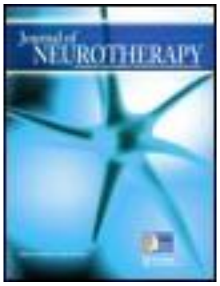

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EEG Asymmetry Analysis of the Left and Right Brain Activities During Simple versus Complex Arithmetic Learning

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ABSTRACT. *Introduction*. Repeated practice of simple arithmetic such as addition, subtraction, and multiplication has been widely used for effective math education. Brain activity patterns during simple and complex arithmetic calculation have been explored by several research groups using magnetic resonance images (MRI) and functional MRI (fMRI), and some have reported that the balanced whole brain (both left and right brain) activities during simple arithmetic in contrast to the predominant left brain activities during complex arithmetic.

Methods. In this work, we have identified the characteristic brainwaves and asymmetric activation patterns of the left and right brain during the process of simple and complex arithmetic by measuring theta, alpha, Sensory Motor Response (SMR), and beta brainwaves of 24 participants from the location FP1 (left brain) and FP2 (right brain) using EEG.

Results. Simple statistics analysis showed the significantly different beta activities from the left brain during complex arithmetic compared to simple arithmetic process, and through the asymmetry analysis of the left and right brain activities, less symmetrical brain activation during complex calculation, that is, specifically higher SMR, and beta brainwaves in the left hemisphere more than right hemisphere was identified, which is consistent with recent fMRI findings.

Conclusion. The results imply that simple arithmetic process may improve the whole brain activities in a balanced way while complex arithmetic induce unbalanced activities of the left and right brain.

KEYWORDS. Asymmetry analysis, complex arithmetic, EEG, simple arithmetic

INTRODUCTION

Many educational materials including repeated simple arithmetic such as addition, subtraction, and multiplication have been used for effective math education. Kumon Inc., one of the companies publishing such material, claims that repeating simple arithmetic activates wider area of both left and right brain, whereas complex arithmetic mostly activates the left hemisphere (Kawashima, 2003). They measured the brain activities of five college students using functional magnetic resonance images (fMRI). This was supported by Delazer et al. (2003), who suggest that the left

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hemisphere is predominantly triggered in the learning processes of complex arithmetic. Other research groups have investigated the brain activity patterns during simple arithmetic using fMRI (Tang et al., 2006; Zhou et al., 2007).

Triggering balanced whole brain activation of both left and right brain is considered important to improve creativity (Hermann, 1991; McCallum & Glynn, 1982). Thus it is worthwhile to explore the asymmetry of left and right brain activation during the process of simple versus complex arithmetic. Although previous work have been performed using fMRI, there has been little investigation comparing four characteristic brainwaves (θ, α, Sensory Motor Response [SMR], and β) of left and right brain during simple and complex arithmetic.

In this work we compared the EEG during simple versus complex arithmetic learning by measuring four characteristic brainwaves (θ, α, SMR, and β) from the location FP1 (left brain) and FP2 (right brain) following the international 10–20 system. The acquired EEG signals from 24 participants were analyzed with an asymmetry index of the left and right brain and canonical correlation analysis.

METHODS

Twenty-four students (5 men and 19 women) volunteered to participate in the study. Participants signed consent forms prior to the experiment. To reduce artifacts, they were taught to restrain from blinking. An eye-closed baseline for 1 min and an eye-open baseline for 1 min were recorded before task activity. In this work, we adopted the eye-open stage, the similar condition to the learning process to identify the differences. Two sessions of 1-min simple arithmetic, and 1 min of complex arithmetic process alternated with 30 sec of a rest period between each session. The problem set for simple arithmetic consisted of simple 26 addition, 26 subtraction, and 26 multiplication problems, and the set of complex problems consists of 15 difficult subtraction, 15 serial subtraction (e.g., 7 – 1 – 54), and 15 multiplication and division mixed problems (e.g., $9 \times 7/3$). Participants solved problems in mental arithmetic and were not required to write the answers on paper. During arithmetic sessions, the participants' brainwave responses in two EEG locations—FP1 and FP2—were monitored with 256 Hz sampling rate using Biotrace^{TM} software coming with Nexus 10 (Mindmedia BVTM, Netherlands).

The EEG signals obtained from each learning process were transformed using Fast Fourier Transform and analyzed to identify significant brainwave changes between simple and complex arithmetic. The difference in brainwaves from the left and right brain (i.e., hemisphere asymmetry) was calculated by the difference between the relative power of signals from the left and right brain (Equation 1). A positive asymmetry index represents the signal from the left brain is stronger than that from the right brain, whereas a negative index means the opposite case. The larger absolute value means the stronger asymmetry in the left and right brain.

asymmetry index = relative power of the left brain − relative power of the right brain

We calculated the mean and standard deviation of four brainwave activities (θ, α, SMR, and β) from the left and right brain during simple and complex arithmetic processes and performed canonical correlation analysis to identify the relationship between factors of simple arithmetic and complex arithmetic processes. Canonical correlation analysis is a statistical method to identify and quantify the associations between two sets of variables (Hotelling, 1935, 1936). Canonical correlation analysis focuses on the correlation between a linear combination of the variables in one set and a linear combination of the variables in another set. Canonical correlations measure the strength of association between the two sets of variables.

The effectiveness of this method is evident because of the following facts. First, it is practical to verify and investigate the level of interaction between the two variable groups. Second, it is useful to verify the relative contribution of individual variables in the correlation between two variables and estimate the other variable group by producing a weight that maximizes the correlation between linear combinations in two variable groups. Third, method can be used to analyze several dependant variables compared to the multiple regression analysis that uses one dependant variable.

RESULTS

To identify characteristic differences of brain activities during simple arithmetic versus complex arithmetic processes, we performed asymmetry analysis and canonical correlation analysis using SPSSWIN 12.0 to brainwave activity measurements from participants while they were solving given arithmetic problems. Table 1 and Figure 1 show basic statistics including mean and standard deviation of four brainwave activities (θ, α, SMR, and β) from left brain and right brain during simple and complex arithmetic processes. Among them, only β brainwave of the left brain shows significant difference ($p < .05$) for simple versus complex arithmetic while no significant difference in right brainwaves though they show similar patterns with those of the right brain.

To investigate whether the given process activates both the left and right brain in a balanced manner, we calculated the difference of relative powers from left and right brain, called "asymmetry index." Positive asymmetry indexes mean that brainwaves from the left brain have higher activity values than those from the right brain, and negative indexes mean the opposite case. Also, the larger magnitude of asymmetry index implies the more asymmetry of brainwaves from the left and right brain. Figure 2 shows that complex arithmetic process yields higher asymmetry index than simple arithmetic for three of four brainwaves, and especially β and SMR brainwaves show significantly higher asymmetry indexes during complex arithmetic

FIGURE 1. Activities of the left and right brain from simple versus complex arithmetic learning.

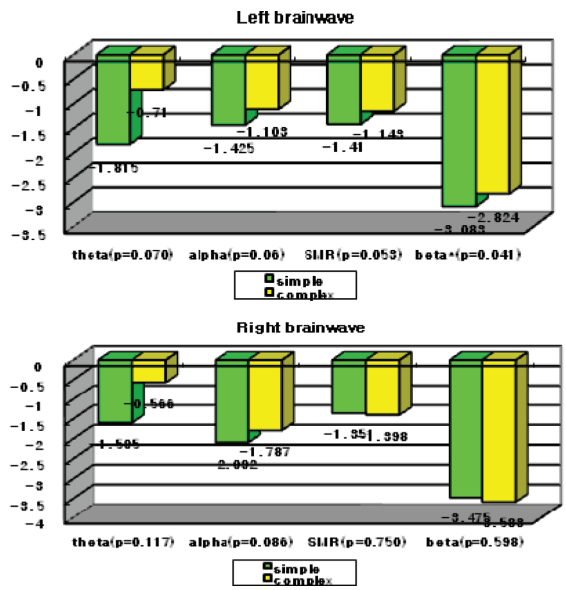
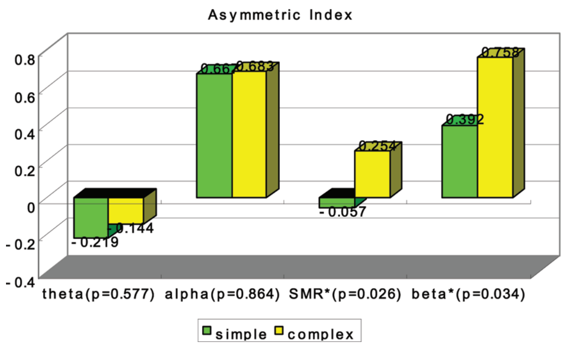


TABLE 1. Mean and standard deviation of the brainwave activities.

Factor	Variable	Left Brain Activities		Right Brain Activities	
		M	*SD*	*M*	*SD*
Simple arithmetic	θ	−1.82	3.5	−1.60	4.3
	α	−1.43	1.3	−2.09	5.8
	SMR	−1.41	0.9	−1.35	1.8
	β	−3.08	2.3	−3.48	3.9
Complex arithmetic	θ	−0.71	4.4	−0.57	5.0
	α	−1.10	1.5	−1.79	5.9
	SMR	−1.14	1.1	−1.34	1.6
	β	−2.82	2.4	−3.58	3.8

Note. SMR = Sensory Motor Response.

FIGURE 2. Asymmetry index for simple versus complex arithmetic (*$p < .05$).



process ($p < .05$). The results suggest that complex arithmetic activates the brain in more unbalanced way, specifically activates the left brain more than right brain, which is consistent with the previous work by Kawashima (2003) and Delazer et al. (2003).

To identify the relationship between factors of simple arithmetic and complex arithmetic, we performed canonical correlation analysis, and the results were summarized in Table 2 and Table 3 for the left and right brain, respectively. In the left brainwave activities, canonical correlation coefficients between brainwaves from simple arithmetic and complex arithmetic are all significant for the four canonical variates (0.995, 0.911, 0.904, and 0.683). Also, top three canonical variates of the left brainwaves explain 65.9% and 66.2% of variance for simple and complex arithmetic, respectively. For both simple and complex arithmetic, SMR, and β brainwaves show the highest importance to the first canonical variate showing higher standardized canonical correlations and canonical loadings.

From the results of the first canonical variates, β and SMR brainwaves from simple arithmetic are identified as the most impacting waves to the brainwaves from complex arithmetic showing their cross loadings -0.928 and -0.573, respectively. Also, those two brainwaves are ranked at top among brainwaves from complex arithmetic in affecting simple arithmetic having cross-loadings -0.916 and -0.555, respectively. However, in the second canonical variates, α and SMR waves take the important portion among brainwaves from both simple and complex arithmetic, and they are the most affecting brainwaves from simple arithmetic to complex arithmetic and also in reverse way.

The results of the right brain activities show that canonical correlation coefficients of the top four canonical variates of brainwaves from simple arithmetic and complex arithmetic are 0.994, 0.987, 0.924, and 0.674, which are all significant. Also, the first two canonical variates of brainwaves from both simple arithmetic and complex arithmetic explain 67.4% and 63.3% of total variance, respectively.

Among the brainwaves of the first canonical variates from both simple and complex arithmetic, α waves take the largest contribution showing the highest magnitude of standardized canonical correlation coefficients and canonical loadings. From the second canonical variates, α, SMR, and β waves have the highest weights among the brainwaves from both simple and complex arithmetic.

From the cross loading analysis of the first canonical variates, the most affected brainwaves of simple computation to brainwaves of complex computation are α, θ, and β, in that order, and their cross loadings are -0.969, -0.627, and -0.480, respectively. They show the same pattern in reverse way showing the cross loading -0.979, -0.606, and -0.500, respectively. However, from the second canonical variates, SMR and β waves are shown to be the most affected brainwaves across simple and complex arithmetic.

To understand characteristics of each participant, we visualized each participant in a plot where the x and y axis represent first canonical scores of brainwaves from simple arithmetic, and complex arithmetic, respectively (Figure 3). In the plot for the left brain, most participants were located in the first quadrant, especially Participants 9, 12, 16, 17, and 19, who showed very high brainwave activities during both simple and complex arithmetic. On the other hand, the plot for the right brain showed all participants except one were near the origin implying that brainwaves from both simple and complex arithmetic are not highly active.

TABLE 2. Canonical correlation analysis of left-sided brainwaves from simple and complex arithmetic.

Left Brainwave	1st Canonical Variates			2nd Canonical Variates			3rd Canonical Variates			4th Canonical Variates		
	SCC	CL	CCL	SCC	CL	CCL	SCC	CL	CCL	SCC	CL	CCL
Simple arithmetic												
θ	−0.112	0.030	0.030	−0.936	−0.047	−0.043	−0.683	−0.596	−**0.539**	−0.690	−0.801	−**0.547**
α	0.233	0.077	0.076	1.203	0.713	**0.649**	−0.943	−0.477	−**0.431**	0.640	−0.508	−0.347
SMR	0.398	−0.576	−**0.573**	0.244	0.500	**0.456**	2.062	0.059	0.053	−1.533	−0.643	−**0.440**
β	−1.302	−0.933	−**0.928**	−0.081	0.285	0.259	−1.373	−0.016	−0.014	0.978	−0.219	−0.149
Complex arithmetic												
θ	−0.200	0.077	0.077	−1.059	−0.134	−0.122	−0.907	−0.618	−**0.559**	−0.407	−0.771	−**0.527**
α	0.307	0.146	0.145	1.082	0.652	**0.594**	−0.763	−0.593	−**0.537**	0.454	−0.448	−0.306
SMR	0.442	−0.558	−**0.555**	0.544	0.422	0.384	1.885	−0.050	−0.045	−1.560	−0.712	−**0.487**
β	−1.322	−0.921	−**0.916**	−0.248	0.313	0.285	−1.340	−0.061	−0.055	0.984	−0.225	−0.154
CCC		0.995**			0.911**			0.904**			0.683*	
χ^2		159.530			75.885			43.165			11.635	
df		16			9			4			1	
p		$< .001$			$< .001$			$< .001$			.001	
Cumulative R^2												
Simple		0.302			0.512			0.659			1.000	
Complex		0.297			0.477			0.662			1.000	

Note. Bold indicates significant correlation SCC = standard canonical correlation coefficient; CL = canonical loading; CCL = cross loading; SMR = Sensory Motor Response; CCC = canonical correlation coefficient.

*$p < .01$. **$p < .001$.

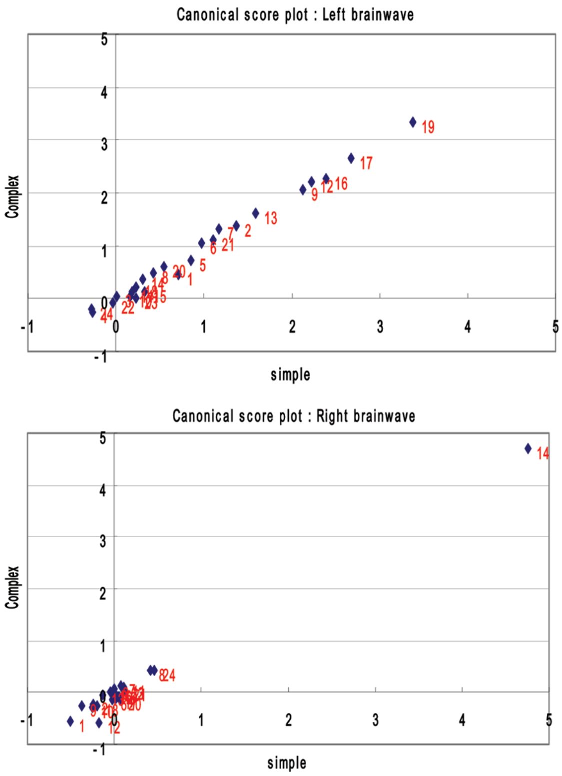
TABLE 3. Canonical correlation analysis of right-sided brainwaves from simple and complex arithmetic.

Right Brainwave	1st Canonical Variates			2nd Canonical Variates			3rd Canonical Variates			4th Canonical Variates		
	SCC	CL	CCL	SCC	CL	CCL	SCC	CL	CCL	SCC	CL	CCL
Simple arithmetic												
θ	−0.023	−0.631	**−0.627**	0.101	0.204	0.201	1.272	−0.245	−0.226	1.805	0.707	**0.477**
α	−1.049	−0.974	**−0.969**	−1.195	0.158	0.156	−1.881	−0.140	−0.129	−1.243	0.077	0.052
SMR	0.233	−0.114	−0.113	−1.243	0.663	**0.654**	−3.358	−0.622	**−0.575**	−0.597	0.400	0.270
β	0.020	−0.483	**−0.480**	2.574	0.774	**0.764**	2.925	−0.356	−0.329	0.290	0.202	0.136
Complex arithmetic												
θ	0.004	−0.609	**−0.606**	0.138	0.019	0.019	0.812	−0.126	−0.117	1.409	0.782	**0.528**
α	−1.074	−0.985	**−0.979**	−1.155	0.121	0.119	−1.239	−0.112	−0.103	−1.009	0.055	0.037
SMR	0.123	−0.128	−0.127	−1.146	0.579	**0.571**	−2.466	−0.721	**−0.666**	−0.275	0.359	0.242
β	0.078	−0.503	**−0.500**	2.386	0.754	**0.744**	2.070	−0.393	−0.363	0.337	0.154	0.104
CCC		0.994**			0.987**			0.924**			0.674*	
χ^2		196.096			113.876			46.807			11.220	
df		16			9			4			1	
p		$<.001$			$<.001$			$<.001$			.001	
Cumulative R^2												
Simple		0.398			0.674			0.822			1.000	
Complex		0.403			0.633			0.809			1.000	

Note. Bold indicates significant correlation. SCC = standard canonical correlation coefficient; CL = canonical loading; CCL = cross loading; SMR = Sensory Motor Response; CCC = canonical correlation coefficient.

*$p < .01$. **$p < .001$.

FIGURE 3. Canonical score plot.



CONCLUSION

We have explored the characteristic brainwaves and asymmetric activation patterns of the left and right brain during the process of simple and complex arithmetic by measuring θ, α, SMR, and β brainwaves from the location FP1 (left brain) and FP2 (right brain) using EEG. The simple statistics of brainwaves shows that β brainwaves of the left brain showed significantly higher activities ($p < .05$) during the complex arithmetic compared to the simple arithmetic process while no significant difference has been identified in the right brainwaves. The higher β brainwaves in the left brain during the complex arithmetic implicate that the complex computation induces more attention and activation in the left brain. Also, asymmetry analysis of the left and right brain activities suggests that complex calculation activates the brain in an unbalanced way, activating the left brain more than right brain, which is consistent with Kawashima (2003) and Delazer et al. (2003).

Brainwaves are manifestation of controlled activities of neurons during thinking and behavior (Nak, 1992; Paula, 2001). It is important for learners to improve their learning capability by using both the left and right brains in a balanced way. Actually, creativity appears to be a product of both left and right hemispheres rather than superior activation in one hemisphere (Torrance, 1982). Thus, more effective learning process to use both the right and left brain in a balanced way needs to be developed to improve our learning capability and creativity (Christensen, 1991).

The results of this work imply that practicing simple arithmetic periodically may improve the whole brain activation resolving the unbalanced left and right activity patterns. In addition, learners showing seriously unbalanced left brain activation induced by continuous complex arithmetic considered important in current school education can perform whole brain learning by taking control of specific brainwaves through neurofeedback training.

Although it is promising to have captured characteristic brainwaves and asymmetric behaviors of the left and right brain during simple and complex arithmetic processes among our four frequency bands, more comprehensive analysis from multiple locations of the brain and further delineation of frequency bands is needed to validate the effectiveness and hemispheric effects of repeated simple arithmetic learning (Kwon & Cho 2007). It also would be helpful in the future to measure attention during the simple and complex arithmetic processes and coregister the changes with EEG activity changes.

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