Analysis of Cognitive Load for Language Processing Based on Brain Activities

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Abstract. The present study attempted to investigate the role of memory or cognitive load in language processing using an EEG. Twelve healthy right-handed male adults were asked to read a story twice and their brain activities were recorded using an EEG: (i) focusing on meaning of the content only (M) and (ii) focusing on both meaning and form or grammar (M+F). The results demonstrated significant differences in upper alpha and upper beta bands according to reading instructions, which indicates different degrees of cognitive load. The findings make a significant contribution to language acquisition in that they offer valuable information regarding memory and cognitive load in language processing. Thus, they help language researchers and educators in the field of second language acquisition (SLA) develop more effective ways of instructional design and in turn lead their students to better learning outcomes.

Keywords: reading comprehension, grammar acquisition, cognitive load, memory load, EEG, attention, second language acquisition.

1 Introduction

The present study investigated the role of cognitive load in second language acquisition (SLA) in terms of brain activities. Cognitive Load Theory (CLT) have been concerned with concocting teaching tools to help learners maintain an optimal level of load in various learning context [1]. SLA researchers have utilized CLT to account for differences in learner performance with regard to different learning tasks and reported that various factors, including learner's different cognitive abilities, level of English proficiency, and types of tasks, can cause cognitive overload which can diminish instructional outcomes [2, 3].

The majority of studies on the effects of cognitive load in language acquisition, including vocabulary acquisition and reading comprehension, have used performance scores and subjective worlkload self-evaluation [4-6]. As Gevins et al. [7, 8] address, performance scores and subjective measurements have provided overall cognitive load but appeared to lack objective and temporal information regarding mental efficiency. Conversely, using an EEG can measure concurrent brain activities and thus contribute to

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guiding better learning situation. Therefore, the present study attempted to compare relative mental efficiency in terms of cognitive load in language processing. Moreover, unlike previous studies that evaluated brain activities using sentence level texts [9], this study used a discourse level text (a story) and aimed to obtain more extended evidence regarding the shift of frequency bands in two reading conditions. Thus, this study can provide the evidence how brain reacts to different amount of attention or memory load in terms of reading comprehension and grammar learning.

This paper is organized as follows: Section 2 briefly introduces CLT for reading comprehension, and the proposed method based on an EEG signal analysis will be followed in Section 3. Section 4 includes the experimental results, and conclusion and future works will be described in Section 5.

2 Cognitive Load Theory and Reading Comprehension

CLT is mental effort for successful completion of a task [10]. CLT has three types of cognitive load: intrinsic (the level of inherent difficulty), extraneous (i.e., instructional materials), and germane (construction and automation of schema) cognitive load. CLT suggests that learning happens best under conditions that are aligned with human cognitive architecture, consisting of working memory that is limited in capacity when dealing with novel information. Some researchers argue that students learn better when provided with an optimum learning condition where cognitive load is minimized as much as possible [7, 8, 11].

Researchers have studied the relationship between cognitive load and language acquisition, For instance, Al-Shehri and Gitsaki's study [2] findings revealed that learners' reading comprehension (RC) performance can be enhanced by reducing the learners' extraneous cognitive load induced by format of instructional materials. For example, the students who read a text physically integrated with RC questions outperformed those presented the text split with the questions on the RC tests. In a similar vein, Akbulut [3] argues that too much input, such as glossaries, illustration, underlined, colored, or bolded words, can interfere with RC due to the increase in cognitive load. Moreover, Gevins el al's study findings [7, 8] also reported that task difficulty resulted in decreases in alpha signals but increases in amplitude of a frontal theta rhythm due to the increased memory load. These findings suggest that it is necessary for educators to eliminate redundant and distractive elements in order to maximize the effects of instruction or input and thus facilitate their students' learning.

3 Methods

3.1 Participants and Design

Twenty right-handed male undergraduate students whose L1 was Korean (eight participants were excluded from data analysis due to noise) participated in the study, and each of them were given a $10 certificate as a token of appreciation. Most of the participants included in the data analysis majored in English Education, except for three students who majored in Electrical Engineering (ages 19-21). Handedness, and gender were screened in order to control confounding variables. Also, all participants were with no history of neurological or psychiatric disorders, and their eyesight was normal or corrected to normal vision.

For this within-subject design experiment, the participants were instructed to read an African folktale, modified by Park, et al. [12], under two instructional conditions at their own pace. Specifically, the degree of attention and cognitive load were manipulated by giving different reading instructions. In the first reading, the participants were asked to simply read the text to understand the meaning of the content (M), whereas in the second reading task, they were asked to pay attention to grammatical features as well as meaning (M+F). The text was divided into eight slides, and four slides contained visually enhanced grammatical features (i.e., gerund and to infinitive), **boldfaced**, colored, and underlined in order to intentionally draw their attention to linguistic features. For instance, for the first reading, the first half of the text was visually enhanced (VIE+), and the second reading, vice versa, as in Figure 1.

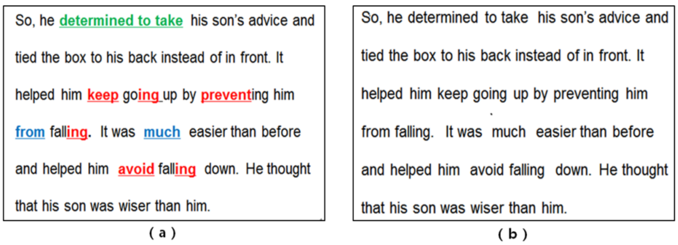

Fig. 1. Text samples presented on the computer screen (a) enhanced text (b) unenhanced text

3.2 EEG Recording and Stimuli

During the recording, the participants comfortably seated in front of a computer monitor in a laboratory and were requested to control blinking, swallowing, and other muscle movements to ensure the quality of the EEG data. Each session lasted about one hour including subject preparation. Based on the 10/20 international system, EEG activities were continuously recorded from 13 scalp locations (F3, F4, Fz, FCz, C3, C4, Cz, CPz, P3, P4, Pz, O1, and O2) by means of Ag/AgCl electrode caps. The electrode impedance was kept below 10 kΩ using a glass ohmmeter. The electrode Fz on the cap served as grounding, while a reference electrode was placed on the right and left ear lobes. The text appeared on a computer monitor, and the participants' brain activities were recorded using an EEG while reading the text by focusing on meaning only and then both meaning and grammar.

The hypothesis is that reading a text to understand the meaning of the content and to focus on grammatical features at the same time can lead to an increase in cognitive load and thus results in selective decreases in upper alpha and upper beta [11, 13]. On the other hand, an escalated cognitive load leads to a selective increase in theta and gamma power [14].

3.3 Data Analysis

All of the data were individually checked and excluded all contaminated with ocular, muscle, or other non-EEG activity. To differentiate the various frequency ranges, the EEG signal as a function of time is transformed into a function of frequency (spectrum) by Fast Fourier Transform (FFT). Broadband EEG was divided into the six frequency ranges: theta (4-7Hz), low alpha (8-10), upper alpha (10-13 Hz), low beta (13-18 Hz), upper beta (18-30.Hz), and gamma (30-70 Hz). Band powers within-subject factors were evaluated using separate paired *t*-tests on the differences in time varying amplitude between the degrees of cognitive load depending on reading conditions. Reading instructions (M/M+F) and two versions of text presentation (VIE- vs. VIE+) served as independent variables while band powers served as dependent variables.

4 Results

The paired *t*-test revealed that there were significant power differences between reading instructions at upper alpha and upper beta bands. In general, the participants spent longer reading time when reading the enhanced text (M = 102.41 s) than the unenhanced text (M = 89.59 s). However, there were no statistically significant power differences induced by visually enhanced input which is supposed to require greater memory and cognitive load. The reading conditions resulted in selective mean differences in upper alpha, upper beta, and theta.

4.1 Analysis of Upper Alpha Band

Reading instructions led significant mean differences at occipital (t = 2.166, P = .041). Also, a marginally significant mean difference was observed at frontal (t = 1.910, P = .068), as in Fig. 2. Specifically, alpha power at the frontal and occipital in the M+F condition was smaller than that of the M condition. The amplitude of both hemispheres was smaller in the M+F condition than that of the M condition, but the differences were marginally significant (t = 1.847, P = .078; t = 1.970, P = .061, respectively).

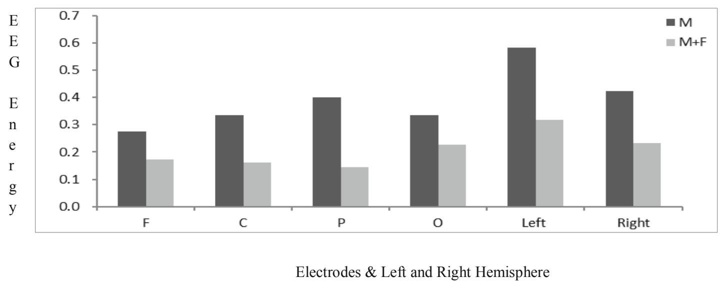

Fig. 2. Mean differences of reading instructions in upper alpha:
*F (Frontal), C (Central), P (Parietal), O (Occipital)

4.2 Analysis of Upper Beta Band

A significant mean difference was observed between the two reading conditions. That is, as shown in Fig. 3, reading the text in the M+F condition resulted in a significant decrease in the amplitude at the frontal, central, and occipital regions than the M condition: F (t = 8.228, P < .001), C (t = 4.082, P < .001), O (t = 3.566, P = .002). Also, hemispheric power declines in the M+F condition were significant compared to the M condition. Specifically, the two conditions yielded significant mean power differences in the right and left hemispheres: t = 7.119, P < .001; t = 3.975, P = .010, respectively.

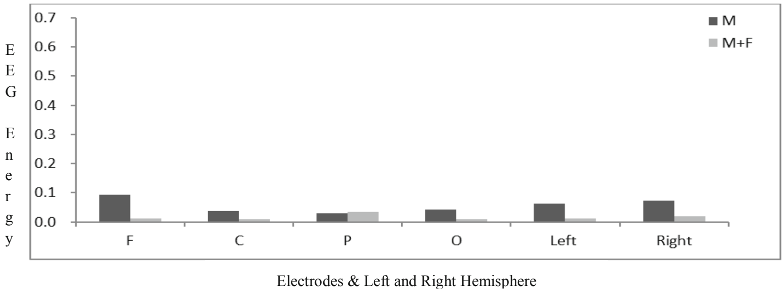

Fig. 3. Mean differences of reading instructions in upper beta:
*F (Frontal), C (Central), P (Parietal), O (Occipital)

4.3 Analysis of Theta Band

Theta power in the parietal region was greater in the M+F condition than that of the M condition, as in Fig. 4. No statistical significances, however, were observed. Also there were no hemispheric mean differences between the two reading conditions.

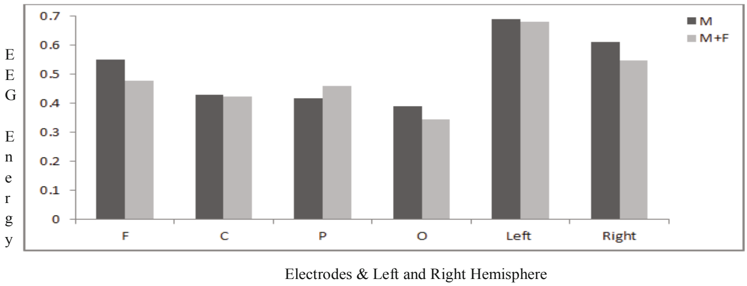

Fig. 4. Mean differences of reading instructions in theta:
*F (Frontal), C (Central), P (Parietal), O (Occipital)

4.4 Analysis of Gamma Band

Surprisingly, no significant mean differences were found between the two reading instructions, as shown in Fig. 5. However, when the participants were reading the text to comprehend the content only, the right hemispheric power of selective regions was greater than that of the left. Particularly, in the M condition, the hemispheric differences were significant at frontal and central regions: t = 3.796, P = .001; t = 2.281, P = .032, respectively. Conversely, reading a text with focusing on both form and meaning resulted in significant differences in frontal and parietal areas: t = 4.808, P < .001; t = 2.529, P = .019, respectively.

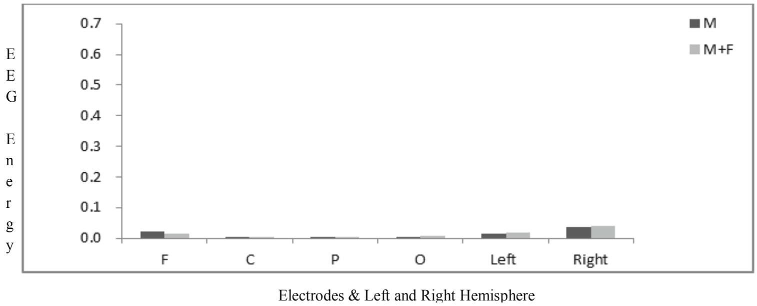

Fig. 5. Mean differences of reading instructions in gamma
*F (Frontal), C (Central), P (Parietal), O (Occipital)

5 Discussion and Conclusion

The present study differentiated cognitive load or mental effort by manipulating reading instructions. First of all, the findings show that the increased task load, reading the text with paying attention to both form and meaning, led to selective decreases in amplitude of upper alpha power at the frontal and occipital regions. The findings partially support Gevins et al's study findings [7, 8] in that reading a text by focusing on both form and meaning simultaneously escalated the level of attentional demands as well as cognitive load. In line with Bastiaansen et al's study [15], upper beta tends to behave like upper alpha. Specifically, upper beta power at frontal, central, and occipital regions attenuated in the M+F condition. As Bastiaansen et al. suggest, the beta response might be related to the sensory processing of the visual input.

In contrast to previous studies [13, 15], theta band power changes between two reading conditions displayed no significant differences in frontal area, although a decrease of theta amplitude in the M+F condition was greater than that of the M condition. Both the right and left hemispheres showed differences between the two reading conditions, which suggests that both hemispheres are related to comprehending meaning and learning grammar through reading.

Unlike Landau et al's study [16] that reported an increased gamma activity in states of attention, no significant mean differences in gamma band were found between the two reading conditions. The unexpected findings suggest that knowing the content of the text through the first reading might alleviate task load which could be induced by comprehending and focusing on grammatical elements concurrently.

Despite the contribution to the EEG literature in language processing, the present study has some limitations. First, this study analysis was based on rather small number of participants, so larger scale future studies are necessary for generalization. Second, this study collected mental effort data during reading a text only; therefore, future study needs to include mental effort or mental efficiency during both reading and testing in order to obtain broader understanding regarding the role of cognitive load in grammar learning as well as reading comprehension.

To conclude, the study revealed that cognitive load seemed to be varied according to the degree of memory or cognitive load manipulated by reading instructions. Specifically, EEG features in upper alpha and upper beta bands were sensitive to load manipulation. No significant correlation, however, between reading instructions and brain activities in theta and gamma bands. The results suggest that deliberate attention to both meaning and form might hinder meaning construction [12]. Nonetheless, cognitive load will have positive effects as long as the load is imposed by relevant activities such as practice which enhances or leads to the construction or automation of schemas [6]. Therefore, language educators should keep in mind not to present excessive load when designing instructional materials: instead, they should guide their students to develop both the construction and automation of schemas and thus learning to occur.

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