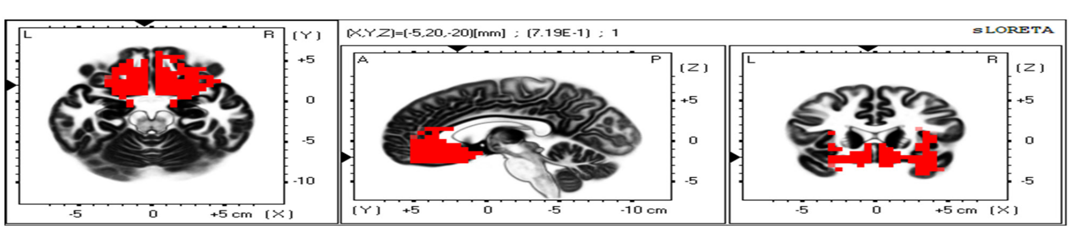



**Fig. 4.** The theta band activation difference in brain regions

**Table 2.** Text memory task and criteria task the theta band activation difference

| Lobe | Region | Cerebral Hemisphere | MNI Coordinate value | | | Voxel value |
|---|---|---|---|---|---|---|
| | | | X | Y | Z | |
| Frontal Lobe | Medial Frontal Gyrus | Left | -5 | 20 | -20 | 0.7189 |
| | Rectal Gyrus | Left | -5 | 20 | -25 | 0.7184 |
| | Orbital Gyrus | Right | 15 | 25 | -25 | 0.7177 |
| | Subcallosal Gyrus | Left | -5 | 20 | -15 | 0.7161 |
| | Inferior Frontal Gyrus | Right | 15 | 25 | -20 | 0.7159 |
| | Middle Frontal Gyrus | Right | 20 | 25 | -15 | 0.7094 |
| | Superior Frontal Gyrus | Right | 20 | 45 | -20 | 0.6916 |
| | Extra-Nuclear | Right | 30 | 20 | -10 | 0.6635 |
| Temporal Lobe | Superior Temporal Gyrus | Right | 25 | 15 | -40 | 0.6777 |
| Limbic Lobe | Anterior Cingulate | Left | -5 | 20 | -10 | 0.7101 |
| | Uncus | Right | 20 | 10 | -40 | 0.6732 |
| | Parahippocampal Gyrus | Right | 20 | 5 | -20 | 0.6360 |
| Sub-lobar | Insula | Right | 30 | 25 | 0 | 0.6730 |
| | Extra-Nuclear | Left | 25 | 20 | -10 | 0.6525 |

In the case of alpha band, the brain regions that showed relatively higher activation during the text memory task than the criteria task are shown in Table 3 and Fig. 5. The results show that the activation of the alpha band in the lingual gyrus of the occipital lobe is relatively higher when performing the textual information memory task compared to the criteria task.

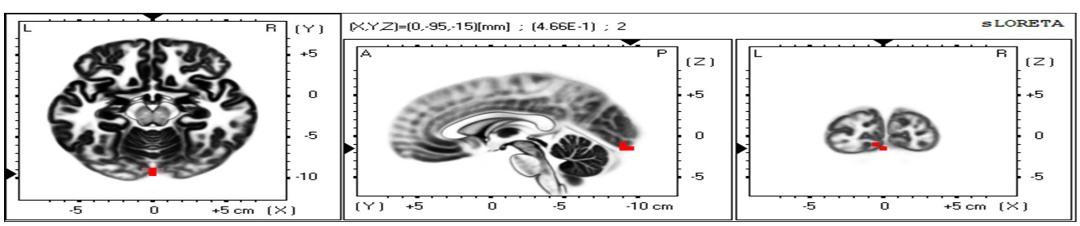



**Fig. 5.** The alpha band activation difference in brain regions

**Table 3.** Text memory task and criteria task the alpha band activation difference

| Lobe | Region | Cerebral Hemisphere | MNI Coordinate value | | | Voxel value |
|---|---|---|---|---|---|---|
| | | | X | Y | Z | |
| Occipital Lobe | Lingual Gyrus | Medial | 0 | -95 | -15 | 0.4656 |

In the case of beta band, the brain regions with relatively higher activation were the precuneus of the parietal lobe, the lingual gyrus of the occipital lobe, the cuneus, the middle occipital gyrus, the precuneus, and the posterior cingulate of the limbic lobe.

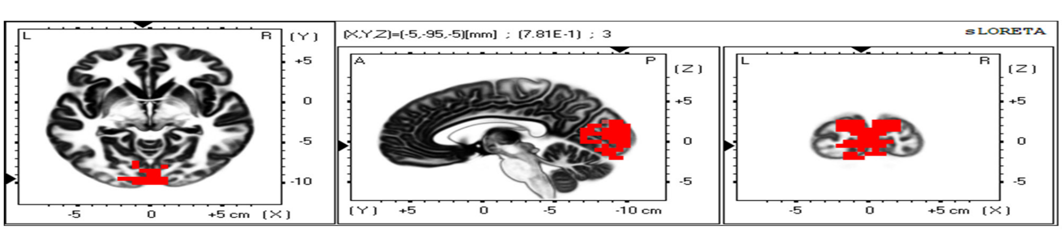



**Fig. 6.** The beta band activation difference in brain regions

**Table 4.** Text memory task and criteria task the beta band activation difference

| Lobe | Region | Cerebral Hemisphere | MNI Coordinate value | | | Voxel value |
|---|---|---|---|---|---|---|
| | | | X | Y | Z | |
| Parietal Lobe | Precuneus | Left | -5 | -75 | 20 | 0.5970 |
| Occipital Lobe | Lingual Gyrus | Left | -5 | -95 | -5 | 0.7810 |
| | Cuneus | Medial | 0 | -100 | -5 | 0.7742 |
| | Middle Occipital Gyrus | Left | -10 | -95 | 10 | 0.7009 |
| | Precuneus | Medial | 0 | -70 | 15 | 0.6006 |
| Limbic Lobe | Posterior Cingulate | Left | -5 | -70 | 10 | 0.6263 |

In the case of gamma band, the brain regions with relatively high activity were the precuneus of the parietal lobe, the cuneus of the occipital lobe, the lingual gyrus, the middle occipital gyrus, the precuneus, the inferior occipital gyrus, the superior occipital gyrus, the fusiform gyrus, the posterior cingulate of the limbic lobe, the cingulate gyrus, and the precuneus.

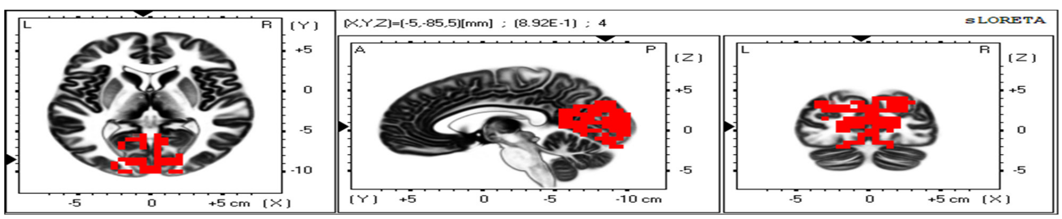



**Fig. 7.** The gamma band activation difference in brain regions

**Table 5.** Text memory task and criteria task the gamma band activation difference

| Lobe | Region | Cerebral Hemisphere | MNI Coordinate value | | | Voxel value |
|---|---|---|---|---|---|---|
| | | | X | Y | Z | |
| Parietal Lobe | Precuneus | Left | -5 | -75 | 20 | 0.8248 |
| Occipital Lobe | Cuneus | Left | -5 | -85 | 5 | 0.8924 |
| | Lingual Gyrus | Left | -5 | -90 | 0 | 0.8904 |
| | Middle Occipital Gyrus | Left | -15 | -90 | 10 | 0.8158 |
| | Precuneus | Medial | 0 | -70 | 15 | 0.8158 |
| | Inferior Occipital Gyrus | Left | -20 | -95 | -15 | 0.6900 |
| | Superior Occipital Gyrus | Left | -30 | -85 | 25 | 0.6674 |
| | Fusiform Gyrus | Left | -20 | -95 | -20 | 0.6641 |
| Limbic Lobe | Posterior Cingulate | Left | -5 | -70 | 10 | 0.8293 |
| | Cingulate Gyrus | Medial | 0 | -60 | 25 | 0.6743 |
| | Precuneus | Left | -15 | -60 | 25 | 0.6109 |

## Illustration Memory Task and Criteria Task EEG Activation Difference

The results of analyzing the EEG activation difference regions between the picture information memory task and the criteria task are shown in Table 6. Compared to the criteria task, there was a statistically significant current density activation in all frequency band of the EEG when performing the textual information memory task (two-tailed A<>B, P=0.0002).

**Table 6.** Analysis result of differences in brain activation areas according to task types

| Division | Log of F ratio of spectral densities | | | ExtremeP |
|---|---|---|---|---|
| | 0.01 | 0.05 | 0.10 | |
| One-Tailed (A>B) | 0.474 | 0.401 | 0.36 | 0.0002 |
| One-Tailed (A<B) | -0.493 | -0.402 | -0.357 | 0.0222 |
| Two-Tailed (A<>B) | 0.523 | 0.436 | 0.401 | 0.0002 |

The results of the analysis of brain regions where the difference in theta activity was observed when performing the picture information memory task compared to the criteria task are shown in Table 7 and Fig. 8. As can be seen from Table 7 and Fig. 8, in the frontal lobe, the middle frontal gyrus, superior frontal gyrus, inferior frontal gyrus, medial frontal gyrus, orbital gyrus, rectal gyrus, subcallosal gyrus, and extra-nuclear regions, in the temporal lobe, the superior temporal gyrus, middle temporal gyrus, and inferior frontal gyrus, in the limbic lobe, the anterior cingulate, uncus, and parahippocampal gyrus, and in the sublobar region, the insula and extra-nuclear, the theta band activity was greater when remembering the information of the illustration task.

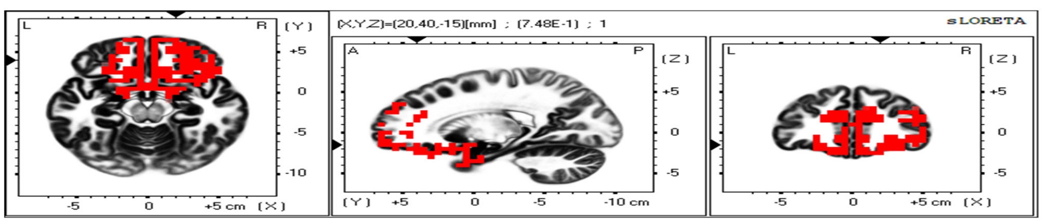



**Fig. 8.** The theta band activation difference in brain regions

**Table 7.** Text memory task and criteria task the gamma band activation difference

| Lobe | Region | Cerebral Hemisphere | MNI Coordinate value | | | Voxel value |
|---|---|---|---|---|---|---|
| | | | X | Y | Z | |
| Frontal Lobe | Middle Frontal Gyrus | Right | 20 | 40 | -15 | 0.7477 |
| | Superior Frontal Gyrus | Right | 25 | 45 | -15 | 0.7471 |
| | Inferior Frontal Gyrus | Right | 20 | 40 | -20 | 0.7458 |
| | Medial Frontal Gyrus | Right | 20 | 45 | -5 | 0.7458 |
| | Orbital Gyrus | Right | 20 | 40 | -25 | 0.7399 |
| | Rectal Gyrus | Right | 10 | 35 | -20 | 0.7315 |
| | Subcallosal Gyrus | Right | 5 | 20 | -15 | 0.7092 |
| | Extra-Nuclear | Right | 30 | 20 | -10 | 0.6684 |
| Temporal Lobe | Superior Temporal Gyrus | Right | 30 | 20 | -30 | 0.6723 |
| | Middle Temporal Gyrus | Right | 35 | 10 | -45 | 0.5698 |
| | Inferior Frontal Gyrus | Right | 35 | 10 | -15 | 0.5336 |
| Limbic Lobe | Anterior Cingulate | Right | 15 | 45 | -5 | 0.7360 |
| | Uncus | Right | 20 | 10 | -40 | 0.6465 |
| | Parahippocampal Gyrus | Right | 20 | 5 | -20 | 0.6114 |
| Sub-lobar | Insula | Right | 30 | 25 | 0 | 0.6950 |
| | Extra-Nuclear | Right | 35 | 20 | 0 | 0.6337 |

As shown in Table 8 and Fig. 9, for alpha band, compared to the performance of the criteria task, the medial frontal gyrus, rectal gyrus, inferior frontal gyrus, precentral gyrus, precuneus, inferior parietal lobule, superior parietal lobule, and anterior cingulate cortex of the frontal lobe showed relatively higher activation during the performance of the picture information memory task.

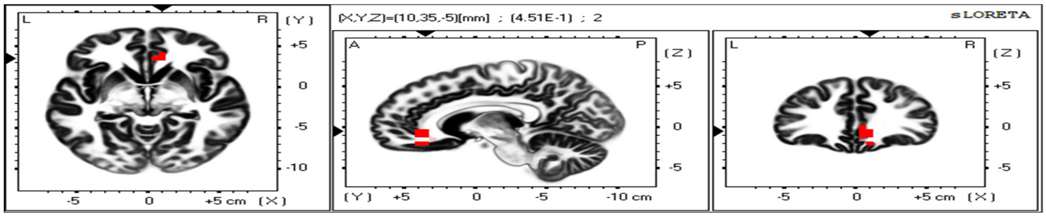



**Fig. 9.** The alpha band activation difference in brain regions

**Table 8.** Illustration information memory task and criteria task the alpha band activation difference

| Lobe | Region | Cerebral Hemisphere | MNI Coordinate value | | | Voxel value |
|---|---|---|---|---|---|---|
| | | | X | Y | Z | |
| Frontal Lobe | Medial Frontal Gyrus | Right | 10 | 40 | -10 | 0.4446 |
| | Rectal Gyrus | Right | 10 | 35 | -20 | 0.4390 |
| | Inferior Frontal Gyrus | Right | 10 | 40 | -20 | 0.4377 |
| | Precentral Gyrus | Left | -35 | -10 | 35 | -0.4360 |
| Parietal Lobe | Precuneus | Left | -25 | -50 | 45 | -0.4492 |
| | Inferior Parietal Lobule | Left | -35 | -40 | 40 | -0.4402 |
| | Superior Parietal Lobule | Left | -30 | -55 | 50 | -0.4394 |
| Limbic Lobe | Anterior Cingulate | Right | 10 | 35 | -5 | 0.4510 |

For beta band, as shown in Table 9 and Fig. 10, the precuneus of the parietal lobe, the lingual gyrus, cuneus, middle occipital gyrus, precuneus, and posterior cingulate cortex of the occipital lobe showed relatively higher activation during the picture information memory task than during the criteria task.

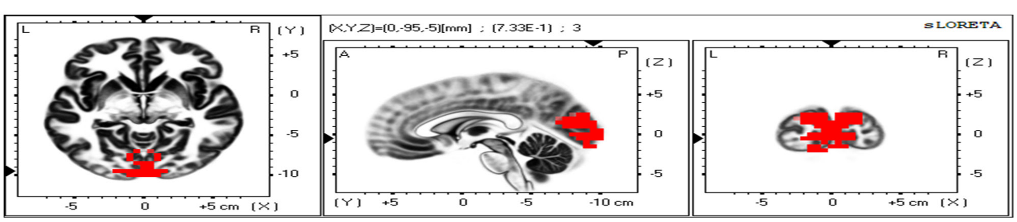



**Fig. 10.** The beta band activation difference in brain regions

**Table 9.** Illustration information memory task and criteria task the beta band activation difference

| Lobe | Region | Cerebral Hemisphere | MNI Coordinate value | | | Voxel value |
|---|---|---|---|---|---|---|
| | | | X | Y | Z | |
| Parietal Lobe | Precuneus | Left | -5 | -75 | 20 | 0.5650 |
| Occipital Lobe | Lingual Gyrus | Medial | 0 | -95 | -5 | 0.7329 |
| | Cuneus | Medial | 0 | -100 | -5 | 0.7255 |
| | Middle Occipital Gyrus | Left | -10 | -95 | 10 | 0.6460 |
| | Precuneus | Medial | 0 | -70 | 15 | 0.5716 |
| Limbic Lobe | Posterior Cingulate | Left | -5 | -70 | 10 | 0.5923 |

For gamma band, the precuneus of the parietal lobe, angular gyrus, and middle temporal gyrus of the temporal lobe showed relatively higher activation during the picture information memory task than during the criteria task. In addition, the cuneus, lingual gyrus, middle occipital gyrus, precuneus, inferior occipital gyrus, superior occipital gyrus, fusiform gyrus of the occipital lobe and the posterior cingulate cortex, cingulate gyrus, and precuneus of the limbic lobe showed relatively higher tgamma band activation during the picture information memory task.

**Table 10.** Illustration information memory task and criteria task the gamma band activation difference

| Lobe | Region | Cerebral Hemisphere | MNI Coordinate value | | | Voxel value |
|---|---|---|---|---|---|---|
| | | | X | Y | Z | |
| Parietal Lobe | Precuneus | Left | -5 | -75 | 20 | 0.8123 |
| Temporal Lobe | Angular Gyrus | Left | -35 | -80 | 30 | 0.5727 |
| | Middle Temporal Gyrus | Left | -35 | -85 | 20 | 0.5443 |
| Occipital Lobe | Cuneus | Left | -5 | -85 | 5 | 0.8754 |
| | Lingual Gyrus | Left | -5 | -90 | 0 | 0.8735 |
| | Middle Occipital Gyrus | Left | -15 | -90 | 10 | 0.8029 |
| | Precuneus | Medial | 0 | -70 | 15 | 0.7949 |
| | Inferior Occipital Gyrus | Left | -20 | -95 | -15 | 0.6744 |
| | Superior Occipital Gyrus | Left | -30 | -85 | 25 | 0.6528 |
| | Fusiform Gyrus | Left | -20 | -95 | -20 | 0.6463 |
| Limbic Lobe | Posterior Cingulate | Left | -5 | -70 | 15 | 0.8124 |
| | Cingulate Gyrus | Left | -5 | -60 | 25 | 0.6633 |
| | Precuneus | Left | -15 | -60 | 25 | 0.6149 |

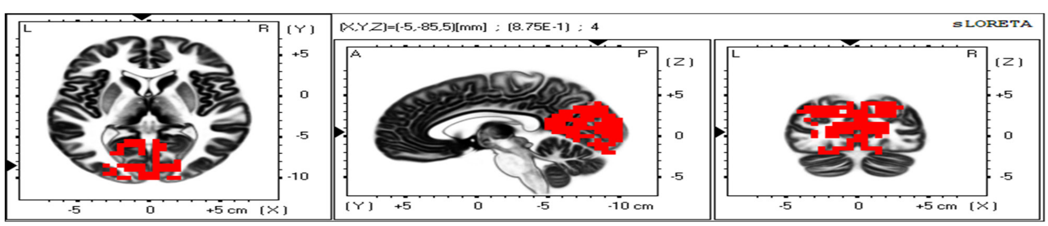



**Fig. 11.** The gamma band activation difference in brain regions

## Task and Illustration EEG Activation Differences

To investigate the differences in EEG activation when information is remembered through picture and text tasks, sLORETA analysis was performed.

**Table 11.** Analysis result of differences in brain activation areas according to task types

| Division | Log of F ratio of spectral densities | | | ExtremeP |
|---|---|---|---|---|
| | 0.01 | 0.05 | 0.10 | |
| One-Tailed (A>B) | 4.072 | 3.564 | 3.315 | 0.19840 |
| One-Tailed (A<B) | -4.001 | -3.544 | -3.302 | 0.00400 |
| Two-Tailed (A<>B) | 4.224 | 3.770 | 3.549 | 0.00940 |

As Table 11 shows, among the current density activations that occurred when information was remembered through dual-coded data (illustration task) and single-coded data (text task), statistically significant activations were observed only in the theta band (Two-tailed A<B, *P*= 0.00940).

As Table 12 and Fig. 12 show, the brain regions where relatively higher theta band activity was observed when performing a text task that only provides character information than a illustration task that provides both picture and character information were the middle frontal gyrus and the inferior frontal gyrus of the frontal lobe.

**Table 12.** Brain regions where differences in the theta band activation according to task types

| Lobe | Region | Cerebral Hemisphere | MNI Coordinate value | | | Voxel value |
|---|---|---|---|---|---|---|
| | | | X | Y | Z | |
| Frontal Lobe | Middle Frontal Gyrus | Left | -45 | 30 | 25 | -4.244 |
| Frontal Lobe | Inferior Frontal Gyrus | Left | -35 | 5 | 30 | -3.857 |

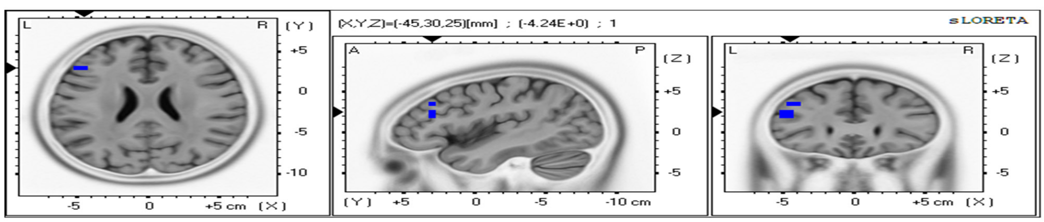



**Fig. 12.** Differences in brain activation regions by different types of memory tasks

## Discussions

Based on the results of this study, the discussion results are as follows:

First, the analysis of the differences in brain activity between the criteria task and the illustration task while remembering information through the text task and the illustration task showed that, in the case of theta band, the main brain areas with significantly increased activity when performing text or illustration information memory tasks compared to the criteria task were the superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus, medial frontal gyrus, orbital gyrus, superior temporal gyrus, anterior cingulate, parahippocampal gyrus, and insula of the temporal lobe.

The superior frontal gyrus, along with the middle frontal gyrus, is a brain region included in the dorsolateral prefrontal cortex (Koch, 2006), which plays an important role in the performance of cognitive thinking such as logical judgments based on analyzed information, maintenance of multiple information in working memory, adjustment of attentional level, selective attention to main information, language understanding, and sentence construction (Koch, 2006; Slotnick, 2017). The inferior frontal gyrus is a brain region known to be involved in the function of expressive language, such as speech, and is an area where activity is observed in the semantic processing of language, which involves understanding and interpreting the meaning of words and sentences (Banich & Compton, 2017; Kim & Jeong, 2021). The medial frontal gyrus is related to the response of recognizing information of visual objects, such as color or form of external visual information (Kim & Jeong, 2016). The orbital gyrus is known to be associated with brain functions such as emotion-related memory, cognitive control, and memory (Takahashi et al., 2019; Yan et al., 2019).

The superior temporal gyrus is a brain area that increases in activity when selectively attending to visual position information (Kim & Jeong, 2016).

The anterior cingulate is a brain region involved in processing stimuli by top-down or bottom-up thinking and allocating appropriate cognitive control to other brain regions, as well as decision-making to select final information (Banich & Compton, 2017). The parahippocampal gyrus is related to the encoding and representation of partial elements of visual objects and working memory for encoded position information (Kim & Jeong, 2016). The insula is activated when representing facts or related information experienced in the past to solve tasks (Kim & Jeong, 2016).

The meaning of the brain activation pattern can be understood through the activation characteristics of theta band, which increase in activity when task difficulty and cognitive load levels increase (Kim & Jeong, 2021; Korean Society for EEG and Neurophysiology, 2017). Through the activation characteristics of theta band, we can examine the changes in brain activity when performing text or illustration tasks compared to the criteria task, and both types of tasks were based on visual information presented on the screen, and the processes of encoding the meaning of words and sentences presented on the screen, representing past experience situations to understand the meaning of the information, and selectively maintaining memory of the information necessary to answer the focus question were performed. In addition, during the process of performing the picture memory task, a visualization process of combining pictures and letters was performed.

In the case of alpha band, the text memory task showed greater activation in the lingual gyrus of the occipital lobe than the criteria task. In contrast, the picture memory task showed greater activation in the medial frontal gyrus, inferior frontal gyrus, precentral gyrus, precuneus, inferior parietal lobule, superior parietal lobule, and anterior cingulate of the parietal lobe.

The medial frontal gyrus is related to the process of thinking about the external features of the observed object (Kim & Jeong, 2016). The inferior frontal gyrus is a brain region involved in language processing (Banich & Compton, 2017; Kim & Jeong, 2021). The precentral gyrus is a brain region involved in the semantic thinking process of encoding information intentionally retrieved and represented (Jeong & Kim, 2022; Talati & Hirsch, 2005).

The precuneus is one of the brain regions that constitute the default mode network (DMN; Default Mode Network System), which is activated when there is no external stimulus, and performs activities to distinguish information to be maintained in memory by reviewing information received from the outside and information stored in the brain as long-term memory (Kim & Jeong, 2021). The precuneus is known to increase in activity when performing cognitive thinking such as memory representation, review, and memory maintenance and inhibition (Li et al., 2019). The inferior parietal lobule is a brain region that is activated when maintaining memory of selected internal brain information for problem solving and retrieving it for task solving (Hester et al., 2007). Finally, the superior parietal lobule is a brain region involved in spatial direction, visual information recognition, attentional focus on spatial information, and working memory, such as mental rotation of objects (Gamberini et al., 2021; Wang et al., 2015).

The lingual gyrus is known to be involved in visual information processing and spatial learning ability (Choi et al., 2018; Kim & Jeong, 2021).

The anterior cingulate is involved in processing stimuli by top-down or bottom-up thinking and allocating appropriate cognitive control to other brain regions, and is also related to attention allocation and decision-making (Banich & Compton, 2017).

Alpha band are known to increase in activity when the level of mental relaxation is high or when the top-down information processing process of performing information-based thinking is carried out (Kim & Jeong, 2021; Korean Society for EEG and Neurophysiology, 2017). Through the characteristics of these alpha band, we can see that when remembering information through a text task, the top-down thinking is mainly performed to understand the structure of the sentence to grasp the meaning of the word and sentence. On the other hand, when recognizing information through an illustration task, the process of semantic encoding of character information, visualization information encoding, association of character information and visualization information, maintenance of memory for selected information, selective retrieval of long-term memory to understand the meaning of selected information, and selective retrieval of information appropriate to the situation are planned and performed through top-down thinking.

In the case of beta band, similar brain areas with increased brain activity were observed when performing text memory tasks or picture memory tasks compared to the criteria task. The brain areas with increased beta band activity compared to the criteria task were the precuneus of the parietal lobe, the lingual gyrus of the occipital lobe, the cuneus, the middle occipital gyrus, and the posterior cingulate of the limbic lobe.

The precuneus is known to increase its activity during cognitive thinking such as memory representation, review, memory maintenance, and inhibition (Li et al., 2019).

The lingual gyrus is a brain area related to spatial learning ability to identify information in a specific space and perception of patterns (Choi et al., 2018; Kim & Jeong, 2021). The cuneus is related to visual working memory (Kim & Jeong, 2019). The middle occipital gyrus is a brain area related to visual information encoding and internal imagery of past experiences and information in the mind without visual stimulation (Kim & Jeong, 2021).

The posterior cingulate cortex is one of the brain areas that constitute the DMN, and it is related to the thinking of selectively maintaining memories based on the necessity of reviewing recognized information (Kim & Jeong, 2021).

Considering that the level of beta band activity increases as the level of attention to actively receive external brain information increases (Kim & Jeong, 2021; Korean Society for EEG and Neurophysiology, 2017), the changes in beta band activity that occurred when performing the two types of tasks compared to the criteria task suggest that when remembering information through text or illustration tasks, it is necessary to focus on understanding the meaning of the presented characters or visualized information on the screen, encoding information that matches the focal question, and maintaining the memory of the encoded information.

In the case of gamma band, areas where significantly greater brain activity was observed than when performing the criteria task, such as alpha band, were more observed when performing the picture memory task. In the case of text memory tasks, greater activity was observed in 11 areas of the parietal lobe's wedge lobes (Precuneus), occipital lobe's Cuneus, lingual Gyrus, Middle Occidental Gyrus, Precuneus, Inferior Occidental Gyrus, Superior Occipital Gyrus, Fusiform Gyrus, Posterior Cingulate, Cingulate Gyrus, and Precuneus, respectively, when performing the criteria task, in 11 areas, greater activity of beta band was observed. On the other hand, in the case of the picture memory task, a larger gamma band activity was observed in 13 areas of the parietal lobe's wedge prefrontal lobe (Precuneus), temporal lobe's Angular Gyrus, temporal temporal gyrus, occipital Gyrus, lingual Gyrus, Middle Occidental Gyrus, Precuneus, Inferior Occidental Gyrus, Superior Occidental Gyrus, Fusiform Gyrus, Posterior Cingule, Cingulate Gyrus, and wedge prefrontal lobes.

The wedge-shaped lobes are one of the brain regions that make up the DMN and are related to memory representation, review of information to selectively maintain the memory, and cognitive thinking of selection (Kim & Jeong, 2021; Li et al., 2019). In particular, the wedge-shaped lobes located in the occipital lobe are also related to cognitive thinking such as internal image rotation of visual information and processing of spatio-temporal information (Crockford et al., 2005). The quite small lobes are related to visual working memory (Kim & Jeong, 2019). The tongue-shaped lobe is a brain region related to spatial learning ability, such as recognizing partial location information by recognizing visual information in a specific area (Choi et al., 2018; Kim & Jeong, 2021). The occipital lobe is related to visual information encoding and internal images that head-in-head situations and information experienced in the past without visual stimulation (Kim & Jeong, 2021). The spindle-shaped lobe is a brain region related to the 'What path' which is a visual information processing process that gives the shape or characteristic of an object (Kim & Jeong, 2016).

The posterior cingulate cortex is associated with thinking that focuses attention on stimuli received from the outside and suppresses memories of unnecessary stimuli (Kim & Jeong, 2021). The posterior cingulate cortex is associated with thinking of finally selecting a stimulus suitable for a given situation (Kim & Jeong, 2021)

Gamma band are EEG frequency band that are characterized by active integration of information received from the outside and increased activity when concentrating fully on the problem-solving process (Kim & Jeong, 2021; Korean Society for EEG and Neurophysiology, 2017).

Looking at the brain activity pattern of text or illustration tasks, which is more active than the criteria task, through the active characteristics of gamma band, it is necessary to perform cognitive thinking related to understanding the structure and meaning of sentences to recognize information appropriate to the focus question presented on the screen, and the process of selectively maintaining memory is performed only on the information judged to correspond to the focus question among the recognized information.

Second, the results of comparing the difference in brain activity when performing the text information memory task and the picture information memory task are as follows. The difference in brain activity when performing the two tasks was only observed in the theta band. When remembering the information from the text task rather than the illustration task, the areas of the brain where the relatively high activity of theta band was observed were the medial and inferior premolar. The cognitive load was also relatively low when students performed double-coded illustration tasks rather than single-coded text tasks, such as planning and implementing tasks, secondary integration of information received from other brain areas, selection of appropriate information, selective memory maintenance and forgetting, and goal-oriented attention concentration were carried out with a lower level of attention. The main findings of this study show that the cognitive thinking procedure performed to achieve the target behavior of remembering information through the text task, which is single-coded data, and the illustration task, which is double-coded data, is similar, but it is a slightly different cognitive activity in terms of cognitive load and attention level for visual information processing for understanding text information, information reconstruction, and selection thinking process.

## Conclusions and Implications

The purpose of this study was to examine the effects of text tasks, which are single-code materials that provide only textual information, and illustration tasks, which are dual-code materials that provide both text and picture information, on human information memory and recall at the level of brain activation. Based on this, we sought to examine the validity of cognitive psychology-based explanations for exploring the relationship between single and dual coding and human cognitive thinking. To this end, brain activity was measured while participating students performed cognitive tasks of recognizing and recalling information through picture and text tasks, and sLORETA analysis, a brain activity analysis method, was performed. The aim was to understand the effects of picture and text tasks on information memory and recall activities from a cognitive thinking perspective through brain activity analysis.

The results of the study are as follows:

First, we compared the brain activation that occurs when performing the criteria task with the brain activation that occurs when extracting and remembering information related to the focal question through the text task, and compared the brain activation that occurs when performing the criteria task with the brain activation that occurs when solving the picture memory task. As a result, we found a significant increase in activation in all EEG frequency band, such as theta, alpha, beta, and gamma band. This shows that the tasks of extracting and maintaining relevant memories through text or illustration tasks are tasks that involve additional cognitive processes than when performing a criteria task with no stimulation.

When looking at the main brain areas that showed increased activation compared to criteria task by task type, in the case of theta band, there was a significant increase in activation in the superior frontal gyrus, middle frontal gyrus, inferior frontal gyrus, medial frontal gyrus of the frontal lobe, superior temporal gyrus of the temporal lobe, anterior cingulate cortex, parahippocampal gyrus of the limbic lobe, and insula in the sublobar region. In the case of alpha band, a significant change in activation was observed in lingual gyrus of occipital lobe. In the case of beta band, significant changes in activation were observed in the precuneus, lingual gyrus, cuneus, middle occipital gyrus, and posterior cingulate cortex of the parietal lobe. In the case of gamma band, significant EEG activation increases were observed in the precuneus, cuneus, lingual gyrus, middle occipital gyrus, precuneus, fusiform gyrus, posterior cingulate cortex, cingulate gyrus, and precuneus of the parietal lobe compared to the criteria task.

In summary, in cognitive activities that require remembering information appropriate to a given situation through tasks such as letters and pictures, the process of composing letters to understand the meaning of the sentence, and selectively focusing attention on the memory of the related information depending on whether the information encoded in the long-term memory state through past experiences is retrieved and utilized to understand the meaning of the sentence received from outside the brain, and the process of inhibiting the memory of information that is not utilized to understand the sentence, are the main cognitive processes.

Second, the significant difference in brain activation between remembering information from text tasks and remembering information from illustration tasks was observed only in the theta band. Theta band showed relatively lower activation in the middle and inferior frontal gyrus when remembering information from illustration tasks than from text tasks.

The middle frontal gyrus is a brain area involved in cognitive thinking, such as maintaining memory of various information in working memory and adjusting attentional levels according to the importance level of information. In addition, the inferior frontal gyrus is involved in cognitive thinking that integrates information in working memory to make choices appropriate to the situation. Finally, theta band have a characteristic of increasing activation when task difficulty level and cognitive load on memory increase.

The fact that theta activity was lower in the middle and inferior frontal gyrus when remembering information through a dual-code task, which provides both text and picture information, than when remembering information through a single-code task, which only provides textual information, suggests that students performed cognitive tasks such as planning and execution for task resolution, secondary integration of information received from other brain areas, selecting appropriate information, selective maintenance and forgetting of memory, and goal-oriented attention with lower attention when performing tasks that provide both picture and textual information. And this means that the level of cognitive load was lower when remembering information through such thinking. These findings support the results of previous studies that have shown that providing two representational formats, such as pictures and textual information, at the same time has a positive effect on cognitive load (kwon, Yoo, & Jeong, 2012; Na & Sung, 2007; Park et al., 2012; Ryu & Jung, 2013). And it supports the results of previous studies that this area plays an important role in the cognitive task of maintaining and handling multiple pieces of information in working memory (Kwon et al., 2016).

The educational implications of these conclusions are as follows:

First, single and dual-code data differ in cognitive load and attentional level in the cognitive task process of generating information relevant to the given question from among various information and the cognitive task performance of maintaining memory of this information. This difference allows us to conclude that dual-code data is advantageous in terms of cognitive load when remembering information.

Second, the meaning of EEG activation can be understood through sLORETA analysis. The sLORETA analysis method has the advantage of being able to extract specific brain areas that are the internal neural current sources affecting EEG activation changes. These two EEG activation analysis methods will not only provide objective scientific evidence for various theories on data organization and presentation strategies presented in the science education domain, but also confirm the cognitive psychological explanation of the cognitive load of single and dual-code data through the results of this study.

Third, scientific knowledge covered in science textbooks includes phenomenal and factual knowledge, proximal knowledge, etc. Each of these types of knowledge describes different content. Knowledge learning is manifested as behavioral changes resulting from cognitive task performance, which is caused by changes in human brain activity. Human cognition can be understood through EEG activation changes with task-specific activation characteristics. In this regard, it is necessary to conduct a cognitive neuroscience-based study to identify effective data presentation methods for each type of scientific knowledge covered in science textbooks. This study can contribute to enhancing the effectiveness of science education and help learners understand and remember various types of scientific knowledge more effectively.

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## Authors' Information

Jeong, Jin-Su: Daegu University, Professor, First Author

Kim, Yong-Seong: The Research Institute for Special Education & Rehabilitation Science, Daegu University, Research Professor, Corresponding Author. https://orcid.org/0000-0001-6782-335X