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Comparing Brain Activation between Students who Use Digital Textbooks and Those who Use Conventional Paper Textbooks

Abstract

The purpose of this study is to compare the effects of digital textbooks and conventional paper textbooks on brain activation during problem solving among elementary-school students. Subjects included 54 6th grade students who used either digital textbooks or paper textbooks. We measured theta waves, alpha waves, beta waves, and gamma waves using PolyG-I (LAXTHA Inc.). We found significant effects of the textbook type for all brainwaves in the prefrontal lobes. Our results suggest that the use of digital textbooks will enhance the development of cognitive and thinking processes during learning.

Keywords: *brainwave, digital textbook*

Introduction

Developments in information technology are leading to the classroom use of digital textbooks in many countries including the United States, Australia, and Finland (Ministry of Education, Science, and Technology [MEST], 2011). Digital textbooks are expected to help overcome some of the limitations of paper textbooks. Such limitations include limited content, difficulty in keeping up with the most current information, and limited types of learning activities. Digital textbooks also hold a promise for enabling individualized, self-directed learning experiences.

Korea has been developing digital textbooks since 1997 under the direction of the MEST. At present in Korea, digital textbooks have been developed for a total of

18 subjects (Korea Education and Research Information Service, 2011). Since 2007, digital textbooks have been used in model schools in Korea with promising results. The entire elementary, middle-school, and high-school curriculum is expected to switch entirely to digital textbooks by 2015 (MEST, 2011).

Students who use digital textbooks have greater opportunities for self-directed learning, higher overall learning achievement (Byun, Seo, Ryu, Yang, Choi, & Jeong, 2008), and enhanced problem-solving skills (Jeong, Lee, Seo, & Cho, 2008; Choi & Seo, 2008) compared with students who use conventional paper textbooks. Digital textbooks can provide personalized education based on the learning ability of each student. The students can receive immediate feedback through an objective assessment of their task-performing ability. Most of the research to date on the use of digital textbooks has focused on assessing students' learning ability and problem-solving skills. No studies have yet been conducted comparing the neurophysiological effects of using digital textbooks with those of using conventional paper textbooks.

Electroencephalography (EEG) is an economical, noninvasive method for examining neurological changes in the brain (Kang, Kang, Yang, Ku, & Kim, 2009). EEG quickly and directly collects data showing the functional state of the brain in real time while the brain is focused on a particular task (Kim & Chang, 2001; Florence, Guerit, & Guenguen, 2004).

Brainwaves are categorized according to the vibration frequency range into theta waves (4–7.99 Hz), alpha waves (8–12.99 Hz), beta waves (13–29.99 Hz), and gamma waves (30–50 Hz) (Kim & Chang, 2001; Jeon, 2010). Theta waves are most common during sleep, but they also appear during a stable waking state. Alpha waves are common during a relaxed and stable state. Beta waves, which have short amplitude, are associated with mental activity, attentive states, and concentration. Gamma waves indicate a nervous, stressed state or a recognition state such as reasoning. Depending on the cognitive style of the subject, the different types of brainwaves vary in their frequency of activation and in the areas of the brain where they occur (Fisher & Wilson, 1995; Jeon, 2010; Laxtha, 2012).

The purpose of this study was to examine the electroneurophysiological effects of digital textbook use. We measured the brainwave activity during problem solving among elementary-school students who use digital textbooks and compared it with that among elementary-school students who use conventional paper textbooks. We analyzed the differences in theta waves, alpha waves, beta waves, and gamma waves to compare brain-function characteristics between the two student groups.

Research Methodology

Sample Cohort

We measured the brainwave activity of 27 6th-grade students from an elementary school in Seoul, Korea, who had been using digital textbooks for longer than 1 year and 27 counterparts using conventional paper textbooks until now. The digital textbook group using digital textbooks included 19 males and 8 females, and the group using conventional paper textbooks included 18 males and 9 females. None of the students had any history of cerebral disease. Twenty-four hours prior to the measurement, we had prohibited all of the students who took part in the study from drinking coffee or soda or using any hair-care substances (such as hair conditioners or hair spray) that could affect the EEG measurements. None of the students had been eating for at least 2 hours prior to the measurement. Before taking the measurements, we had fully informed each of the students about the nature of the EEG and about the matters that would require their attention during the measurements.

We conducted a power analysis using G-Power 3.1 program (from http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3). We determined that with the effect size of 0.8, the power of 0.8, and the significance level of 0.05, the optimum number of sample subjects for a t-test was 58. However, we were only able to recruit 54 students who met the inclusion criteria (27 students each in the experimental and control groups).

Instrument and Procedures

We measured the brainwaves using PolyG-I (LAXTHA Inc., Daejeon, Korea), a computerized EEG meter. We converted the brainwave measurements to digital signals through a 12-bit A/D converter and saved them on a laptop computer in real-time through a RS-232 Port via a receiver. We used the sampling frequency of 256 Hz with the low-frequency cutoff of 0.7 Hz and the high-frequency cutoff of 50 Hz. We used 60 Hz for the notch filter. We used disk electrodes made of ion-plated gold.

We collected the brainwave measurements as follows. The student sat in the school counseling room, where there was minimum noise. We attached electrodes to the student's scalp and explained the tasks that the student would be asked to perform. We then instructed the student to maintain a stable state with eyes closed. During the measurement, we asked the student to maintain a stable state without moving their body and to focus on performing the task.

We placed electrodes on eight sites on the scalp including Fp1 (left prefrontal lobe), Fp2 (right prefrontal lobe), F3 (left frontal lobe), F4 (right frontal lobe), C5 (left central sulcus), C6 (right central sulcus), P3 (left parietal lobe), and P4 (right parietal lobe), according to the International 10/20 System of Electrode Placement. We used the point under the left ear as the reference and the point under the right ear as the ground.

For step 1 of the measurement, we measured brainwaves in the stable state while the student gazed naturally at a blank wall for 3 minutes. For step 2 of the measurement, we collected brainwave data starting at the moment a problem was given to the student. The students who used digital textbooks in class received their problem on a tablet PC. The students who used conventional paper textbooks in class received their problem on a piece of paper. We instructed the students in both groups to read the problem silently and then solve it.

Ethical Consideration

We obtained permission to conduct our study from the principal of the target school and from the classroom teachers. We provided the guardians of each student with a full description of the study and the EEG procedure, and we obtained written consent from each of the guardians for their children to participate. We indicated to the guardians that we would treat the students in an ethical manner, and that the students would not be harmed in any way by the study. We also indicated that the students or guardians could withdraw consent to participate at any time if they did not wish to participate, and that the collected data would be treated anonymously and used only for the purpose of this study. We confirmed that those who chose to participate in the study fully understood the goals and methods of the study, and we obtained written informed consent from each of the students and their guardians prior to performing any tests.

Data Analysis

We analyzed the data using SAS 9.1.3 as follows. First, we analyzed the general characteristics of the two groups using descriptive statistics, and we performed chi-squared tests or t-tests to evaluate the homogeneity of the general characteristics between the groups. Within each group, we computed the mean change and standard deviation in brainwave activity between the resting, stable state and the problem-solving state for each frequency range and electrode position. Then, we performed t-tests to compare the changes in brainwave activity between the two groups. We used the significance level of 95% for all of our statistical tests.

Results

General Characteristics

The general characteristics of the subjects are summarized in Table 1. The tests for homogeneity between the two groups showed that the groups were homogenous in all categories. The students who used digital textbooks reported 1.76 hours of daily computer use, while those who used conventional paper textbooks reported 1.46 hours of daily computer use. Most of the students reported that they used computers mostly in their home. There were no significant differences between the average numbers of years the students in each group reported having used computers. The students' academic performance in both groups was mostly in the upper range. The students in both groups reported, on average, being "very satisfied" with their school life.

Table 1. General characteristics

Characteristics		Digital textbook N=27 N (%)	Paper textbook N=27 N (%)	χ^2 or t	p-value
Gender	male	19 (70.4)	18 (66.7)	0.790	0.770
	female	8 (29.6)	9 (33.3)		
Length of computer usage (hr/day) Mean (SD)		1.76 (1.12)	1.46 (0.78)	0.680 (t)	0.262
Place of computer usage	school	1 (3.7)	0 (0.0)	5.360	0.813
	internet cafe	2 (7.4)	3 (11.1)		
	home	21 (77.7)	20 (74.0)		
	other	3 (11.1)	4 (14.8)		
Total years of computer usage (yr) Mean (SD)		5.89 (1.67)	5.78 (1.37)	0.840 (t)	0.792
Communication time with family per week	under 1 hr	11 (40.7)	4 (14.8)	1.020	0.075
	1 hr~3 hrs	11 (40.7)	13 (48.1)		
	over 3 hrs	5 (18.5)	10 (37.0)		
Grade	upper	15 (55.5)	11 (40.7)	3.180	0.687
	middle	10 (37.0)	13 (48.1)		
	lower	2 (7.4)	3 (11.1)		
Satisfaction with school-life Mean (SD)		4.21 (0.97)	3.98 (1.01)	0.160 (t)	0.292

Comparison Results

Table 2 shows the differences in brainwave activity between the resting state and the problem-solving state for each combination of frequency range, electrode position, and study group. We found significant differences between the two study groups in the Fp1 theta waves (p = 0.031), Fp1 alpha waves (p = 0.041), Fp1 beta waves (p = 0.031), Fp2 beta waves (p = 0.043), Fp1 gamma waves (p = 0.038), and Fp2 gamma waves (p = 0.033).

The theta-wave activity and alpha-wave activity in the left prefrontal lobe decreased in both study groups during problem solving. The beta-wave activity in the left and right prefrontal lobes increased during problem solving among the students who used digital textbooks; whereas it decreased during problem solving among the students who used conventional paper textbooks. The gamma-wave activity in the left and right prefrontal lobes increased in both groups during problem solving.

Table 2. The results of the ratio of brainwave activity difference between the stable and problem solving states

wave	location	Mean (SD)		t	p-value
		digital	textbook		
theta	Fp1	-0.086 (0.038)	-0.024 (0.039)	2.368	0.031
	Fp2	-0.091 (0.171)	-0.023 (0.242)	-1.201	0.235
	F3	-0.011 (0.115)	-0.014 (0.149)	0.082	0.935
	F4	-0.010 (0.087)	-0.019 (0.136)	0.286	0.776
	C5	0.003 (0.089)	0.009 (0.160)	-0.168	0.867
	C6	-0.018 (0.081)	0.000 (0.172)	-0.485	0.630
	P3	0.023 (0.077)	-0.016 (0.138)	1.254	0.215
	P4	0.021 (0.086)	-0.023 (0.142)	1.378	0.174
alpha	Fp1	-0.011 (0.051)	-0.004 (0.041)	-0.615	0.041
	Fp2	-0.007 (0.052)	-0.002 (0.037)	-0.391	0.097
	F3	-0.051 (0.077)	-0.049 (0.058)	-0.080	0.937
	F4	-0.045 (0.069)	-0.046 (0.060)	0.063	0.950
	C5	-0.027 (0.066)	-0.037 (0.065)	0.603	0.549
	C6	-0.034 (0.053)	-0.025 (0.061)	-0.570	0.571
	P3	-0.110 (0.107)	-0.100 (0.095)	-0.377	0.708
	P4	-0.114 (0.105)	-0.095 (0.078)	-0.752	0.456

wave	location	Mean (SD)		t	p-value
		digital	textbook		
beta	Fp1	0.039 (0.090)	-0.004 (0.116)	1.535	0.031
	Fp2	0.045 (0.086)	-0.001 (0.135)	1.487	0.043
	F3	0.024 (0.059)	0.009 (0.080)	0.813	0.420
	F4	0.016 (0.047)	0.012 (0.069)	0.207	0.837
	C5	0.014 (0.049)	-0.001 (0.080)	0.844	0.403
	C6	0.016 (0.055)	-0.005 (0.091)	1.015	0.315
	P3	0.031 (0.048)	0.038 (0.064)	-0.459	0.649
	P4	0.035 (0.054)	0.028 (0.058)	0.460	0.647
gamma	Fp1	0.645 (0.769)	0.273 (0.483)	2.128	0.038
	Fp2	0.605 (0.722)	0.314 (0.678)	1.525	0.033
	F3	0.517 (0.920)	0.443 (0.499)	0.370	0.713
	F4	0.584 (1.344)	0.376 (0.577)	0.740	0.463
	C5	1.227 (1.395)	0.953 (1.265)	0.756	0.453
	C6	1.500 (1.614)	1.382 (1.535)	0.277	0.783
	P3	0.630 (1.251)	0.569 (0.359)	0.245	0.807
	P4	0.623 (1.122)	0.603 (0.385)	0.084	0.933

Discussion

We measured the brainwaves of elementary-school students during a stable, resting state with eyes open and during a problem-solving state in order to compare the level of brain activation between the students who used digital textbooks and those who used conventional paper textbooks. We found significant differences between the student groups in the brainwave activity at the Fp1 and Fp2 electrodes in the prefrontal lobe. The activities of theta waves and alpha waves at the Fp1 electrode decreased in both groups during problem solving. Low levels of theta waves and alpha waves indicate an emotionally relaxed state (Jeon, 2010, pp. 13–16). Thus, our results indicate that both groups of students were in a relaxed state while they solved their problems. The theta-wave activity and alpha-wave activity were lower among the students who used digital textbooks, suggesting that they were more relaxed and concentrated during problem solving than the students who used conventional paper textbooks. Our findings are consistent with those of Kim and Shim, who reported a low degree of theta-wave activity associated with a concentrated state in middle-school students (Kim & Shim, 2010, p. 39). Another

study that measured brainwave activity in elementary-school students who had difficulties concentrating reported finding lowered levels of theta-wave activity and alpha-wave activity after the students improved their concentration abilities by participating in a "brain education" program (Bae, 2009, pp. 71–72).

The beta-wave activities in the left and right prefrontal lobes increased during problem solving among the students who used digital textbooks and decreased during problem solving among the students who used conventional paper textbooks. High levels of beta-wave activity are associated with mental concentration (Jeon, 2010, pp. 13–16). We observed an increase in beta-wave activity among the students who used digital textbooks before and after the problem-solving process. Our findings are similar to those of Shim and Ko, who measured brainwaves in adolescents and observed a high degree of beta-wave activity when the subjects were in a concentrated state (Shim & Ko, 2009, pp. 17–19).

The gamma-wave activity in the left and right prefrontal lobes increased in both groups during problem solving. The activation of gamma waves during problem solving indicates that both groups were in the recognition state while solving their problems (Laxtha, 2012). Our results suggest that the students who used digital textbooks were more concentrated while they solved problems than the students who used conventional paper textbooks.

According to the findings of this study, the use of digital textbooks in elementary-school classrooms helps students to concentrate during problem solving. One reason digital textbooks may improve cognitive and thinking mechanisms is that their interactive nature makes them more interesting to the students. Our results support the expectation that the use of digital textbooks will have positive effects on student learning by increasing student interest in the curriculum.

Because this study only included one elementary school, further research is necessary to interpret and generalize the results. In addition, because the period of utilization of the digital textbooks in this study was only 1 year and 6 months, future research should be conducted to measure more long-term effects of the use of digital textbooks on the growth and development of students.

Conclusions

We measured the brainwaves of elementary-school students during problem solving in order to compare the electroneurophysiological effects of digital textbook use with those of conventional paper textbook use. We found significant differences in the brainwave patterns in the prefrontal lobes between the students

who used digital textbooks and those who used conventional paper textbooks. Our results suggest that digital textbooks are superior to conventional paper textbooks for improving the abilities of students to concentrate while engaged in cognitive and thinking processes such as problem solving. We expect that the use of digital textbooks will have a positive impact on learning through its positive effects on brain activation.

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